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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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Natural Resource Stewardship and Science
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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Comment 1 Changing relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

Comment 2These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

Comment 3 Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Continued warming of the atmosphere will cause sea levels to continue to rise, which will have a significant impact on how we protect and manage our public lands. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi- empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Comment 4 Peek et al. (2015) estimated that the cost of sea level rise in 40 National Park Service units could exceed $40 billion if these units were exposed to one-meter of sea level rise. The aim of this report is to: 1) quantify projections of sea level rise over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

When Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). Comment 5 This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change. Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2□5 billion and a 500 year storm surge could cost $5□11 billion(Aerts et al. 2013). Comment 5, contd. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” is used to refer to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

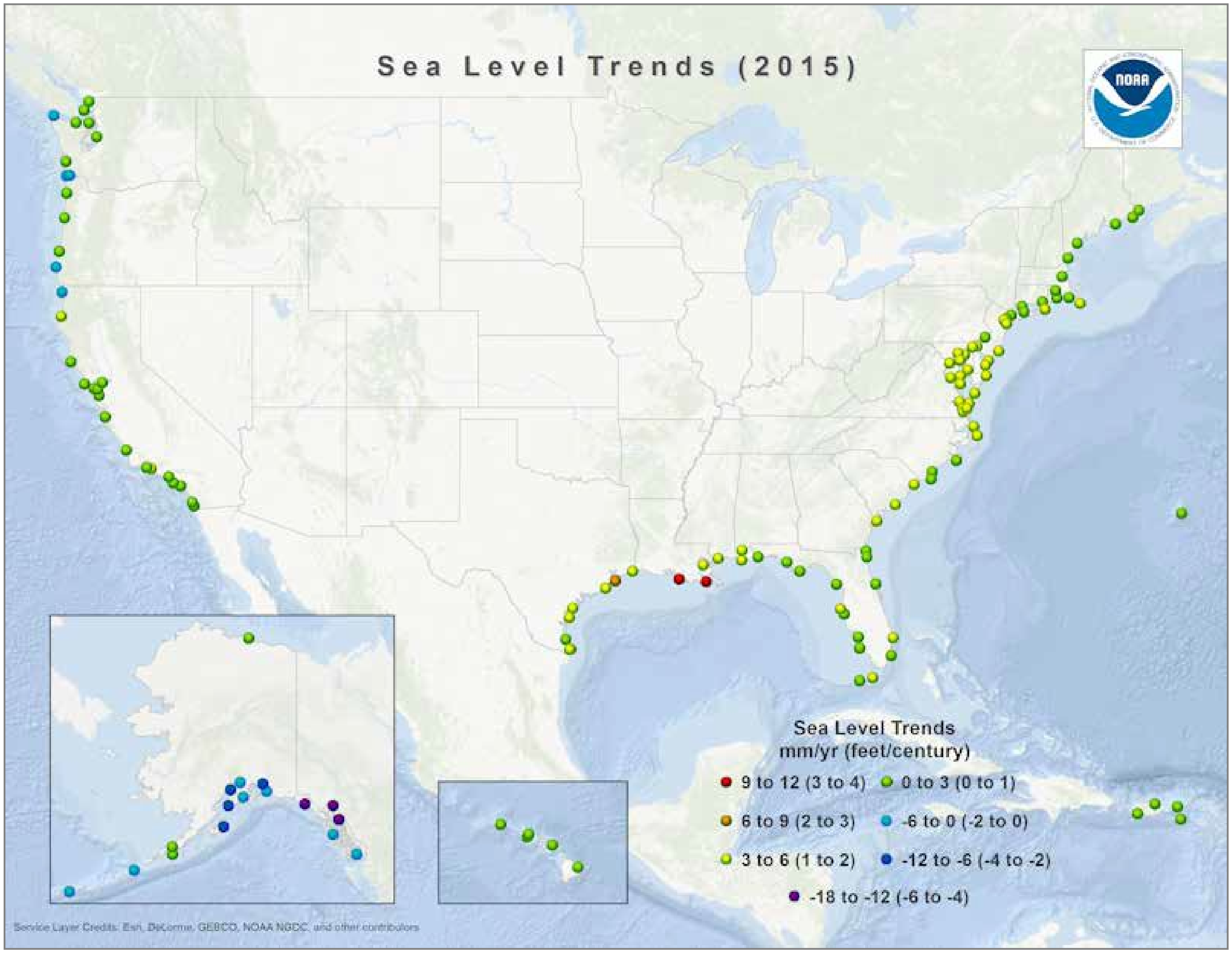

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on recommendations from regional personnel, three National Park Service units were selected as sites for wayside exhibits: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore. The finished wayside designs are in Appendix C. Each design is different, customized to reflect the messaging and/or themes of each unit.

Sea Level Rise Data

Comment 6 Sea level rise is caused by numerous factors. As human activities release CO2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013, Gillett et al. 2013, Frolicher et al. 2014). Rising global temperatures cause ice located on land and in the sea to melt.
The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

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[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{total}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of

maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

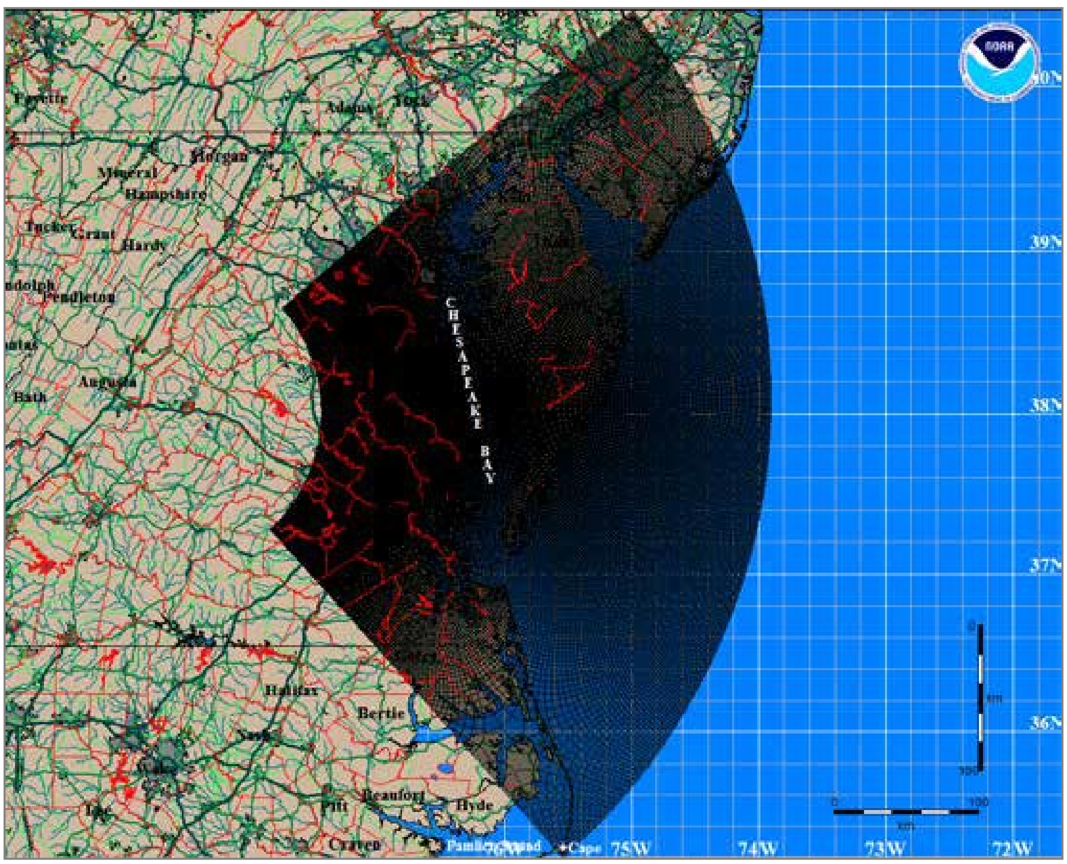

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$a e = E_0 - e_i + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address: https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link: http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

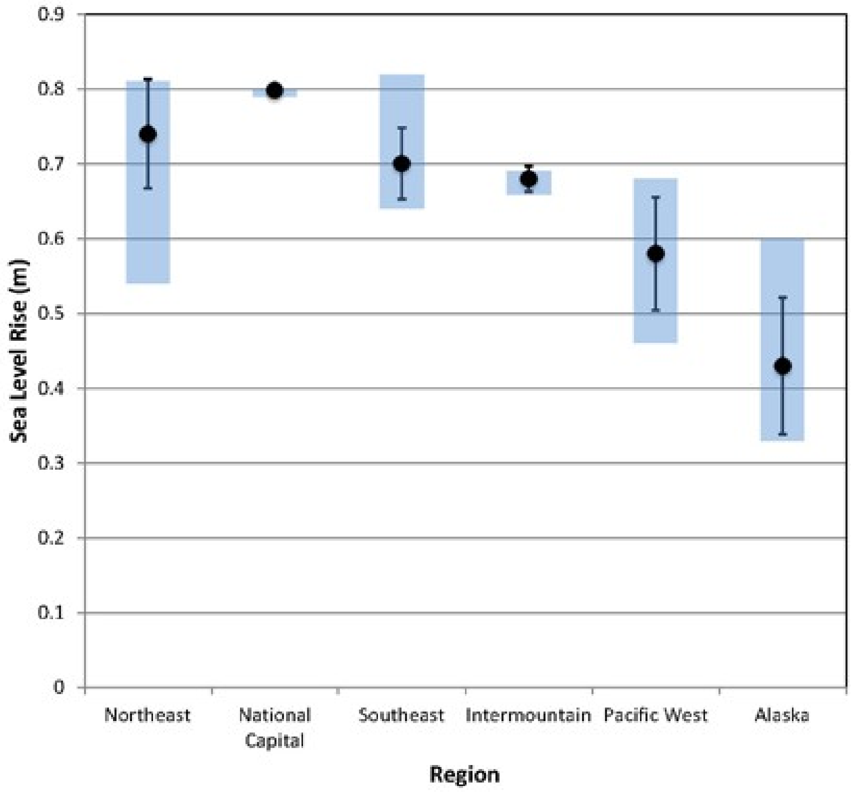

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National

Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

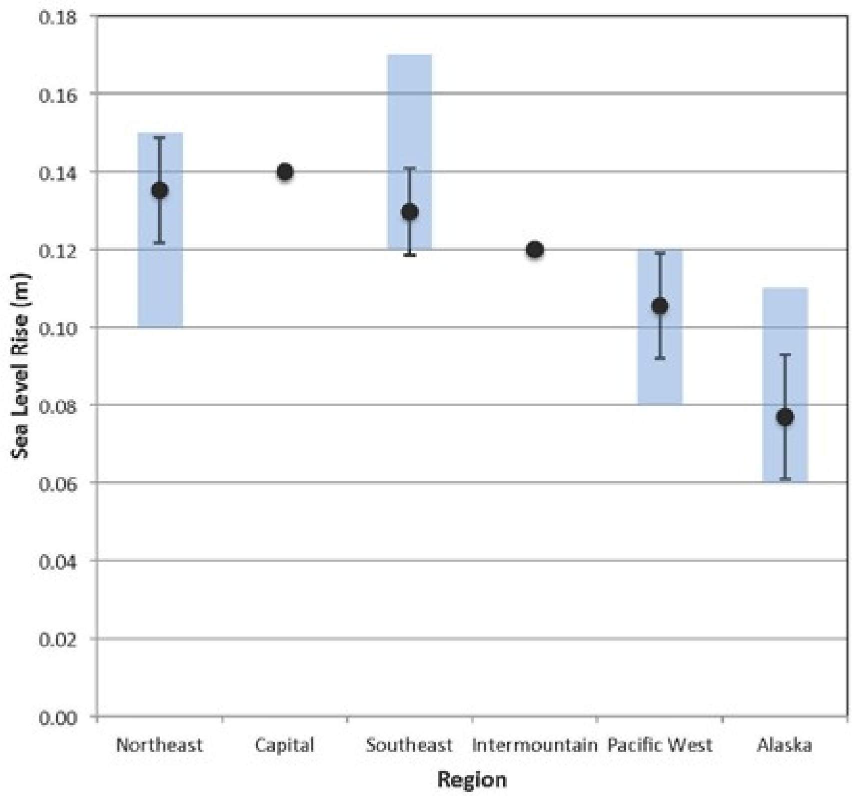

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

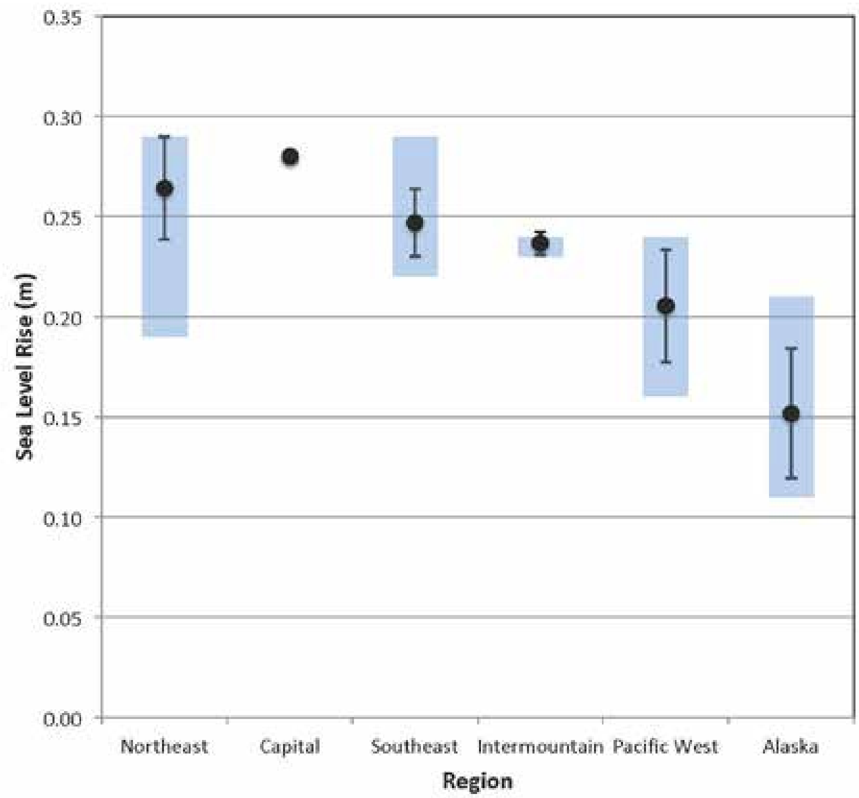

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

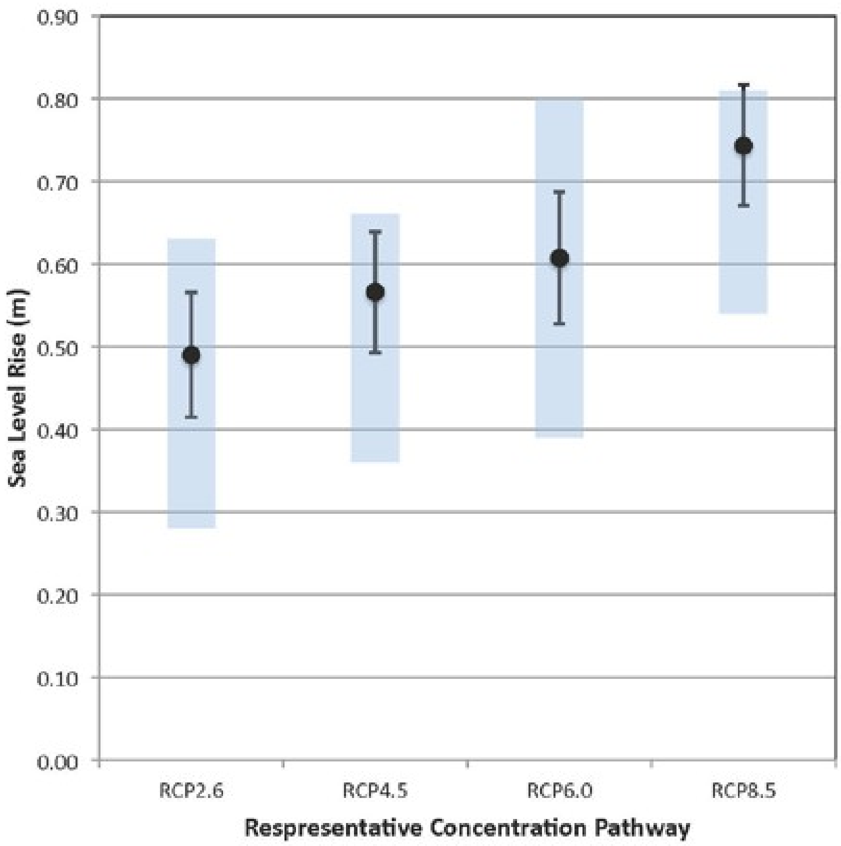

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms.

Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

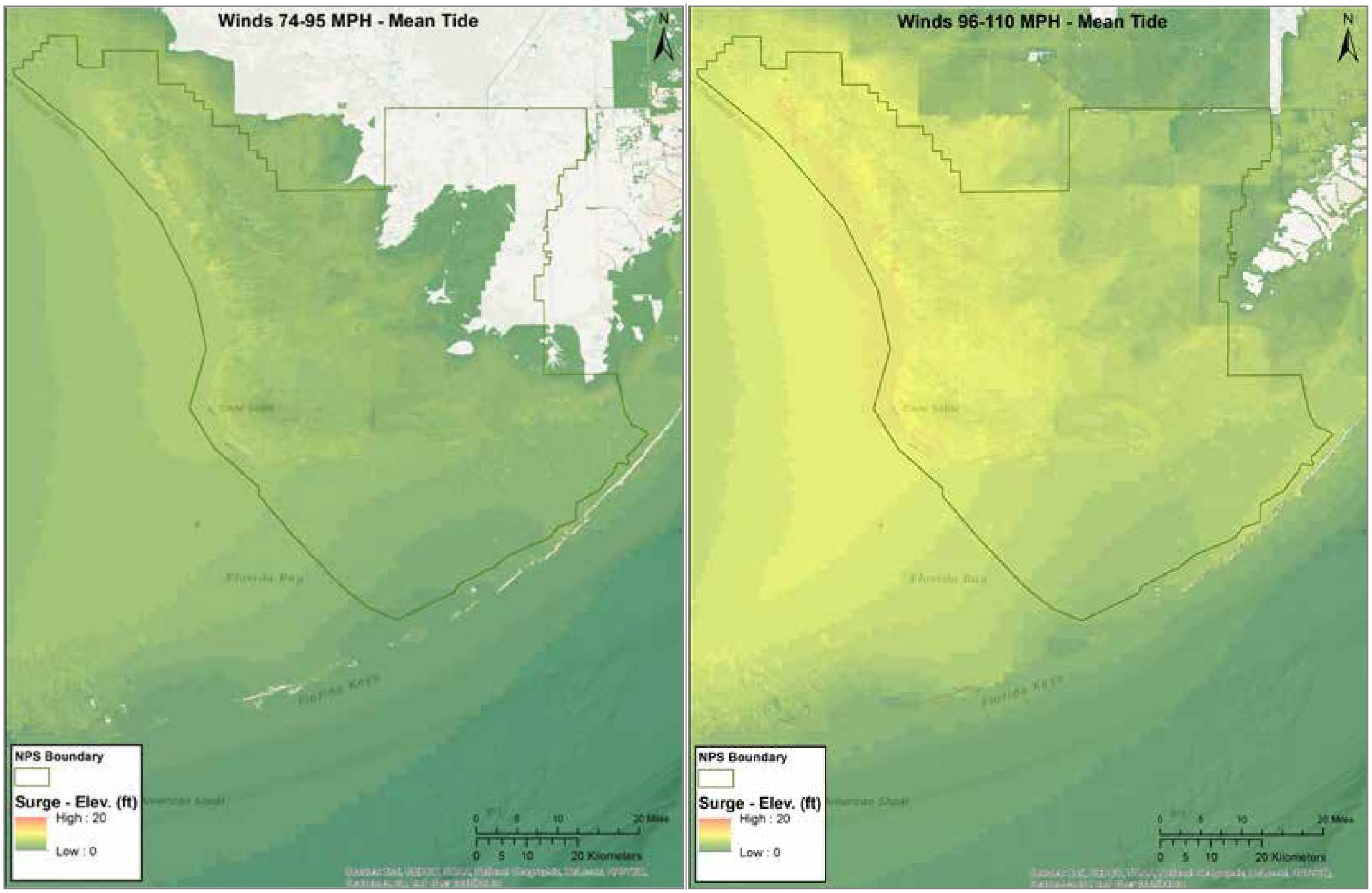

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

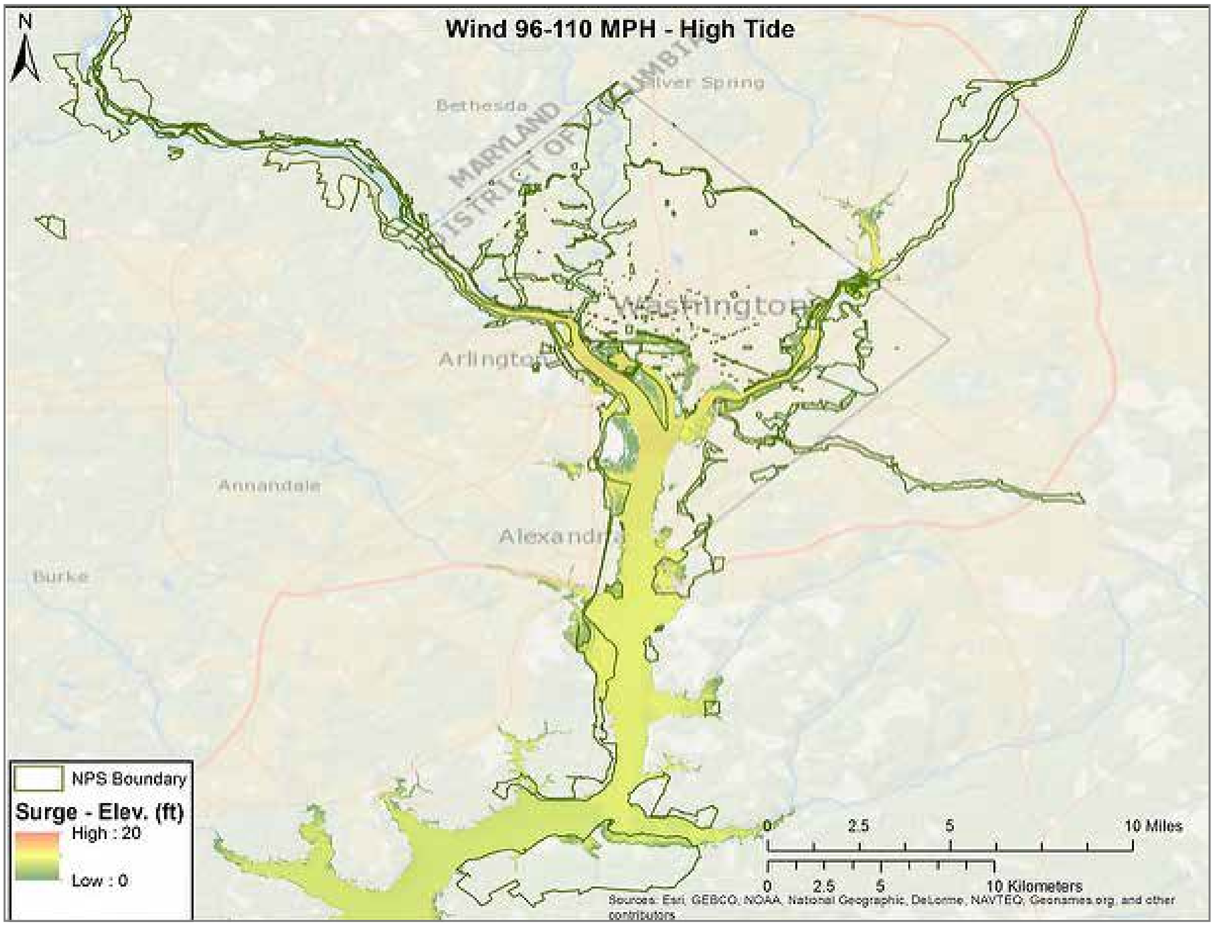

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

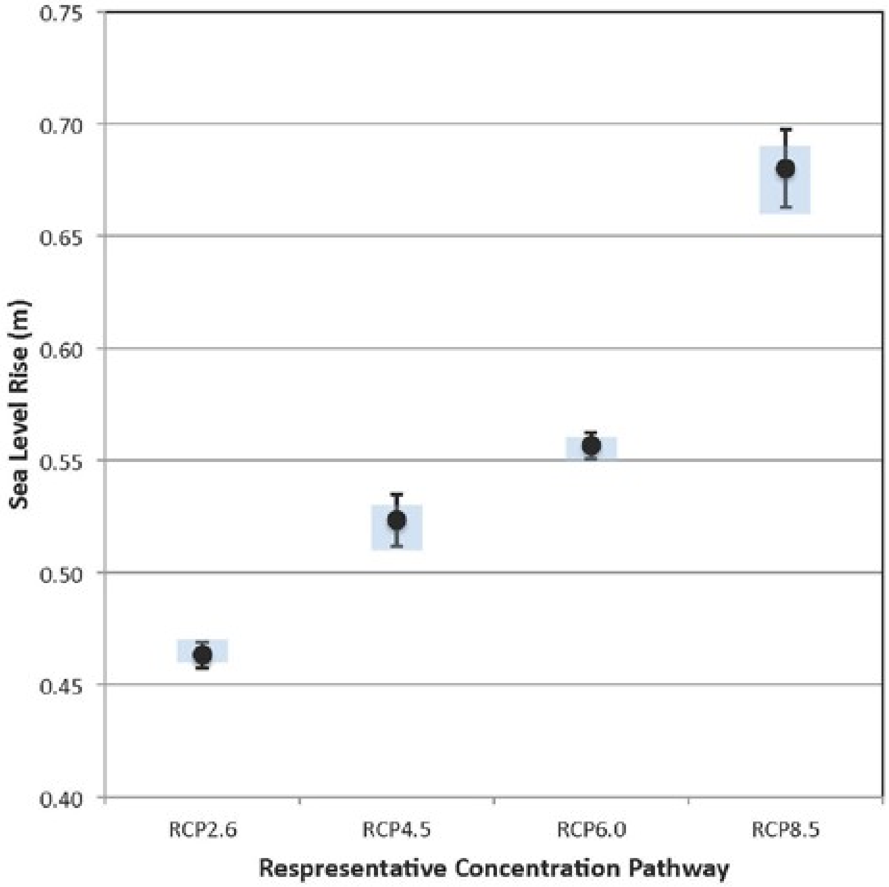

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

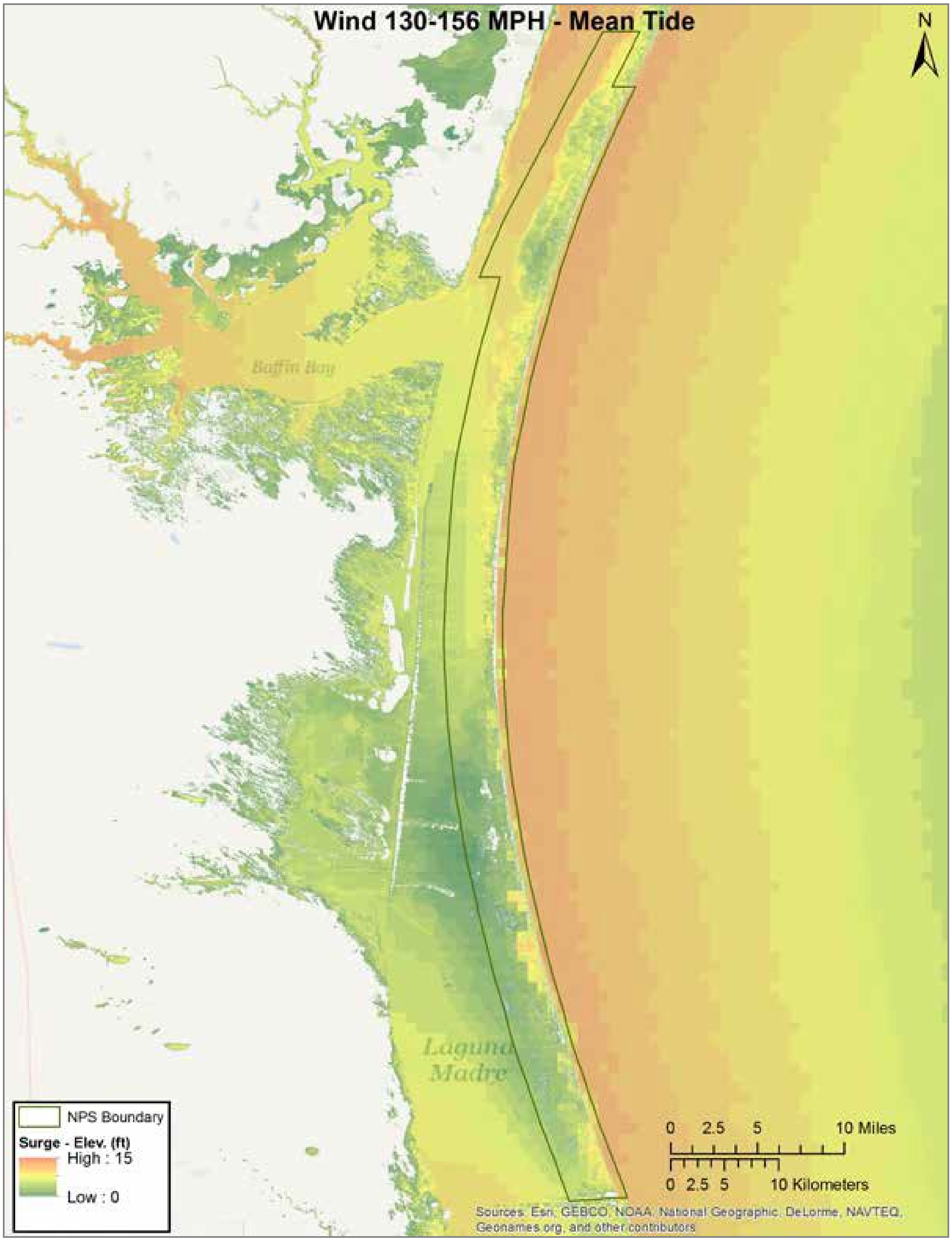

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Comment 7 Slangan et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

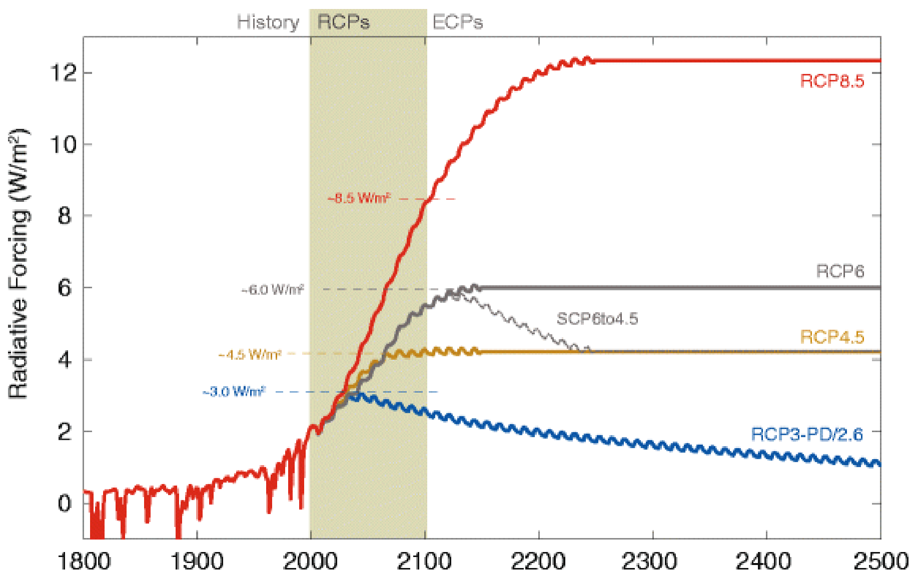

Figure 13. Radiative forcing for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. Comment 9 We expect the latest, state-of-the-art land level estimates to be released by NASA in 2017. In the meantime, we can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Waysides

The following pages show the final designs for waysides that were installed in parks as part of the funding for this project. Gulf Islands National Seashore received two waysides that were received in 2015. Jean Lafitte National Historical Park and Preserve and Fire Island National Seashores waysides were installed in 2016.

See Change...

The earth's climate is changing, raising sea level and increasing the frequency of storm surges. Erosion and rising sea level change the shape and size of barrier islands and mainland shorelines along the Gulf Coast.

The roots of coastal plants slow erosion by anchoring the land. As sea level rises, increased salt content in the soil will kill the plants leaving the land exposed to more erosion. In many places, the amount of dry land is decreasing at a significant rate.

The Gulf Coast draws millions of visitors to relax in the bright sun, play in the crystal blue surf, explore the snow white beaches, and watch for wildlife. Yet, this dry land, at the edge of rising waters, could be claimed by the Gulf of Mexico forever.

Gulf Islands National Seashore is investing in energy efficient equipment and seeking new sustainable solutions to help keep these shores from disappearing beneath the rising sea.

Each year, erosion, storms, coastal development, and rising sea level shrink the nesting beach habitat of sea turtles. When a female sea turtle is ready to lay her eggs, she will try to return to the same sandy beach every two to three years. Will her nesting home still be here?

Please join the National Park Service in protecting these beaches, so that you and your children may watch her hatchlings return to lay their eggs.

The road at Fort Pickens gets overwashed with storm waves. As the sea level rises, these events are becoming more common

See Change...

The earth's climate is changing, raising sea level and increasing the frequency of storm surges. Erosion and rising sea level change the shape and size of barrier islands and mainland shorelines along the Gulf Coast.

The roots of coastal plants slow erosion by anchoring the land. As sea level rises, increased salt content in the soil will kill the plants leaving the land exposed to more erosion. In many places, the amount of dry land is decreasing at a significant rate.

The Gulf Coast draws millions of visitors to relax in the bright sun, play in the crystal blue surf, explore the historic forts, and watch for wildlife. Yet, this dry land, at the edge of rising waters, could be claimed by the Gulf of Mexico forever.

Gulf Islands National Seashore is investing in energy efficient equipment and seeking new sustainable solutions to help keep these shores from disappearing beneath the rising sea.

Fighting the Rising Sea

Each year, erosion, storms, shipping channels, and rising sea level are changing the shoreline of the barrier islands. The National Park Service and Corp of Engineers work together on renourishment projects to rebuild the coastline around historic Fort Massachusetts. The fort is often battered by waves, putting the structure in jeopardy.

Please join the National Park Service in protecting our seashore, so that you and your children may continue to enjoy these historic places.

Sinking Land, Rising Water

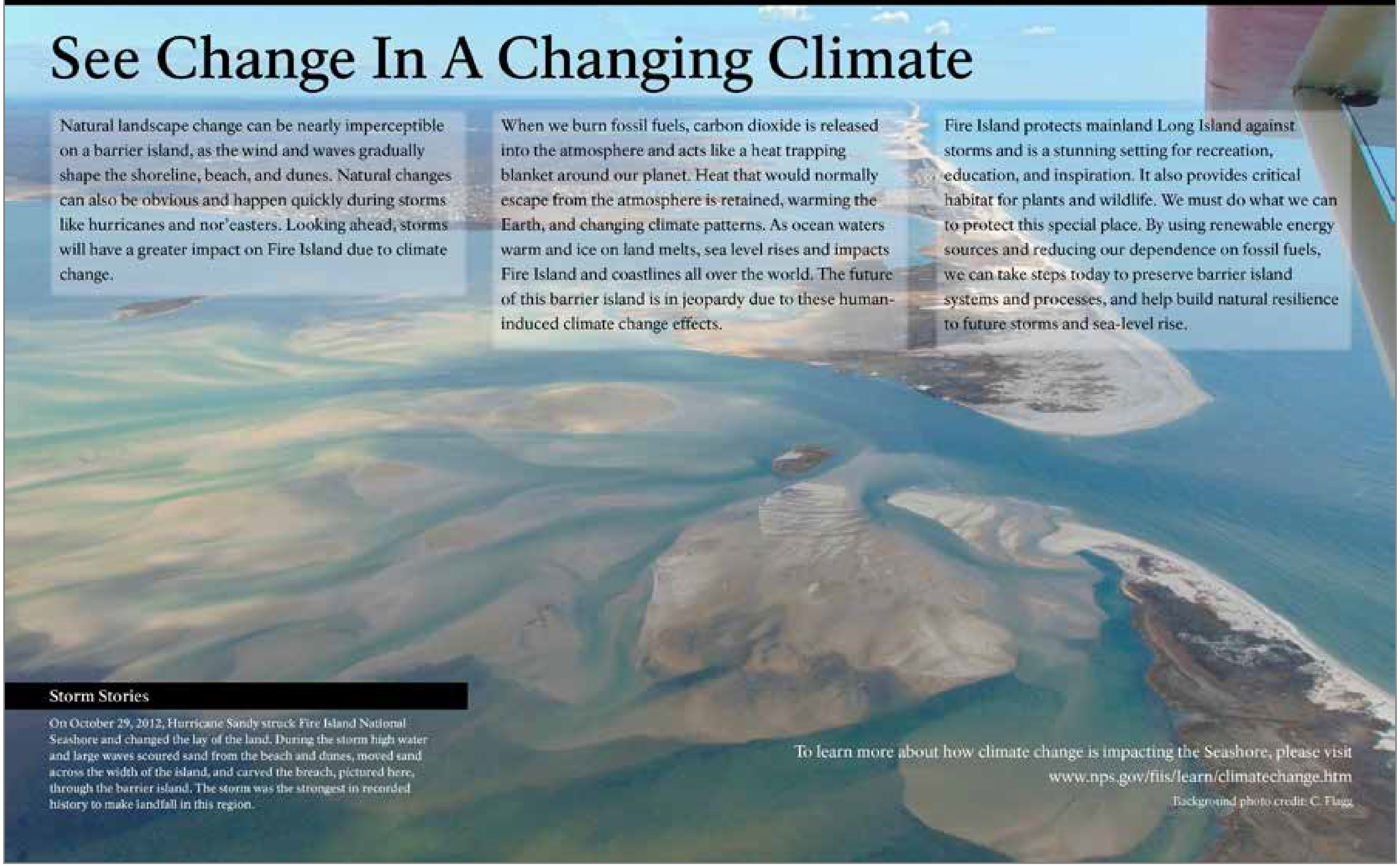
This is the Barataria Basin, built of soil washed to this area by the Mississippi River. This soil is still compacting and sinking, a process called subsidence. Most of the Barataria Preserve is less than two feet above sea level, and its subsidence rate is nearly half an inch a year.

Meanwhile, glaciers and polar ice sheets are melting and our warming climate is heating oceans everywhere, making their waters expand just like water does when you heat it on the stove. Everywhere on the planet, the oceans are a little higher every day.

The combination of the Barataria Basin's sinking land and global sea level rise means that the ocean is creeping in faster here than almost anywhere else in North America.

- Floods are becoming more frequent and lasting longer
- Coastal wetlands are disappearing as land sinks and water rises
- Less land is available to buffer Gulf of Mexico storms
- Storm and flooding threats to homes, communities, and infrastructure like highways, ports, and energy facilities are increasing
- Salt water from the Gulf is moving into freshwater wetlands, killing the plants that hold the land together
- Death of plants, animals, and microbes that cannot tolerate increased flooding or salt water

The photo shows two feet of flooding on Barataria Boulevard after Hurricane Isaac in August 2012. The map shows predicted consequences of 18 inches of sea level rise in the preserve; blue areas would be flooded and brown areas would remain land.



See Change In A Changing Climate

Natural landscape change can be nearly imperceptible on a barrier island, as the wind and waves gradually shape the shoreline, beach, and dunes. Natural changes can also be obvious and happen quickly during storms like hurricanes and nor'easters. Looking ahead, storms will have a greater impact on Fire Island due to climate change.

When we burn fossil fuels, carbon dioxide is released into the atmosphere and acts like a heat trapping blanket around our planet. Heat that would normally escape from the atmosphere is retained, warming the Earth, and changing climate patterns. As ocean waters warm and ice on land melts, sea level rises and impacts Fire Island and coastlines all over the world. The future of this barrier island is in jeopardy due to these human-induced climate change effects.

Fire Island protects mainland Long Island against storms and is a stunning setting for recreation, education, and inspiration. It also provides critical habitat for plants and wildlife. We must do what we can to protect this special place. By using renewable energy sources and reducing our dependence on fossil fuels, we can take steps today to preserve barrier island systems and processes, and help build natural resilience to future storms and sea-level rise.

Storm Stories

On October 29, 2012, Hurricane Sandy struck Fire Island National Seashore and changed the lay of the land. During the storm high water and large waves scoured sand from the beach and dunes, moved sand across the width of the island, and carved the breach, pictured here, through the barrier island. The storm was the strongest in recorded history to make landfall in this region.

To learn more about how climate change is impacting the Seashore, please visit www.nps.gov/fiis/learn/climatechange.htm

Background photo credit: C. Flagg

Appendix D

Data Tables

Table D1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore‡	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*[‡]	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument[‡]	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site[‡]	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site‡	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument‡	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*‡	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*‡	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve‡	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield‡	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park‡	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve‡	Fernandina Beach, FL (8720030)	N	110	0.600

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial‡	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve[‡]	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park[‡]	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park‡	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve‡	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site‡	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*‡	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*‡	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park‡	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*‡	Seattle, WA (9447130)	N	109	0.540

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore‡	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial‡	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*‡	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*‡	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument‡	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*‡	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve‡	No data	No data	No data	No data

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Table D1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument‡	No data	No data	No data	No data
	Glacier Bay National Park*‡	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*‡	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park‡	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park‡	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park‡	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park‡	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve‡	Cordova, AK (9454050)	N	43	3.450

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Table D2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14‡	0.13	0.12	0.12
		2050	0.24‡	0.23	0.21	0.24
		2100	0.47‡	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14‡	0.13	0.13‡	0.12
		2050	0.25‡	0.24	0.24‡	0.24
		2100	0.50‡	0.54	0.59‡	0.68
	Cape Hatteras National Seashore	2030	0.15‡	0.15	0.15	0.14
		2050	0.26‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Cape Lookout National Seashore§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve†§	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway[§]	2030	0.15[‡]	0.15	0.15[‡]	0.14
		2050	0.26[‡]	0.27	0.26[‡]	0.28
		2100	0.53[‡]	0.62	0.66[‡]	0.79
	Harpers Ferry National Historical Park*[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*] Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†] Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡] No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu’uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area[§]	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve[§]	2030	0.09[‡]	0.09	0.09	0.09
		2050	0.15[‡]	0.17	0.16	0.18
		2100	0.31[‡]	0.38	0.4	0.51

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve§	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument§	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park†§	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve†	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve†§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table D3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table D3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table D3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President’s Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table D3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey’s Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu’uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table D3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

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1 2 Attachment 2018-01-26 Recommended Edits_CHH.pdf

Comment 1: First Paragraph of Executive Summary (p vii)

~~Changing~~ Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Comment 2: Third Paragraph of Executive Summary (p vii)

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system.~~located along the coast~~. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety. ~~These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service.~~

Comment 3: First Paragraph of Introduction (p 1) Sentence shown in green font hasn't changed from the draft report. Suggest changing it back to black font. Yellow highlight text is very user-unfriendly; can we fix this at the same time?

Global sea level is rising at an increasing rate. ~~While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise~~ (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Continued warming of the atmosphere will cause sea levels to continue to rise, which will have a significant impact on how we protect and manage our public lands. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

Comment 4: Second Paragraph of Introduction (p 1)

Peek et al. (2018) estimate that the cost of sea level rise in 100 National Park Service units could exceed $23 billion if these units were exposed to one-meter of sea level rise. The aim of this report is to: 1) quantify projections of sea level rise over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks. [report to be cited as In Preparation]

Comment 5: Third Paragraph of Introduction (p 1)

When Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to climate change, but the storm surge occurred over a sea whose level had risen due to climate change. Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2-5 billion and a 500 year storm surge could cost $5-11 billion (Aerts et al. 2013). Under future scenarios of increasing greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015).

Comment 6: First Paragraph of Methods >> Sea Level Rise Data (p 4)

Sea level rise is caused by numerous factors. Ice located on land and in the sea melts with the rise of mean global temperatures (IPCC 2013, Gillett et al. 2013, Frolicher et al. 2014). The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

Comment 7: First Paragraph of Discussion (p 26)
Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangan et al. (2016) found that emissions of greenhouse gases have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

Comment 8: Caption of Figure 13 (p 26)
Radiative forcing for each of the Representative Concentration Pathways (RCPs). Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy ~~will cause warming~~warms the earth, resulting in ~~that can be measured as~~ higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011. SAME CHANGE REQUIRED ON p v IN THE TABLE OF CONTENTS, LIST OF FIGURES

Comment 9: Sixth Paragraph of Discussion (p 27)
These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We expect the latest, state-of-the-art land level estimates to be released by NASA in 2018.

2 Re_ Invitation_ Briefing - Sea Level Rise Proje....pdf

From: Perez, Larry
To: Claire Shields
Cc: Raymond Sauvajot; Cat Hoffman; Guy Adema; Brian Carlstrom; Wyse, Jennifer
Subject: Re: Invitation: Briefing - Sea Level Rise Projections Report @ Fri Feb 9, 2018 11am - 11:50am (MST) (larry_perez@nps.gov)
Date: Tuesday, February 06, 2018 4:57:31 PM

Team,

Please use this information to join us for Friday's call:

Sea Level Rise & Storm Surge Projections Report

Fri, Feb 9, 2018 11:00 AM - 11:50 AM MST

Please join my meeting from your computer, tablet or smartphone.
[redacted]

Join the conference call:
Conference Line: [redacted]
Passcode: [redacted]

First GoToMeeting? Let's do a quick system check: https://link.gotomeeting.com/system-check

Thanks for organizing, Claire!

-L

On Tue, Feb 6, 2018 at 3:25 PM, Claire Shields <claire_shields@nps.gov> wrote:

> **Briefing - Sea Level Rise Projections Report** **more details »**
>
> When Fri Feb 9, 2018 11am – 11:50am Mountain Time
>
> Where Webinar Info TBC (map)
>
> Calendar larry_perez@nps.gov
>
> Who
> - claire_shields@nps.gov - organizer
> - larry_perez@nps.gov
> - ray_sauvajot@nps.gov
> - cat_hawkins_hoffman@nps.gov
> - guy_adema@nps.gov
> - brian_carlstrom@nps.gov
> - jennifer_wyse@nps.gov
>
> Going? **Yes** - **Maybe** - **No** more options »
>
> Invitation from Google Calendar
>
> You are receiving this email at the account larry_perez@nps.gov because you are subscr bed for invitations on calendar larry_perez@nps.gov.
>
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>
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Larry Perez, Communications Coordinator
Climate Change Response Program
Natural Resource Stewardship and Science
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Fort Collins, CO 80525
Office: 970-267-2136
Fax: 970-225-3585
Email: larry_perez@nps.gov

3 Telephone today on ethics.pdf

From:	Patrick Gonzalez NPS
To:	Trudy Hawkins
Subject:	Telephone today on ethics
Date:	Wednesday, February 07, 2018 11:42:15 AM

Thanks, Trudy, for making time to talk. I'll call you at 12 PM AK.

Jon shared that guidance with us and it seems clear. I wish to ask for guidance on something else.

Thanks,

Patrick

From: "Hawkins, Trudy" <trudy_hawkins@nps.gov>
Subject: Re: Scheduling telephone call on ethics
Date: February 7, 2018 at 10:38:15 AM PST
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Cc: Marlene Doty <marlene_doty@nps.gov>

I'm available at noon, my time (1:00 yours), Patrick -

Might a subject of our conversation be the Ethics advice former Director Jarvis received from Matt Parsons, Departmental Ethics Attorney?

Thanks,
Trudy M. Hawkins, Acting Deputy Ethics Counselor
Alaska Region Ethics Program Manager
National Park Service
240 W. 5th Street
Anchorage, Alaska 99501
trudy_hawkins@nps.gov
907 644-3357 (Office)
907 644-3822 (Fax)

"Never doubt that a small group of thoughtful, committed people can change the world. Indeed, it is the only thing that ever has." ~ Margaret Mead

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~~~~~~

On Wed, Feb 7, 2018 at 8:28 AM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

Dear Trudy,

Would you have time today to talk at 12 PM AKST (1 PM PST)? That is best in my schedule. Otherwise, we can select another time.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
Department of Environmental Science, Policy, and Management
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: "Doty, Marlene" <marlene_doty@nps.gov>
Subject: Re: Schedule telephone call on ethics
Date: February 7, 2018 at 6:08:46 AM PST
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Cc: Trudy Hawkins <trudy_hawkins@nps.gov>

Sorry I have a standing 2 pm meeting here in DC, right now my calendar is open for Thursday, I work 6am to 3:30pm Eastern Time tomorrow. Please note Trudy Hawkins and I are sharing the Deputy Ethics Counselor duties, if it would be easier for you to reach her you may do so,she is in Anchorage, AK. Her email is Trudy_Hawkins@nps.gov. Please note she has the same meeting as I do today but she may have time either before or after that matches what you have available.

If you want to speak with me tomorrow just send me a meeting invite. Thank you.

Marlene Doty

NPS Deputy Ethics Counselor (Acting)
202-354-1981
202-631-6397 Cell

On Tue, Feb 6, 2018 at 1:40 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

Dear Marlene,

I need guidance on a particular ethics issue and I wish to talk by telephone when you have time. I am part of the NPS Washington office, though stationed in California. Tomorrow 2 PM EST (11 AM PST) is good in my schedule. Otherwise, I have some open times on Thursday.

Thank you,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
Department of Environmental Science, Policy, and Management
University of California, Berkeley

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

4 SLR _ SS Report Call.pdf

From:	Perez, Larry
To:	Beavers, Rebecca; Patrick Gonzalez
Cc:	Cat Hoffman
Subject:	SLR / SS Report Call
Date:	Saturday, February 10, 2018 1:01:23 PM

Rebecca & Patrick,

Cat and I would like to organize a call with all authors to review the report.

I propose we plan to meet via webinar at 2:00 MT on February 21...immediately following our large group call. I'll send a calendar invite shortly.

Rebecca, would you kindly forward the invite to Maria as well...we're hopeful she is willing and able to join.

Thanks,

L

____

Larry Perez, Communications Coordinator
Climate Change Response Program
Natural Resource Stewardship and Science
1201 Oakridge Drive. Suite 200
Fort Collins, CO 80525
Office: 970-267-2136
Fax: 970-225-3585
Email: larry_perez@nps.gov

5 Out of the office - Absent du bureau - Re_ SLR ....pdf

From: Gonzalez, Patrick
To: larry_perez@nps.gov
Subject: Out of the office - Absent du bureau - Re: SLR / SS Report Call
Date: Saturday, February 10, 2018 1:01:30 PM

Hi - i am out of the office February 9, 2018. Thanks for your patience in awaiting a reply to your message.

Best regards, Patrick

Bonjour - Je vous remercie pour votre message. Je suis en congé le 9 février 2018. Je prendrai connaissance de votre courriel dans les meilleurs délais.

Cordialement, Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
Department of Environmental Science, Policy, and Management
University of California, Berkeley

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patrick_gonzalez@nps.gov
+1 (510) 643-9725
....

--

....
Patrick Gonzalez, Ph.D.

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https://ourenvironment.berkeley.edu/people/patrick-gonzalez

131 Mulford Hall, Berkeley, CA 94720-3114 USA
patrick_gonzalez@nps.gov
+1 (510) 643-9725
....

6 Invitation_ SLR_SS Report Author Call @ Wed Feb....pdf

From:	larry_perez@nps.gov
To:	patrick_gonzalez@nps.gov; cat_hawkins_hoffman@nps.gov; rebecca_beavers@nps.gov
Subject:	Invitation: SLR/SS Report Author Call @ Wed Feb 21, 2018 1pm - 2pm (PST) (patrick_gonzalez@nps.gov)
Attachments:	invite.ics

HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid MDVpdnRqYWlmOTllN2FrdTZvNmtoNDJ1NmIgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MTkjbGFycnlfcGVyZXpAbnBzLmdvdjdlYzRhYTRkZDBhMzg2NzU4YWUxNGY2N2U5NDc0YmMyZjRkYWVjN2U&ctz America/Los_Angeles&hl en" more details »

SLR/SS Report Author Call
New Meeting
Wed, Feb 21, 2018 2:00 PM - 3:00 PM MST

Please join my meeting from your computer tablet or smartphone.
HYPERLINK [redacted]

Join the conference call:
Conference Line [redacted]
Passcode [redacted]

First GoToMeeting? Let's do a quick system check: HYPERLINK "https://www.google.com/url?q https%3A%2F%2Flink.gotomeeting.com%2Fsystem-check&sa D&ust 1518300275937000&usg AFQjCNFhOVMXtgtQfO4vtZJE9fs6tRbpLg" https://link.gotomeeting.com/system-check
When Wed Feb 21, 2018 1pm – 2pm Pacific Time
Where See GoToMeeting Info Below (HYPERLINK "https://maps.google.com/maps?q See GoToMeeting Info Below&hl en" map)
Video call HYPERLINK "https://plus.google.com/hangouts/_/doi.gov/larry-perez?hceid bGFycnlfcGVyZXpAbnBzLmdvdg.05ivtjaif99e7aku6o6kh42u6b" https://plus.google.com/hangouts/_/doi.gov/larry-perez
Calendar patrick_gonzalez@nps.gov
Who • larry_perez@nps.gov - organizer
• patrick_gonzalez@nps.gov
• cat_hawkins_hoffman@nps.gov
• rebecca_beavers@nps.gov

Going? HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MDVpdnRqYWlmOTllN2FrdTZvNmtoNDJ1NmIgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 1&tok MTkjbGFycnlfcGVyZXpAbnBzLmdvdjdlYzRhYTRkZDBhMzg2NzU4YWUxNGY2N2U NDc0YmMyZjRkYWVjN2U&ctz America/Los_Angeles&hl en"
Yes - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MDVpdnRqYWlmOTllN2FrdTZvNmtoNDJ1NmIgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 3&tok MTkjbGFycnlfcGVyZXpAbnBzLmdvdjdlYzRhYTRkZDBhMzg2NzU4YWUxNGY2N2U NDc0YmMyZjRkYWVjN2U&ctz America/Los_Angeles&hl en"
Maybe - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MDVpdnRqYWlmOTllN2FrdTZvNmtoNDJ1NmIgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 2&tok MTkjbGFycnlfcGVyZXpAbnBzLmdvdjdlYzRhYTRkZDBhMzg2NzU4YWUxNGY2N2U NDc0YmMyZjRkYWVjN2U&ctz America/Los_Angeles&hl en"
No HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid MDVpdnRqYWlmOTllN2FrdTZvNmtoNDJ1NmIgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MTkjbGFycnlfcGVyZXpAbnBzLmdvdjdlYzRhYTRkZDBhMzg2NzU4YWUxNGY2N2U5NDc0YmMyZjRkYWVjN2U&ctz America/Los_Angeles&hl en" more options »

7 Accepted_ SLR_SS Report Author Call @ Wed Feb 2....pdf

From:	Google Calendar on behalf of Patrick Gonzalez
To:	larry_perez@nps.gov
Subject:	Accepted: SLR/SS Report Author Call @ Wed Feb 21, 2018 2pm - 3pm (MST) (larry_perez@nps.gov)
Attachments:	invite.ics

Patrick Gonzalez has accepted this invitation
SLR/SS Report Author Call
New Meeting
Wed, Feb 21, 2018 2:00 PM - 3:00 PM MST

Please join my meeting from your computer, tablet or smartphone
HYPERLIN [redacted]

Join the conference call:
Conference Line [redacted]
Passcode: [redacted]

First GoToMeeting? Let's do a quick system check: HYPERLINK "https://www google com/url?q=https%3A%2F%2Flink gotomeeting com%2Fsystem-check&sa=D&ust=1518729678814000&usg=AFQjCNEztqn2x8WNrfbz5blLLu5p7ceung" https://link gotomeeting com/system-check
When Wed Feb 21, 2018 2pm – 3pm Mountain Time
Where See GoToMeeting Info Below (HYPERLINK "https://maps google com/maps?q=See+GoToMeeting+Info+Below&hl=en" map)
Video call HYPERLINK "https://plus google com/hangouts/_/doi gov/larry-perez?hceid=bGFycnlfcGVyZXpAbnBzLmdvdg 05ivtjaif99e7aku6o6kh42u6b" https://plus google com/hangouts/_/doi gov/larry-perez
Calendar larry_perez@nps gov
Who • larry_perez@nps gov - organizer
• rebecca_beavers@nps gov
• cat_hawkins_hoffman@nps gov
• patrick_gonzalez@nps gov

8 Re_ Discussing scientific integrity.pdf

From: Patrick Gonzalez NPS
To: Maria Caffrey
Subject: Re: Discussing scientific integrity
Date: Tuesday, February 20, 2018 10:59:58 AM

Hi Maria - Thanks for making time. It would be fine in 20 minutes. I’m in the office: (510) 643-9725.

Patrick

——

From: Maria Caffrey <maria.caffrey@colorado.edu>
Subject: Re: Discussing scientific integrity
Date: February 20, 2018 at 9:55:44 AM PST
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

Hi Patrick

Yes, we definitely need to talk. I’m (b) (6) . Is it ok if I call you after that? I’ll probably be around 20 minutes.

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

> On Feb 20, 2018, at 10:41 AM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
>
> Hi Maria,
>
> Rebecca has probably told you that they have scheduled a telephone call tomorrow at 2 PM MST (1 PM PST) to discuss the sea level rise report.
>
> I’d like to talk to you before that and hope that you might have time today or tomorrow. Today is OK most of the day and tomorrow 11 AM MST (10 AM PST) is OK.
>
> Thanks,
>
> Patrick
>
> ....
> Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
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131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

9 Canceled event_ SLR_SS Report Author Call @ Wed....pdf

From:	larry_perez@nps.gov
To:	rebecca_beavers@nps.gov; cat_hawkins_hoffman@nps.gov; patrick_gonzalez@nps.gov
Subject:	Canceled event: SLR/SS Report Author Call @ Wed Feb 21, 2018 2pm - 3pm (MST) (rebecca_beavers@nps.gov)
Attachments:	invite.ics

This event has been canceled and removed from your calendar
SLR/SS Report Author Call
New Meeting
Wed, Feb 21, 2018 2:00 PM - 3:00 PM MST

Please join my meeting from your computer, tablet or smartphone
HYPERLINK (b) (5) [redacted]

Join the conference call:
Conference Line: (b) (5) [redacted]
Passcode (b) (5) [redacted]

First GoToMeeting? Let's do a quick system check: HYPERLINK "https://www google com/url?q=https%3A%2F%2Flink gotomeeting com%2Fsystem-check&sa=D&ust=1519176804056000&usg=AFQjCNH-ixT3OIpMr5KJO_0m5fiJQkKLxw" https://link gotomeeting com/system-check
When Wed Feb 21, 2018 2pm – 3pm Mountain Time
Where See GoToMeeting Info Below (HYPERLINK "https://maps google com/maps?q=See+GoToMeeting+Info+Below&hl=en" map)
Video call HYPERLINK "https://plus google com/hangouts/_/doi gov/larry-perez?hceid=bGFycnlfcGVyZXpAbnBzLmdvdg 05ivtjaif99e7aku6o6kh42u6b" https://plus google com/hangouts/_/doi gov/larry-perez
Calendar rebecca_beavers@nps gov
Who • larry_perez@nps gov - organizer
• rebecca_beavers@nps gov
• cat_hawkins_hoffman@nps gov
• patrick_gonzalez@nps gov

Invitation from HYPERLINK "https://www google com/calendar/" Google Calendar
You are receiving this email at the account rebecca_beavers@nps gov because you are subscribed for cancellations on calendar rebecca_beavers@nps gov
To stop receiving these emails, please log in to https://www google com/calendar/ and change your notification settings for this calendar
Forwarding this invitation could allow any recipient to modify your RSVP response HYPERLINK "https://support google com/calendar/answer/37135#forwarding" Learn More

10 Canceled event_ SLR_SS Report Author Call @ Wed...(1).pdf

From:	larry_perez@nps.gov
To:	rebecca_beavers@nps.gov; cat_hawkins_hoffman@nps.gov; patrick_gonzalez@nps.gov
Subject:	Canceled event: SLR/SS Report Author Call @ Wed Feb 21, 2018 1pm - 2pm (PST) (patrick_gonzalez@nps.gov)
Attachments:	invite.ics

This event has been canceled and removed from your calendar
SLR/SS Report Author Call
New Meeting
Wed, Feb 21, 2018 2:00 PM - 3:00 PM MST

Please join my meeting from your computer, tablet or smartphone
HYPERLINK (b) (5) [redacted]

Join the conference call:
Conference Line: (b) (5) [redacted]
Passcode: (b) (5) [redacted]

First GoToMeeting? Let's do a quick system check: HYPERLINK "https://www google com/url?q=https%3A%2F%2Flink gotomeeting com%2Fsystem-check&sa=D&ust=1519176804025000&usg=AFQjCNEf4jHFn-u-Tyc83Cjrxrs6TliN5A" https://link gotomeeting com/system-check
When Wed Feb 21, 2018 1pm – 2pm Pacific Time
Where See GoToMeeting Info Below (HYPERLINK "https://maps google com/maps?q=See+GoToMeeting+Info+Below&hl=en" map)
Video call HYPERLINK "https://plus google com/hangouts/_/doi gov/larry-perez?hceid=bGFycnlfcGVyZXpAbnBzLmdvdg 05ivtjaif99e7aku6o6kh42u6b" https://plus google com/hangouts/_/doi gov/larry-perez
Calendar patrick_gonzalez@nps gov
Who • larry_perez@nps gov - organizer
• rebecca_beavers@nps gov
• cat_hawkins_hoffman@nps gov
• patrick_gonzalez@nps gov

Invitation from HYPERLINK "https://www google com/calendar/" Google Calendar
You are receiving this email at the account patrick_gonzalez@nps gov because you are subscribed for cancellations on calendar patrick_gonzalez@nps gov
To stop receiving these emails, please log in to https://www google com/calendar/ and change your notification settings for this calendar
Forwarding this invitation could allow any recipient to modify your RSVP response HYPERLINK
"https://support google com/calendar/answer/37135#forwarding" Learn More

11 They canceled tomorrow’s telephone call - Cance....pdf

From: Patrick Gonzalez NPS
To: Maria Caffrey
Subject: They canceled tomorrow"s telephone call - Canceled event: SLR/SS Report Author Call
Date: Tuesday, February 20, 2018 4:36:25 PM
Attachments: Mail Attachment.ics
invite.ics

Hi Maria,

Larry just canceled the call. We'll see when they reschedule. We no longer need to talk tomorrow at 5 PM MST.

Thanks,

Patrick

From: Larry Perez <larry_perez@nps.gov>
Subject: Canceled event: SLR/SS Report Author Call @ Wed Feb 21, 2018 1pm - 2pm (PST) (patrick_gonzalez@nps.gov)
Date: February 20, 2018 at 3:33:24 PM PST
To: patrick_gonzalez@nps.gov
Reply-To: Larry Perez <larry_perez@nps.gov>

This event has been canceled and removed from your calendar.

SLR/SS Report Author Call

New Meeting
Wed, Feb 21, 2018 2:00 PM - 3:00 PM MST

Please join my meeting from your computer, tablet or smartphone.
(b) (5) [redacted]

Join the conference call:
Conference Line: (b) (5) [redacted]
Passcode: (b) (5) [redacted]

First GoToMeeting? Let's do a quick system check: https://link.gotomeeting.com/system-check

When	Wed Feb 21, 2018 1pm – 2pm Pacific Time
Where	See GoToMeeting Info Below (map)
Video call	https://plus.google.com/hangouts/_/doi.gov/larry-perez
Calendar	patrick_gonzalez@nps.gov
Who	• larry_perez@nps.gov - organizer • rebecca_beavers@nps.gov • cat_hawkins_hoffman@nps.gov • patrick_gonzalez@nps.gov

12 thanks for the discussion.pdf

From: Hoffman, Cat
To: Maria Caffrey; Rebecca Beavers; Patrick Gonzalez
Subject: thanks for the discussion
Date: Tuesday, February 27, 2018 2:55:07 PM

Thanks to all of you for taking time and being willing to talk through the suggested changes to the report.

I have another call in a few minutes, but will get the track-changes version to you later this afternoon/evening Maria. Having trouble figuring out how to delete the wayside images, but will figure that out.

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

13 Re_ Upholding scientific integrity.pdf

From:	Maria Caffrey
To:	Patrick Gonzalez NPS
Subject:	Re: Upholding scientific integrity
Date:	Wednesday, February 28, 2018 3:43:00 PM
Attachments:	NPS attempted deletions Caffrey report 2018-02-27 1240.png NPS attempted deletions Caffrey report 2018-02-27 1256.png NPS attempted deletions Caffrey report 2018-02-27 1258.png NPS attempted deletions Caffrey report 2018-02-27 1309.png NPS attempted deletions Caffrey report 2018-02-27 1311.png NPS attempted deletions Caffrey report 2018-02-27 1313.png NPS attempted deletions Caffrey report 2018-02-27 1314.png

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Hi Patrick

Thanks for this. Good idea to get screen shots. Cat sent me a copy of the file. I will forward it to you. I will share my edits to you once I get around to them. That probably won't be until Monday at the earliest.

Cheers

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

On Feb 28, 2018, at 10:44 AM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Maria,
>
> You will see attached seven files that are screen shots of your National Park Service (NPS) sea level rise report that Cat Hawkins Hoffman showed us yesterday by webinar. I'm sending these to you because we had not, at the time of yesterday's telephone call, been sent the Word file. NPS is attempting to delete the words "anthropogenic climate change" or any text on how greenhouse gas emissions from human activities are the cause of climate change. The Intergovernmental Panel on Climate Change (2013) and the U.S. Global Change Research Program (2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change.
>
> Intergovernmental Panel on Climate Change. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.
>
> U.S. Global Change Research Program. 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC.

The attempt to alter scientific content or meaning for non-science and non-policy reasons violates scientific integrity and U.S. Department of the Interior policy. Therefore, if the scientific content and words are not restored to the report, I will remove my name as a co-author.

I really appreciate your invitation to me to serve as a co-author on your report and working with you. We have spoken about this situation and I greatly appreciate your understanding that I would remove my name in order to uphold scientific integrity.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
Department of Environmental Science, Policy, and Management
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
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<NPS attempted deletions Caffrey report 2018-02-27 1240.png><NPS attempted deletions Caffrey report 2018-02-27 1256.png><NPS attempted deletions Caffrey report 2018-02-27 1258.png><NPS attempted deletions Caffrey report 2018-02-27 1309.png><NPS attempted deletions Caffrey report 2018-02-27 1311.png><NPS attempted deletions Caffrey report 2018-02-27 1313.png><NPS attempted deletions Caffrey report 2018-02-27 1314.png>

13 1 Attachment NPS attempted deletions Caffrey report 2018-02.pdf

13 2 Attachment NPS attempted deletions Caffrey report 2018-02_1.pdf

Executive Summary

Ongoing changes in~~Changing~~ relative sea levels and the potential for increasing storm surges ~~due to anthropogenic climate change~~ present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

13 3 Attachment NPS attempted deletions Caffrey report 2018-02_2.pdf

GoToMeeting File Edit Options View Webcams Zoom Window Help 63% 12:58:18 PM

Talking: Now viewing Cat's screen

Webcams Zoom: 56% Screenshot

2018-02-09 Sea Level Change Report - Feb 27 2018.docx - Word

File Home Insert Design Layout References Mailings Review View ACROBAT Tell me what you want to do... Hoffman, Cat H Share

Introduction

Global sea level is rising at an increasing rate. ~~While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014).~~ Continued warming of the atmosphere will cause sea levels ~~to continue~~ to rise, which will ~~have a significant~~ impact ~~on~~ how ~~we we protect and~~ manage our public lands. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change ~~due to climate change~~ for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (20185) estimated that the cost of sea level rise in 10040 National Park Service units could exceed $2340 billion if these units were exposed to one-meter of sea level rise. The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

When Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). ~~This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change.~~ Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013). Under future

Hoffman, Cat H.
Include relevant cites

Hoffman, Cat H.
I think we should keep this

Perez, Larry
Report to be cited in preparation

Hoffman, Cat H.
Should be "cost of addressing potential damage caused by sea level rise" or some similar wording

Perez, Larry
What are we trying to achieve? Context? Focus on this as an example rather than a statement of impending doom. Why is it important to understand SLR and SS?

Perez, Larry
Suggested alternative to this paragraph:

The passage of Hurricane Sandy in 2012—and more recently with Hurricanes Harvey, Irma, and Maria—brought extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to local economies, investments in recovery, and/or the irrevocable loss of unique resources. Future scenarios of increasing greenhouse gas emissions project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units should, therefore, marry these projections for the future with lessons learned from our past.

Hoffman, Cat H.

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continue to rise, which will have a significant impact on how we we protect and manage our public lands. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (20185in prep: be sure to check this in bibliog) estimated that the value of infrastructure at risk cost of sea level rise in 10040 National Park Service units could exceed $2340 billion if these units were exposed to one-meter of sea level rise. The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

When Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change. Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013). Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential

Perez, Larry
Report to be cited in preparation

Perez, Larry
What are we trying to achieve? Context? Focus on this as an example rather than a statement of impending doom. Why is it important to understand SLR and SS?

Perez, Larry
Suggested alternative to this paragraph:

The passage of Hurricane Sandy in 2012—and more recently with Hurricanes Harvey, Irma, and Maria—brought extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to local economies, investments in recovery, and/or the irrevocable loss of unique resources. Future scenarios of increasing greenhouse gas emissions project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units should, therefore, marry these projections for the future with lessons learned from our past.

Hoffman, Cat H.
Suggestion for first sentence: "The impacts of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure…

Second sentence: should we say "impacts to gateway communities"? to be more clear than "local economies" (whose local economies?) and keep this anchored in looking at parks and park-related issues

Suggestion for last sentence: Management decisions and investments in coastal national park units can benefit from analyzing projections for the future in conjunction with lessons learned from the past.

Page 13 of 93 24440 words Saving AutoRecovery file 2018-02-09 Sea Level Change Report - Feb 27 2018.docx

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Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on recommendations from regional personnel, three National Park Service units were selected as sites for wayside exhibits: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore. The finished wayside designs are in Appendix C. Each design is different, customized to reflect the messaging and/or themes of each unit.

Sea Level Rise Data

Sea level rise is caused by numerous factors. Ice located on land and in the sea melts with the rise of mean global temperatures ~~As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase~~ (IPCC 2013, Gillett et al. 2013, Frolicher et al. 2014). ~~Rising global temperatures cause ice located on land and in the sea to melt.~~ The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

Hoffman, Cat H.
These may not be relevant references for the suggested "new" 2nd sentence; may need to delete these references.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal

13 6 Attachment NPS attempted deletions Caffrey report 2018-02_5.pdf

approach.

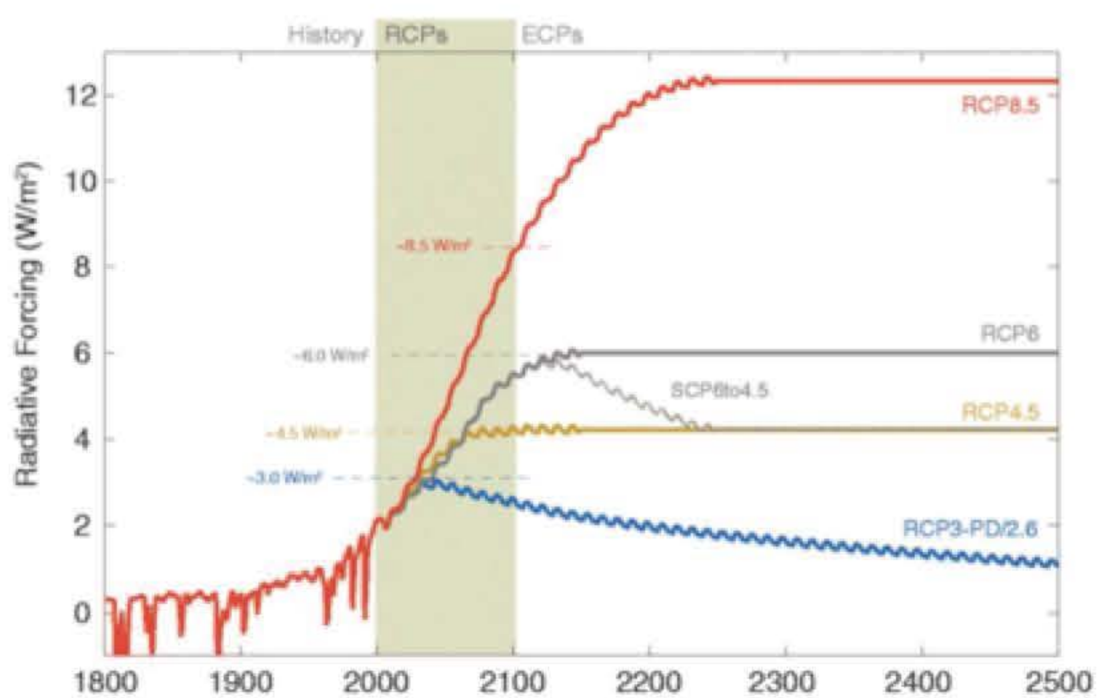


Figure 13. Radiative forcing for each of the Representative Concentration Pathways (RCPs). Revise to be consistPositive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures. An ~~increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures.~~ RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

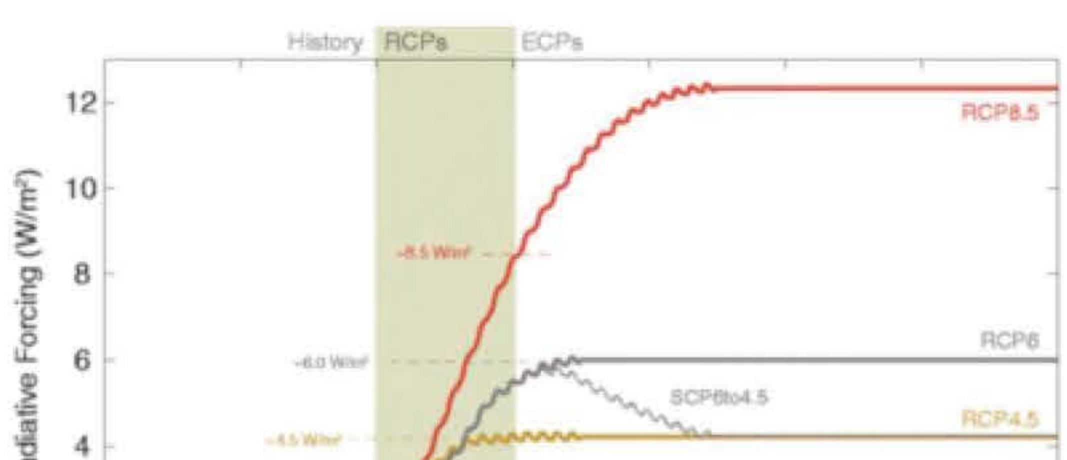
13 7 Attachment NPS attempted deletions Caffrey report 2018-02_6.pdf

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangan et al. (2016) found that emissions of greenhouse gases ~~from human activities~~ have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

> **Hoffman, Cat H.**
> Let's discuss

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.



14 Scientific resources on the term anthropogenic ....pdf

From:	Patrick Gonzalez NPS
To:	Raymond Sauvajot
Cc:	Guy Adema; Cat Hoffman; Maria Caffrey
Subject:	Scientific resources on the term anthropogenic climate change
Date:	Friday, March 09, 2018 5:41:38 PM
Attachments:	Anthropogenic climate change Web of Science title.pdf Anthropogenic climate change Web of Science text.pdf IPCC 2013 Anthropogenic climate change.pdf USGCRP 2017 Anthropogenic climate change.pdf Abatzoglou and Williams 2016.pdf

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Hi Ray,

Thank you for taking much time out of your schedule yesterday to discuss the NPS sea level rise report by Maria Caffrey, I'm writing to follow up on one point in the discussion.

I've compiled resources on the term anthropogenic climate change in the peer-reviewed scientific literature. I conducted searches on the Thomson Reuters Web of Science, which, as you know, is the authoritative database of peer-reviewed scientific journal articles and complied other key examples.

You'll find attached pdf files of:

1. Web of Science results of search on "anthropogenic climate change" in article title - 163 results total, list of 50 most recent

2. Web of Science results of search on "anthropogenic climate change" in article text - 1683 results total, list of 50 most recent

3. Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK. - one page illustration of one of the numerous uses of the phrase in the authoritative global scientific assessment of climate change

4. U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I. USGCRP, Washington, DC. - one page illustration of one of the numerous uses of the phrase in the authoritative U.S. Government assessment of climate change

5. Abatzoglou, J.T. and A.P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences of the USA 113: 11 770-11 775. - A key reference with the phrase in the title

This evidence clearly shows that anthropogenic climate change is a standard scientific term. Of course, it refers to the human cause of climate change, overwhelmingly supported by published scientific research.

I hope that you will find the attached files helpful in explaining to anyone who may need an explanation that it is a standard scientific term.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
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1. **An introduction to the special issue on the Benefits of Reduced Anthropogenic Climate changE (BRACE)**
By: O'Neill, Brian C.; Gettelman, Andrew
CLIMATIC CHANGE Volume: 146 Issue: 3-4 Special Issue: SI Pages: 277-285 Published: FEB 2018
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2. **The Benefits of Reduced Anthropogenic Climate changE (BRACE): a synthesis**
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CLIMATIC CHANGE Volume: 146 Issue: 3-4 Special Issue: SI Pages: 287-301 Published: FEB 2018
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3. **Emulating mean patterns and variability of temperature across and within scenarios in anthropogenic climate change experiments**
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CLIMATIC CHANGE Volume: 146 Issue: 3-4 Special Issue: SI Pages: 319-333 Published: FEB 2018
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4. **Extreme heat in India and anthropogenic climate change**
By: van Oldenborgh, Geert Jan; Philip, Sjoukje; Kew, Sarah; et al.
NATURAL HAZARDS AND EARTH SYSTEM SCIENCES Volume: 18 Issue: 1 Pages: 365-381 Published: JAN 24 2018
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5. **Soil organic carbon in savannas decreases with anthropogenic climate change**
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6. **Anthropogenic climate change detected in European renewable freshwater resources**

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NATURE CLIMATE CHANGE Volume: 7 Issue: 11 Pages: 813-+ Published: NOV 2017

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Times Cited: 0
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7. **A Hydrologic Drying Bias in Water-Resource Impact Analyses of Anthropogenic Climate Change**

By: Milly, P. C. D.; Dunne, Krista A.
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION Volume: 53 Issue: 4 Pages: 822-838 Published: AUG 2017

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8. **Plant species dispersed by Galapagos tortoises surf the wave of habitat suitability under anthropogenic climate change**

By: Ellis-Soto, Diego; Blake, Stephen; Soultan, Alaaeldin; et al.
PLOS ONE Volume: 12 Issue: 7 Article Number: e0181333 Published: JUL 20 2017

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9. **The changing hail threat over North America in response to anthropogenic climate change**

By: Brimelow, Julian C.; Burrows, William R.; Hanesiak, John M.
NATURE CLIMATE CHANGE Volume: 7 Issue: 7 Pages: 516-+ Published: JUL 2017

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10. **Impact of Anthropogenic Climate Change on the East Asian Summer Monsoon**

By: Burke, Claire; Stott, Peter
JOURNAL OF CLIMATE Volume: 30 Issue: 14 Pages: 5205-5220 Published: JUL 2017

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11. **Half of Students Interested in Civil Engineering Do Not Believe in Anthropogenic Climate Change**

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JOURNAL OF PROFESSIONAL ISSUES IN ENGINEERING EDUCATION AND PRACTICE Volume: 143 Issue: 3 Article Number: D4016003 Published: JUL 2017

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12. **Anthropogenic climate change has altered primary productivity in Lake Superior**

By: O'Beirne, M. D.; Werne, J. P.; Hecky, R. E.; et al.
NATURE COMMUNICATIONS Volume: 8 Article Number: 15713 Published: JUN 9 2017

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13. **Five years of REDD plus governance: The use of market mechanisms as a response to anthropogenic climate change**

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FOREST POLICY AND ECONOMICS Volume: 79 Special Issue: SI Pages: 8-16 Published: JUN 2017

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14. **Attribution of the Observed Spring Snowpack Decline in British Columbia to Anthropogenic Climate Change**

By: Najafi, Mohammad Reza; Zwiers, Francis; Gillett, Nathan
JOURNAL OF CLIMATE Volume: 30 Issue: 11 Pages: 4113-4130 Published: JUN 2017

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15. **Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events (vol 7, pg 45242, 2017)**

By: Mann, Michael E.; Rahmstorf, Stefan; Kornhuber, Kai; et al.
SCIENTIFIC REPORTS Volume: 7 Article Number: 46822 Published: MAY 26 2017

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16. **Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events**

By: Mann, Michael E.; Rahmstorf, Stefan; Kornhuber, Kai; et al.
SCIENTIFIC REPORTS Volume: 7 Article Number: 45242 Published: MAR 27 2017

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17. **Climatic microrefugia under anthropogenic climate change: implications for species redistribution**

By: Lenoir, Jonathan; Hattab, Tarek; Pierre, Guillaume
ECOGRAPHY Volume: 40 Issue: 2 Published: FEB 2017

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18. **Anthropogenic Climate Change is Urban not Modern: Towards an alternate critical urban geography**

By: Taylor, Peter J.; O'Brien, Geoff; O'Keefe, Phil
ACME-AN INTERNATIONAL E-JOURNAL FOR CRITICAL GEOGRAPHIES Volume: 16 Issue: 4 Pages: 781-803

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By: Armah, Frederick Ato; Yengoh, Genesis T.; Ung, Mengieng; et al.
JOURNAL OF ENVIRONMENTAL PLANNING AND MANAGEMENT   Volume: 60   Issue: 12   Pages: 2150-2173   Published: 2017

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20. **The growing role of methane in anthropogenic climate change**

By: Saunois, M.; Jackson, R. B.; Bousquet, P.; et al.
ENVIRONMENTAL RESEARCH LETTERS   Volume: 11   Issue: 12   Article Number: 120207   Published: DEC 2016

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21. **Impact of anthropogenic climate change on wildfire across western US forests**

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26. **The impact of SST biases on projections of anthropogenic climate change: A greater role for atmosphere-only models?**

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Environmental Research Letters Volume: 11 Issue: 7 Article Number: 074006 Published: JUL 2016

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PUBLIC UNDERSTANDING OF SCIENCE Volume: 25 Issue: 5 Pages: 560-575 Published: JUL 2016

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JOURNAL OF EXPERIMENTAL PSYCHOLOGY-GENERAL Volume: 145 Issue: 6 Pages: 755-771 Published: JUN 2016

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33. **Anthropogenic climate change affects meteorological drought risk in Europe**

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35. **Anthropogenic climate change drives shift and shuffle in North Atlantic phytoplankton communities**

By: Barton, Andrew D.; Irwin, Andrew J.; Finkel, Zoe V.; et al.
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA Volume: 113 Issue: 11 Pages: 2964-2969 Published: MAR 15 2016
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36. **Leveraging story telling, natural history, and spirituality to educate the public about anthropogenic climate change and ocean acidification**

By: Mcclintock, J. B.
Conference: Annual Meeting of the Society-for-Integrative-and-Comparative-Biology (SICB) Location: Portland, OR Date: JAN 03-07, 2016
Sponsor(s): Soc Integrat & Comparat Biol
INTEGRATIVE AND COMPARATIVE BIOLOGY Volume: 56 Supplement: 1 Pages: E332-E332 Meeting Abstract: P1.9 Published: MAR 2016

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37. **The responsibility narrative - anthropogenic climate change, migration as injury, and interference in place of reparation**

By: Mayer, Benoit
Book Author(s): Mayer, B
CONCEPT OF CLIMATE MIGRATION: ADVOCACY AND ITS PROSPECTS Book Series: Elgar Studies in Climate Law Pages: 186-255 Published: 2016

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By: Fasullo, J. T.; Lawrence, D. M.; Swenson, S. C.
ADVANCES IN METEOROLOGY Article Number: 4830603 Published: 2016

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- Climate models now include more cloud and aerosol processes, and their interactions, than at the time of the AR4, but there remains *low confidence* in the representation and quantification of these processes in models. {7.3, 7.6, 9.4, 9.7}

- There is robust evidence that the downward trend in Arctic summer sea ice extent since 1979 is now reproduced by more models than at the time of the AR4, with about one-quarter of the models showing a trend as large as, or larger than, the trend in the observations. Most models simulate a small downward trend in Antarctic sea ice extent, albeit with large inter-model spread, in contrast to the small upward trend in observations. {9.4}

- Many models reproduce the observed changes in upper-ocean heat content (0–700 m) from 1961 to 2005 (*high confidence*), with the multi-model mean time series falling within the range of the available observational estimates for most of the period. {9.4}

- Climate models that include the carbon cycle (Earth System Models) simulate the global pattern of ocean-atmosphere CO_2 fluxes, with outgassing in the tropics and uptake in the mid and high latitudes. In the majority of these models the sizes of the simulated global land and ocean carbon sinks over the latter part of the 20th century are within the range of observational estimates. {9.4}

D.2 Quantification of Climate System Responses

Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing. {Box 12.2, Box 13.1}

- The net feedback from the combined effect of changes in water vapour, and differences between atmospheric and surface warming is *extremely likely* positive and therefore amplifies changes in climate. The net radiative feedback due to all cloud types combined is *likely* positive. Uncertainty in the sign and magnitude of the cloud feedback is due primarily to continuing uncertainty in the impact of warming on low clouds. {7.2}

- The equilibrium climate sensitivity quantifies the response of the climate system to constant radiative forcing on multi-century time scales. It is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration. Equilibrium climate sensitivity is *likely* in the range 1.5°C to 4.5°C (*high confidence*), *extremely unlikely* less than 1°C (*high confidence*), and *very unlikely* greater than 6°C (*medium confidence*)[16]. The lower temperature limit of the assessed *likely* range is thus less than the 2°C in the AR4, but the upper limit is the same. This assessment reflects improved understanding, the extended temperature record in the atmosphere and ocean, and new estimates of radiative forcing. {TS TFE.6, Figure 1; Box 12.2}

- The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. Estimates of these quantities for recent decades are consistent with the assessed *likely* range of the equilibrium climate sensitivity to within assessed uncertainties, providing strong evidence for our understanding of anthropogenic climate change. {Box 12.2, Box 13.1}

- The transient climate response quantifies the response of the climate system to an increasing radiative forcing on a decadal to century timescale. It is defined as the change in global mean surface temperature at the time when the atmospheric CO_2 concentration has doubled in a scenario of concentration increasing at 1% per year. The transient climate response is *likely* in the range of 1.0°C to 2.5°C (*high confidence*) and *extremely unlikely* greater than 3°C. {Box 12.2}

- A related quantity is the transient climate response to cumulative carbon emissions (TCRE). It quantifies the transient response of the climate system to cumulative carbon emissions (see Section E.8). TCRE is defined as the global mean

[16] No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies.

14 4 Attachment USGCRP 2017 Anthropogenic climate change.pdf

ture was higher than normal in 2012 despite the surface drying, due to wet conditions in prior years, indicating the long time scales relevant below the surface.[22]

The recent California drought, which began in 2011, is unusual in different respects. In this case, the precipitation deficit from 2011 to 2014 was a result of the "ridiculously resilient ridge" of high pressure. This very stable high pressure system steered storms towards the north, away from the highly engineered California water resource system.[13, 23, 24] A slow-moving high sea surface temperature (SST) anomaly, referred to as "The Blob"—was caused by a persistent ridge that weakened the normal cooling mechanisms for that region of the upper ocean.[25] Atmospheric modeling studies showed that the ridge that caused The Blob was favored by a pattern of persistent tropical SST anomalies that were warm in the western equatorial Pacific and simultaneously cool in the far eastern equatorial Pacific.[23, 26] It was also favored by reduced arctic sea ice and from feedbacks with The Blob's SST anomalies.[27] These studies also suggest that internal variability likely played a prominent role in the persistence of the 2013–2014 ridge off the west coast of North America. Observational records are not long enough and the anomaly was unusual enough that similarly long-lived patterns have not been often seen before. Hence, attribution statements, such as that about an increasing anthropogenic influence on the frequency of geopotential height anomalies similar to 2012–2014 (e.g., Swain et al. 2014[24]), are without associated detection (Ch. 3: Detection and Attribution). A secondary attribution question concerns the anthropogenic precipitation response in the presence of this SST anomaly. In attribution studies with a prescribed 2013 SST anomaly, a consistent increase in the human influence on the chances of very dry California conditions was found.[18]

Anthropogenic climate change did increase the risk of the high temperatures in California in the winters of 2013–2014 and 2014–2015, especially the latter,[13, 28, 29] further exacerbating the soil moisture deficit and the associated stress on irrigation systems. This raises the question, as yet unanswered, of whether droughts in the western United States are shifting from precipitation control[30] to temperature control. There is some evidence to support a relationship between mild winter and / or warm spring temperatures and drought occurrence,[31] but long-term warming trends in the tropical and North Pacific do not appear to have led to trends toward less precipitation over California.[32] An anthropogenic contribution to commonly used measures of agricultural drought, including the Palmer Drought Severity Index (PDSI), was found in California[28, 33] and is consistent with previous projections of changes in PDSI[10, 34, 35] and with an attribution study.[36] Due to its simplicity, the PDSI has been criticized as being overly sensitive to higher temperatures and thus may exaggerate the human contribution to soil dryness.[37] In fact, this study also finds that formulations of potential evaporation used in more complicated hydrologic models are similarly biased, undermining confidence in the magnitude but not the sign of projected surface soil moisture changes in a warmer climate. Seager et al.[13] analyzed climate model output directly, finding that precipitation minus evaporation in the southwestern United States is projected to experience significant decreases in surface water availability, leading to surface runoff decreases in California, Nevada, Texas, and the Colorado River headwaters even in the near term. However, the criticisms of PDSI also apply to most of the CMIP5 land surface model evapotranspiration formulations. Analysis of soil moisture in the CMIP5 models at deeper levels is complicated by the wide variety in sophistication of their component land models. A pair of studies reveals less

14 5 Attachment Abatzoglou and Williams 2016.pdf

Impact of anthropogenic climate change on wildfire across western US forests

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Increased forest fire activity across the western continental United States (US) in recent decades has likely been enabled by a number of factors, including the legacy of fire suppression and human settlement, natural climate variability, and human-caused climate change. We use modeled climate projections to estimate the contribution of anthropogenic climate change to observed increases in eight fuel aridity metrics and forest fire area across the western United States. Anthropogenic increases in temperature and vapor pressure deficit significantly enhanced fuel aridity across western US forests over the past several decades and, during 2000–2015, contributed to 75% more forested area experiencing high (>1 σ) fire-season fuel aridity and an average of nine additional days per year of high fire potential. Anthropogenic climate change accounted for ∼55% of observed increases in fuel aridity from 1979 to 2015 across western US forests, highlighting both anthropogenic climate change and natural climate variability as important contributors to increased wildfire potential in recent decades. We estimate that human-caused climate change contributed to an additional 4.2 million ha of forest fire area during 1984–2015, nearly doubling the forest fire area expected in its absence. Natural climate variability will continue to alternate between modulating and compounding anthropogenic increases in fuel aridity, but anthropogenic climate change has emerged as a driver of increased forest fire activity and should continue to do so while fuels are not limiting.

wildfire | climate change | attribution | forests

Widespread increases in fire activity, including area burned (1, 2), number of large fires (3), and fire season length (4, 5), have been documented across the western United States (US) and in other temperate and high latitude ecosystems over the past half century (6, 7). Increased fire activity across western US forests has coincided with climatic conditions more conducive to wildfire (2 4, 8). The strong interannual correlation between forest fire activity and fire season fuel aridity, as well as observed increases in vapor pressure deficit (VPD) (9), fire danger indices (10), and climatic water deficit (CWD) (11) over the past several decades, present a compelling argument that climate change has contributed to the recent increases in fire activity. Previous studies have implicated anthropogenic climate change (ACC) as a contributor to observed and projected increases in fire activity globally and in the western United States (12 19), yet no studies have quantified the degree to which ACC has contributed to observed increases in fire activity in western US forests.

Changes in fire activity due to climate, and ACC therein, are modulated by the co occurrence of changes in land management and human activity that influence fuels, ignition, and suppression. The legacy of twentieth century fire suppression across western continental US forests contributed to increased fuel loads and fire potential in many locations (20, 21), potentially increasing the sensitivity of area burned to climate variability and change in recent decades (22). Climate influences wildfire potential primarily by modulating fuel abundance in fuel limited environments, and by modulating fuel aridity in flammability limited environments (1, 23, 24). We constrain our attention to climate processes that promote fuel aridity that encompass fire behavior characteristics of landscape ignitability, flammability, and fire spread via fuel desiccation in primarily flammability limited western US forests by considering eight fuel aridity metrics that have well established direct interannual relationships with burned area in this region (1, 8, 24, 25). Four metrics were calculated from monthly data for 1948 2015: (*i*) reference potential evapotranspiration (ETo), (*ii*) VPD, (*iii*) CWD, and (*iv*) Palmer drought severity index (PDSI). The other four metrics are daily fire danger indices calculated for 1979 2015: (*v*) fire weather index (FWI) from the Canadian forest fire danger rating system, (*vi*) energy release component (ERC) from the US national fire danger rating system, (*vii*) McArthur forest fire danger index (FFDI), and (*viii*) Keetch Byram drought index (KBDI). These metrics are further described in the *Materials and Methods* and *Supporting Information*. Fuel aridity has been a dominant driver of regional and subregional interannual variability in forest fire area across the western US in recent decades (2, 8, 22, 25). This study capitalizes on these relationships and specifically seeks to determine the portions of the observed increase in fuel aridity and area burned across western US forests attributable to anthropogenic climate change.

The interannual variability of all eight fuel aridity metrics averaged over the forested lands of the western US correlated significantly ($R^2 = 0.57$ 0.76, $P < 0.0001$; Table S1) with the logarithm of annual western US forest area burned for 1984 2015, derived from the Monitoring Trends in Burn Severity product for 1984 2014 and the Moderate Resolution Imaging Spectroradiometer (MODIS) for 2015 (*Supporting Information*). The record of standardized fuel aridity averaged across the eight metrics (hereafter, all metric mean) accounts for 76% of the variance in the burned area record, with significant increases in both records for 1984 2015 (Fig. 1). Correlation between fuel aridity and forest fire area remains highly significant ($R^2 = 0.72$, all metric mean) after removing the linear least squares trends for each time series for 1984 2015, supporting the mechanistic relationship between fuel aridity and

Significance

Increased forest fire activity across the western United States in recent decades has contributed to widespread forest mortality, carbon emissions, periods of degraded air quality, and substantial fire suppression expenditures. Although numerous factors aided the recent rise in fire activity, observed warming and drying have significantly increased fire-season fuel aridity, fostering a more favorable fire environment across forested systems. We demonstrate that human-caused climate change caused over half of the documented increases in fuel aridity since the 1970s and doubled the cumulative forest fire area since 1984. This analysis suggests that anthropogenic climate change will continue to chronically enhance the potential for western US forest fire activity while fuels are not limiting.

Author contributions: J.T.A. and A.P.W. designed research, performed research, contributed new reagents/analytic tools, analyzed data, and wrote the paper.

The authors declare no conflict of interest.

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See Commentary on page 11649.

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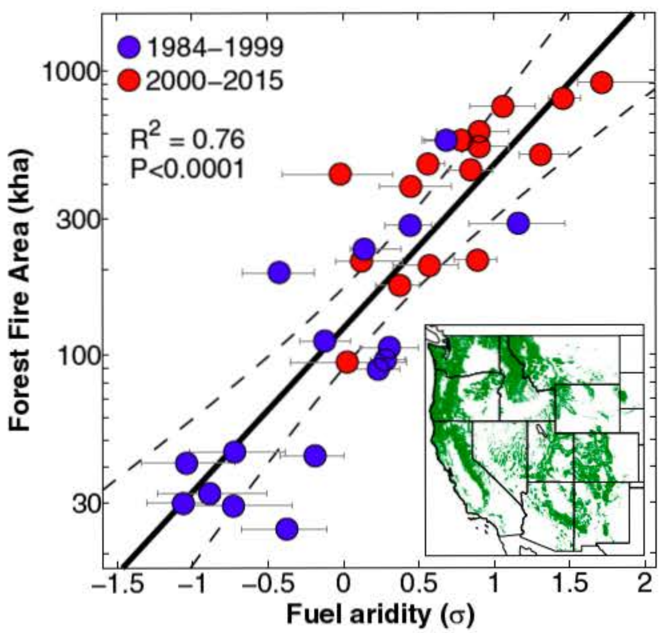

Fig. 1. Annual western continental US forest fire area versus fuel aridity: 1984 2015. Regression of burned area on the mean of eight fuel aridity metrics. Gray bars bound interquartile values among the metrics. Dashed lines bounding the regression line represent 95% confidence bounds, ex panded to account for lag 1 temporal autocorrelation and to bound the confidence range for the lowest correlating aridity metric. The two 16 y periods are distinguished to highlight their 3.3 fold difference in total forest fire area. *Inset* shows the distribution of forested land across the western US in green.

forest fire area. It follows that co occurring increases in fuel aridity and forest fire area over multiple decades would also be mechanistically related.

We quantify the influence of ACC using the Coupled Model Intercomparison Project, Phase 5 (CMIP5) multimodel mean changes in temperature and vapor pressure following Williams et al. (26) (Fig. S1; *Methods*). This approach defines the ACC signal for any given location as the multimodel mean (27 CMIP5 models) 50 y low pass filtered record of monthly temperature and vapor pressure anomalies relative to a 1901 baseline. Other anthropogenic effects on variables such as precipitation, wind, or solar radiation may have also contributed to changes in fuel aridity but anthropogenic contributions to these variables during our study period are less certain (22). We evaluate differences between fuel aridity metrics computed with the observational record and those computed with observations that exclude the ACC signal to determine the contribution of ACC to fuel aridity. To exclude the ACC signal, we subtract the ACC signal from daily and monthly temperature and vapor pressure, leaving all other variables unchanged and preserving the temporal variability of observations. The contribution of ACC to changes in fuel aridity is shown for the entire western United States; however, we constrain the focus of our attribution and analysis to forested environments of the western US (Fig. 1, *Inset*; *Methods*).

Anthropogenic increases in temperature and VPD contributed to a standardized (σ) increase in all metric mean fuel aridity av eraged for forested regions of +0.6 σ (range of +0.3 σ to +1.1 σ across all eight metrics) for 2000 2015 (Fig. 2). We found similar results with reanalysis products (all metric mean fuel aridity in crease of +0.6 σ for two reanalysis datasets considered; *Methods*), suggesting robustness of the results to structural uncertainty in observational products (Figs. S2 S4 and Table S2). The largest anthropogenic increases in standardized fuel aridity were present across the intermountain western United States, due in part to larger modeled warming rates relative to more maritime areas (27). Among aridity metrics, the largest increases tied to the ACC signal were for VPD and ETo because the interannual variability of these variables is primarily driven by temperature for much of the study area (28). By contrast, PDSI and ERC showed more subdued ACC driven increases in fuel aridity because these metrics are more heavily influenced by precipitation variability.

Fuel aridity averaged across western US forested areas showed a significant increase over the past three decades, with a linear trend of +1.2 σ (95% confidence: 0.42 2.0 σ) in the all metric mean for 1979 2015 (Fig. 3*A*, *Top* and Table S1). The all metric mean ACC contribution since 1901 was +0.10 σ by 1979 and +0.71 σ by 2015. The annual area of forested lands with high fuel aridity (>1 σ) increased significantly during 1948 2015, most notably since 1979 (Fig. 3*A*, *Bottom*). The observed mean annual areal extent of for ested land with high aridity during 2000 2015 was 75% larger for the all metric mean (+27% to +143% range across metrics) than was the case where the ACC signal was excluded.

Significant positive trends in fuel aridity for 1979 2015 across forested lands were observed for all metrics (Fig. 3*B* and Table S1). Positive trends in fuel aridity remain after excluding the ACC signal, but the remaining trend was only significant for ERC. Anthropogenic forcing accounted for 55% of the observed positive trend in the all metric mean fuel aridity during 1979 2015, including at least two thirds of the observed increase in ETo, VPD, and FWI, and less than a third of the observed in crease in ERC and PDSI. No significant trends were observed for monthly fuel aridity metrics from 1948 1978.

The duration of the fire weather season increased significantly across western US forests (+41%, 26 d for the all metric mean) during 1979 2015, similar to prior results (10) (Fig. 4*A* and Table S2). Our analysis shows that ACC accounts for ~54% of the in crease in fire weather season length in the all metric mean (15 79% for individual metrics). An increase of 17.0 d per year of high fire potential was observed for 1979 2015 in the all metric mean (11.7 28.4 d increase for individual metrics), over twice the rate of increase calculated from metrics that excluded the ACC signal (Fig. 4*B* and Table S2). This translates to an average of an addi tional 9 d (7.8 12.0 d) per year of high fire potential during 2000 2015 due to ACC.

Given the strong relationship between fuel aridity and annual western US forest fire area, and the detectable impact of ACC on fuel aridity, we use the regression relationship in Fig. 1 to model

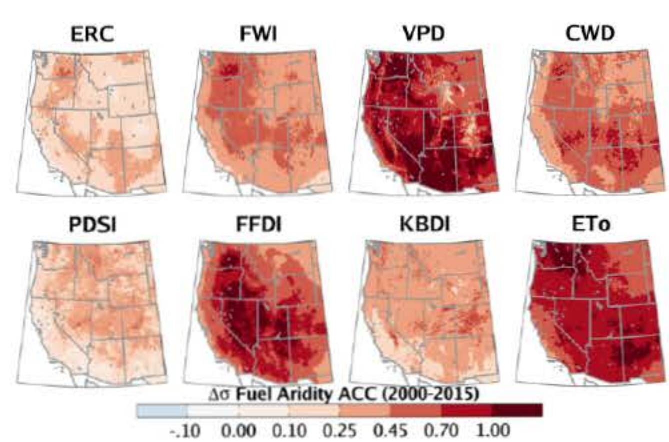

Fig. 2. Standardized change in each of the eight fuel aridity metrics due to ACC. The influence of ACC on fuel aridity during 2000 2015 is shown by the difference between standardized fuel aridity metrics calculated from observations and those calculated from observations excluding the ACC signal. The sign of PDSI is reversed for consistency with other aridity measures.

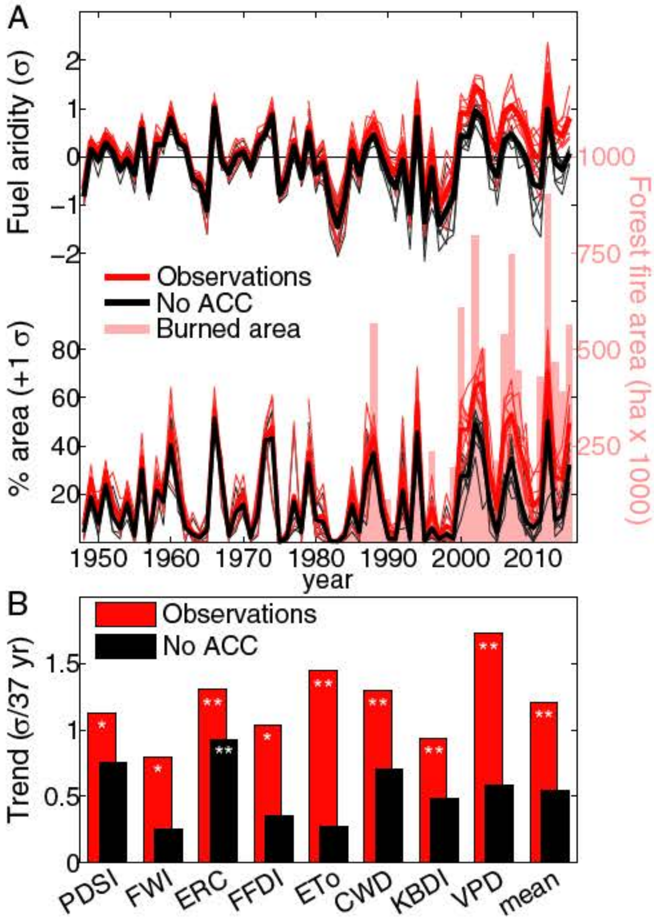

Fig. 3. Evolution and trends in western US forest fuel aridity metrics over the past several decades. (*A*) Time series of (*Upper*) standardized annual fuel aridity metrics and (*Lower*) percent of forest area with standardized fuel aridity exceeding one SD. Red lines show observations and black lines show records after exclusion of the ACC signal. Only the four monthly metrics extend back to 1948. Daily fire danger indices begin in 1979. Bold lines in dicate averages across fuel aridity metrics. Bars in the background of *A* show annual forested area burned during 1984 2015 for visual comparison with fuel aridity. (*B*) Linear trends in the standardized fuel aridity metrics during 1979 2015 for (red) observations and (black) records excluding the ACC signal (differences attributed to ACC). Asterisks indicate positive trends at the (*) 95% and (**) 99% significance levels.

the contribution of ACC on western US forest fire area for the past three decades (Fig. 5 and Fig. S5). ACC driven increases in fuel aridity are estimated to have added ~4.2 million ha (95% confidence: 2.7 6.5 million ha) of western US forest fire area during 1984 2015, similar to the combined areas of Massachusetts and Connecticut, accounting for nearly half of the total modeled burned area derived from the all metric mean fuel aridity. Re peating this calculation for individual fuel aridity metrics yields ACC contributions of 1.9 4.9 million ha, but most individual fuel aridity metrics had weaker correlations with burned area and thus may be less appropriate proxies for attributing burned area. The effect of the ACC forcing on fuel aridity increased during this period, contributing ~5.0 (95% confidence: 4.2 5.9) times more burned area in 2000 2015 than in 1984 1999 (Fig. 5*B*). During 2000 2015, the ACC forced burned area likely exceeded the burned area expected in the absence of ACC (Fig. 5*B*). A more conservative method that uses the relationship between detrended records of burned area and fuel aridity (2) still indicates a substantial impact of ACC on total burned area, with a 19% (95% confidence: 12 24%) reduction in the proportion of total burned area attributable to ACC (Fig. S5).

Our attribution explicitly assumes that anthropogenic increases in fuel aridity are additive to the wildfire extent that would have arisen from natural climate variability during 1984 2015. Because the influence of fuel aridity on burned area is exponential, the influence of a given ACC forcing is larger in an already arid fire season such as 2012 (Fig. 5*A* and Fig. S5*C*). Anthropogenic in creases in fuel aridity are expected to continue to have their most prominent impacts when superimposed on naturally occurring extreme climate anomalies. Although numerous studies have projected changes in burned area over the twenty first century due to ACC, we are unaware of other studies that have attempted to quantify the contribution of ACC to recent forested burned area over the western United States. The near doubling of forested burned area we attribute to ACC exceeds changes in burned area projected by some modeling efforts to occur by the mid twenty first century (29, 30), but is proportionally consistent with mid twenty first century increases in burned area projected by other modeling efforts (17, 31 33).

Beyond anthropogenic climatic changes, several additional factors have caused increases in fuel aridity and forest fire area since the 1970s. The lack of fuel aridity trends during 1948 1978 and persistence of positive trends during 1979 2015 even after removing the ACC signal implicates natural multidecadal climate variability as an important factor that buffered anthropogenic

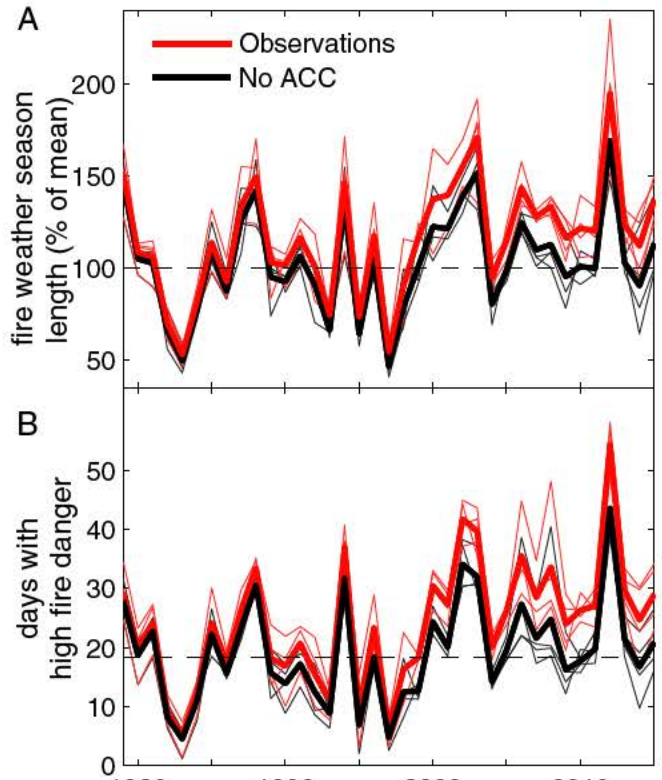

Fig. 4. Changes in fire weather season length and number of high fire danger days. Time series of mean western US forest (*A*) fire weather season length and (*B*) number of days per year when daily fire danger indices exceeded the 95th percentile. Baseline period: 1981 2010 using observa tional records that exclude the ACC signal. Red lines show the observed record, and black lines show the record that excludes the ACC signal. Bold lines show the average signal expressed across fuel aridity metrics.

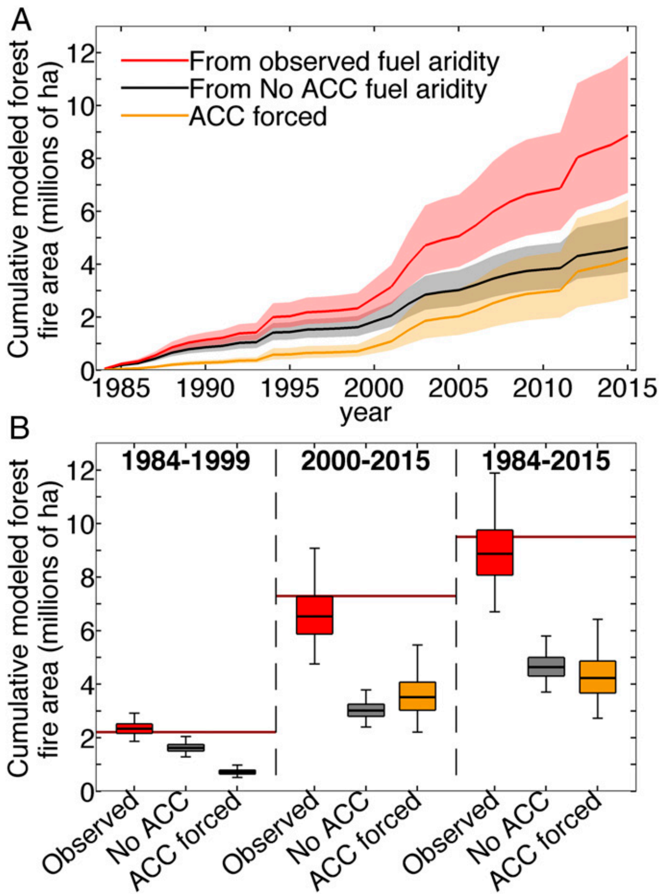

Fig. 5. Attribution of western US forest fire area to ACC. Cumulative forest fire area estimated from the (red) observed all metric mean record of fuel aridity and (black) the fuel aridity record after exclusion of ACC (No ACC). The (orange) difference is the forest fire area forced by anthropogenic in creases in fuel aridity. Bold lines in *A* and horizontal lines within box plots in *B* indicate mean estimated values (regression values in Fig. 1). Boxes in *B* bound 50% confidence intervals. Shaded areas in *A* and whiskers in *B* bound 95% confidence intervals. Dark red horizontal lines in *B* indicate observed forest fire area during each period.

effects during 1948 1978 and compounded anthropogenic effects during 1979 2015. During 1979 2015, for example, observed Mar Sep vapor pressure decreased significantly across many US forest areas, in marked contrast to modeled anthropogenic in creases (Fig. S6) (34). Significant declines in spring (Mar May) precipitation in the southwestern United States and summer (Jun Sep) precipitation throughout parts of the northwestern United States during 1979 2015 (Fig. S7 *A* and *B*) hastened in creases in fire season fuel aridity, consistent with observed in creases in the number of consecutive dry days across the region (10). Natural climate variability, including a shift toward the cold phase of the interdecadal Pacific Oscillation (35), was likely the dominant driver of observed regional precipitation trends (36) (Fig. S7 *B* and *D*).

Our quantification of the ACC contribution to observed in creases in forest fire activity in the western United States adds to the limited number of climate change attribution studies on wildfire to date (37). Previous attribution efforts have been re stricted to a single GCM and biophysical variable (14, 16). We complement these studies by demonstrating the influence of ACC derived from an ensemble of GCMs on several biophysical metrics that exhibit strong links to forest fire area. However, our attribution effort only considers ACC to manifest as trends in mean climate conditions, which may be conservative because cli mate models also project anthropogenic increases in the temporal variability of climate and drought in the western United States (34, 38, 39). In focusing exclusively on the direct impacts of ACC on fuel aridity, we do not address several other pathways by which ACC may have affected wildfire activity. For example, the fuel aridity metrics that we used may not adequately capture the role of mountain snow hydrology on soil moisture. Nor do we account for the influence of climate change on lightning activity, which may increase with warming (40). We also do not account for how fire risk may be affected by changes in biomass/fuel due to increases in atmospheric CO_2 (41), drought induced vegetation mortality (42), or insect outbreaks (43).

Additionally, we treat the impact of ACC on fire as inde pendent from the effects of fire management (e.g., suppression and wildland fire use policies), ignitions, land cover (e.g., exur ban development), and vegetation changes beyond the degree to which they modulate the relationship between fuel aridity and forest fire area. These factors have likely added to the area burned across the western US forests and potentially amplified the sensitivity of wildfire activity to climate variability and change in recent decades (2, 22, 24, 44). Such confounding influences, along with nonlinear relationships between burned area and its drivers (e.g., Fig. 1), contribute uncertainty to our empirical attri bution of regional burned area to ACC. Our approach depends on the strong observed regional relationship between burned area and fuel aridity at the large regional scale of the western United States, so the quantitative results of this attribution effort are not nec essarily applicable at finer spatial scales, for individual fires, or to changes in nonforested areas. Dynamical vegetation models with embedded fire models show emerging promise as tools to diagnose the impacts of a richer set of processes than those considered here (41, 45) and could be used in tandem with empirical approaches (46, 47) to better understand contributions of observed and pro jected ACC to changes in regional fire activity. However, dynamic models of vegetation, human activities, and fire are not without their own lengthy list of caveats (2). Given the strong empirical relationship between fuel aridity and wildfire activity identified here and in other studies (1, 2, 4, 8), and substantial increases in western US fuel aridity and fire weather season length in recent decades, it appears clear from empirical data alone that increased fuel aridity, which is a robustly modeled result of ACC, is the proximal driver of the observed increases in western US forest fire area over the past few decades.

Conclusions

Since the 1970s, human caused increases in temperature and vapor pressure deficit have enhanced fuel aridity across western continental US forests, accounting for approximately over half of the observed increases in fuel aridity during this period. These anthropogenic increases in fuel aridity approximately doubled the western US forest fire area beyond that expected from nat ural climate variability alone during 1984 2015. The growing ACC influence on fuel aridity is projected to increasingly pro mote wildfire potential across western US forests in the coming decades and pose threats to ecosystems, the carbon budget, human health, and fire suppression budgets (13, 48) that will collectively encourage the development of fire resilient land scapes (49). Although fuel limitations are likely to eventually arise due to increased fire activity (17), this process has not yet substantially disrupted the relationship between western US forest fire area and aridity. We expect anthropogenic climate change and associated increases in fuel aridity to impose an in creasingly dominant and detectable effect on western US forest fire area in the coming decades while fuels remain abundant.

Methods

We focus on climate variables that directly affect fuel moisture over forested areas of the western continental United States, where fire activity tends to be flammability limited rather than fuel or ignition limited (1) (study region shown in Fig. 1, *Inset*). There are a variety of climate based metrics that have been used as proxies for fuel aridity, yet there is no universally preferred metric across different vegetation types (24). We consider eight frequently used fuel aridity metrics that correlate well with fire activity variables, including annual burned area (Fig. 1 and Table S1), in western US forests.

Fuel aridity metrics are calculated from daily surface meteorological data (50) on a 1/24° grid for 1979 2015 for the western United States (west of 103°W). Although we calculated metrics across the entire western United States, we focus on forested lands defined by the climax succession vegetation stages of "forest" or "woodland" in the Environmental Site Potential product of LANDFIRE (landfire.gov). Forested 1/24° grid cells are defined by at least 50% forest coverage aggregated from LANDFIRE. We extended the aridity metrics calculated at the monthly timescale (ETo, VPD, CWD, and PDSI) back to 1948 using monthly anomalies relative to a common 1981 2010 period from the dataset developed by the Parameterized Regression on Independent Slopes Model group (51) for temperature, precipitation, and vapor pressure, and by bilinearly interpolating NCEP NCAR reanalysis for wind speed and surface solar radiation. We aggregated data to annualized time series of mean May Sep daily FWI, KBDI, ERC, and FFDI; Mar Sep VPD and ETo; Jun Aug PDSI; and Jan Dec CWD. We also calculated the aridity metrics strictly from ERA INTERIM and NCEP NCAR reanalysis products for 1979 2015 covering the satellite era (*Supporting Information*).

Days per year of high fire potential are quantified by daily fire danger indices (ERC, FWI, FFDI, and KBDI) that exceed the 95th percentile threshold defined during 1981 2010 from observations after removing the ACC signal. Observational studies have shown that fire growth preferentially occurs during high fire danger periods (52, 53). We also calculate the fire weather season length for the four daily fire danger indices following previous studies (10).

The ACC signal is obtained from ensemble members taken from 27 CMIP5 global climate models (GCMs) regridded to a common 1° resolution for 1850 2005 using historical forcing experiments and for 2006 2099 using the Representative Concentration Pathway (RCP) 8.5 emissions scenario (Table S3 and *Supporting Information*). These GCMs were selected based on availability of monthly outputs for maximum and minimum daily temperature (T_{max} and T_{min}, respectively), specific humidity (*huss*), and surface pressure. Saturation vapor pressure (e_s), vapor pressure (e), and VPD were calculated using standard methods (*Supporting Information*). A variety of approaches exist to estimate the ACC signal (26). We define the anthropogenic signals in T_{max}, T_{min}, e, e_s, VPD, and relative humidity by a 50 y low pass filter time series (using a 10 point Butterworth filter) averaged across the 27 GCMs using the following methodology: For each GCM, variable, month, and grid cell, we converted each annual time series to anomalies relative to a 1901 2000 baseline. We averaged annual anomalies across all realizations (model runs) for each GCM and calculated a single 50 y low pass filter annual time series for each of the 12 mo for 1850 2099. We averaged each month's low pass filtered time series across the 27 GCMs and additively adjusted so that all smoothed records pass through zero in 1901. The resultant ACC signal represents the CMIP5 modeled anthropogenic impact since 1901 for each variable, grid cell, and month (*Supporting Information*).

We bilinearly interpolated the 1° CMIP5 multimodel mean 50 y low pass time series to the 1/24° spatial resolution of the observations and subtracted the ACC signal from the observed daily and monthly time series. We consider the remaining records after subtraction of the ACC signal to indicate climate records that are free of anthropogenic trends (26).

Annual variations in fuel aridity metrics are presented as standardized anomalies (σ) to accommodate differences across geography and metrics. All fuel aridity metrics are standardized using the mean and SD from 1981 to 2010 for observations that excluded the ACC signal. Although the selection of a reference period can bias results (54), our findings were similar when using the full 1979 2015 time period or the observed data (without removal of ACC) for the reference period. The influence of anthropogenic forcing on fuel aridity metrics is quantified as the difference between metrics calculated with observations and those calculated with observations that excluded the ACC signal. Area weighted standardized anomalies and the spatial extent of western US forested land that experienced high (>1 σ) aridity are computed for each aridity metric. Annualized burned area as well as aggregated fuel aridity metrics calculated with data from ref. 50 and the two reanalysis products are provided in Datasets S1 S3.

We use the regression relationship between the annual western US forest fire area and the all metric mean fuel aridity index in Fig. 1 to estimate the forcing of anthropogenic increases in fuel aridity on forest fire area during 1984 2015. Uncertainties in the regression relationship due to imperfect correlation and temporal autocorrelation are propagated as estimated confidence bounds on the anthropogenic forcing of forest fire area. This approach was repeated using a more conservative definition of the regression relationship, where we removed the linear least squares trend for 1984 2015 from both the area burned and fuel aridity time series before regression to reduce the possibility of spurious correlation due to common but unrelated trends (Fig. S5). Statistical significance of all linear trends and correlations reported in this study are assessed using both Spearman's rank and Kendall's tau statistics. Trends are considered significant if both tests yield $P < 0.05$.

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Supporting Information

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Fuel Aridity Metrics

We use eight metrics as proxies for fuel aridity that have established interannual links to area burned in forested systems: (*i*) reference evapotranspiration (ETo) (55, 56), (*ii*) vapor pressure deficit (VPD) (25), (*iii*) fire weather index (FWI) from the Canadian forest fire danger rating system (57), (*iv*) energy release component (ERC) from the US national fire danger rating system (8), (*v*) climatic water deficit (CWD) (17), (*vi*) McArthur forest fire danger index (FFDI) (10), (*vii*) Keetch Byram drought index (KBDI) (25), and (*viii*) Palmer drought severity index (PDSI) (58). Each metric varies in terms of its input requirements, serial correlation, and sensitivity to the driving meteorological fields (59 61).

Daily surface meteorological data from ref. 50 are used to calculate the fuel aridity metrics. These data combine the tem poral attributes and multiple variables from the North American Land Data Assimilation System 2 meteorological forcing dataset (NLDAS2; ref. 62) and the spatial attributes of the monthly dataset developed by the Parameterized Regression on Independent Slopes Model (PRISM) group at Oregon State University (51).

Monthly climate data are used to calculate PDSI, ETo, CWD, and VPD. We calculate ETo using the Penman Monteith method (63). PDSI is calculated using monthly ETo, precipitation, and soil water holding capacity derived from State Soil Geographic (STATGO) database and aggregated to the 1/24° grid (26). CWD is calculated using a monthly water balance runoff model that has been modified to account for snowpack dynamics (11, 64).

Monthly mean vapor pressure (e) is estimated from monthly mean specific humidity and an estimate of surface pressure based on elevation (63). Monthly mean saturation vapor pressure (e_s) is calculated from mean daily maximum and minimum temperature (T_{max} and T_{min}, respectively), resulting in maximum and minimum saturation vapor pressure values ($e_{s\ max}$ and $e_{s\ min}$, respectively). Monthly mean e_s is calculated as the mean of $e_{s\ max}$ and $e_{s\ min}$. Monthly mean VPD is calculated as e_s minus e.

Daily meteorological fields are used to calculate ERC, FWI, KBDI, and FFDI. ERC is an output of the US national fire danger rating system and represents the potential daily fire intensity for a static fuel type [we use model G (65), which is dense conifer with heavy fuels] exposed to the cumulative drying effect on the 100 and 1,000 h fuels forced by temperature, precipitation, relative humidity, and solar radiation (66). The FWI is an output of the Canadian forest fire danger rating system that integrates several fire danger indices to provide a numerical rating of frontal fire intensity that accounts for fuel dryness and potential fire spread. KBDI is a proxy for the cumulative soil moisture deficit calculated using precipitation, temperature, and latitude. The FFDI is an em pirical approach for assessing fire danger developed in Australia that uses temperature, wind speed, humidity, and a drought factor (67, 68). To accommodate the requirements of ERC and FWI that incorporate observations at 1300 and 1200 local standard time, respectively, we use daily T_{max} and minimum relative humidity. Each fire danger index has different input requirements and sensitivities to changes in individual meteorological variables. For example, wind speed has no impact on calculated ERC or KBDI, but does impact FWI and FFDI.

We repeated our analyses using the European Centre for Medium Range Weather Forecasts Re Analysis Interim (ERA INTERIM) and National Centers for Environmental Prediction National Center for Atmospheric Research (NCEP NCAR) reanalysis products to assess structural uncertainty in observa tions and the resultant impact on our study. Reanalyses from ERA INTERIM and NCEP NCAR are acquired at 0.75 and 2.5 degree spatial resolution, respectively. Daily maximum and mini mum relative humidity are not readily available from reanalysis, and are instead estimated using daily mean specific humidity (or dew point temperature) and maximum and minimum temperature (69). Any biases in estimated relative humidity imparted by this approach should not substantially impact calculated trends. Forest or wood land cover from the Environmental Site Potential product of LANDFIRE are aggregated up to the native resolution of ERA INTERIM, where ERA INTERIM grid cells are considered for ested if composed of at least 50% woodland or forest. To maintain relatively similar spatial coverage across reanalysis products, we bilinearly interpolate aggregated forest cover from the ERA INTERIM grid to the NCEP NCAR grid.

Fig. S7 *A* and *B* shows linear least squares trends in 250 hPa geopotential height and precipitation for 1979 2015 for Mar May and Jun Sep. Geopotential height trends are computed using data from ERA INTERIM reanalysis products. Seasonal precipitation trends are computed using data from PRISM (product version AN81m: M3) (51).

Annual time series of standardized fuel aridity indices, number of days per year of high fire danger, and fire weather season length aggregated for western US forested areas, both based on ob servations and based on observations after exclusion of the anthropogenic climate signal are provided in Supplemental Datasets S1 S3.

Fire Data

Satellite derived burned area for 1984 2014 are obtained from the Monitoring Trends in Burn Severity (MTBS; ref. 70). This re cord consists of only large wildfires at least 404 ha in size, but these fires account for over 92% of the total burned area in forests across the western United States (2). Area burned for 2015 is estimated using the MODIS burned area product version 5.1 (71). MODIS annual burned area values were bias corrected to the MTBS record across the overlap period (2001 2014). Annual records of the log arithm of western US forest fire area derived from MTBS and MODIS were highly correlated (r = 0.97, P < 0.01) during the overlap period.

Climate Models

We obtained monthly means of daily 2 m T_{max} (*tasmax*), T_{max} (*tasmin*), specific humidity (*huss*), and surface pressure (*ps*) from available ensemble members of 27 GCMs participating in the fifth phase of the Climate Model Intercomparison Project (Table S3). We appended historical model simulations for 1850 2005 with simulations for experiment RCP8.5 for 2006 2099 (72). CMIP5 models were used to obtain an anthropogenic climate signal that could be removed from the observational record. In addition, we evaluated CMIP5 trends in seasonal precipitation (*pr*) and 250 hPa geopotential height (gz_{250}) for 39 models to evaluate the mag nitude of anthropogenic impacts on precipitation during 1979 2015 relative to observed trends during this period.

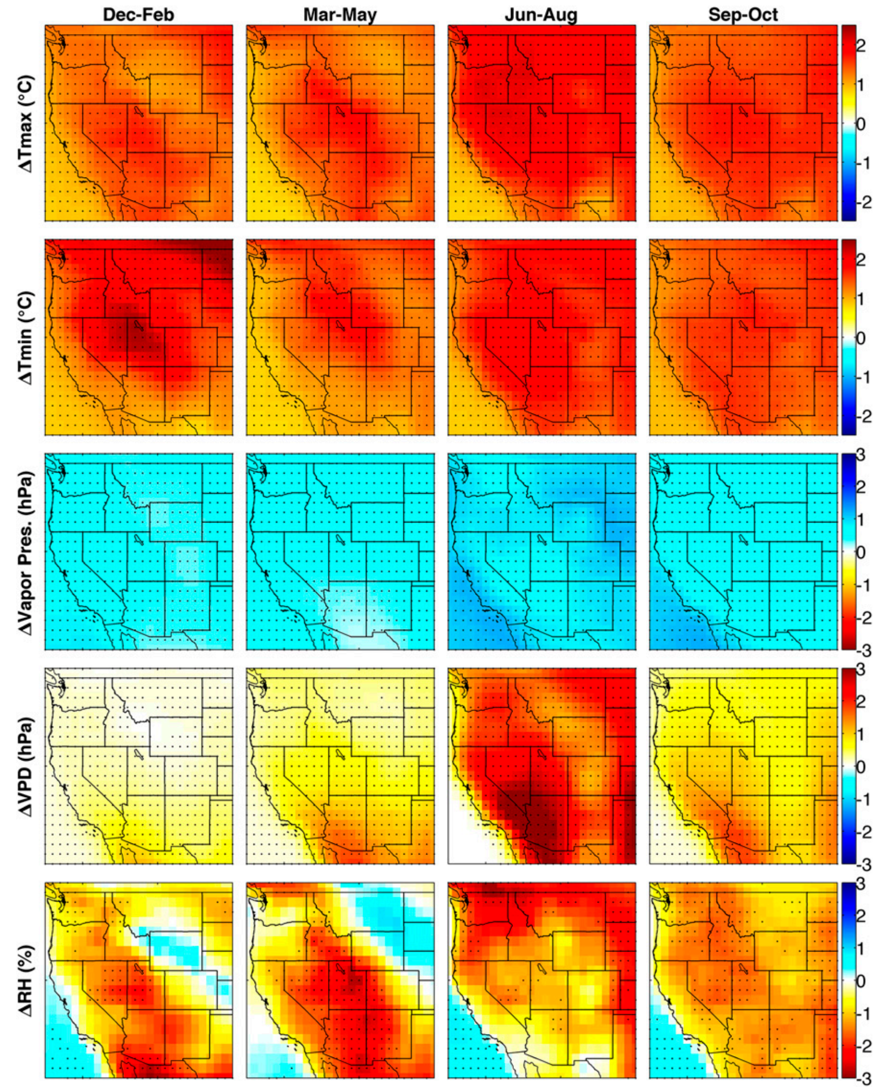

Fig. S1. Multimodel mean anthropogenic climate change signal of 50 y smoothed values for 2015 minus those for 1901 for (*Left* to *Right*) Dec Feb, Mar May, Jun Aug, and Sep Nov for (*Top* to *Bottom*) maximum temperature, minimum temperature, vapor pressure, vapor pressure deficit, mean relative humidity, maximum relative humidity, and minimum relative humidity. Black dots show grid cells where at least 20 (>74%) of the 27 models agree on the direction of the trend.

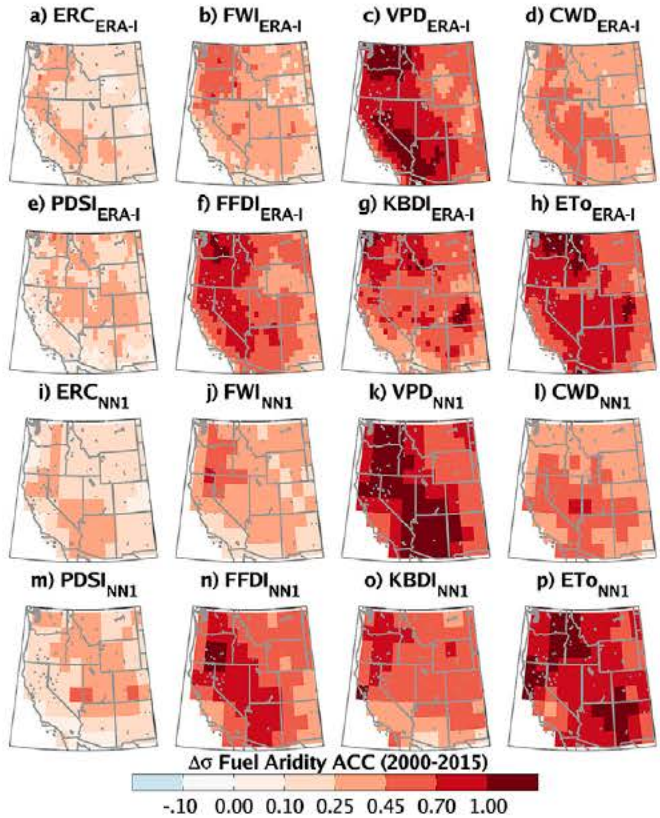

Fig. S2. As in Fig. 2 but for (*A H*) ERA INTERIM and (*I P*) NCEP NCAR reanalysis. The influence of ACC on fuel aridity during 2000 2015 is shown by the difference between standardized fuel aridity metrics calculated from observations and those calculated from observations excluding the ACC signal. The sign of PDSI is reversed for consistency with other aridity measures.

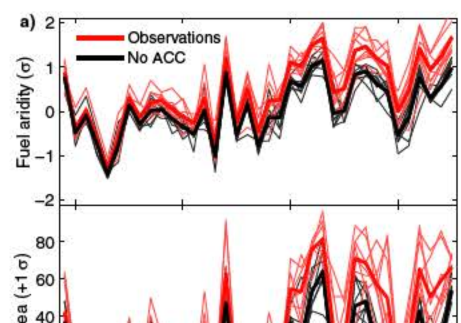

Fig. S3. As in Fig 3 but for ERA INTERIM. (*A*) Time series of (*Top*) standardized annual fuel aridity metrics and (*Bottom*) percent of forest area with standardized fuel aridity exceeding one SD. Red lines show observations and black lines show records after exclusion of the ACC signal. Only the four monthly metrics extend back to 1950. Daily fire danger indices are constrained to 1979 2015. Bold lines indicate averages across fuel aridity metrics. (*B*) Linear trends in the standardized fuel aridity metrics during 1979 2015 for (red) observations and (black) records excluding the ACC signal (black). Asterisks indicate positive trends at the (*) 95% and (**) 99% significance levels.

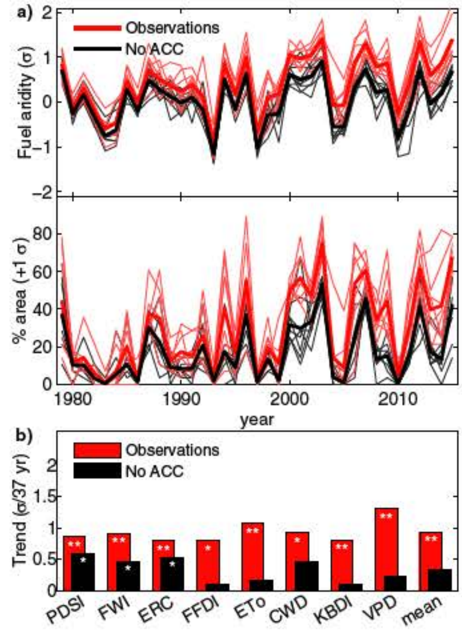

Fig. S4. As in Fig 3 but for NCEP NCAR reanalysis. (*A*) Time series of (*Top*) standardized annual fuel aridity metrics and (*Bottom*) percent of forest area with standardized fuel aridity exceeding one SD. Red lines show observations and black lines show records after exclusion of the ACC signal. Only the four monthly metrics extend back to 1950. Daily fire danger indices are constrained to 1979 2015. Bold lines indicate averages across fuel aridity metrics. (*B*) Linear trends in the standardized fuel aridity metrics during 1979 2015 for (red) observations and (black) records excluding the ACC signal (black). Asterisks indicate positive trends at the (*) 95% and (**) 99% significance levels.

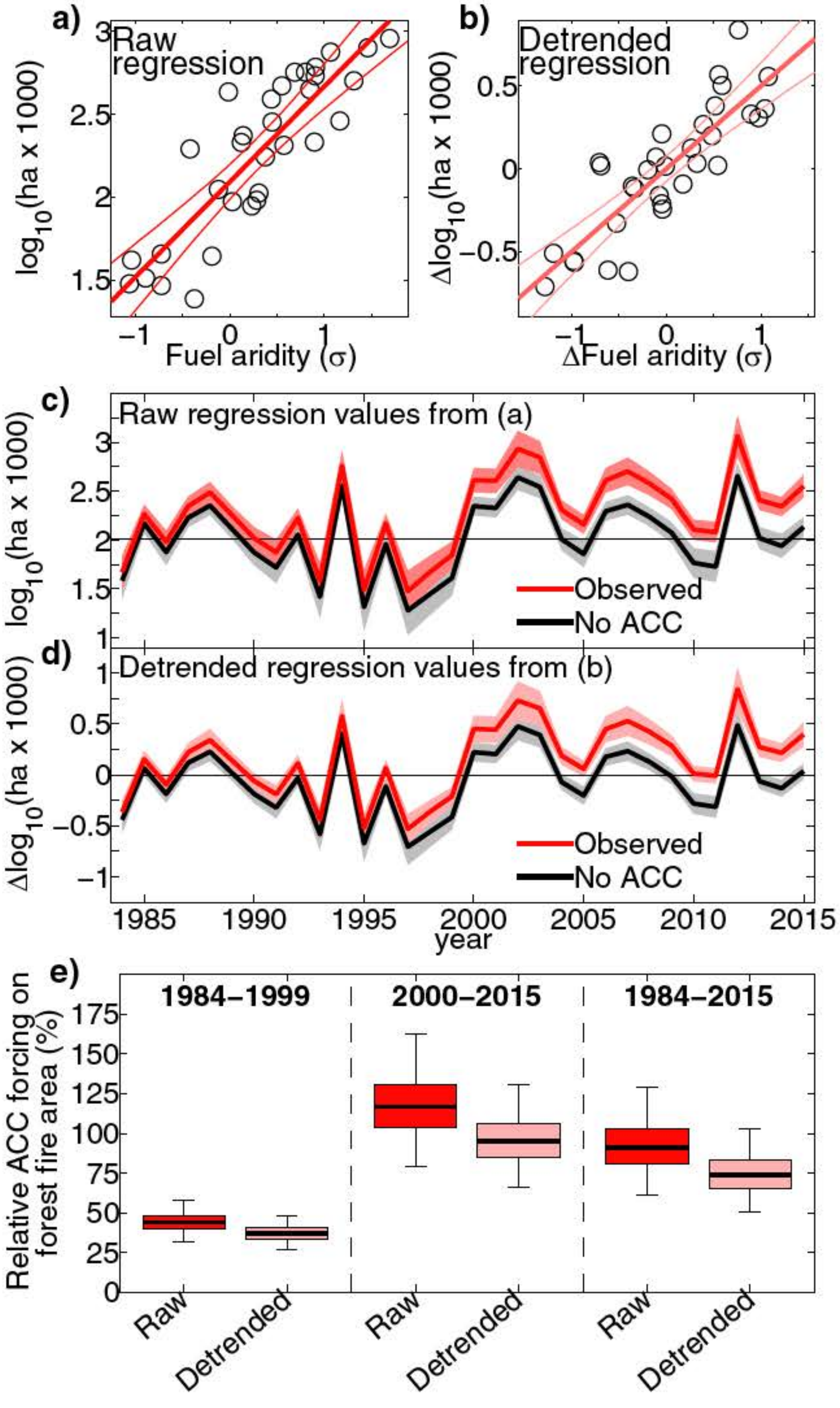

Fig. S5. Relationships between all metric mean fuel aridity anomalies and burned area in western US forests (*A* and *B*) are used to model the annual response of forest fire area to fuel aridity (*C* and *D*) under observed fuel aridity conditions and those recalculated after the removal of ACC. Two methods are used to derive the response of forest fire area: (*A*) derived from raw data (as presented in the article) and (*B*) derived from detrended data for 1984 2015. This al ternate approach is more conservative because it reduces risk of assuming an artificially strong relationship caused by common but unrelated trends. (*E*) The estimated relative forcing of ACC on cumulative burned area, calculated as the relative difference between burned area modeled from observed fuel aridity and burned area modeled in the absence of ACC. In *A D*, areas bounding the central lines correspond to 95% confidence intervals around the regression lines. In *E*, boxes and whiskers indicate 50% and 95% confidence intervals, respectively.

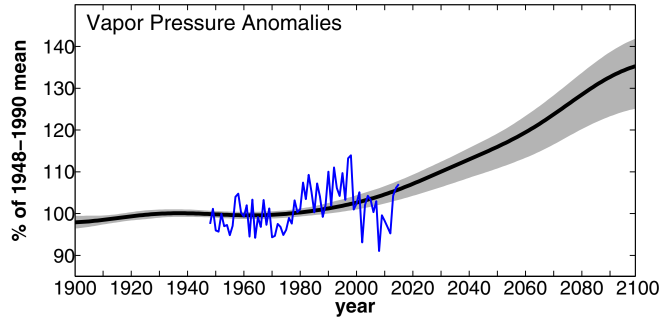

Fig. S6. Observations (blue) versus CMIP5 projections (black and gray) of March September vapor pressure anomalies (relative to 1948 1990 mean) in western US forest areas. Thick black line is the multimodel (n = 27) mean and gray area bounds the interquartile values. CMIP5 projections have had a 50 y low pass filter applied to exclude high frequency variations caused by natural climate variability.

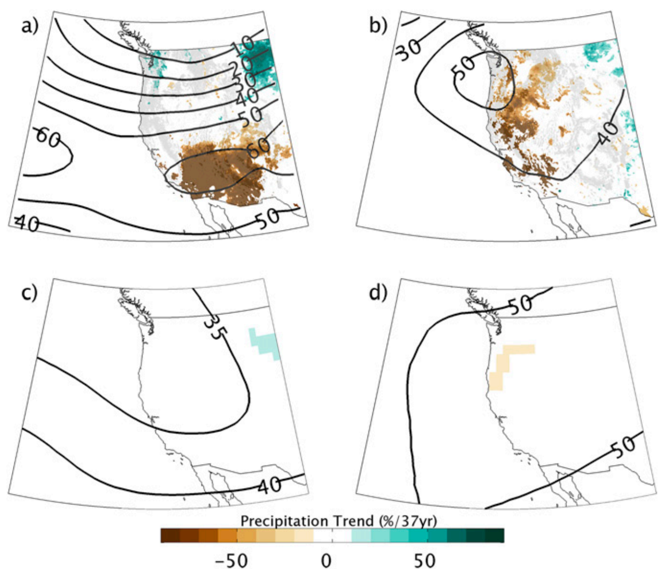

Fig. S7. Linear trend in (*A*) March May, and (*B*) June September (contours) 250 hPa geopotential height (in meters, data source: ERA INTERIM) and (back ground) precipitation (percent of 1979 2015 average, data source: PRISM an81m) during 1979 2015. Only precipitation trends significant at the $P < 0.1$ level are shown. *Lower* shows CMIP5 ensemble mean trends for the same variables during 1979 2015 for (*C*) March May and (*B*) June September (n = 39 models). For precipitation, trends are only shown if at least 75% of models agree on the sign of the trend. Trends are reported in units per 37 y. The location of western US forests is shown in gray in *A* and *B*.

Table S1. Pearson's correlation coefficients between standardized fuel aridity metrics and log-10 area burned (1984–2015), and linear change in in the standardized duel aridity metrics during 1979–2015

Metric	gridMET	No ACC gridMET	ERA I	No ACC ERA I	NN1	No ACC NN1
Interannual correlation with log 10 of area burned						
PDSI	0.76**	0.71**	0.74**	0.72**	0.72**	0.67**
FWI	0.80**	0.71**	0.87**	0.86**	0.75**	0.69**
ERC	0.87**	0.85**	0.86**	0.85**	0.75**	0.71**
FFDI	0.83**	0.74**	0.86**	0.85**	0.76**	0.64**
ETo	0.81**	0.65**	0.82**	0.73**	0.71**	0.54**
CWD	0.87**	0.81**	0.87**	0.85**	0.78**	0.72**
KBDI	0.80**	0.74**	0.79**	0.73**	0.73**	0.60**
VPD	0.87**	0.77**	0.83**	0.81**	0.75**	0.60**
MEAN	0.87**	0.79**	0.87**	0.85**	0.80**	0.70**
Linear trend in standardized fuel aridity metric per 37 years						
PDSI	1.12*	0.75	1.28**	1.03**	0.86**	0.59*
FWI	0.79*	0.25	1.64**	1.15**	0.91**	0.46*
ERC	1.30**	0.93**	1.61**	1.34**	0.79**	0.52*
FFDI	1.04*	0.35	2.03**	1.18**	0.79*	0.10
ETo	1.45**	0.27	1.81**	0.86*	1.07**	0.16
CWD	1.30**	0.70	1.63**	1.22**	0.92*	0.47
KBDI	0.94**	0.49	1.63**	0.72*	0.80**	0.09
VPD	1.73**	0.58	2.24**	1.26**	1.30**	0.23
MEAN	1.21**	0.54	1.73**	1.10**	0.93**	0.33

Units of the trends are SDs per 37 y, as in Fig. 3. Columns labeled as "No ACC" indicate that these variables have been recalculated after subtraction of the CMIP5 ensemble mean trends in temperature and vapor pressure. Correlations and trends are shown using the gridded meteorological dataset (gridMET) (50), ERA INTERIM (ERA I), and NCEP NCAR (NN1). Asterisks indicate significance at the (*) 95% and (**) 99% levels. Significance was evaluated using a two tailed test for correlations and a single tailed test for trends.

Table S2. Linear trend in the relative fire weather season length and number of days of high fire potential (exceeding the 95th percentile of observations) per 37 y averaged over western forests from 1979 to 2015

Metric	gridMET	No ACC gridMET	ERA I	No ACC ERA I	NN1	No ACC NN1
Trend in fire weather season length (percent) per 37 years						
KBDI	50.0%*	20.7%	80.6**	37.3%*	13.7%	4.2%
FFDI	37.1%*	7.9%	57.8%**	34.3%**	19.5%*	0.5%
FWI	33.6%*	9.3%	57.7%**	41.3%**	25.1%**	11.7%
ERC	45.1%**	38.4%**	45.3%**	40.5%**	19.5%**	16.6%*
MEAN	41.4%*	19.1%	60.4%**	38.3%**	19.5%*	5.8%
Trend in number of days with high fire potential per 37 years						
KBDI	12.7*	4.9	26.0**	10.0	11.3	2.9
FFDI	15.1**	3.2	19.8**	8.0*	4.3	4.2
FWI	11.7*	2.9	17.1**	11.2**	6.4*	2.7
ERC	28.4**	20.0**	32.2**	24.1**	10.7*	2.6
MEAN	17.0**	7.8	23.8**	13.3**	8.2*	0.3

Columns labeled as "No ACC" indicate that these variables have been recalculated after subtraction of the CMIP5 ensemble mean trends in temperature and vapor pressure. Trends are shown using the gridded meteorological dataset (gridMET) (50), ERA INTERIM (ERA I), and NCEP NCAR (NN1). Asterisks indicate significant trends at the (*) 95% and (**) 99% levels. Significance was evaluated using a single tailed test for trends.

Table S3. List of the 39 climate models from the CMIP5 used in the study

	Resolution	Variables		Ensemble size	
Name	lat x lon	*tasmax, tasmin, huss, ps*	*pr*, gz_{250}	Historical	rcp8.5
ACCESS1 0	1.25° x 1.875°	x	x	3	1
ACCESS1 3	1.25° x 1.875°	x	x	3	1
BCC CSM1 1 M	1.1215° x 1.125°	x	x	3	1
BCC CSM1 1	2.7905° x 2.8125°	x	x	3	1
BNU ESM	2.7905° x 2.8125°		x	1	1
CANESM2	2.7905° x 2.8125°	x	x	5	5
CCSM4	0.9424° x 1.25°	x	x	8	6
CESM1 BGC	0.9424° x 1.25°	x	x	1	1
CESM1 CAM5	0.9424° x 1.25°	x	x	3	3
CESM1 WACCM	1.8947° x 2.5°	x	x	7	3
CNRM CM5	1.4008° x 1.4063°	x	x	10	5
CSIRO MK3 6 0	1.8652° x 1.875°	x	x	10	10
CMCC CESM	3.711° x 3.75°		x	1	1
CMCC CM	0.7484° x 0.75°		x	1	1
CMCC CMS	1.8652° x 1.875°		x	1	1
FGOALS G2	2.7905° x 2.8125°		x	5	1
FIO ESM	2.7905° x 2.8125°		x	3	3
GFDL CM3	2° x 2.5°	x	x	5	1
GFDL ESM2G	2.0225° x 2.5°	x	x	1	1
GFDL ESM2M	2.0225° x 2.5°	x	x	1	1
GISS E2 H	2° x 2.5°	x	x	18	5
GISS E2 R	2° x 2.5°	x	x	24	5
GISS E2 H CC	2° x 2.5°		x	1	1
GISS E2 R CC	2° x 2.5°		x	1	1
HADGEM2 CC	1.25° x 1.875°	x	x	3	3
HADGEM2 ES	1.25° x 1.875°	x	x	5	4
INMCM4	1.5° x 2°	x	x	1	1
IPSL CM5A LR	1.8947° x 3.75°	x	x	6	4
IPSL CM5A MR	1.2676° x 2.5°	x	x	3	1
IPSL CM5B LR	1.8947° x 3.75°	x	x	1	1
MIROC ESM CHEM	2.7905° x 2.8125°	x	x	1	1
MIROC ESM	2.7905° x 2.8125°	x	x	3	1
MIROC5	1.4008° x 1.4063°	x	x	5	3
MRI CGCM3	1.1215° x 1.125°	x	x	5	1
MPI ESM LR	1.8652° x 1.875°		x	3	3
MPI ESM MR	1.8652° x 1.875°		x	3	1
MRI ESM1	1.1215° x 1.125°		x	1	1
NORESM1 M	1.8947° x 2.5°	x	x	3	1
NORESM1 ME	1.8947° x 2.5°		x	1	1

All of these models had monthly output for precipitation (*pr*) and 250 hPa geopotential height (gz_{250}). The 27 models that had monthly mean output of daily 2 m T_{max} (*tasmax*), T_{min} (*tasmin*), specific humidity (*huss*), and surface pressure (*ps*) and denoted with an x in the third column. The number of ensemble realizations for the historical (1850 2005) and rcp8.5 (2006 2099) experiments are shown in the fifth and sixth columns, respectively.

Other Supporting Information Files

Dataset S1 (CSV)
Dataset S2 (CSV)
Dataset S3 (CSV)

15 Re_ sorry!.pdf

From:	Hoffman, Cat
To:	Patrick Gonzalez NPS
Subject:	Re: sorry!
Date:	Saturday, March 10, 2018 1:02:21 PM

Hi Patrick -- I also meant to say that in hindsight, rearranging the order in which we discussed the sea level change report and the broader discussion with Ray wasn't a good idea. It seemed to make sense at the time, because he anticipated providing the same "backdrop" to each of the sessions. Clearly I should've anticipated that it would run a bit long though, and I really do regret that the shortened time meant you couldn't participate in the full discussion.

On Fri, Mar 9, 2018 at 5:26 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> right...thanks for the JOTR reminder re. Monday. Enjoy being in the field.
>
> On Fri, Mar 9, 2018 at 5:08 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
>
>> Hi Cat,
>>
>> Thanks for the message. It was unfortunate that the first meeting with Ray ran long and squeezed the critical meeting on the sea level rise report with Maria. The two of us spoke and she derived how the rest of the time went.
>>
>> It’s good that you found the meetings this week went well. The discussions were productive and we did accomplish most of what was on the list. Thanks for (b) (6) [redacted] and the dinner with everybody.
>>
>> I leave Sunday for Joshua Tree and will be in the field counting trees with staff and partners all day Monday. So, no telephone call then, but we will talk the next Monday.
>>
>> Thanks,
>>
>> Patrick
>>
>> ______
>>
>> **From:** "Hoffman, Cat" <cat_hawkins_hoffman@nps.gov>
>> **Subject: sorry!**
>> **Date:** March 8, 2018 at 8:07:41 PM PST
>> **To:** Patrick Gonzalez <patrick_gonzalez@nps.gov>
>>
>> Patrick -- I'm really sorry that I didn't catch you in time as you had to head for your shuttle. I wanted to tell you goodbye, and that I appreciated having you in Fort Collins for the last couple days. I was pleased that we got a lot done, and whether the rest of you concur, I thought we had good/beneficial discussions!
>>
>> I do really regret that we didn't have adequate time before you had to leave to finish the discussion with Ray. I probably should've anticipated that, and perhaps asked you to stay over one more night, or tried to organize the discussion earlier in the day with Ray. I felt

> > that we ended up in a reasonable place as we talked through text further along in the document -- at least that was my perspective. Maria will be in touch with you on a couple sections.
> >
> > hope your trip back was uneventful, and thanks again for coming out Patrick.   Talk with you next week.
> >
> > --
> > *Cat Hawkins Hoffman*
> > **National Park Service**
> >
> > **Chief, NPS Climate Change Response Program**
> > **1201 Oakridge Drive**
> > **Fort Collins, CO 80525**
> > **cat_hawkins_hoffman@nps.gov**
> > **office: 970-225-3567**
> > **cell: 970-631-5634**
> >
> > Adaptation websites: public, NPS managers
> > Climate Change Response Resources
>
> --
> *Cat Hawkins Hoffman*
> **National Park Service**
>
> **Chief, NPS Climate Change Response Program**
> **1201 Oakridge Drive**
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Cat Hawkins Hoffman
National Park Service

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cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

16 Copy of the SLR report.pdf

From:	Maria Caffrey
To:	Perez, Larry
Cc:	Patrick Gonzalez NPS
Subject:	Copy of the SLR report
Date:	Monday, March 12, 2018 9:15:27 AM

Hi Larry,

Would it be possible for you to email me and Patrick a copy of the report that includes the notes following from our discussion with Ray?

I just opened the flash drive you gave me and the report isn't on it. All it has are 508 files.

Thanks!

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

17 Re_ Time to go over edits_.pdf

From:	Maria Caffrey
To:	Patrick Gonzalez NPS
Subject:	Re: Time to go over edits?
Date:	Sunday, March 18, 2018 6:31:09 PM

Hi Patrick

Sure, that works for me I thought they had shared it with you They couldn't put it on the drive because my NPS profile got deleted (Rebecca told IT I had left so they purged my account) Larry tried to give me the file on a flash drive but the file somehow didn't get transferred onto it, so Cat sent an email last week with a link to a ftp site I'll see if I can forward it to you

Maria Caffrey, Ph D

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey com

On Mar 18, 2018, at 6:25 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps gov> wrote:

Hi Maria,

If 1:30 PM MDT (12:30 PM PDT) is OK in your schedule, let's talk then I can't talk at 10 AM MDT

Another negative aspect of this situation is that they have not shared the Word file with you, the lead author All authors should be able to have the report I have not seen a message from Larry He can easily post the file on Google Drive for both of us

Thanks,

Patrick

From Maria Caffrey <maria.caffrey@colorado.edu>
Subject Re Time to go over edits?
Date March 12, 2018 at 8:18 01 AM PDT
To Patrick Gonzalez NPS <patrick_gonzalez@nps gov>

Hi Patrick,

Let's plan to go over it next Monday. I'm free all day on Monday, so just let me know what works for you. I thought I had a copy of the file, but it turns out it didn't get copied over to the flash drive Larry gave me. I have asked Larry to email us both a copy.

Cheers,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Sent: Friday, March 9, 2018 5 02:48 PM
To: Maria Caffrey
Subject: Re: Time to go over edits?

Hi Maria,

I am working in Joshua Tree this Sunday through Wednesday, then I am off Thursday and Friday. If next Monday (March 19) is too far from now, then I could find time on Thursday. I don't think it will take us more than an hour.

May you please send me the Word file. We don't need to have a webinar if we both have the same file.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor
Department of Environmental Science, Policy, and Management
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Maria Caffrey <maria.caffrey@colorado.edu>
Subject: Time to go over edits?
Date: March 9, 2018 at 12:40:31 PM PST
To: "patrick_gonzalez@nps.gov" <patrick_gonzalez@nps.gov>

Hi Patrick

Do you have some time to go over the edits next week? I'm free everyday except Monday and Friday afternoon.

Thanks,

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

18 Fwd_ File for your use.pdf

From: Maria Caffrey
To: patrick_gonzalez@nps.gov
Subject: Fwd: File for your use
Date: Sunday, March 18, 2018 6:33:18 PM

Patrick

Apologies this didn’t get sent to you. I assumed you had been sent a copy given that you’re a co-author. No idea why they didn’t send this to you too.

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

Begin forwarded message:

> **From:** "Hoffman, Cat" <cat_hawkins_hoffman@nps.gov>
> **Date:** March 14, 2018 at 9:22:37 AM MDT
> **To:** Patrick Gonzalez <patrick_gonzalez@nps.gov>
> **Cc:** Maria Caffrey <maria.caffrey@colorado.edu>
> **Subject: Fwd: File for your use**
>
> Hi Patrick -- I hope you had a really successful visit to Joshua Tree (and also a rejuvenating time being out in the field...that's always so valuable).
>
> I know you are traveling today, and scheduled to be off tomorrow and Friday. Just wanted to be sure that you're able to download this file so that you and Maria can talk through the suggested changes. I think there were only a few flagged for discussion, and as soon as you and Maria have a chance to discuss, I will get the final version to Fagan as a priority for completion so that we can post the report.
>
> Thanks,
>
> Cat
>
> ---------- Forwarded message ----------
> From: **larry_perez@nps.gov** <doi_secure_file_transfer@doi.gov>
> Date: Mon, Mar 12, 2018 at 3:12 PM
> Subject: File for your use
> To: patrick_gonzalez@nps.gov, cat_hawkins_hoffman@nps.gov, maria.caffrey@colorado.edu, larry_perez@nps.gov
>
> You have received 1 file from larry_perez@nps.gov.

Maria,

So sorry for the trouble. Hard to imagine I could screw up saving a file to a hard drive, but I'll chalk that one up to having too many windows open on my desktop ;)

-L

2018-03-08 Sea Level Change Report_4Maria.docx
123.90 MB
File links expire: Mar 26, 2018

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--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

19 Accepted_ SLR_SS Report Edits @ Mon Mar 19, 201....pdf

From:	Google Calendar on behalf of Patrick Gonzalez
To:	maria_caffrey@partner.nps.gov
Subject:	Accepted: SLR/SS Report Edits @ Mon Mar 19, 2018 1:30pm - 2:30pm (MDT) (maria_caffrey@partner.nps.gov)
Attachments:	invite.ics

Patrick Gonzalez has accepted this invitation.
SLR/SS Report Edits
Meeting to discuss the proposed edits to the sea level and storm surge report.
Maria will call Patrick. A link will be sent just before the meeting so we can share screens.
When Mon Mar 19, 2018 1:30pm – 2:30pm Mountain Time
Video call HYPERLINK "https://hangouts.google com/hangouts/_/doi.gov/maria-caffrey-p?hceid=bWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y.3ofs034jdofllusa0co6onjf81" https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p
Calendar maria_caffrey@partner.nps.gov
Who • maria_caffrey@partner.nps.gov - organizer
• patrick_gonzalez@nps.gov

20 Sea level rise report Word file.pdf

From: Patrick Gonzalez NPS
To: Larry Perez
Cc: Cat Hoffman; Maria Caffrey
Subject: Sea level rise report Word file
Date: Monday, March 19, 2018 9:17:55 AM

Hi Larry,

Thank you for sending the ftp link, but I don’t see the file in my ftp folder. If you could upload the Word file to Google Drive, that will work.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: "larry_perez@nps.gov" <doi_secure_file_transfer@doi.gov>
Subject: File for your use
Date: March 12, 2018 at 2:12:01 PM PDT
To: patrick_gonzalez@nps.gov, cat_hawkins_hoffman@nps.gov, maria.caffrey@colorado.edu, larry_perez@nps.gov
Reply-To: larry_perez@nps.gov

You have received 1 file from larry_perez@nps.gov.

Maria,

So sorry for the trouble. Hard to imagine I could screw up saving a file to a hard drive, but I'll chalk that one up to having too many windows open on my desktop ;)

-L

2018-03-08 Sea Level Change Report_4Maria.docx
123.90 MB
File links expire: Mar 26, 2018

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21 Updated invitation_ SLR_SS Report Edits @ Mon M....pdf

From:	maria_caffrey@partner.nps.gov
To:	patr ck_gonzalez@nps.gov
Subject:	Updated nvitation: SLR/SS Report Ed ts @ Mon Mar 19, 2018 12:30pm - 1:30pm (PDT) (patrick_gonzalez@nps.gov)
Attachments:	invite.ics

This event has been changed.
HYPERLINK "https://www.google.com/calendar/event?
action VIEW&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1" more details »

SLR/SS Report Edits
Meeting to discuss the proposed edits to the sea level and storm surge report.
Maria will call Patrick. A link will be sent just before the meeting so we can share screens.
When Changed: Mon Mar 19, 2018 12:30pm – 1:30pm Pacific Time
Video call HYPERLINK "https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p?hceid bWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y.3ofs034jdofllusa0co6onjf81" https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p
Calendar patrick_gonzalez@nps.gov
Who • maria_caffrey@partner.nps.gov - organizer
• patrick_gonzalez@nps.gov

Going? HYPERLINK "https://www google.com/calendar/event?
action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 1&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
Yes - HYPERLINK "https://www.google com/calendar/event?
action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 3&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
Maybe - HYPERLINK "https://www.google.com/calendar/event?
action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 2&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
No HYPERLINK "https://www.google.com/calendar/event?
action VIEW&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1" more options »

22 2nd Attempt.pdf

From: larry_perez@nps.gov
To: cat_hawkins_hoffman@nps.gov; maria.caffrey@colorado.edu; patrick_gonzalez@nps.gov
Subject: 2nd Attempt
Date: Monday, March 19, 2018 9:29:00 AM

You have received 1 file from larry_perez@nps.gov.

Patrick,

Let's try this FTP once more. As you'll see, the file is pretty massive.

2018-03-08 Sea Level Change Report_4Maria.docx
123.90 MB
File links expire: Apr 2, 2018

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23 Updated invitation_ SLR_SS Report Edits @ Mon M...(1).pdf

From:	maria_caffrey@partner.nps.gov
To:	patr ck_gonzalez@nps.gov
Subject:	Updated nvitation: SLR/SS Report Ed ts @ Mon Mar 19, 2018 1:30pm - 2:30pm (PDT) (patrick_gonzalez@nps.gov)
Attachments:	invite.ics

This event has been changed.
HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1" more details »

SLR/SS Report Edits
Meeting to discuss the proposed edits to the sea level and storm surge report.
Maria will call Patrick. A link will be sent just before the meeting so we can share screens.
When Changed: Mon Mar 19, 2018 1:30pm – 2:30pm Pacific Time
Video call HYPERLINK "https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p?hceid bWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y.3ofs034jdofllusa0co6onjf81" https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p
Calendar patrick_gonzalez@nps.gov
Who • maria_caffrey@partner.nps.gov - organizer
• patrick_gonzalez@nps.gov

Going? HYPERLINK "https://www google.com/calendar/event?action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 1&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
Yes - HYPERLINK "https://www.google com/calendar/event?action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 3&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
Maybe - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&rst 2&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1"
No HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid M29mczAzNGpkb2ZsbHVzYTBjbzZvbmpmODEgcGF0cmlja19nb256YWxlekBucHMuZ292&tok MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y3NjUyNmIwZTRkZGY5ZGNhZTM0NGNlNWU1MGJmNTEyYjhlZjZlYTE3&ctz America%2FLos_Angeles&hl en&es 1" more options »

24 Thanks - Sea level rise Word file.pdf

From: Patrick Gonzalez NPS
To: Larry Perez
Cc: Cat Hoffman; Maria Caffrey; maria_caffrey@partner.nps.gov
Subject: Thanks - Sea level rise Word file
Date: Monday, March 19, 2018 9:58:37 AM

Hi Larry,

Thanks. That link worked and I downloaded the file.

Patrick

From: "larry_perez@nps.gov" <doi_secure_file_transfer@doi.gov>
Subject: 2nd Attempt
Date: March 19, 2018 at 8:27:54 AM PDT
To: cat_hawkins_hoffman@nps.gov, maria.caffrey@colorado.edu, patrick_gonzalez@nps.gov
Reply-To: larry_perez@nps.gov

You have received 1 file from larry_perez@nps.gov.

Patrick,

Let's try this FTP once more. As you'll see, the file is pretty massive.

2018-03-08 Sea Level Change Report_4Maria.docx
123.90 MB
File links expire: Apr 2, 2018

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25 Re_ Sea level - can you call at 2_30 PM MDT (1_....pdf

From:	Maria Caffrey
To:	Patrick Gonzalez NPS
Subject:	Re: Sea level - can you call at 2:30 PM MDT (1:30 PM PDT)
Date:	Monday, March 19, 2018 10:34:48 AM

Sure thing. I just updated the invite.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Sent: Monday, March 19, 2018 9:36:17 AM
To: Maria Caffrey
Cc: Maria Caffrey
Subject: Sea level - can you call at 2:30 PM MDT (1:30 PM PDT)

Hi Maria,

Cat just scheduled an unrelated telephone call at the same time. I hope that it will be possible to talk an hour later, at 2:30 PM MDT (1:30 PM PDT).

Your idea of sharing your screen is indeed the best way. If you could arrange that, it would be great.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

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131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Maria Caffrey <maria_caffrey@partner.nps.gov>
Subject: Updated invitation: SLR/SS Report Edits @ Mon Mar 19, 2018 12:30pm - 1:30pm (PDT) (patrick_gonzalez@nps.gov)
Date: March 19, 2018 at 7:55:54 AM PDT
To: patrick_gonzalez@nps.gov
Reply-To: Maria Caffrey <maria_caffrey@partner.nps.gov>

This event has been changed.

SLR/SS Report Edits

more details »

Meeting to discuss the proposed edits to the sea level and storm surge report.
Maria will call Patrick. A link will be sent just before the meeting so we can share screens.

When **Changed:** Mon Mar 19, 2018 12:30pm – 1:30pm Pacific Time

Video call https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p

Calendar patrick_gonzalez@nps.gov

Who
- maria_caffrey@partner.nps.gov - organizer
- patrick_gonzalez@nps.gov

Going? **Yes** - **Maybe** - **No** more options »

27 KEMP_et_al-2013-Journal_of_Quaternary_Science.pdf

From: Patrick Gonzalez NPS
To: Maria Caffrey U Colorado
Subject: KEMP_et_al-2013-Journal_of_Quaternary_Science.pdf
Date: Monday, March 19, 2018 4:00:03 PM
Attachments: KEMP_et_al-2013-Journal_of_Quaternary_Science.pdf

27 1 Attachment KEMP_et_al-2013-Journal_of_Quaternary_Science_1.pdf

JOURNAL OF QUATERNARY SCIENCE (2013) 28(6) 537 541 ISSN 0267 8179. DOI: 10.1002/jqs.2653

Rapid Communication

Contribution of relative sea-level rise to historical hurricane flooding in New York City

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Received 13 March 2013; Revised 20 June 2013; Accepted 5 July 2013

ABSTRACT: Flooding during hurricanes is a hazard for New York City. Flood height is determined by storm surge characteristics, timing (high or low tide) and relative sea level (RSL) change. The contribution from these factors is estimated for seven historical hurricanes (1788 2012) that caused flooding in New York City. Measurements from The Battery tide gauge and historical accounts are supplemented with a RSL reconstruction from Barnegat Bay, New Jersey. RSL was reconstructed from foraminifera preserved in salt marsh sediment that was dated using marker horizons of lead and copper pollution and ^{137}Cs activity. Between the 1788 hurricane and Hurricane Sandy in 2012, RSL rose by 56 cm, including 15 cm from glacio isostatic adjustment. Storm surge characteristics and timing with respect to astronomical tides remain the dominant factors in determining flood height. However, RSL rise will raise the base level for flood heights in New York City and exacerbate flooding caused by future hurricanes.

KEYWORDS: Hurricane Sandy; New Jersey; salt marsh; storm surge; tide gauge.

Introduction

Flooding during hurricanes is a hazard and economic burden to New York City (Coch, 1994; Gornitz *et al.*, 2001; Colle *et al.*, 2008). In October 2012, Hurricane Sandy caused an estimated $50 billion of damage, making it the second costliest hurricane (after Katrina in 2005) to hit the United States (Blake *et al.*, 2013). In New York City, coastal New Jersey, and elsewhere along the US north east Atlantic coast, this damage was caused predominantly by flooding. Notable historical flooding from hurricanes in New York City also occurred in 1985 (Hurricane Gloria), 1960 (Hurricane Donna), 1938, 1893, 1821, and 1788 (unnamed; Coch, 1994; Scileppi and Donnelly, 2007).

The height of flooding attained during a hurricane is the product of storm surge height, timing in the astronomical tidal cycle and relative sea level (RSL) change. Storm surge height is unique to each hurricane, being governed by meteorological conditions and coastal geomorphology (Irish *et al.*, 2008; Lin *et al.*, 2010). Worse flooding occurs when a hurricane's impact is coincident with higher tides. Conversely, lower tides provide vertical space to accommodate a storm surge and to lessen, or prevent, flooding. RSL changes through time and is ultimately the base level on which astronomical tides and storm surges are superimposed. Consequently, the flood height reached at a particular location in New York City (e.g. a building or landmark) during one hurricane compared with another is partly attributed to RSL change. In the 21st century, RSL rise will impact New York City by augmenting the height of storm surges and tides (Bindoff *et al.*, 2007; Yin *et al.*, 2009).

The contribution of RSL change to flooding in New York City during Hurricane Sandy compared with earlier historical events is unknown. We reconstruct RSL for the past ~230 years from salt marsh sediment in northern New Jersey and show that RSL rose by 56 ± 4 cm between the 1788 hurricane and Hurricane Sandy in 2012. Ongoing glacio isostatic adjustment accounted for an estimated 15 cm of this change. These results demonstrate that future RSL rise will add to flood heights attained during hurricanes, but that variability among storm surges and timing remain the dominant controls on flooding in New York City.

Historical hurricane flooding in New York City

The National Hurricane Center defines a storm tide as the water level reached from the combined effects of astronomical tides and storm surge and expressed relative to a contemporary tidal datum. Storm surge height at a tide gauge is the difference between the observed water level and the predicted astronomical tide for that time. Tide level reflects the daily rising and falling of the tides and also position in the astronomical cycle of spring and neap tides. Great diurnal tidal range at The Battery tide gauge in New York City is currently 1.54 m. Wave heights are excluded from these definitions because they are filtered out by tide gauge measurements. RSL is the height of the ocean surface relative to the land at a given location, where zero commonly refers to present (Shennan *et al.*, 2012). It is what an observer on a coast would experience and the net effect of many processes acting simultaneously, including glacio isostatic adjustment. RSL rise between hurricanes raises the base level on which tides and storm surges are superimposed.

The digitized instrumental record of individual hurricane flooding events in New York City is available from the National Ocean Survey since 1920, although archival data from as early as 1835 exist (Talke and Jay, 2013). Tide gauge data from The Battery on the southern tip of Manhattan (Fig. 1) show that Hurricane Sandy (October 2012) generated a 2.81 m storm surge that occurred with a high astronomical tide (0.67 m above mean tide level; MTL) resulting in a storm tide of 3.48 m MTL (Fig. 2). The King's Point tide gauge in

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28 Sea level - 2_30 PM MDT (1_30 PM PDT).pdf

From: Patrick Gonzalez NPS
To: Maria Caffrey U Colorado
Subject: Sea level - 2:30 PM MDT (1:30 PM PDT)
Date: Monday, March 19, 2018 4:23:22 PM

Thanks, Maria I will be in the office at (510) 643-9725

Patrick

———

From Maria Caffrey <maria.caffrey@colorado.edu>
Subject Re Sea level - can you call at 2 30 PM MDT (1 30 PM PDT)
Date March 19, 2018 at 8:39:40 AM PDT
To Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

Sure thing. I just updated the invite.

Maria Caffrey, PhD
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Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Sent: Monday, March 19, 2018 9:36:17 AM
To: Maria Caffrey
Cc: Maria Caffrey
Subject: Sea level - can you call at 2:30 PM MDT (1:30 PM PDT)

Hi Maria,

Cat just scheduled an unrelated telephone call at the same time. I hope that it will be possible to talk an hour later, at 2:30 PM MDT (1:30 PM PDT).

Your idea of sharing your screen is indeed the best way. If you could arrange that, it would be great.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
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131 Mulford Hall, Berkeley, CA 94720-3114 USA
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From: Maria Caffrey <maria_caffrey@partner.nps.gov>
Subject: Updated invitation: SLR/SS Report Edits @ Mon Mar 19, 2018 12:30pm - 1:30pm (PDT) (patrick_gonzalez@nps.gov)
Date: March 19, 2018 at 7:55:54 AM PDT
To: patrick_gonzalez@nps.gov
Reply-To: Maria Caffrey <maria_caffrey@partner.nps.gov>

This event has been changed.

SLR/SS Report Edits **more details »**

Meeting to discuss the proposed edits to the sea level and storm surge report.
Maria will call Patrick. A link will be sent just before the meeting so we can share screens.

When	**Changed:** Mon Mar 19, 2018 12:30pm – 1:30pm Pacific Time
Video call	https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-p
Calendar	patrick_gonzalez@nps.gov
Who	• maria_caffrey@partner.nps.gov - organizer • patrick_gonzalez@nps.gov

Going? **Yes** - **Maybe** - **No** more options »

29 Re_ SLR_SS report.pdf

From:	Hoffman, Cat
To:	Maria Caffrey
Cc:	Patrick Gonzalez NPS
Subject:	Re: SLR/SS report
Date:	Monday, March 19, 2018 5:10:26 PM

That sounds great Maria -- thank you.

Cat

On Mon, Mar 19, 2018 at 4:27 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:

> Hi Cat,
>
> Just wanted to let you know that Patrick and I just spent the last couple hours going over the report. I still need to check the references, but I need to (b) (6) so I won't be able to get to it until tomorrow. Hope that's ok.
>
> Cheers,
>
> Maria Caffrey, PhD
> Research Associate
> Geological Sciences,
> UCB 399,
> 2200 Colorado Ave,
> Boulder, CO 80309
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> Office: (303) 969-2097
> Cell: (303) 518-3419
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--

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office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

30 Caffrey et al Sea Level Change Report_Final ver....pdf

From: Maria Caffrey (via Google Drive)
To: patrick_gonzalez@nps.gov
Cc: cat_hawkins_hoffman@nps.gov; rebecca_beavers@nps.gov
Subject: Caffrey et al Sea Level Change Report_Final version .docx
Date: Wednesday, March 21, 2018 12:57:09 PM

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maria_caffrey@partner.nps.gov has shared the following document:

W Caffrey et al Sea Level Change Report_Final version .docx

Open

31 Re_ Sea level and storm surge report.pdf

From:	Patrick Gonzalez NPS
To:	Maria Caffrey
Cc:	Maria Caffrey U Colorado
Subject:	Re: Sea level and storm surge report
Date:	Wednesday, March 21, 2018 1:02:17 PM
Attachments:	Caffrey et al Sea Level Change Report Final version without pics .docx

Dear Maria,

I greatly appreciate you agreeing with me to maintain scientific integrity by restoring all instances of “anthropogenic climate change” and “human-caused climate change” into the report after they had tried to delete them.

Thanks,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
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....

From: "Caffrey, Maria" <maria_caffrey@partner.nps.gov>
Subject: Sea level and storm surge report
Date: March 21, 2018 at 11:55:52 AM PDT
To: Cat Hoffman <cat_hawkins_hoffman@nps.gov>
Cc: Rebecca Beavers <rebecca_beavers@nps.gov>, Patrick Gonzalez <patrick_gonzalez@nps.gov>

Cat,

Here is a link to the sea level and storm surge report: https://drive.google.com/file/d/1_Vbnz2c3JZOKUIyy582xoDsMfzAZaGSd/view?usp=sharing

I am also attaching a version of it to this email that does not include the pictures so we can keep track of the versions, but the full version (including pictures) is now up on the drive for you to download.

Cheers,

--
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www.nps.gov/subjects/wetlands

31 1 Attachment Caffrey et al Sea Level Change Report_Final v.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

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NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate’s Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside

for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or “perfect storm”). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA’s SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$\mathrm{a}e = \mathrm{E}_0 - e_\mathrm{i} + \mathrm{R}$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand,

Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of

using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by

explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*[‡]	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument[‡]	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site‡	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site‡	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument‡	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*‡	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*‡	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve‡	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield‡	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park‡	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve‡	Fernandina Beach, FL (8720030)	N	110	0.600

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial[‡]	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve[‡]	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park[‡]	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park‡	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve‡	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site‡	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*‡	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*‡	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park‡	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*‡	Seattle, WA (9447130)	N	109	0.540

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore[‡]	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial[‡]	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*[‡]	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument[‡]	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*[‡]	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve[‡]	No data	No data	No data	No data

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument[‡]	No data	No data	No data	No data
	Glacier Bay National Park*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park[‡]	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park[‡]	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park[‡]	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park[‡]	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve[‡]	Cordova, AK (9454050)	N	43	3.450

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*] Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†] Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡] No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Saugus Iron Works National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve§	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14‡	0.13	0.12	0.12
		2050	0.24‡	0.23	0.21	0.24
		2100	0.47‡	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14‡	0.13	0.13‡	0.12
		2050	0.25‡	0.24	0.24‡	0.24
		2100	0.50‡	0.54	0.59‡	0.68
	Cape Hatteras National Seashore	2030	0.15‡	0.15	0.15	0.14
		2050	0.26‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Cape Lookout National Seashore§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument§	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore[§]	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve[†§]	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

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[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway§	2030	0.15‡	0.15	0.15‡	0.14
		2050	0.26‡	0.27	0.26‡	0.28
		2100	0.53‡	0.62	0.66‡	0.79
	Harpers Ferry National Historical Park*§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*] Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†] Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡] No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14[‡]	0.12	0.12[‡]	0.12
		2050	0.23[‡]	0.23	0.22[‡]	0.23
		2100	0.47[‡]	0.51	0.55[‡]	0.66
	Palo Alto Battlefield National Historical Park*[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu’uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve§	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument§	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park†§	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve†	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve†§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park†§	2030	0.09‡	0.08	0.08‡	0.08
		2050	0.15‡	0.14	0.14‡	0.15
		2100	0.30‡	0.33	0.34‡	0.44
	Klondike Gold Rush National Historical Park*†§	2030	0.06‡	0.06	0.06‡	0.06
		2050	0.11	0.11	0.11‡	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*†	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park†	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park§	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*§	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President's Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
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www.nature.nps.gov

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32 Re_ Sea level and storm surge report(1).pdf

From: Cat Hoffman
To: Caffrey, Maria
Cc: Rebecca Beavers; Patrick Gonzalez
Subject: Re: Sea level and storm surge report
Date: Wednesday, March 21, 2018 1:02:29 PM

THANK YOU Maria. I'm in a training session but will keep this moving.
Really appreciate the time that you and Patrick gave to this.

Sent from my iPhone

> On Mar 21, 2018, at 12:55 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
> Cat,
>
> Here is a link to the sea level and storm surge report:
> https://drive.google.com/file/d/1_Vbnz2c3JZOKUIyy582xoDsMfzAZaGSd/view?usp=sharing
>
> I am also attaching a version of it to this email that does not include the
> pictures so we can keep track of the versions, but the full version
> (including pictures) is now up on the drive for you to download.
>
> Cheers,
>
> --
> Maria Caffrey, Ph.D.
> NPS Water Resources Division
> PO Box 25287
> Denver CO 80225
>
> Office: 303-969-2097
> Cell: 303-518-3419
>
> www nps.gov/subjects/wetlands
> <Caffrey et al Sea Level Change Report_Final version_without pics .docx>

33 Priority - scheduling an author call on the report.pdf

From:	Hoffman, Cat
To:	Maria Caffrey; Patrick Gonzalez; Rebecca Beavers; Caffrey, Maria
Subject:	Priority - scheduling an author call on the report
Date:	Thursday, March 22, 2018 5:09:42 PM

Hi all -- I apologize for this short notice -- I'm reaching out to ask if you could be available sometime tomorrow/Friday for a call to discuss the last work that Maria and Patrick did on the sea level report.

Please let me know of any times that you could be available, if not tomorrow, then Monday or Tuesday next week. If there's no time that works for all of us, I'll speak with you individually when you have time, or any combination according to schedules. Patrick and I will both be in Bethesda MD at a National Climate Assessment meeting next week, but this is a priority and I'll make time for it (after hours when I'm back east would be fine).

Thanks.

Cat

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

34 suggested revisions.pdf

From: Hoffman, Cat
To: Patrick Gonzalez
Subject: suggested revisions
Date: Tuesday, March 27, 2018 12:01:15 AM
Attachments: Caffrey et al Sea Level Change Report_no pics.3.26.2018.docx

---

Hi Patrick -- related to our conversation earlier today (whoops; it's 2 am, so I guess that was yesterday) -- here are the changes I'm recommending to the Caffrey et al report. (I deleted photos and graphics so the document wouldn't be so large...this is just to show the suggested text changes)

I haven't heard from Maria regarding her availability for a call at our lunch hour today. I will try to reach her by phone to explain my thoughts behind this and then send it to her. Will of course allow everyone time to review.

Cat

--
Cat Hawkins Hoffman
National Park Service

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Adaptation websites: public, NPS managers
Climate Change Response Resources

34 1 Attachment Caffrey et al Sea Level Change Report_no pics.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

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NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers and stakeholders understand these changes and their implications so we may better steward the resources under our care. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for staff, the report also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS Coastal Adaptation Strategies Handbook, and Coastal Adaptation Case Studies.

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Comment [HCH1]: The importance of the "threat" to parks -- which is the reason to provide this information to support managers-- is the point to make here

Comment [HCH2]: redundant

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic

Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration ~~for~~ and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history. (reference a picture #x of Statue of Liberty) But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units of the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the post-industrial era was greater than during any preceding century in at least 2,800 years ~~anthropogenic climate change has significantly increased the rate of global sea level rise ((~~cite Climate Science Special Report, 2017, Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This analysis unified approach to identify how sea level change may affect coastal park units of the National Park System. This report provides estimates of sea level change due to climate change for~~

Comment [HCH3]: IMO, this is a more effective, impactful statement

Comment [HCH4]: From CSSR 2017: "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Comment [HCH5]: I thought this was an important point from the Methods section to include here (in summary form)

~~118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

Consider paragraph "A" below as a substitute for this paragraph and the next one:

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

"A" The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM (we can ask Rich Turk for this information). Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from analyzing projections for the future in conjunction with lessons learned from the past.

Comment [HCH6]: Relation of temperature increase to rising sea level already noted above No need to say "we'll tell you more about it below"

Comment [HCH7]: Ray (during his first reading of the draft as "fresh eyes") remarked that it's not clear why this text is here – it needs to be more directly relevant to parks i e why talk about the cost of damage in New York City (which has infrastructure far beyond anything in parks of course) – instead, we could talk about damage in parks Rich Turk could likely provide the estimate of damage caused in parks (GATE, FIIS, STLI, etc) from Sandy

Comment [HCH8]: See notes about these citations below

Comment [HCH9]: This would need a ciation

Comment [HCH10]: Check whether this reference is relevant to the point; from my (cursory) reading of it, it appears inconclusive on attribution

Comment [HCH11]: Similar to Knutson et al – does this reference substantiate the point you are making here? Seems focused on managing risks of climate change, including GHG mitigation, but not focused on attribution(?)

Comment [HCH12]: Does this reference substantiate your point?

Conclusions include "the model simulations indicate that aerosol forcing has been more effective in causing potential intensity (PI) than the corresponding GHG forcing: the decrease in PI due to aerosols and increase due to GHG largely cancel each other Thus, PI increases in the recent 30 years appears to be dominated by multidecadal natural variability associated with the positive phase of the Atlantic multidecadal variability (AMV) "

Comment [HCH13]: This text was suggested in an earlier round of comments as a substitute for the two paragraphs above

Whether this text or some other description is used, need to add acknowledgement of hurricanes Harvey, Irma, and Maria AND tie this discussion more directly to parks

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Comment [HCH14]: Did Tahzay Jones review the Alaska information (based on the concerns he had with the Alaska data)?

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

~~Sea Level Rise Data~~ Understanding Sea Level Rise and Storm Surge

Numerous factors cause ~~S~~sea level rise. ~~is caused by numerous factors.~~ As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

Need to add some explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise

Sea Level Rise Data

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The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are

reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are

shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and 2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

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NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$\mathrm{a}e = \mathrm{E}_0 - e_{\mathrm{i}} + \mathrm{R}$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the

nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix ~~D~~C. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor’easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the “Labor Day Hurricane” that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane str king the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane str king the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington’s Olympic Peninsula and in the San Juan Islands, affecting Ebey’s Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea

level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved

towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

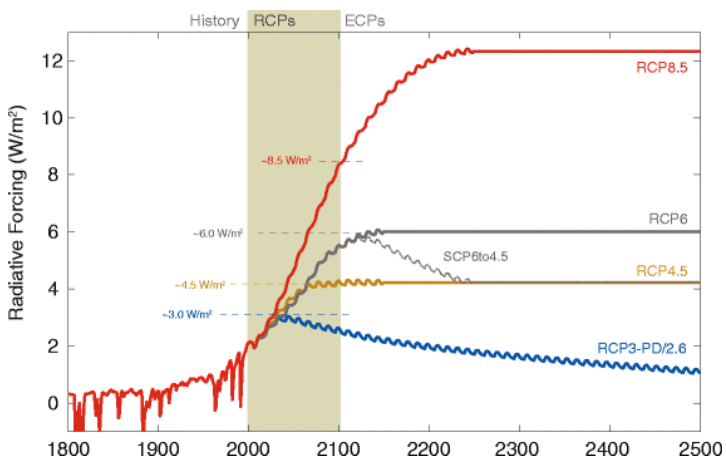

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region’s units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long “hotspot” along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

35 Re_ would you be available tomorrow_Tuesday, ~1....pdf

From: Hoffman, Cat
To: Caffrey, Maria
Cc: Rebecca Beavers; Patrick Gonzalez
Subject: Re: would you be available tomorrow/Tuesday, ~10 am Mtn?
Date: Tuesday, March 27, 2018 10:02:06 AM

Hi Maria -- Yes, we can talk later....Patrick and I are in our respective chapter sessions and at least for mine, we have quite a lot of work to do. Patrick suggested that e-mail may suffice; I'll send more later today or this evening after our sessions end.

On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

> Hi Cat,
>
> I'm afraid I can't do it today. Can we do it later in the week?
>
> On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>
>> Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.
>>
>> Cat
>>
>> --
>> ***Cat Hawkins Hoffman***
>> **National Park Service**
>>
>> **Chief, NPS Climate Change Response Program**
>> **1201 Oakridge Drive**
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--
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Adaptation websites: public, NPS managers
Climate Change Response Resources

36 suggestions to improve the report.pdf

From:	Hoffman, Cat
To:	Jeffrey Olson; Jeremy Barnum; Jennifer Wyse
Cc:	Larry Perez; Guy Adema
Subject:	suggestions to improve the report
Date:	Tuesday, March 27, 2018 11:33:54 AM
Attachments:	Caffrey et al Sea Level Change Report_no pics.3.26.2018.docx

Here are my recommendations to improve the report -- intent is to provide a better summary for NPS coastal park managers for SLR projections specific to their parks, as well as a quick reference to the scientific basis for deriving the projections. I'm also asking Maria to re-check some of the citations she's used; there are at least 2-3 that I think may be inappropriately cited since they don't support a point she makes in the text. So still some clean up to do.

FYI, to reduce size for transmitting, this version doesn't contain all the photos and graphics...only indicates recommended text changes.

Maria hasn't been available so hasn't seen these suggestions yet. Patrick concurred with refocusing this more specifically as a reference for park managers, but hasn't had a chance to review the exact text after I sent it to him last evening. Rebecca is on leave through mid-week; she's advocated a more specific focus on parks and told me she would be fine with any such changes.

This does not propose wholesale changes so not a heavy lift to incorporate and get this to final. But the author team will need to hear from Maria, which I hope to do over the next couple days.

Cat

--

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Adaptation websites: public, NPS managers
Climate Change Response Resources

36 1 Attachment Caffrey et al Sea Level Change Report_no pics_1.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers and stakeholders understand these changes and their implications so we may better steward the resources under our care. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for staff, the report also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS Coastal Adaptation Strategies Handbook, and Coastal Adaptation Case Studies.

Comment [HCH1]: The importance of the "threat" to parks -- which is the reason to provide this information to support managers-- is the point to make here

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Comment [HCH2]: redundant

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic

Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration ~~for~~ and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history. (reference a picture #x of Statue of Liberty) But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units of the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the post-industrial era was greater than during any preceding century in at least 2,800 years ~~anthropogenic climate change has significantly increased the rate of global sea level rise (~~(cite Climate Science Special Report, 2017, Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This analysis unified approach to identify how sea level change may affect coastal park units of the National Park System. This report provides estimates of sea level change due to climate change for~~

Comment [HCH3]: IMO, this is a more effective, impactful statement

Comment [HCH4]: From CSSR 2017: "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Comment [HCH5]: I thought this was an important point from the Methods section to include here (in summary form)

~~118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

Consider paragraph "A" below as a substitute for this paragraph and the next one:

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

"A" The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM (we can ask Rich Turk for this information). Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from analyzing projections for the future in conjunction with lessons learned from the past.

Comment [HCH6]: Relation of temperature increase to rising sea level already noted above No need to say "we'll tell you more about it below"

Comment [HCH7]: Ray (during his first reading of the draft as "fresh eyes") remarked that it's not clear why this text is here – it needs to be more directly relevant to parks i e why talk about the cost of damage in New York City (which has infrastructure far beyond anything in parks of course) – instead, we could talk about damage in parks Rich Turk could likely provide the estimate of damage caused in parks (GATE, FIIS, STLI, etc) from Sandy

Comment [HCH8]: See notes about these citations below

Comment [HCH9]: This would need a ciation

Comment [HCH10]: Check whether this reference is relevant to the point; from my (cursory) reading of it, it appears inconclusive on attribution

Comment [HCH11]: Similar to Knutson et al – does this reference substantiate the point you are making here? Seems focused on managing risks of climate change, including GHG mitigation, but not focused on attribution(?)

Comment [HCH12]: Does this reference substantiate your point?

Conclusions include "the model simulations indicate that aerosol forcing has been more effective in causing potential intensity (PI) than the corresponding GHG forcing: the decrease in PI due to aerosols and increase due to GHG largely cancel each other Thus, PI increases in the recent 30 years appears to be dominated by multidecadal natural variability associated with the positive phase of the Atlantic multidecadal variability (AMV) "

Comment [HCH13]: This text was suggested in an earlier round of comments as a substitute for the two paragraphs above

Whether this text or some other description is used, need to add acknowledgement of hurricanes Harvey, Irma, and Maria AND tie this discussion more directly to parks

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Comment [HCH14]: Did Tahzay Jones review the Alaska information (based on the concerns he had with the Alaska data)?

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

~~Sea Level Rise Data~~ Understanding Sea Level Rise and Storm Surge

Numerous factors cause ~~S~~sea level rise. ~~is caused by numerous factors.~~ As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

---

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

Need to add some explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise

Sea Level Rise Data

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The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are

reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are

shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and 2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

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NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the

nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix ~~D~~C. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane str king the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane str king the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington’s Olympic Peninsula and in the San Juan Islands, affecting Ebey’s Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea

level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved

towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

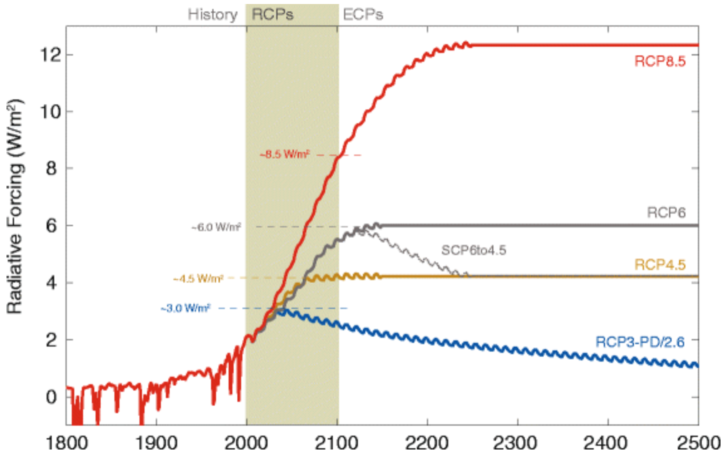

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region’s units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long “hotspot” along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

37 Caffrey et al Sea Level Change Report_Final ver...(1).pdf

From: Maria Caffrey (via Google Drive)
To: patrick_gonzalez@nps.gov
Subject: Caffrey et al Sea Level Change Report_Final version with irma data .docx
Date: Tuesday, March 27, 2018 2:20:13 PM

---

maria_caffrey@partner.nps.gov has shared the following document:

Caffrey et al Sea Level Change Report_Final version with irma data .docx

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Patrick,

Cat contacted me last week to see if I could make some more edits following on from what we submitted to her. I told her that it was inappropriate to discuss making edits without all the authors being present, however she pressed me to make changes. She requested the following:

1. Remove any mention of the word "anthropogenic" or human causes of climate change.
2. Update the paragraph discussing Hurricane Sandy to reflect the storms that occurred in 2017.
3. Remove the references to Lin et al and Knutson et al.

After looking at the report I have decided to do the following:

1. NOT remove any reference to the word "anthropogenic" or the human causes of climate change.
2. I have included some information in the Sandy paragraph that makes mention of the cost of the most recent hurricanes.
3. I have removed Lin et al, but kept Knutson et al. I have also added a reference to Bacmeister.

I thought I would share these edits with you first to see if you agree with them before I send them out to our co-authors. My email to the co-authors will be accompanied with a discussion on why I think it is inappropriate to suggest any further edits without scientific merit, so I need to make sure you are comfortable with these new edits I have made to accommodate the Cat's suggestions from last week. Some of her edits might have scientific merit (specifically #2 and #3), which is why I have made these changes, but I believe #1 is a violation of our scientific integrity and so I refuse to comply with that request.

Open

38 Re_ Final revisions.pdf

From:	Caffrey, Maria
To:	Hoffman, Cat
Cc:	Rebecca Beavers; Patrick Gonzalez; Larry Perez
Subject:	Re: Final revisions
Date:	Wednesday, March 28, 2018 11:07:32 AM

Cat,

I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.

On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi all --
>
> My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.
>
> It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while I'm (b) (6) [redacted]
>
> I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.
>
> this remains a priority and I will work on it as necessary while I'm on annual leave.
>
> Cat
>
> On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
> > Hi Cat,
> >
> > I'm afraid I can't do it today. Can we do it later in the week?
> >
> > On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
> >
> > > Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.

> > Cat
> >
> > --
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> > **Chief, NPS Climate Change Response Program**
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> > **cat_hawkins_hoffman@nps.gov**
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Cell: 303-518-3419

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39 Re_ Final revisions(1).pdf

From:	Hoffman, Cat
To:	Caffrey, Maria; John Gross
Cc:	Rebecca Beavers; Patrick Gonzalez; Larry Perez
Subject:	Re: Final revisions
Date:	Wednesday, March 28, 2018 12:36:28 PM
Attachments:	Caffrey et al Sea Level Change Report_no pics.3.27.2018.docx

Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.

The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.

The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.

However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.

Cat

On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

> Cat,
>
> I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.
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39 1 Attachment Caffrey et al Sea Level Change Report_no pics_2.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers understand these changes and their implications so we may better steward the resources under our care and provide for visitor use. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, the report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

Comment [HCH1]: Executive summary answers the "why" – why is this important to parks a succinct statement of the reason we invested in this work I E we have an affirmative responsibility to address the threat of sea level rise (change) and storm surge in order to protect resources and visitor opportunities The drivers that cause sea level change and the science behind it are included in the document as a useful reference for our managers

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Comment [HCH2]: Redundant with first sentence

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration ~~for~~ and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth

receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge(?)

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (reference a picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the post-industrial era was greater than during any preceding century in at least 2,800 years ~~anthropogenic climate change has significantly increased the rate of global sea level rise~~ (Kopp et al. 2016, Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect many national parks.~~how we protect and manage our national parks~~. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.~~ ~~As temperature increases, sea levels~~

Comment [HCH3]: I thought this was an important point from the Methods section to include here (in summary form)

Comment [HCH4]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19th century began To me this is much more clear than "significant increase" – it's an effective, impactful statement that negates any perceptions that "well, sea level is always changing "

From USGCRP Climate Science Special Report, 2017: "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Source from which the CSSR derived this information:
Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016: Temperature-driven global sea-level variability in the Common Era *Proceedings of the National Academy of Sciences*, **113**, E1434-E1441 http://dx doi org/10 1073/pnas 1517056113

Comment [HCH5]: Moved this text earlier in the document

~~rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

Suggest using paragraph "A" below as a substitute for this paragraph and the next one:
For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Suggest deleting this paragraph; part of it is combined below and is more specific to parks Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

"A" The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM (we can ask Rich Turk for this information). Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

Comment [HCH6]: Relation of temperature increase to rising sea level already noted above No need to say "we'll tell you more about it below"

Comment [HCH7]: The text needs to be more directly relevant to parks In a report about parks, it would be more useful to discuss the cost of damage in parks from Sandy, vs the cost of damage in New York City (which has infrastructure far beyond anything in parks) We could get reasonable ballpark figures from Rich Turk regarding damage caused in parks (GATE, FIIS, STLI, etc) from Sandy

Comment [HCH8]: See notes about these citations below

Comment [HCH9]: This would need a citation

Comment [HCH10]: Check whether this reference is relevant to the point; from my (cursory) reading of it, it appears inconclusive on attribution

Comment [HCH11]: Similar to Knutson et al – not sure this reference substantiates the point about models projecting increasing storm intensities under scenarios of increasing GHG emissions Seems focused on managing risks of climate change, including GHG mitigation

Comment [HCH12]: Not sure this reference substantiates the point

Conclusions include "the model simulations indicate that aerosol forcing has been more effective in causing potential intensity (PI) than the corresponding GHG forcing: the decrease in PI due to aerosols and increase due to GHG largely cancel each other Thus, PI increases in the recent 30 years appears to be dominated by multidecadal natural variability associated with the positive phase of the Atlantic multidecadal variability (AMV) "

Comment [HCH13]: Suggest using this text instead of the two paragraphs above

Whether this text or some other description is used, definitely need to acknowledge the recent hurricanes Harvey, Irma, and Maria AND directly tie this discussion to parks, and why it's important to parks

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Comment [HCH14]: Did Tahzay Jones review the Alaska information (based on the concerns he had with the Alaska data)?

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

~~Sea Level Rise Data~~ Understanding Sea Level Rise and Storm Surge

Numerous factors cause ~~S~~sea level rise. ~~is caused by numerous factors.~~ As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

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[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

Need to add some explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise – 2-3 sentences would suffice.

Sea Level Rise Data

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The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1° x 1° from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are

reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are

shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and 2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

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NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $\mathrm{a}e = \mathrm{E}_0 - e_\mathrm{i} + \mathrm{R}$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the

nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address: https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link: http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix ~~D~~C. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane str king the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane str king the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington’s Olympic Peninsula and in the San Juan Islands, affecting Ebey’s Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea

level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved

towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

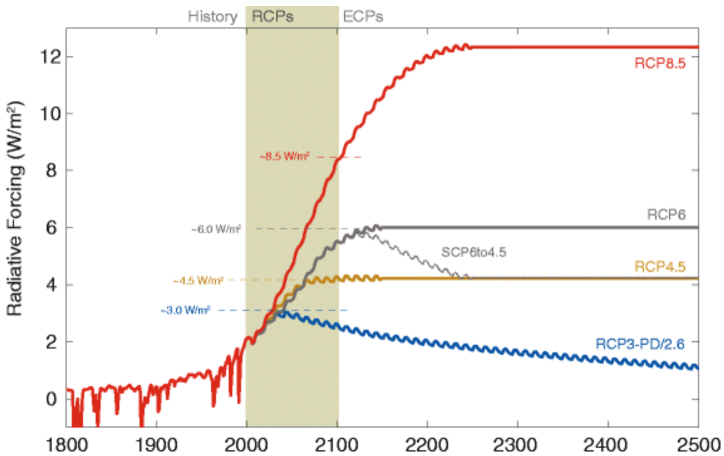

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

40 Re_ Final revisions(2).pdf

From:	Caffrey, Maria
To:	Hoffman, Cat
Cc:	John Gross; Rebecca Beavers; Patrick Gonzalez; Larry Perez
Subject:	Re: Final revisions
Date:	Wednesday, March 28, 2018 2:01:37 PM

Hi Cat,

Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.

Thanks,

M.

On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.
>
> The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.
>
> The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.
>
> However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.
>
> Cat
>
> On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
>> Cat,
>>
>> I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.
>>
>> On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov>

wrote:

Hi all --

My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.

It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while (b) (4) [redacted]

I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.

this remains a priority and I will work on it as necessary while I'm on annual leave.

Cat

On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Hi Cat,

I'm afraid I can't do it today. Can we do it later in the week?

On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.

Cat

--

Cat Hawkins Hoffman
National Park Service

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Adaptation websites: public, NPS managers
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www.nps.gov/subjects/wetlands

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41 Re_ Final revisions(3).pdf

From:	Caffrey, Maria
To:	Hoffman, Cat
Cc:	John Gross; Rebecca Beavers; Patrick Gonzalez; Larry Perez
Subject:	Re: Final revisions
Date:	Wednesday, March 28, 2018 4:10:50 PM

Hi Cat,

Yes, I remember you saying that, but my point is that term is not a suitable substitution for the word anthropogenic. I explained why there are scientific reasons why it is not suitable, and yet you have still made that change. So my point is that the edits you made go beyond just clarifying the document for park staff -- it alters the scientific message too, hence why we need to resend it out for scientific review if you insist on using it.

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria,
>
> In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "*greater than in any preceding century in at least 2,800 years*" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report. It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park. Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."
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The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.

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>> Cat
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>> --
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42 [EXTERNAL] Re_ Cost estimates from Sandy_.pdf

From:	Maria Caffrey
To:	Hoffman, Cat; Turk, Rich
Cc:	Patrick Gonzalez; Rebecca Beavers
Subject:	[EXTERNAL] Re: Cost estimates from Sandy?
Date:	Wednesday, March 28, 2018 4:27:08 PM

Cat,

See here: https://www.ncdc.noaa.gov/billions/events/US/1980-2017

Billion-Dollar Weather and Climate Disasters: Table of ...

www.ncdc.noaa.gov

Below is a historical table of U.S. Billion-dollar disaster events, summaries, report links and statistics for the 1980–2017 period of record.

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Web: mariacaffrey.com

From: Hoffman, Cat <cat_hawkins_hoffman@nps.gov>
Sent: Wednesday, March 28, 2018 4:22:14 PM
To: Turk, Rich
Cc: Maria Caffrey; Patrick Gonzalez; Rebecca Beavers
Subject: Cost estimates from Sandy?

Hi Rich --

we're working to get a sea level rise report to the finish line and I wondered if you could help us with some cost estimate information.

This may not be the final wording we'll use for this paragraph, but it's sufficient to give you context for what we're after. Do you have a figure that we can use for the $XX below for Hurricane Sandy? (And just curious whether there are (as yet) estimates for Irma and Maria in San Juan?)

thanks for any input.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010 , Lin et al. 2012 , Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

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43 Re_ [EXTERNAL] Re_ Cost estimates from Sandy_.pdf

From:	Hoffman, Cat
To:	Maria Caffrey
Cc:	Turk, Rich; Patrick Gonzalez; Rebecca Beavers
Subject:	Re: [EXTERNAL] Re: Cost estimates from Sandy?
Date:	Wednesday, March 28, 2018 4:33:02 PM

Thanks Maria; that's a useful website.

I should clarify for Rich that I was looking for the costs for repairs in national parks due to damage from Hurricane Sandy.

On Wed, Mar 28, 2018 at 4:26 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:

> Cat,
>
> See here: https://www.ncdc.noaa.gov/billions/events/US/1980-2017
>
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44 Re_ Final revisions(4).pdf

From:	Hoffman, Cat
To:	Gross, John
Cc:	Caffrey, Maria; Rebecca Beavers; Patrick Gonzalez; Larry Perez
Subject:	Re: Final revisions
Date:	Wednesday, March 28, 2018 9:13:59 PM
Attachments:	Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf

John -- Thank's for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

Maria, Rebecca, Patrick -- I've attached for your consideration a revision of the introductory text removing "pre-industrial" and adding information (and citation) regarding the greatly accelerated rate of sea level rise since 1993.

I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and in (b) (6) [redacted]
but I will continue to make this a priority and can make time for a call if needed.

Cat

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:

> Folks,
>
> I read the comments and emails below very carefully, and here are my opinions on the changes.
>
> First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.
>
> Page Viii:
>
> As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.
>
> Page 1:
>
> I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “..., recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like

"… with the greatest rates occurring since 1970." This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO2 emissions. I think a more important issue in this paragraph is that it simply says "Further warming of the atmosphere will cause sea levels to continue to rise", when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.

Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.

Page 2:

This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn't adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it's not critical and it does not alter the key results of the report.

So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.

Respectfully,
John Gross

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria,
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> In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "*greater than in any preceding century in <u>at least 2,800 years</u>*" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report.   It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park.   Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."
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John Gross, PhD
Climate Change Ecologist, NPS

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44 1 Attachment Caffrey et al Sea Level Change Report_no pics..pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (reference a picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years, with rates almost doubling since 1993 (Titus, et al. 2009, ~~anthropogenic climate change has significantly increased the rate of global sea level rise~~, Kopp et al. 2016, Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect many national parks ~~how we protect and manage our national parks~~. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.~~ ~~As temperature increases, sea levels~~

Commented [HCH3]: I thought this was an important point from the Methods section to include here (in summary form)

Commented [HCH4]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19th century began To me this is much more clear than "significant increase" – it's an effective, impactful statement that negates any perceptions that "well, sea level is always changing "

From USGCRP Climate Science Special Report, 2017: "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Source from which the CSSR derived this information: Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016: Temperature-driven global sea-level variability in the Common Era *Proceedings of the National Academy of Sciences*, **113**, E1434-E1441 http://dx doi org/10 1073/pnas 1517056113

Commented [HCH5]: Titus, J.G., E K. Anderson, D R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research https://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf.

Commented [HCH6]: Moved this text earlier in the document

45 Fwd_ Cost estimates from Sandy_.pdf

From:	Cat Hoffman
To:	Maria Caffrey; Rebecca Beavers; Patrick Gonzalez
Cc:	Larry Perez; John Gross
Subject:	Fwd: Cost estimates from Sandy?
Date:	Thursday, March 29, 2018 7:55:48 AM

I'll add info to text when I get to [redacted]

Sent from my iPhone

Begin forwarded message:

> **From:** "Hudson, Tim" <tim_hudson@nps.gov>
> **Date:** March 29, 2018 at 9:24:58 AM EDT
> **To:** "Turk, Rich" <rich_turk@nps.gov>
> **Cc:** Cat Hoffman <cat_hawkins_hoffman@nps.gov>
> **Subject: Re: Cost estimates from Sandy?**
>
> The Sandy special appropriation was $348 million, but that year had a sequestration that amounted to some $18.185 million, so we effectively had about $330 million. There was also the ERFO money that paid for damage. I don't have an exact on that, but it was about $40 to $43 million. I suspect that is close enough to what you are looking for. WASO Budget will not have that number. Kristie Franzmann is probably the best one to go to for an exact number. We also added money to the projects out of Repair/Rehab very recently as the $348 pot is about out. Brian Strack is running that, but I don't think you'll get a final number from him and you are safe to use the "at least" $330 plus the $40.
>
> As for IRMIA (Irma and Maria), I believe that they allocated $207 million. You can check that number with John Spernoga - that would probably be better than John Powers at this point. I got the $207 from Jessica Bowron when I was in her office a couple of weeks ago.
>
> That's what I know - hope it helps a little.
>
> Tim
>
> Tim Hudson
> Superintendent
> Katahdin Woods and Waters National Monument
> National Park Service
> PO Box 446
> Patten, ME 04765
> http://www.nps.gov/kaww
>
> 207 242-0186 Work Cell
> 907 350-8058 Personal Cell

On Wed, Mar 28, 2018 at 7:05 PM, Turk, Rich <rich_turk@nps.gov> wrote:

Tim.....

I was looking for a number for Cat Hoffman......ran some totals off you very old reporting spreadsheet.....and could confirm estimates in excess of $325M. Was wondering who might have the final numbers? any suggestions?? John Powers? NERO?

How are things going up there in the north woods?

Rich

---------- Forwarded message ----------
From: **Hoffman, Cat** <cat_hawkins_hoffman@nps.gov>
Date: Wed, Mar 28, 2018 at 4:22 PM
Subject: Cost estimates from Sandy?
To: "Turk, Rich" <rich_turk@nps.gov>
Cc: Maria Caffrey <maria.caffrey@colorado.edu>, Patrick Gonzalez <patrick_gonzalez@nps.gov>, Rebecca Beavers <rebecca_beavers@nps.gov>

Hi Rich --

we're working to get a sea level rise report to the finish line and I wondered if you could help us with some cost estimate information.

This may not be the final wording we'll use for this paragraph, but it's sufficient to give you context for what we're after. Do you have a figure that we can use for the $XX below for Hurricane Sandy? (And just curious whether there are (as yet) estimates for Irma and Maria in San Juan?)

thanks for any input.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010 , Lin et al. 2012 , Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525

cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

--
Richard G. Turk
Construction Program Management Division
Value Analysis Program Coordinator
National Park Service

Link to CPMD SharePoint Site: http://share.inside.nps.gov/sites/WASO/PPFL/CPM/default.aspx

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Denver, CO 80225-0287
Phone: 303-969-2470
Fax: 303-969-2423

46 [EXTERNAL] Re_ Final revisions.pdf

From: Maria Caffrey
To: Gonzalez, Patrick
Subject: [EXTERNAL] Re: Final revisions
Date: Thursday, March 29, 2018 12:09:49 PM

Thanks Patrick. I’m sorry it has devolved into this. I got a little frustrated that Cat is making more edits after having had at least two other opportunities to edit in the past. It’s starting to feel like these edits are just an excuse to work in a way to remove the term “anthropogenic.”

In my conversation with Cat last week she agreed that the term could possibly stay in later parts of the document, but she wants it removed from the executive summary and introduction because she feels that would garner attention.

Perhaps these edits are entirely valid and I’m overreacting here — please do tell me if that’s the case. It just feels like an excuse to make me remove certain words regarding the human cause of climate change.

Cheers

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

> On Mar 29, 2018, at 12:02 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote:
>
> Hi Maria,
>
> I had been working on a deadline yesterday for the National Climate
> Assessment. That is finished for now, so I can turn to this string of
> e-mails. Sorry for the delay.
>
> Patrick
>
>
>
> ---------- Forwarded message ----------
> From: Cat Hoffman <cat_hawkins_hoffman@nps.gov>
> Date: Thu, Mar 29, 2018 at 5:00 AM
> Subject: Re: Final revisions
> To: "Gross, John" <john_gross@nps.gov>
> Cc: "Caffrey, Maria" <maria_caffrey@partner nps.gov>, Rebecca Beavers
> <rebecca_beavers@nps.gov>, Patrick Gonzalez
> <patrick_gonzalez@nps.gov>, Larry Perez <larry_perez@nps.gov>
>
>
> Just realized the suggested revision needs to include “in the last
> century”, ie “the rate of SLR in the last century is...”
>
> Sorry for my incomplete work on this last night
>
> Sent from my iPhone
>
> On Mar 28, 2018, at 11:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>

> John -- Thank's for giving your time to this on short notice and for
> your prompt review and comments. It's helpful to have your
> perspective from a "fresh look."
>
> Maria, Rebecca, Patrick -- I've attached for your consideration a
> revision of the introductory text removing "pre-industrial" and adding
> information (and citation) regarding the greatly accelerated rate of
> sea level rise since 1993.
>
> I know Rebecca and Patrick are still traveling and/or off. I'm hoping
> we can complete this by early next week and move it over to Fagan so
> that it might be formatted and available by the end of the week. I'll
> be on a plane and driving tomorrow, and in (b) (6) [redacted]
> but I will continue to make this a priority and can make time for a
> call if needed.
>
> Cat
>
>
>
>
>
>
>
>
>
>> On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:
>>
>> Folks,
>>
>> I read the comments and emails below very carefully, and here are my opinions on the changes.
>>
>> First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.
>>
>> Page Viii:
>>
>> As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.
>>
>> Page 1:
>>
>> I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “…, recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like “… with the greatest rates occurring since 1970.” This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO2 emissions. I think a more important issue in this paragraph is that it simply says “Further warming of the atmosphere will cause sea levels to continue to rise”, when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.
>>
>> Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.
>>
>> Page 2:

>>
>> This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn’t adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it’s not critical and it does not alter the key results of the report.
>>
>> So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.
>>
>> Respectfully,
>> John Gross
>>
>>> On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>
>>> Hi Maria,
>>>
>>> In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "greater than in any preceding century in at least 2,800 years" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report.   It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park.   Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."
>>>
>>> I know you haven't agreed with my point on this but wanted to say again the suggested revision here isn't about "anthropogenic."
>>>
>>>
>>>> On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner nps.gov> wrote:
>>>>
>>>> Hi Cat,
>>>>
>>>> Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.
>>>>
>>>> Thanks,
>>>>
>>>> M.
>>>>
>>>>> On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>>>
>>>>> Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.
>>>>>
>>>>> The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but

strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.
>>>>>
>>>>> The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.
>>>>>
>>>>> However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists.   Thank you.
>>>>>
>>>>> Cat
>>>>>
>>>>>> On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>>>>>>
>>>>>> Cat,
>>>>>>
>>>>>> I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.
>>>>>>
>>>>>>> On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>>>>>
>>>>>>> Hi all --
>>>>>>>
>>>>>>> My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.
>>>>>>>
>>>>>>> It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while [redacted]
>>>>>>>
>>>>>>> I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.
>>>>>>>
>>>>>>> this remains a priority and I will work on it as necessary while I'm on annual leave.
>>>>>>>
>>>>>>> Cat
>>>>>>>
>>>>>>>
>>>>>>>
>>>>>>>> On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner nps.gov> wrote:
>>>>>>>>
>>>>>>>> Hi Cat,
>>>>>>>>
>>>>>>>> I'm afraid I can't do it today. Can we do it later in the week?
>>>>>>>>

>>>>>>>>> On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>>>>>>>
>>>>>>>>> Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.
>>>>>>>>>
>>>>>>>>> Cat
>>>>>>>>>
>>>>>>>>> --
>>>>>>>>> Cat Hawkins Hoffman
>>>>>>>>> National Park Service
>>>>>>>>>
>>>>>>>>> Chief, NPS Climate Change Response Program
>>>>>>>>> 1201 Oakridge Drive
>>>>>>>>> Fort Collins, CO 80525
>>>>>>>>> cat_hawkins_hoffman@nps.gov
>>>>>>>>> office: 970-225-3567
>>>>>>>>> cell: 970-631-5634
>>>>>>>>>
>>>>>>>>> Adaptation websites: public, NPS managers
>>>>>>>>> Climate Change Response Resources
>>>>>>>>>
>>>>>>>>
>>>>>>>>
>>>>>>>>
>>>>>>>> --
>>>>>>>> Maria Caffrey, Ph.D.
>>>>>>>> NPS Water Resources Division
>>>>>>>> PO Box 25287
>>>>>>>> Denver CO 80225
>>>>>>>>
>>>>>>>> Office: 303-969-2097
>>>>>>>> Cell: 303-518-3419
>>>>>>>>
>>>>>>>> www nps.gov/subjects/wetlands
>>>>>>>
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>> --
>> John Gross, PhD
>> Climate Change Ecologist, NPS
>>
>
>
>
> --
> Cat Hawkins Hoffman
> National Park Service
>
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> 1201 Oakridge Drive
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>
> Adaptation websites: public, NPS managers
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>
> <Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>

47 Re_ Cost estimates from Sandy_.pdf

From:	Turk, Rich
To:	Hudson, Tim
Cc:	Cat Hoffman
Subject:	Re: Cost estimates from Sandy?
Date:	Thursday, March 29, 2018 2:41:07 PM

Thanks Tim......I might have put it all together but knew you probably had it off the top of your heard.

Sounds like if we needed a deeper, more project specific dive...Brian would be a place to go or at least start.

Rich

On Thu, Mar 29, 2018 at 7:24 AM, Hudson, Tim <tim_hudson@nps.gov> wrote:

> The Sandy special appropriation was $348 million, but that year had a sequestration that amounted to some $18.185 million, so we effectively had about $330 million. There was also the ERFO money that paid for damage. I don't have an exact on that, but it was about $40 to $43 million. I suspect that is close enough to what you are looking for. WASO Budget will not have that number. Kristie Franzmann is probably the best one to go to for an exact number. We also added money to the projects out of Repair/Rehab very recently as the $348 pot is about out. Brian Strack is running that, but I don't think you'll get a final number from him and you are safe to use the "at least" $330 plus the $40.
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>>
>> How are things going up there in the north woods?

Rich

---------- Forwarded message ----------
From: **Hoffman, Cat** <cat_hawkins_hoffman@nps.gov>
Date: Wed, Mar 28, 2018 at 4:22 PM
Subject: Cost estimates from Sandy?
To: "Turk, Rich" <rich_turk@nps.gov>
Cc: Maria Caffrey <maria.caffrey@colorado.edu>, Patrick Gonzalez <patrick_gonzalez@nps.gov>, Rebecca Beavers <rebecca_beavers@nps.gov>

Hi Rich --

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This may not be the final wording we'll use for this paragraph, but it's sufficient to give you context for what we're after. Do you have a figure that we can use for the $XX below for Hurricane Sandy? (And just curious whether there are (as yet) estimates for Irma and Maria in San Juan?)

thanks for any input.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010 , Lin et al. 2012 , Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

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Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
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cat_hawkins_hoffman@nps.gov
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Adaptation websites: public, NPS managers
Climate Change Response Resources

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Richard G. Turk
Construction Program Management Division
Value Analysis Program Coordinator
National Park Service

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Fax: 303-969-2423

48 [EXTERNAL] Re_ Final revisions(1).pdf

From:	Maria Caffrey
To:	Gonzalez, Patrick
Subject:	[EXTERNAL] Re: Final revisions
Date:	Thursday, March 29, 2018 3:09:54 PM

Patrick,

I forgot to mention in my previous email that I have spoken to the University of Colorado about this matter. Their PR team have asked that I stop making revisions given the open FOIA/CORA and forthcoming article about this. I have checked with the contracting officer for this and she has also said that I should stop making edits and that the CESU agreement ensures that this report is my intellectual property and that I get final say on its content. Cat would be in breech of the master agreement is she alters it without my permission or removes my name from it.

So now I have to make a decision whether I want to continue taking edits from Cat. If you feel that her edits are good, then I'm willing to look at them. However, at this point I think it prudent that I comply with the University's wishes. If that means that Cat decides not to release this then that's fine -- I'll just write it up as a journal article. It's sad that it has come to this and I'm especially sad that this has tainted my relationship with CCRP.

As I said though, I'll look at the edits if you think they improve the report. I really respect your professional opinion. You've been a great colleague through this.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Gonzalez, Patrick <patrick_gonzalez@nps.gov>
Sent: Thursday, March 29, 2018 12:00:55 PM
To: Maria Caffrey; Maria Caffrey
Subject: Re: Final revisions

Hi Maria,

I had been working on a deadline yesterday for the National Climate Assessment. That is finished for now, so I can turn to this string of e-mails. Sorry for the delay.

Patrick

---------- Forwarded message ----------
From: Cat Hoffman <cat_hawkins_hoffman@nps.gov>

Date: Thu, Mar 29, 2018 at 5:00 AM
Subject: Re: Final revisions
To: "Gross, John" <john_gross@nps.gov>
Cc: "Caffrey, Maria" <maria_caffrey@partner.nps.gov>, Rebecca Beavers
<rebecca_beavers@nps.gov>, Patrick Gonzalez
<patrick_gonzalez@nps.gov>, Larry Perez <larry_perez@nps.gov>

Just realized the suggested revision needs to include "in the last century", ie "the rate of SLR in the last century is..."

Sorry for my incomplete work on this last night

Sent from my iPhone

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I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and in (b) (6) [redacted] but I will continue to make this a priority and can make time for a call if needed.

Cat

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:
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> Folks,
>
> I read the comments and emails below very carefully, and here are my opinions on the changes.
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> First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.
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> Page Viii:

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>>>>>>
>>>>>> It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while (b) (6) [redacted].
>>>>>>
>>>>>> I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.
>>>>>>
>>>>>> this remains a priority and I will work on it as necessary while I'm on annual leave.
>>>>>>
>>>>>> Cat
>>>>>>
>>>>>>
>>>>>>
>>>>>> On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>>>>>>>
>>>>>>> Hi Cat,
>>>>>>>
>>>>>>> I'm afraid I can't do it today. Can we do it later in the week?
>>>>>>>
>>>>>>> On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>>>>>>
>>>>>>>> Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.
>>>>>>>>
>>>>>>>> Cat
>>>>>>>>
>>>>>>>> --
>>>>>>>> Cat Hawkins Hoffman
>>>>>>>> National Park Service
>>>>>>>>
>>>>>>>> Chief, NPS Climate Change Response Program
>>>>>>>> 1201 Oakridge Drive

>>>>>>>> Fort Collins, CO 80525
>>>>>>>> cat_hawkins_hoffman@nps.gov
>>>>>>>> office: 970-225-3567
>>>>>>>> cell: 970-631-5634
>>>>>>>>
>>>>>>>> Adaptation websites: public, NPS managers
>>>>>>>> Climate Change Response Resources
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>>>>>>> Maria Caffrey, Ph.D.
>>>>>>> NPS Water Resources Division
>>>>>>> PO Box 25287
>>>>>>> Denver CO 80225
>>>>>>>
>>>>>>> Office: 303-969-2097
>>>>>>> Cell: 303-518-3419
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> --
> John Gross, PhD

> Climate Change Ecologist, NPS
>

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Adaptation websites: public, NPS managers
Climate Change Response Resources

<Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>

49 Re_ Cost estimates from Sandy_(1).pdf

From:	Cat Hoffman
To:	Hudson, Tim
Cc:	Turk, Rich
Subject:	Re: Cost estimates from Sandy?
Date:	Thursday, March 29, 2018 8:25:00 PM

Thank you Tim. We may use only the Sandy figures since repair of the 2017 hurricane damage is still in early stages. But I'll contact Dennis if we do decide to use these. Really appreciate your help.

Sent from my iPhone

On Mar 29, 2018, at 11:09 AM, Hudson, Tim <tim_hudson@nps.gov> wrote:

> Good. Be careful about your verbiage on IRMIA as the NPS damage in Puerto Rico is pretty small (we only have the fort and it is a big mass so didn't get much more than cosmetic damage, from what I understand). Flamingo (EVER) took some damage as did Fort Jefferson (Dry Tortuga's) but the big damage is in the Virgin Islands - that is where the bulk of that money will need to go. If you want someone to talk about IRMIA estimates, I would probably give Dennis McCarthy a call/note. Rich knows him well, if you don't.
>
> Tim
>
> Tim Hudson
> Superintendent
> Katahdin Woods and Waters National Monument
> National Park Service
> PO Box 446
> Patten, ME 04765
> http://www.nps.gov/kaww
>
> 207 242-0186 Work Cell
> 907 350-8058 Personal Cell
>
> On Thu, Mar 29, 2018 at 9:54 AM, Cat Hoffman <cat_hawkins_hoffman@nps.gov> wrote:
>
>> Thank you Tim; this is exactly what we need, and it doesn't have to be exact. Thanks for the help, and Rich, thanks for forwarding.
>>
>> Sent from my iPhone
>>
>> On Mar 29, 2018, at 9:24 AM, Hudson, Tim <tim_hudson@nps.gov> wrote:
>>
>>> The Sandy special appropriation was $348 million, but that year had a sequestration that amounted to some $18.185 million, so we effectively had about $330 million. There was also the ERFO money that paid for damage. I don't have an exact on that, but it

was about $40 to $43 million. I suspect that is close enough to what you are looking for. WASO Budget will not have that number. Kristie Franzmann is probably the best one to go to for an exact number. We also added money to the projects out of Repair/Rehab very recently as the $348 pot is about out. Brian Strack is running that, but I don't think you'll get a final number from him and you are safe to use the "at least" $330 plus the $40.

As for IRMIA (Irma and Maria), I believe that they allocated $207 million. You can check that number with John Spernoga - that would probably be better than John Powers at this point. I got the $207 from Jessica Bowron when I was in her office a couple of weeks ago.

That's what I know - hope it helps a little.

Tim

Tim Hudson
Superintendent
Katahdin Woods and Waters National Monument
National Park Service
PO Box 446
Patten, ME 04765
http://www.nps.gov/kaww

207 242-0186 Work Cell
907 350-8058 Personal Cell

On Wed, Mar 28, 2018 at 7:05 PM, Turk, Rich <rich_turk@nps.gov> wrote:

> Tim.....
>
> I was looking for a number for Cat Hoffman..... ran some totals off you very old reporting spreadsheet.....and could confirm estimates in excess of $325M. Was wondering who might have the final numbers? any suggestions?? John Powers? NERO?
>
> How are things going up there in the north woods?
>
> Rich
>
> ---------- Forwarded message ----------
> From: **Hoffman, Cat** <cat_hawkins_hoffman@nps.gov>
> Date: Wed, Mar 28, 2018 at 4:22 PM
> Subject: Cost estimates from Sandy?
> To: "Turk, Rich" <rich_turk@nps.gov>
> Cc: Maria Caffrey <maria.caffrey@colorado.edu>, Patrick Gonzalez <patrick_gonzalez@nps.gov>, Rebecca Beavers <rebecca_beavers@nps.gov>

Hi Rich --

we're working to get a sea level rise report to the finish line and I wondered if you could help us with some cost estimate information.

This may not be the final wording we'll use for this paragraph, but it's sufficient to give you context for what we're after. Do you have a figure that we can use for the $XX below for Hurricane Sandy? (And just curious whether there are (as yet) estimates for Irma and Maria in San Juan?)

thanks for any input.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy exceeded $XXM. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010 , Lin et al. 2012 , Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

--
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--
Richard G. Turk
Construction Program Management Division
Value Analysis Program Coordinator
National Park Service

Link to CPMD SharePoint Site: http://share.inside.nps.gov/sites/WASO/PPFL/CPM/default.aspx

WASO(Denver)-PPFL-CPMD
12795 W. Alameda Parkway
PO BOX 25287
Denver, CO 80225-0287
Phone: 303-969-2470
Fax: 303-969-2423

50 More on sea level rise revisions.pdf

From: Gonzalez, Patrick
To: Maria Caffrey
Subject: More on sea level rise revisions
Date: Friday, March 30, 2018 10:13:38 AM

Hi Maria,

Thanks for your patience in awaiting my input. I was completely occupied on long days and nights with the National Climate Assessment deadline.

While some of the suggested edits, which try to link the results with park management issues, might be fine as additions to the existing text, they are apparently used as excuses to delete the term "anthropogenic climate change." The repeated efforts of various National Park Service staff over the past year to delete the references to the human cause of climate change, which is the subject of scientific agreement in Intergovernmental Panel on Climate Change reports and the U.S. National Climate Assessment, and the year-long blocking of the release of the report unless you accepted the deletions have constituted coercive manipulation to suppress scientific content and violated the policy on scientific integrity of the U.S. Department of the Interior.

I agree with you that it would be regrettable for your National Park Service report not be released. One option is to leave the original text intact, add the recently suggestions as additional text, and submit that as a final version for National Park Service administrative approval. This option is somewhat time consuming and may not change anything. You could work on it yourself or we could work on it together on a webinar again next week. An alternative approach is what you proposed, namely, inform the National Park Service of the legal advice, and ask for administrative approval again on the current text with no changes.

I support whatever you decide. In any case, you should really draft a scientific journal manuscript for submission, on your University of Colorado time. It is original research that merits publication. I recommend that you start as soon as you find the time.

Thanks for your positive feedback and for including me.

Best regards,

Patrick

....

Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management

Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

131 Mulford Hall, Berkeley, CA 94720-3114 USA
patrick_gonzalez@nps.gov
+1 (510) 643-9725
....

---------- Forwarded message ----------
From: Maria Caffrey <maria.caffrey@colorado.edu>
Date: Thu, Mar 29, 2018 at 2:09 PM
Subject: [EXTERNAL] Re: Final revisions
To: "Gonzalez, Patrick" <patrick_gonzalez@nps.gov>

Patrick,

I forgot to mention in my previous email that I have spoken to the University of Colorado about this matter. Their PR team have asked that I stop making revisions given the open FOIA/CORA and forthcoming article about this. I have checked with the contracting officer for this and she has also said that I should stop making edits and that the CESU agreement ensures that this report is my intellectual property and that I get final say on its content. Cat would be in breech of the master agreement is she alters it without my permission or removes my name from it.

So now I have to make a decision whether I want to continue taking edits from Cat. If you feel that her edits are good, then I'm willing to look at them. However, at this point I think it prudent that I comply with the University's wishes. If that means that Cat decides not to release this then that's fine -- I'll just write it up as a journal article. It's sad that it has come to this and I'm especially sad that this has tainted my relationship with CCRP.

As I said though, I'll look at the edits if you think they improve the report. I really respect your professional opinion. You've been a great colleague through this.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Gonzalez, Patrick <patrick_gonzalez@nps.gov>
Sent: Thursday, March 29, 2018 12:00:55 PM
To: Maria Caffrey; Maria Caffrey
Subject: Re: Final revisions

Hi Maria,

I had been working on a deadline yesterday for the National Climate Assessment. That is finished for now, so I can turn to this string of e-mails. Sorry for the delay.

Patrick

---------- Forwarded message ----------
From: Cat Hoffman <cat_hawkins_hoffman@nps.gov>
Date: Thu, Mar 29, 2018 at 5:00 AM
Subject: Re: Final revisions
To: "Gross, John" <john_gross@nps.gov>
Cc: "Caffrey, Maria" <maria_caffrey@partner.nps.gov>, Rebecca Beavers <rebecca_beavers@nps.gov>, Patrick Gonzalez <patrick_gonzalez@nps.gov>, Larry Perez <larry_perez@nps.gov>

Just realized the suggested revision needs to include "in the last century", ie "the rate of SLR in the last century is..."

Sorry for my incomplete work on this last night

Sent from my iPhone

On Mar 28, 2018, at 11:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

John -- Thank's for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

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>>>>>>>> 1201 Oakridge Drive
>>>>>>>> Fort Collins, CO 80525
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<Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>

51 [EXTERNAL] Re_ More on sea level rise revisions.pdf

From: Maria Caffrey
To: Gonzalez, Patrick
Subject: [EXTERNAL] Re: More on sea level rise revisions
Date: Friday, March 30, 2018 10:28:22 AM

Hi Patrick,

Thanks for taking the time to look at this. I was starting to feel that perhaps I am being unreasonable here. I really respect John and his email really made me second guess myself, although I understand he is in a difficult position between me and Cat. I'm going to sleep on this and let you know what I decide. I fear things are getting a little acrimonious between me and Cat, so I don't want emotions to get in way of a decision on this.

Have a great weekend.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Gonzalez, Patrick <patrick_gonzalez@nps.gov>
Sent: Friday, March 30, 2018 10:12:52 AM
To: Maria Caffrey
Subject: More on sea level rise revisions

Hi Maria,

Thanks for your patience in awaiting my input. I was completely occupied on long days and nights with the National Climate Assessment deadline.

While some of the suggested edits, which try to link the results with park management issues, might be fine as additions to the existing text, they are apparently used as excuses to delete the term "anthropogenic climate change." The repeated efforts of various National Park Service staff over the past year to delete the references to the human cause of climate change, which is the subject of scientific agreement in Intergovernmental Panel on Climate Change reports and the U.S. National Climate Assessment, and the year-long blocking of the release of the report unless you accepted the deletions have constituted coercive manipulation to suppress scientific content and violated the policy on scientific integrity of the U.S. Department of the Interior.

I agree with you that it would be regrettable for your National Park Service report not be released. One option is to leave the original text intact, add the recently suggestions as additional text, and submit that as a final version for National Park Service administrative approval. This option is somewhat time consuming and may not change anything. You could work on it yourself or we could work on it together on a webinar again next week. An alternative approach is what you proposed, namely, inform the National Park Service of the legal advice, and ask for administrative approval again on the current text with no changes.

I support whatever you decide. In any case, you should really draft a scientific journal manuscript for submission, on your University of Colorado time. It is original research that merits publication. I recommend that you start as soon as you find the time.

Thanks for your positive feedback and for including me.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

131 Mulford Hall, Berkeley, CA 94720-3114 USA
patrick_gonzalez@nps.gov
+1 (510) 643-9725
....

---------- Forwarded message ----------
From: Maria Caffrey <maria.caffrey@colorado.edu>
Date: Thu, Mar 29, 2018 at 2:09 PM
Subject: [EXTERNAL] Re: Final revisions
To: "Gonzalez, Patrick" <patrick_gonzalez@nps.gov>

Patrick,

I forgot to mention in my previous email that I have spoken to the University of Colorado about this matter. Their PR team have asked that I stop making revisions given the open FOIA/CORA and forthcoming article about this. I have checked with the contracting officer for this and she has also said that I should stop making edits and that the CESU agreement ensures that this report is my intellectual property and that I get final say on its content. Cat would be in breech of the master agreement is she alters it without my permission or removes my name from it.

So now I have to make a decision whether I want to continue taking edits from Cat. If you feel that her edits are good, then I'm willing to look at them. However, at this point I think it prudent that I comply with the University's wishes. If that means that Cat decides not to release this then that's fine -- I'll just write it up as a journal article. It's sad that it has come to this and I'm especially sad that this has tainted my relationship with CCRP.

As I said though, I'll look at the edits if you think they improve the report. I really respect your professional opinion. You've been a great colleague through this.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
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2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

____
From: Gonzalez, Patrick <patrick_gonzalez@nps.gov>
Sent: Thursday, March 29, 2018 12:00:55 PM
To: Maria Caffrey; Maria Caffrey
Subject: Re: Final revisions

Hi Maria,

I had been working on a deadline yesterday for the National Climate Assessment. That is finished for now, so I can turn to this string of e-mails. Sorry for the delay.

Patrick

---------- Forwarded message ----------
From: Cat Hoffman <cat_hawkins_hoffman@nps.gov>
Date: Thu, Mar 29, 2018 at 5:00 AM
Subject: Re: Final revisions
To: "Gross, John" <john_gross@nps.gov>

Cc: "Caffrey, Maria" <maria_caffrey@partner.nps.gov>, Rebecca Beavers <rebecca_beavers@nps.gov>, Patrick Gonzalez <patrick_gonzalez@nps.gov>, Larry Perez <larry_perez@nps.gov>

Just realized the suggested revision needs to include "in the last century", ie "the rate of SLR in the last century is..."

Sorry for my incomplete work on this last night

Sent from my iPhone

On Mar 28, 2018, at 11:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

John -- Thank's for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

Maria, Rebecca, Patrick -- I've attached for your consideration a revision of the introductory text removing "pre-industrial" and adding information (and citation) regarding the greatly accelerated rate of sea level rise since 1993.

I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and (b(b) (6) [redacted] but I will continue to make this a priority and can make time for a call if needed.

Cat

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:
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> Folks,
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> I read the comments and emails below very carefully, and here are my opinions on the changes.
>
> First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.
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> Page Viii:
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> As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic

climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.
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> Page 1:
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> I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “…, recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like “… with the greatest rates occurring since 1970.” This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO2 emissions. I think a more important issue in this paragraph is that it simply says “Further warming of the atmosphere will cause sea levels to continue to rise”, when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.
>
> Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.
>
> Page 2:
>
> This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn’t adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it’s not critical and it does not alter the key results of the report.
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> So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.
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> Respectfully,
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> On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
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>> Hi Maria,
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>> In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "greater than in any preceding century in at least 2,800 years" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report. It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park. Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail

about, and substantiates that the rate of contemporary sea level rise is not "normal."
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>> I know you haven't agreed with my point on this but wanted to say again the suggested revision here isn't about "anthropogenic."
>>
>>
>> On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>>>
>>> Hi Cat,
>>>
>>> Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.
>>>
>>> Thanks,
>>>
>>> M.
>>>
>>> On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>>>
>>>> Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.
>>>>
>>>> The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.
>>>>
>>>> The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.
>>>>
>>>> However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.
>>>>
>>>> Cat
>>>>
>>>> On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>>>>>
>>>>> Cat,
>>>>>
>>>>> I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.

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<Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>

52 Re_ Final revisions(5).pdf

From:	Hoffman, Cat
To:	Gross, John; Caffrey, Maria; Rebecca Beavers; Patrick Gonzalez
Cc:	Larry Perez
Subject:	Re: Final revisions
Date:	Sunday, April 01, 2018 10:33:58 PM
Attachments:	Caffrey et al Sea Level Change Report_no pics.4.01.2018.docx

Hi all -- first, just a quick note to say I hope you had a wonderful Easter. I got to spend it with family.. (b) (6) [redacted]

I've attached my last recommended changes to the document in which I incorporated the costs of damage to parks from Hurricane Sandy (provided by Tim Hudson), added one sentence and citation in the Introduction as a bridge between these two sentences (shown here in purple font), and added 3 citations to Literature Cited as noted in additions to the text.

> Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet, et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise....

I see just a few remaining tasks:

> (1) find a good photo of the Statue of Liberty (Matt is working on that).
> (2) check these references (Knutson et al. 2010; Lin et al. 2012, and Ting et al. 2015) to verify that they do speak to the point about models projecting increasing storm intensities under scenarios of increasing GHG emissions -- I read each of these references and had questions about whether they substantiate this point, but Maria, you know these better than any of us; could you please advise.
> (3) verify that the concerns Tahzay and the Alaska region had are resolved (I think so) and that text in the report is satisfactory to AKR (likely this was done, but I just don't know) (Maria or Rebecca)
> (4) put these changes into the main document and get it to Fagan (Larry is ready to do so).

Are there other tasks?

Please let all authors know by noon on Tuesday if you are ready to move this to Fagan.

Thanks.

Cat

On Thu, Mar 29, 2018 at 6:00 AM, Cat Hoffman <cat_hawkins_hoffman@nps.gov> wrote:

> Just realized the suggested revision needs to include "in the last century", ie "the rate of SLR in the last century is..."

Sorry for my incomplete work on this last night

Sent from my iPhone

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First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.

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Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.

Page 2:

This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn't adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it's not critical and it does not alter the key results of the report.

So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.

Respectfully,
John Gross

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On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Hi Cat,

Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.

Thanks,

M.

On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.

The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.

The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.

However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.

Cat

On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Cat,

I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.

On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

Hi all --

My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.

It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while (b) (6) [redacted]

I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.

this remains a priority and I will work on it as necessary while I'm on annual leave.

Cat

On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Hi Cat,

I'm afraid I can't do it today. Can we do it later in the week?

On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat
<cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.
>
> Cat
>
> --
> ***Cat Hawkins Hoffman***
> **National Park Service**
>
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<Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>

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Adaptation websites: public, NPS managers
Climate Change Response Resources

52 1 Attachment Caffrey et al Sea Level Change Report_no pics_3.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

Maria A. Caffrey[1], Rebecca L. Beavers[2], Patrick Gonzalez[3], Cat Hawkins Hoffman[4]

Comment [HCH1]: No hyphen

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers understand these changes and their implications so we may better steward the resources under our care and provide for visitor use. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, the report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

Comment [HCH2]: Executive summary answers the "why" – why is this important to parks a succinct statement of the reason we invested in this work I E we have an affirmative responsibility to address the threat of sea level rise (change) and storm surge in order to protect resources and visitor opportunities The drivers that cause sea level change and the science behind it are included in the document as a useful reference for our managers

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Comment [HCH3]: Redundant with first sentence

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration ~~for~~ and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth

receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Comment [HCH4]: Source: https://www nhc noaa gov/surge/surge_intro pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009, ~~anthropogenic climate change has significantly increased the rate of global sea level rise~~ Grinsted et al. 2010, Church and White 2011).~~;~~ ~~Slangen et al. 2016, Fasullo et al. 2016~~). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet, et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect many national parks.~~how we protect and manage our national parks~~. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

Comment [HCH5]: I thought this was an important point from the Methods section to include here (in summary form)

Comment [HCH6]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19th century began To me this is much more clear than "significant increase" – it's an effective, impactful statement that negates any perceptions that "well, sea level is always changing "

From USGCRP Climate Science Special Report, 2017 (Sea level rise chapter, Sweet et al 2017): "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Source from which the CSSR derived this information:
Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016: Temperature-driven global sea-level variability in the Common Era *Proceedings of the National Academy of Sciences*, **113**, E1434-E1441 http://dx doi org/10 1073/pnas 1517056113

Comment [HCH7]: Titus, J.G., E.K. Anderson, D.R. Cahoon S. Gill R.E. Thieler and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research.https //downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms) affecting infrastructure and ecosystems, including those of national parks. Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

~~**Suggest using paragraph "A" below as a substitute for this paragraph and the next one:** For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

~~**Suggest deleting this paragraph; part of it is combined below and is more specific to parks**Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).~~

~~"A"~~ The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

Comment [HCH8]: Moved this text earlier in the document

Comment [HCH9]: Relation of temperature increase to rising sea level already noted above No need to say "we'll tell you more about it below"

Comment [HCH10]: The text needs to be more directly relevant to parks In a report about parks, it would be more useful to discuss the cost of damage in parks from Sandy, vs the cost of damage in New York City (which has infrastructure far beyond anything in parks) We could get reasonable ballpark figures from Rich Turk regarding damage caused in parks (GATE, FIIS, STLI, etc) from Sandy

Comment [HCH11]: See notes about these citations below

Comment [HCH12]: This would need a citation

Comment [HCH13]: Check whether this reference is relevant to the point; from my (cursory) reading of it, it appears inconclusive on attribution

Comment [HCH14]: Similar to Knutson et al – not sure this reference substantiates the point about models projecting increasing storm intensities under scenarios of increasing GHG emissions Seems focused on managing risks of climate change, including GHG mitigation

Comment [HCH15]: Not sure this reference substantiates the point

Conclusions include "the model simulations indicate that aerosol forcing has been more effective in causing potential intensity (PI) than the corresponding GHG forcing: the decrease in PI due to aerosols and increase due to GHG largely cancel each other Thus, PI increases in the recent 30 years appears to be dominated by multidecadal natural variability associated with the positive phase of the Atlantic multidecadal variability (AMV) "

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Comment [HCH16]: Did Tahzay Jones review the Alaska information (based on the concerns he had with the Alaska data)?

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

~~Sea Level Rise Data~~ Understanding Sea Level Rise and Storm Surge

Numerous factors cause ~~S~~sea level rise. ~~is caused by numerous factors.~~ As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

Need to add some explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise – 2-3 sentences would suffice.

Sea Level Rise Data

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The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1° x 1° from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are

reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are

shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and 2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

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NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the

nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix ~~D~~C. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane str king the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane str king the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea

level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved

towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

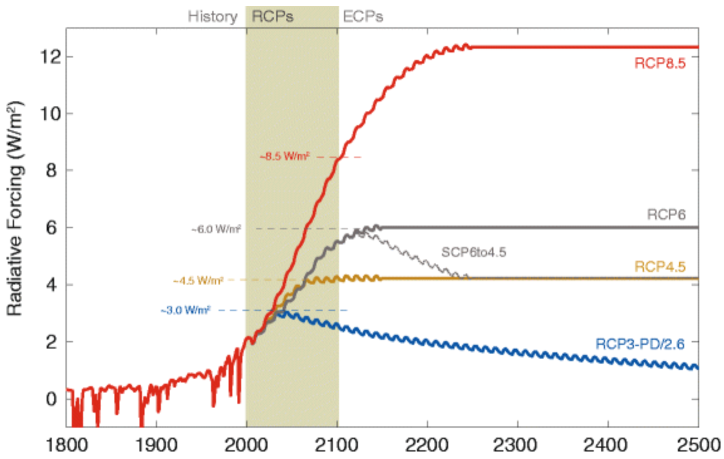

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

ADD TO LITERATURE CITED

Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016 "Temperature-driven global sea-level variability in the Common Era " *Proceedings of the National Academy of Sciences*, **113**, E1434-E1441 http://dx doi org/10 1073/pnas 1517056113

Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. "Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research." https://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf.

Sweet, W.V., R. Horton, R.E. Kopp, A.N. LeGrande, and A. Romanou, 2017. 'Sea level rise." In: *Climate Science Special Report Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 333-363, doi: 10.7930/J0VM49F2.

53 Wipeout_ Human role in climate change removed f....pdf

From: Cat Hoffman
To: Maria Caffrey; Rebecca Beavers; Patrick Gonzalez
Subject: Wipeout: Human role in climate change removed from science report | Reveal
Date: Monday, April 02, 2018 6:43:36 AM

I expect you may have seen, but forwarding just in case.

Please review my message from last evening. I would appreciate a response from all authors as soon as possible, but no later than tomorrow morning.

https://www.revealnews.org/article/wipeout-human-role-in-climate-change-removed-from-science-report/

Sent from my iPhone

54 Re_ Final revisions(6).pdf

From: Caffrey, Maria
To: Hoffman, Cat
Cc: Rebecca Beavers; Patrick Gonzalez; maria.caffrey@colorado.edu
Subject: Re: Final revisions
Date: Monday, April 02, 2018 8:35:00 AM

Hi Cat,

Thanks for taking the time to make these edits. I really appreciate all the time you have put into this. I spent some time last week looking over the things we discussed and here are a few of my thoughts:

1) The Knutson and Lin references should stay. The Knutson text you had highlighted was in reference to the data that included past storms, not anthropogenic climate change. Knutson's projections use IPCC scenarios that are based on CO2 emissions, so I think it is a good thing to keep the references.

2) The Alaska issue is related to the DEMs we used to map the scenarios, it is not related to the scenarios themselves, so it is fine to include the Alaska information.

Unfortunately, I've been asked by the University of Colorado to not make any further changes to the document. They feel that with the Reveal article that this could result in more media interest and possibly more CORA/FOIA requests in the future. I spent a good chunk of last Friday consulting with various staff at the University of Colorado to find out what this means for the report. The master agreement for the CESU lays out that this report is my intellectual property. You are welcome to publish what I sent you on 3/21 without making any edits to it. According to the master agreement, you can attach a disclaimer to the front stating that this report does not represent the views of the NPS. You also have the option to not publish it, which is fine. I have already spoken to Patrick about possibly releasing this as a journal article, although this would undoubtedly further slow down getting this information out to the parks.

I'd be happy to setup a call with Denitta Ward at the University of Colorado if you would like to discuss this further.

On Sun, Apr 1, 2018 at 10:33 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi all -- first, just a quick note to say I hope you had a wonderful Easter. I got to spend it with family...(b) (6) [redacted]
>
> I've attached my last recommended changes to the document in which I incorporated the costs of damage to parks from Hurricane Sandy (provided by Tim Hudson), added one sentence and citation in the Introduction as a bridge between these two sentences (shown here in purple font), and added 3 citations to Literature Cited as noted in additions to the text.
>
>> Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet, et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise....

I see just a few remaining tasks:

> (1) find a good photo of the Statue of Liberty (Matt is working on that).
> (2) check these references (Knutson et al. 2010; Lin et al. 2012, and Ting et al. 2015) to verify that they do speak to the point about models projecting increasing storm intensities under scenarios of increasing GHG emissions -- I read each of these references and had questions about whether they substantiate this point, but Maria, you know these better than any of us; could you please advise.
> (3) verify that the concerns Tahzay and the Alaska region had are resolved (I think so) and that text in the report is satisfactory to AKR (likely this was done, but I just don't know) (Maria or Rebecca)
> (4) put these changes into the main document and get it to Fagan (Larry is ready to do so).

Are there other tasks?

Please let all authors know by noon on Tuesday if you are ready to move this to Fagan.

Thanks.

Cat

On Thu, Mar 29, 2018 at 6:00 AM, Cat Hoffman <cat_hawkins_hoffman@nps.gov> wrote:

Just realized the suggested revision needs to include "in the last century", ie "the rate of SLR in the last century is..."

Sorry for my incomplete work on this last night

Sent from my iPhone

On Mar 28, 2018, at 11:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

John -- Thank's for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

Maria, Rebecca, Patrick -- I've attached for your consideration a revision of the introductory text removing "pre-industrial" and adding information (and citation) regarding the greatly accelerated rate of sea level rise since 1993.

I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and in (b) (6) [redacted] but I will continue to make this a priority and can make time for a call if needed.

Cat

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:

> Folks,
>
> I read the comments and emails below very carefully, and here are my opinions on the changes.
>
> First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.
>
> Page Viii:
>
> As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.
>
> Page 1:
>
> I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “…, recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like “… with the greatest rates occurring since 1970.” This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO_2 emissions. I think a more important issue in this paragraph is that it simply says “Further warming of the atmosphere will cause sea levels to continue to rise”, when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.
>
> Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.
>
> Page 2:
>
> This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the

combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn't adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it's not critical and it does not alter the key results of the report.

So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.

Respectfully,
John Gross

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria,
>
> In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "*greater than in any preceding century in at least 2,800 years*" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report. It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park. Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."
>
> I know you haven't agreed with my point on this but wanted to say again the suggested revision here isn't about "anthropogenic."
>
> On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
>> Hi Cat,
>>
>> Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.
>>
>> Thanks,

M.

On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus hurricane Sandy information on parks instead of on New York City.
>
> The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.
>
> The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.
>
> However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.
>
> Cat
>
> On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
>> Cat,
>>
>> I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.
>>
>> On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>>
>>> Hi all --
>>>
>>> My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize

this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.

It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while (b) (6) [redacted].

I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.

this remains a priority and I will work on it as necessary while I'm on annual leave.

Cat

On Tue, Mar 27, 2018 at 9:17 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

> Hi Cat,
>
> I'm afraid I can't do it today. Can we do it later in the week?
>
> On Mon, Mar 26, 2018 at 9:38 AM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>
>> Hi Maria -- I just spoke with Patrick about our schedule here...would you be available during our lunch tomorrow, ca. 10 am (we have 1/2 hour)? If that works for you, I'll send a calendar invitation.
>>
>> Cat
>>
>> --

>> ***Cat Hawkins Hoffman***
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John Gross, PhD
Climate Change Ecologist, NPS

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> > <Caffrey et al Sea Level Change Report_no pics.3.27.2018.Introduction.pdf>
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www.nps.gov/subjects/wetlands

55 Re_ Boulder CA.pdf

From: Wood, Melanie
To: Cat Hoffman
Subject: Re: Boulder CA
Date: Monday, April 02, 2018 11:27:34 AM
Attachments: P13AC01178 Executed.pdf
Signed 1550759 Caffrey Mod 1 FE.pdf
P13AC01178 - Mod 004 - FE.pdf
P13AC01178 03 (signed).pdf
ROMO_2014_cooperative_agreement.pdf

Here is the 2014 cooperative agreement, as well as the 2013 task agreement and modifications I have for Maria. The 2013 agreement would have been under an older CA than 2014 (obviously) but that one isn't posted any more.

2013 agreement has 4 modifications, I only have 3 of them (missing Mod 002)

On Mon, Apr 2, 2018 at 10:58 AM, Wood, Melanie <melanie_wood@nps.gov> wrote:

> --
>
> Melanie A. Wood
> Project Manager
> Climate Change Response Program
> National Park Service
> 1201 Oakridge Dr., Suite 200
> Fort Collins, CO 80525
> 970-267-2198 office | 970-420-7206 mobile | 970-225-3585 fax
> Melanie_Wood@nps.gov

--

Melanie A. Wood
Project Manager
Climate Change Response Program
National Park Service
1201 Oakridge Dr., Suite 200
Fort Collins, CO 80525
970-267-2198 office | 970-420-7206 mobile | 970-225-3585 fax
Melanie_Wood@nps.gov

55 1 Attachment P13AC01178 Executed.pdf

Task Agreement Number P13AC01178
Under
Cooperative Agreement Number H2370094000
Between
The United States Department of the Interior
National Park Service
And
The Regents of the University of Colorado

PROVIDING SEA LEVEL CHANGE AND STORM SURGE PROJECTIONS FOR COASTAL PARKS

ARTICLE I – BACKGROUND AND OBJECTIVES

Cooperative Agreement Number H2370094000 was entered into by and between the Department of the Interior, National Park Service (NPS), and The Regents of the University of Colorado (University of Colorado Boulder) for the purpose of the operation and maintenance of the Rocky Mountains Cooperative Ecosystem Studies Unit (RM-CESU) to assist in providing research, technical assistance and education. Unless otherwise specified herein, the terms and conditions as stated in the Cooperative Agreement will apply to this Task Agreement.

Project Title: Providing Sea Level Change and Storm Surge Projections for Coastal Parks

Climate change is an issue increasingly discussed by park managers as many parks develop foundation documents, resource stewardship strategies, or various implementation plans such as shoreline management plans. In addition to rising temperatures and changing precipitation regimes, increases in relative sea level (RSL) threaten to alter the natural and cultural resources of many parks, and may completely engulf several coastal parks. Approximately 105 coastal parks are potentially affected by changing RSL; this number will be higher when potential storm surges are included. To support planning and management decisions, NPS coastal units (including Alaska and the Pacific islands) require better information on potential RSL and storm surge events over the next 40–100 years.

NPS and the University of Colorado Boulder will collaborate to develop sea level and storm surge projections. Rising sea levels will compound effects from increased intensity, and possibly frequency, of storms, particularly hurricanes, nor'easters, and typhoons. Phase I of the project will be a service-wide assessment to project the height of relative sea level in each coastal park unit coupled with storm surge projections. Phase II will focus on three pilot parks to develop specific adaptation actions for individual park adaptation strategies. The project will assess multiple time horizons by calculating rates of sea level change by 2050 and 2100, paired with projected storm surge data.

In meeting a public purpose, the resulting products will be served on several public websites that can be accessed by other agencies, university students and faculty, and the public who are interested in sea level and storm surge change information and in interpretations of the potential impact of climate change through the National Park Service coastal zone. Further educational outreach and engagement will be in the form of wayside exhibits.

ARTICLE II – <u>AUTHORITY</u>

NPS enters into this Agreement pursuant to:

A. 16 U.S.C. §1a-2(j) Cooperative research and training programs

B. 16 U.S.C. §5933 Cooperative agreements

CFDA No. 15.945 Cooperative Research and Training Programs – Resources of the National Park System

ARTICLE III – <u>STATEMENT OF WORK</u>

A. University of Colorado Boulder agrees to:

1. Design, develop, and implement sea level change projections for 105 coastal parks. The results of these projections will be detailed in a "Sea level change in the National Park System" report that follows a similar format (i.e. summary for policymakers, technical summary) to current Intergovernmental Panel on Climate Change (IPCC) reports.
2. Design, develop, and implement an interactive website that will be linked to nps.gov.
3. Provide information and assist in the educational development of three wayside exhibits in three separate park units that promote an increased understanding on the science of sea level and storm surge change.

B. NPS agrees to:

1. Assign an Agreement Technical Representative who will work closely with the University of Colorado Boulder staff and the Principal Investigator to facilitate the accomplishment of the various tasks of this agreement, and provide any needed technical support as it pertains to the use and application of sea level or storm surge data within the NPS.
2. Identify workload needs and priorities, discuss how to meet those needs, and explore opportunities to institute new approaches to maximize project efficiencies.
3. Meet as needed, but at a minimum quarterly, with the University of Colorado Boulder staff, as well provide frequent communication via phone and email to discuss progress, and to ensure that work performed and products developed are meeting the needs of the project.
4. Provide office space, telecommunications, computer equipment, internet access, access to printers and plotters, and information technology (IT) support to the University of Colorado Boulder staff assigned to the project, and working in NPS offices in Fort Collins, Colorado.

ARTICLE IV – TERM OF AGREEMENT

This Task Agreement will become effective on the date of final signature and extend through December 31, 2016.

ARTICLE V – KEY OFFICIALS

A. Key officials are essential to ensure maximum coordination and communication between the parties and the work being performed. They are:

   1. **For the NPS:**

      Agreement Technical Representative (ATR):

      Dr. Rebecca Beavers
      Coastal Geologist
      National Park Service
      WASO, NRSS, Geologic Resources Division
      7333 W. Jefferson Avenue
      Lakewood, CO 80235
      Phone: (303) 987-6945
      Email: rebecca_beavers@nps.gov

      Awarding Officer:

      Andrew E. Lubner
      Awarding Officer
      National Park Service
      WASO, Washington Contracting and Procurement Office (WCP)
      P.O. Box 25287, MS WCP
      Denver, CO 80225-0287
      Phone: (303) 969-2378
      Email: andrew_lubner@nps.gov

   2. **For the University of Colorado Boulder:**

      Principal Investigator (PI):

      Dr. Maria Caffrey
      Research Associate
      Geological Sciences
      University of Colorado Boulder
      Boulder, CO 80309
      Phone: (303) 969-2097
      Email: maria.caffrey@colorado.edu

Administrator:

Denitta D. Ward
Associate Director
Office of Contracts and Grants
University of Colorado Boulder
3100 Marine Street, Room 461
Boulder, CO 80303
Phone: (303) 735-6624
Email: denitta.ward@colorado.edu

B. **Communications –** University of Colorado Boulder will address any communication regarding this Agreement to the ATR with a copy to the NPS Awarding Officer. Communications that relate solely to routine operational matters described in the current work plan may be sent only to the ATR

C. **Changes in Key Officials** - Neither the NPS nor the University of Colorado Boulder may make any permanent change in a key official without written notice to the other party reasonably in advance of the proposed change. The notice will include a justification with sufficient detail to permit evaluation of the impact of such a change on the scope of work specified within this Agreement. Any permanent change in key officials will be made only by modification to this Agreement.

ARTICLE VI – AWARD AND PAYMENT

A. Financial Assistance (FA): NPS will provide funding to the University of Colorado Boulder in an amount not to exceed $199,898.00 for the work described in Article III and in accordance with the approved budget (Attachment A). Any award beyond the current fiscal year is subject to availability of funds.

NPS Account Information:

Line Item Number: 00010
Line Item Amount: $199,898.00
Account ID: 1
Accounting Code: 01
Account Assignment: K
G/L Account: 6100.411C0
Business Area: P000
Commitment Item: 411C00
Cost Center: PPWONRAD00
Functional Area: PPMRSNR1W.NG0000
Fund: 133P103601
Fund Center: PPWONRAD00

Project/WBS: PX.P0192415A.00.1
PR Acct Assign Line: 01

B. University of Colorado Boulder shall request payment in accordance with the following:

1. **Method of Payment**. Payment will be made by advance and/or reimbursement through the Department of Treasury's ASAP system.

2. **Requesting Advances**. Requests for advances must be made submitted via the ASAP system. Requests may be submitted as frequently as required to meet the needs of the Financial Assistance (FA) recipient to disburse funds for the Federal share of project costs. If feasible, each request should be timed so that payment is received on the same day that the funds are dispersed for direct project costs and/or the proportionate share of any allowable indirect costs. If same-day transfers are not feasible, advance payments must be as close to actual disbursements as administratively feasible.

3. **Requesting Reimbursement**. Requests for reimbursements must be submitted via the ASAP system. Requests for reimbursement should coincide with normal billing patterns. Each request must be limited to the amount of disbursements made for the Federal share of direct project costs and the proportionate share of allowable indirect costs incurred during that billing period.

4. **Adjusting payment requests for available cash**. Funds that are available from repayments to, and interest earned on, a revolving fund, program income, rebates, refunds, contract settlements, audit recoveries, credits, discounts, and interest earned on any of those funds must be disbursed before requesting additional cash payments.

5. **Bank Accounts**. All payments are made through electronic funds transfer to the bank account identified in the U.S Treasury ASAP system by the FA recipient.

6. **Supporting Documents and Agency Approval of Payments**. Additional supporting documentation and prior Agency (NPS) approval of payments may be required when/if a FA recipient is determined to be "high risk" or has performance issues. If prior Agency payment approval is in effect for an award, the ASAP system will notify the FA recipient when they submit a request for payment. The Recipient must then notify the NPS Awarding Officer identified on the Assistance Agreement that a payment request has been submitted. The NPS Awarding Officer may request additional information from the recipient to support the payment request prior to approving the release of funds, as deemed necessary. The FA recipient is required to comply with these requests. Supporting documents may include invoices, copies of contracts, vendor quotes, and other expenditure explanations that justify the reimbursement requests.

ARTICLE VII – REPORTS AND/OR DELIVERABLES

A. Within 90 days of the end of the agreement a final Standard Form (SF) 425 Federal Financial Report (FFR) shall be provided to the NPS Awarding Officer.

B. Within 90 days of the end of the agreement a final performance report shall be provided to the NPS Awarding Officer.

C. Specific projects or activities for which funds are advanced will be tracked and reported by semi-annual submission of a SF-425 Federal Financial Report (FFR). A final SF-425 shall be submitted at the completion of the Agreement. The following reporting period end dates shall be used for interim reports: 6/30, 12/31.

ARTICLE VIII – MODIFICATION AND TERMINATION

This task agreement may be modified at any time, prior to the expiration date, by the mutual concurrence of the University of Colorado Boulder and the NPS. Modifications will be in writing, approved and signed by the NPS Awarding Officer and the University of Colorado Boulder signatory official.

ARTICLE IX – ATTACHMENTS

The following documents are attached and made a part of this Task Agreement:

A. Budget (One page)
B. Project Scope of Work (Four pages)
C. Rocky Mountain (RM) CESU Information (Two pages)

ARTICLE X - SIGNATURES

IN WITNESS WHEREOF, the parties hereto have executed this Task Agreement on the date(s) set forth below.

FOR THE UNIVERSITY OF COLORADO BOULDER

Digitally signed by Denitta D. Ward, J.D.
DN: cn=Denitta D. Ward, J.D., o=University of Colorado Boulder, ou=Office of Contracts and Grants, email=denitta.ward@colorado.edu, c=US
Date: 2013.08.22 11:51:58 -06'00'

08/22/2013
Date

Name Denitta D. Ward, J.D.
Title Deputy Director, Office of Contracts and Grants

FOR THE NATIONAL PARK SERVICE

8/26/13
Date

Andrew E. Lubner
Awarding Officer

Attachment A: Budget

Salaries	
Research Associate – Sea Level Rise and Storm Surge Project Manager/Principal Investigator (PI) (M. Caffrey - 12 months, full time)	$64,000
Graduate Research Assistant (GRA) – Geology (A. Forget, 9 – months, part-time term salary)	$16,865
Graduate Research Assistant – Geology (A. Forget, 3 – months, full time summer salary)	$11,243
Graduate Research Assistant – Geologist/Aerospace Engineer – (12 months, part-time)	$26,931
Subtotal	**$119,039**
Fringe Benefits, (PI 30.9%, GRAs 7.9%)	$24,124
Travel (domestic, professional meetings & park visits)	$3,000
Supplies	$4,127
Other Direct Costs (tuition remission)	$19,836
Total Direct:	**$170,126**
Overhead (17.5%)	**$29,772**
Total	**$199,898**

Attachment B: Project Scope of Work

Providing Sea Level Change and Storm Surge Projections for All Coastal Parks Project

University of Colorado Boulder Dr. Maria Caffrey, Research Associate
Principal Investigator (PI) Department of Geological Sciences

NPS Agreement Technical Representative (ATR) Dr. Rebecca Beavers, Coastal Geologist
Geologic Resources Division

PMIS Number 192415

Scope of Work and Budget

PURPOSE OF PROJECT:

The purpose of this project is to create sea level and storm surge change projections that will enable the University of Colorado Boulder faculty and students, National Park Service (NPS) staff, as well as other researchers, educators, and the public sector to better understand the potential impact of climate change in the coastal zone in our national parks. Information and data will be collected, stored, archived, analyzed, and disseminated to help foster temporal and spatial analysis at a variety of scales and will be made readily available to the public via wayside exhibits and a University of Colorado Boulder website. First, a document showing projected rates of sea level and storm surge change will be developed. This data will be shared within the NPS to help guide park planners and managers in 105 coastal parks. Second, the data will be condensed into a web-based graphical display package that will be made available to the public. Lastly, further educational outreach and engagement will be in the form of wayside exhibits. Wayside exhibits will be designed and developed in collaboration with NPS staff. The location of wayside exhibits will be decided by the NPS after sea level and storm surge change data has been collected for 105 coastal parks.

BACKGROUND

Climate change is an issue increasingly discussed by park managers as many parks develop foundation documents, resource stewardship strategies, or various implementation plans such as shoreline management plans. In addition to rising temperatures and changing precipitation regimes, increases in relative sea level (RSL) threaten to alter the natural and cultural resources of many parks, and may completely engulf several coastal parks. Approximately 105 coastal parks are potentially affected by changing RSL; this number will be higher when potential storm surges are included.

To support planning and management decisions, NPS coastal units (including Alaska and the Pacific islands) require better information on potential RSL and storm surge events over the next 40–100 years. Since the most recent Intergovernmental Panel on Climate Change (IPCC) report describes only global RSL rise without describing rates or regional projections, park managers must base climate change adaptation plans on either interpolated levels of RSL rise, or reports released by their individual states (e.g. California and Florida), or academics. Individual projects that are underway in various areas of the country (e.g. California's Our Coast Our Future Project) do not provide a specific focus on park units, nor is there national coverage from these individual efforts. NPS line item construction projects currently rely on partners and contractors (such as the U.S. Army Corps of Engineers (USACE)) for information on design water levels (e.g. revetment at Cockspur Lighthouse, Fort Pulaski in 2011). Other information sources include National Oceanic and Atmospheric Administration's (NOAA) trend data as part of their National Water Level Observation Network that shows how sea levels have changed over the past century. However, this trend data does not account for projected rates of glacial ice melt and thermal expansion of the oceans that will add to mean sea level in the future.

Because models of global sea level change cannot include variability within each region, such as beach morphology, rate of isostatic (elevation of the land) change, or the types of engineered structures/barriers that exist; current sea level studies report on a mean global scale (an average rate of sea level change if calculated for the whole world). In addition to local geomorphologic controls, the rate of sea level change also varies temporally, depending on changes in global rates of carbon dioxide ($CO_{2)}$ emissions, ocean response (lag) time between initial warming and associated glacial melting and thermal expansion, and the weakening of ocean currents. Coastal flooding will increase over coming decades, particularly during storm seasons when projected increases in storm intensity and possibly frequency will further compound the impact of changing RSL. Using only projected rises in RSL without storm surge data misses much information required for contingency planning and sensitivity analyses. In addition to RSL rise, the scientific literature also indicates that storm (particularly hurricane) intensity has increased over the past 35 year and will likely continue to increase in the future. Given recent impacts of Hurricanes Katrina (2005), Irene (2011), and Sandy (2012) on NPS units, we aim to examine how the extent of storm surges will change when sea levels change over this century.

OBJECTIVES:
The major objectives of this project are as follows:

1. Gather data to determine projected rates of RSL using the latest academic literature (particularly the forthcoming IPCC report that will be published in 2013) available for each region. Projections will be based on multiple time horizons (2050 and 2100) and emissions scenarios (currently A1FI, A1T, A1B, A2, B1, B2, although this could be converted to representative concentration pathways (RCPs) if emissions scenarios begin to reported as RCPs).

2. Project future storm surge heights for multiple strength storms using the NOAA SLOSH (The Sea Lake, and Overland Surges from Hurricanes) model to calculate individual maximum envelopes of water (MEOWs) generated from historical storms that can be used to create a composite future projection based on the MOM (maximum of MEOWs) for basins in both the gulf of Mexico and Atlantic and Pacific Oceans.

3. Identify and incorporate the latest available data regarding local geomorphic controls to provide park managers with a more accurate projection of RSL. This information can support park planning (including foundation documents), as well as interpretive materials and partnership activities. The project will also canvas the literature and record data gaps where these exist regarding physiographic or isostasy information needed for each park. By combining global projections of RSL for 2050 and 2100 with more localized projections of storm surges (based on the NOAA models) we will provide coastal parks with a range of expected RSL for their area over the next century.

4. To use the data developed for objectives 1–3 to create a comprehensive “Sea level change in the National Park System” report that follows a similar format (i.e. summary for policymakers, technical summary) to current IPCC reports.

5. Develop an interactive website for park managers, interpreters, and the public to see how coastal parks will be impacted nationally by RSL. This website will be designed in collaboration with NPS staff so that it can be made available on nps.gov.

6. Collaborate with the NPS regions to prepare interpretive wayside exhibits for three pilot parks that are considered especially vulnerable to RSL.

Output/Products

1. An annual accomplishment report will be submitted at the end of the first year, no later than October 31, 2013. This report will contain an abstract outlining the work accomplished, as well as a more detailed report on the work conducted. This accomplishment report will largely detail sea level change and National Oceanic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Maximum of MEOWS (MOM) model output results and present raw data. Preliminary data analysis and interpretation are anticipated at this time.

2. A comprehensive “Sea level change in the National Park System” report that follows a similar format (i.e. summary for policymakers, technical summary) to current IPCC reports. This report will not only provide guidance for natural and cultural resource managers but will also contain language for policy makers and facilities and planning. In addition to these sections the report will include the following:

   i. Storm surge data generated using NOAA SLOSH. Historical storm surge data will also be included for each park. Future storm surge numbers will be calculated for a Saffir-Simpson 1–5 hurricane category. These data will mostly cover the Atlantic and Gulf of Mexico coasts. The SLOSH MOM model consists of 38 basins that calculate storm surge using either an elliptical, hyperbolic or polar grid. Grid cells vary in size; where, data resolution is finest near the shoreline. Cell sizes currently range between 500–7000 m, however resolution of the data is expected to improve as NOAA updates the SLOSH software. Output depths and land elevations are projected using the North American vertical datum (NADV 88).

   For the Pacific coast, PI Maria Caffrey is working with personnel at NOAA to develop a tool that can predict future storm surges. At a minimum, each Pacific coast park will be given a list of historical storm surges for the region. It is worth noting that Patrick Barnard (USGS) is also interested in developing a storm surge tool for the Pacific coast but has yet to develop one yet (he is working a project related to this right now).

   ii. A graduate student at the University of Colorado Boulder will work with the PI to include case studies of dynamic modeling techniques. A dynamic model example will be prepared for two Atlantic Coast and one Pacific coast park unit to be named at a later date. This modeling is based on work she is currently undertaking with Dr. Steven Nerem in areas adjacent to Canaveral as part of a NASA sea level rise project.

iii. In addition to citing the latest IPCC estimates, sea level rise data will be calculated using the following equation:

$$E(t) = 0.0017t + bt^2$$

Where E is eustasy, t is time, and b is based on USACE sea level rise coefficients (low = historical rate; intermediate = 0.0000271; high = 0.0001130). This equation will be applied to the nearest tide gauge data to each NPS unit with a record greater than 30 years. For some units this equation cannot be used if the nearest tide gauge station is greater than 100 km away or if the gauge is located in a place that does not share a similar oceanographic setting to the park unit (e.g. the gauge is in an area where there is stronger/weaker upwelling or currents or if the gauge is located in an isolated back bay area when the park is ocean facing). These data will be used to project regional sea level in 2030, 2050, and 2100.

The report will include a scale displaying the accuracy/reliability of the sea level numbers. There will be a section that discusses the weaknesses of this approach in certain regions where the tide gauge data is lacking.

3. Three wayside exhibits that incorporate the information from the “Sea level change in the National Park System” report. Wayside exhibits will be developed in cooperation with Betsy Ehrlich at Harpers Ferry.

<u>Tasks</u>

The following are the Sea Level and Storm Surge Project Tasks

1. Compile sea level change and storm surge projections for multiple time horizons for 105 assigned parks and create a report titled “Sea level change in the National Park System” that will be archived on the NPS Integrated Resource Management Applications (IRMA) Portal, as well as on the NPS coastal geology website.
2. Complete maps (where possible) for the assigned parks displaying rates of sea level change and projected storm surge and display them on the NPS website.
3. Collaboratively develop wayside exhibits for three national park units.
4. Hold quarterly meetings with NPS and the University of Colorado Boulder project staff, with frequent communication via the phone and e-mail to discuss progress, and to ensure that work performed and products developed are meeting the needs of the project.
5. An annual accomplishment report will be submitted at the end of the each year, no later than October 31. This report will contain an abstract outlining the work accomplished, as well as a more detailed report on the work conducted.

Attachment C: Rocky Mountain (RM) CESU Information

Final Report: Distribution

Upon project completion, the NPS park/unit must submit a copy of the final products and/or final report to the NPS RM-CESU Research Coordinator and to the RM-CESU host university (The University of Montana). Send electronic copies to **rmcesu@forestry.umt.edu** and kathy_tonnessen@nps.gov/peilin_yu@nps.gov. Mail CDs or DVDs to RM-CESU, The University of Montana, College of Forestry and Conservation, Missoula, MT 59812. The RM-CESU does not require hard copies. If a report is "sensitive", then we need to receive a short completion report.

In addition, send a copy of the final report to the NPS Technical Information Center, which is the official repository for all NPS technical reports: National Park Service, Technical Information Center, P.O. Box 25287, Denver, CO 80225.

RM-CESU Contacts:

People who need to get a copy of the final report, and who can assist with NPS, RM-CESU questions:

Kathy Tonnessen
National Park Service Research Coordinator
Rocky Mountains CESU
The University of Montana
College of Forestry and Conservation
Missoula, MT 59812
Phone: (406) 243-4449
Fax: (406) 243-4845
Email: kathy_tonnessen@nps.gov

Pei-Lin Yu
National Park Service, Cultural Resource Specialist
Rocky Mountains CESU
The University of Montana
Department of Anthropology
Missoula, MT 59812
Phone: (406) 243-2660
Email: peilin_yu@nps.gov

The person who needs to get a copy of the final report for posting on RM-CESU web-site, and someone who can answer questions about the RM-CESU partners:

Lisa Gerloff
Executive Coordinator

Rocky Mountains CESU
The University of Montana
College of Forestry and Conservation
Phone: (406)243-5346
Fax: (406) 243-4845
Email: lisa.gerloff@umontana.edu

55 2 Attachment Signed 1550759 Caffrey Mod 1 FE.pdf

Modification Number 01 to
Task Agreement Number P13AC01178
Under
Cooperative Agreement H2370094000
Between
The United States Department of the Interior
National Park Service
And
The Regents of the University of Colorado

GENERAL

The purpose of this modification is to modify ARTICLE IV, Term of Agreement and ARTICLE VI Award and Payment Section A to extend the period of performance from August 27, 2014 to August 27, 2015 and to add funds to continue the current work into year two.

MODIFICATION

1. ARTICLE IV – TERM OF AGREEMENT. This is modified as follows:

   This Task Agreement will become effective on the date of final signature and extend through August 27, 2015

2. ARTICLE VI – AWARD AND PAYMENT. This is modified as follows:

   Financial Assistance (FA): NPS will provide funding to the University of Colorado Boulder in an amount no to exceed $369,898.00 for the work described in Article III and in accordance with the approved Budget (Attachment A). Any award beyond the current fiscal year is subject to availability of funds. This modification is adding $170,000.00 to the original award of $199,898.00 for total funding in the amount of $369,898.00.

3. All other provisions remain unchanged.

IN WITNESS WHEREOF, the parties hereto have executed this modification on the date(s) set forth below.

FOR THE REGENTS OF THE UNIVERSITY OF COLORADO-BOULDER

Digitally signed by uhes
DN: cn=uhes,
email=james.uhes@colorado.edu
Date: 2014.07.24 07:46:03 -06'00'

Denitta Ward
Associate Director,
Office of Contracts and Grants

Date

FOR THE NATIONAL PARK SERVICE

Andrew E. Lubner
Awarding Officer

7/30/14
Date

ATTACHMENT A – BUDGET

Salaries	
Research Associate — Sea level change and storm surge project manager/principal investigator, 12 months, full time	$65,920
Graduate Research Assistant — 9 months, part-time	$17,371
Graduate Research Assistant — 3 months, full time	$11,580
Subtotal	**$94,871**
Fringe benefits (PI 30.9%, GRA 7.9%)	$22,656
Travel	$6740
Wayside exhibit	$10,000
Other direct costs (tuition remission)	$10,414
Total Direct Costs	**$144,681**
Overhead (17.5%)	**$25,319**
Total	**$170,000**

55 3 Attachment P13AC01178 - Mod 004 - FE.pdf

Modification Number 004 to
Task Agreement Number P13AC01178
Under
Cooperative Agreement P14AC00728 Between
The United States Department of the Interior
National Park Service
And
The Regents of the University of Colorado
DUNS No: 007431505
3100 Marine St., Room 479, 572 UCB
Boulder, CO 80303

CFDA: 15.945 Cooperative Research & Training Programs
Project Title: Sea Level and Storm Surge Projections for Coastal Parks
Previous Federal Funding: $496,898
Federal Funds Obligated by this Action: $68,000
Total Amounts Federal Funds Obligated: $564,898
Total Amount of Award *(Includes all cost share)*: $564,898
Period of Performance: Date of Signature –March 31, 2018

GENERAL

The purpose of this modification is to modify ARTICLE III, statement of work Sections A1 and B4, ARTICLE IV, Term of Agreement and ARTICLE VI, award and payment Section A-Financial Assistance to extend the period of performance from August 26, 2013 through March 31, 2017 to August 26, 2013 through March 31, 2018 and to add funds to continue work into year four. This modification also adds ARTICLE X, Minimum Wages Under Executive Order 13658, and amends the numbering of ARTICLE IX, Attachments to ARTICLE XI, and ARTICLE XI, Signatures to ARTICLE XII.

MODIFICATION

1. The cooperative agreement number has been amended from H2370094000 to P14AC00728 to reflect the most recent master cooperative agreement that was signed on May 14, 2014.

2. ARTICLE III – STATEMENT OF WORK. This is modified as follows:

September 2016: Work with Leanne Lestak to 1) Create arcgis vs 10.2 map documents; 2) Finalize the SLR values at the coast for each park; 3) Add the SLR and SLOSH layers used for each park to each .mxd document and add the table in #2. Send project results report out for external review.

December 2016: Upload GIS data (including metadata) and reports to IRMA.

Develop a "social media plan" for further outreach primarily through the geologic resources division with input from the Climate Change Response Program.

March 2017: Provide all material to NPS for website release.

3. ARTICLE IV – TERM OF AGREEMENT. This is modified as follows:

   This Task Agreement will become effective on the date of final signature and extend through March 31, 2018.

4. ARTICLE VI – AWARD AND PAYMENT. This is modified as follows:

   Financial assistance (FA): NPS will provide funding to Recipient in an amount not to exceed $531,898 for the work described in Article III and in accordance with the approved budget (Attachment A). Through modification 004, $68,000 is added to this task agreement — in accordance with approved budget (Attachment A) — which changes the task agreement amount from $496,898 to $564,898. Any award beyond the current fiscal year is subject to availability of funds.

5. ARTICLE X – MINIMUM WAGES UNDER EXECTUTIVE ORDER 13658 was added.

6. ARTICLE IX – ATTACHMENTS and ARTICLE X – SIGNATURES were amended to ARTICLE XI – ATTACHMENTS and ARTICLE XII – SIGNATURES.

7. All other provisions remain unchanged.

IN WITNESS WHEREOF, the parties hereto have executed this modification on the date(s) set forth below.

FOR RECIPIENT

DocuSigned by:
Denitta D. Ward
C78CE4A0A43640F...
Denitta Ward
Associate Director,
Office of Contracts and Grants

6/17/2016
Date

FOR THE NATIONAL PARK SERVICE

Andrew Lubner
Awarding Officer

6/17/16
Date

ATTACHMENT A: Detailed Budget

Salaries	
Research Associate – Project PI, Maria Caffrey (58.66% of 12 months @ $68,128/12months)	$39,965
Fringe Benefits (37.3%)	$15,722
GIS specialist (30.95% of 12 months @ $84,722/12 months)	$2185
Total Direct Costs	**$57,872**
Overhead (17.5%)	**$10,128**
Total	**$68,000**

55 4 Attachment P13AC01178 03 (signed).pdf

Modification Number 0003 to
Task Agreement Number P13AC01178
Under
Cooperative Agreement H2370094000
Between
The United States Department of the Interior
National Park Service
And
The Regents of the University of Colorado
DUNS No: 007431505
3100 Marine St., Room 479, 572 UCB
Boulder, CO 80303

CFDA: 15.945, Cooperative Research & Training Programs-Resources of NPS CESUs
Project Title: Sea Level and Storm Surge Projections for Coastal Parks
Previous Federal Funding: $369,898.00
Federal Funds Obligated by this Action: $127,000.00
Total Amounts Federal Funds Obligated: $496,898.00
Total Amount of Award *(Includes all cost shares)*: $496,898.00
Period of Performance: August 26, 2013 –March 31, 2017

GENERAL

The purpose of this modification is to modify ARTICLE III, Statement of Work Sections A1 and B4, ARTICLE IV, Term of Agreement and ARTICLE VI, award and payment Section A-Financial Assistance to extend the period of performance from August 26, 2015 to March 31, 2017 and to add funds to continue work into year three.

MODIFICATION

1. ARTICLE III – STATEMENT OF WORK. This is modified as follows:

The University of Colorado Boulder agrees to design, develop, and implement sea level change projections for 118 coastal parks. The results of these projections will be detailed in a "Sea Level Change in the National Park Service" report. Rising sea levels compound effects from increased intensity, and possibly frequency, of storms, particularly hurricanes, nor'easters, and typhoons. Phase I of the project was to conduct a service-wide assessment to project the height of relative sea level in each coastal park unit coupled with storm surge projections. Phase II will focus on three pilot parks to develop specific adaptation actions for individual park adaptation strategies. Specifically, Phase II will develop one wayside for each park. The waysides will be coordinated with park staff (at GUIS, JELA, and one more park to be identified) and will focus on the issue of sea level change and/or storm surge.

NPS agrees to provide office space, telecommunications, computer equipment, and internet access, access to printers and plotters, and information technology (IT) support to the University of Colorado Boulder staff assigned to the project, and working in NPS offices in Lakewood, Colorado.

2. ARTICLE IV – TERM OF AGREEMENT. This is modified as follows:

   This modification extends the period of performance until March 31, 2017.

3. ARTICLE VI – AWARD AND PAYMENT. This is modified as follows:

   Financial assistance (FA): NPS will provide funding to Recipient in an amount not to exceed $496,898.00 for the work described in Article III and in accordance with the approved budget (Attachment A). Modification 0003 adds $127,000.00 to this task agreement — in accordance with approved budget (Attachment A) — which changes the task agreement amount from $369,898.00 to $496,898.00. Any award beyond the current fiscal year is subject to availability of funds.

4. All other provisions remain unchanged.

IN WITNESS WHEREOF, the parties hereto have executed this modification on the date(s) set forth below.

FOR RECIPIENT

Marcella Bentley-Salmon

Digitally signed by Marcella Bentley-Salmon, Sr. Contract Officer
DN: cn=Marcella Bentley-Salmon, Sr. Contract Officer, o=University of Colorado, ou=Officer of Contracts and Grants, email=Marcella.BentleySalmon@colorado.edu, c=US
Date: 2015.09.21 14:03:54 -06'00'

Denitta Ward
Associate Director,
Office of Contracts and Grants

Date

FOR THE NATIONAL PARK SERVICE

Andrew E. Lubner
Awarding Officer

9/22/15
Date

PROPOSED BUDGET DETAILS

Institution: The Regents of the University of Colorado, 572 UCB, Boulder, CO 80309-0572

Title: Provide Sea Level Rise and Storm Surge Projections for All Coastal Parks

Principal Investigator

Duration: 7/1/2013 - 6/30/16

	Year 1	Year 2	Year 3	Totals
A. Salaries and Wages				
Principal Investigator				
100% time, 12 mos.	64,000	65,920	67,898	197,818
Graduate Research Asst. #1: TBD				
50% time, 9 mos. AY	16,865	17,371	0	34,236
100% time, 3 months summer	11,243	11,580	0	22,823
Graduate Research Asst. #2: TBD				
47% time, 9 mos. AY	15,688	0	0	15,688
100% time, 3 months summer	11,243	0	0	11,243
Total Salaries and Wages	119,039	94,871	67,898	281,808
B. Fringe Benefits				
PI: 30.9%	19,776	20,369	20,980	61,125
GRA: 7.9%	4,348	2,287	0	6,635
Total Fringe Benefits	24,124	22,656	20,980	67,760
C. Travel				
Domestic	3,000	6,740	0	9,740
Total Travel	3,000	6,740	0	9,740
D. Other Direct Costs				
1) Materials and Supplies:				
Computer Equipment	4,126	0	0	4,126
2) Other:				
a. Wayside exhibits (3 x $10,000)	0	10,000	19,207	29,207
b. Tuition remission (GRA #1)	9,918	10,414	0	20,332
c. Tuition remission (GRA #2)	9,918	0	0	9,918
Total Other Direct Costs	23,962	20,414	19,207	63,583
Total Direct Costs	170,125	144,681	108,085	422,891
E. Indirect Costs				
17.5% of TDC (per CESU Cooperative Agreement, 12 June, 2013)	29,773	25,319	18,915	74,007
F. Total Costs	199,898	170,000	127,000	496,898

Total requested for three years: $496,898

55 5 Attachment ROMO_2014_cooperative_agreement.pdf

BLM # no number issued
USBR # 06AG602112
USGS # G14AC00138
NPS #s (WASO) P14AC00728
(IMR) P14AC00749
USFWS # 60181AJ402
USDA FS # 14-JV-11221611-080
NRCS # 68-3A75-14-137
USACE-CW # W912HZ-08-2-0006
DOD ODUSD (I&E) # W9126G-14-2-0012

ROCKY MOUNTAINS
COOPERATIVE ECOSYSTEM STUDIES UNIT

COOPERATIVE and JOINT VENTURE AGREEMENT

between

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Land Management
U.S. Bureau of Reclamation
U.S. Geological Survey
National Park Service
U.S. Fish and Wildlife Service

U.S. DEPARTMENT OF AGRICULTURE
U.S. Forest Service
Natural Resources Conservation Service

U.S. DEPARTMENT OF DEFENSE
U.S. Army Corps of Engineers – Civil Works
Office of the Deputy Under Secretary of Defense
(Installations and Environment)

and

THE UNIVERSITY OF MONTANA – MISSOULA (HOST)
Colorado State University
Montana State University
Salish Kootenai College
University of Colorado at Boulder
University of Colorado Denver
University of Idaho
University of Wyoming
Utah State University
Washington State University

University of Northern Colorado
The Governors of the University of Calgary
Metropolitan State University of Denver
Little Big Horn College
Northwest College
University of Utah
Blackfeet Community College
Chief Dull Knife College
University of Waterloo
Wildlife Conservation Society

ARTICLE I. BACKGROUND AND OBJECTIVES

A. This Cooperative and Joint Venture Agreement (hereinafter called Agreement) between the Bureau of Land Management, U.S. Bureau of Reclamation, U.S. Geological Survey, National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, Natural Resources Conservation Service, U.S. Army Corps of Engineers – Civil Works, and Office of the Deputy Under Secretary of Defense (Installations and Environment) (hereinafter called Federal Agencies), and the University of Montana – Missoula and its partner institutions is a continuation for a five (5) year term to provide for the operation and maintenance of the Rocky Mountains Cooperative Ecosystem Studies Unit (CESU). This continuation of the Rocky Mountains CESU is implemented by mutual consent of the parties and is consistent with the prior Agreement and the express intent of the request for proposals for that Agreement. The Rocky Mountains CESU is associated with a national network of CESUs.

B. The objectives of the Rocky Mountains Cooperative Ecosystem Studies Unit are to:

- Provide research, technical assistance and education to federal land management, environmental and research agencies and their potential partners;
- Develop a program of research, technical assistance and education that involves the biological, physical, social, and cultural sciences needed to address resources issues and interdisciplinary problem-solving at multiple scales and in an ecosystem context at the local, regional, and national level; and
- Place special emphasis on the working collaboration among federal agencies and universities and their related partner institutions.

C. The Bureau of Land Management (hereinafter called BLM) administers public lands within a framework of numerous laws. The most comprehensive of these is the Federal Land Policy and Management Act of 1976 (FLPMA). All Bureau policies, procedures, and management actions must be consistent with FLPMA and the other laws that govern use of the public lands. It is the mission of the BLM to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations (43 U.S.C. § 1701 et seq.). In accordance with 43 U.S.C. § 1737(b), the BLM is authorized to enter into contracts and cooperative agreements involving the management, protection, development, and sale of public lands; and is thereby authorized to enter into this cooperative agreement to continue the Rocky Mountains CESU to assist in providing research, technical assistance and education.

D. The U.S. Bureau of Reclamation (hereinafter called USBR) manages, develops, and protects water and related resources in an environmentally and economically sound manner in the interest of the American public (43 U.S.C. Chapter 12). In accordance with the authority delegated in 255 DM 14.1 (U.S. Department of the Interior, Departmental Manual), which states that the Commissioner is delegated so much of the authority of the Secretary under the Fish and Wildlife Coordination Act (16 U.S.C. § 661 et seq.) as is necessary to provide assistance, through grants or cooperative agreements, to public or private organizations for the improvement of fish and wildlife habitat associated with water systems or water supplies affected by Reclamation projects; and in accordance with the Omnibus Public Land Management Act of 2009 (Pub. L. 111-11), Subtitle F-Secure Water, §§ 9502, 9504, and 9509, the USBR is authorized to enter into this cooperative agreement to continue the Rocky Mountains CESU to assist in providing research, technical assistance, and education.

E. The U.S. Geological Survey (hereinafter called USGS) serves the Nation by providing reliable scientific information to describe and understand the Earth, minimize the loss of life and property from natural disasters, manage water, biological, energy, and mineral resources, and enhance and protect our quality of life. USGS has authority to enter into this Agreement pursuant to Pub. L. 99-591, that bestows permanent authority on the USGS to “prosecute projects in cooperation with other agencies, Federal, state, and private” (43 U.S.C. § 36(c)), the USGS Organic Act of March 3,1879, as amended (43 U.S.C. § 31 et seq.), 16 U.S.C. § 1(a)(2)(j), 16 U.S.C. § 1(g), 16 U.S.C. § 5933, and 16 U.S.C. § 753a to continue the Rocky Mountains CESU to assist in providing research, technical assistance, and education.

F. The National Park Service (NPS) manages areas of the National Park System “to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations” (16 U.S.C. § 1 et seq.). In support of this broad mission, the Secretary of the Interior is authorized and directed to assure that management of units of the National Park System is enhanced by the availability and utilization of a broad program of the highest quality science and information (16 U.S.C. § 5932), and to enter into cooperative agreements with colleges and universities, including but not limited to land grant schools, in partnership with other Federal and State agencies, to establish cooperative study units to conduct multi-disciplinary research and develop integrated information products on the resources of the National Park System, or the larger region of which parks are a part (16 U.S.C. § 5933). The NPS is authorized to enter into cooperative agreements with public or private educational institutions, States, and their political subdivisions, for the purpose of developing adequate, coordinated, cooperative research and training activities concerning the resources of the National Park System (16 U.S.C. § 1a-2(j)); with State, local and tribal governments, other public entities, educational institutions, and private nonprofit organizations for the public purpose of carrying out National Park Service programs (16 U.S.C. § 1g); with State, local, or tribal governments, other Federal agencies, other public entities, educational institutions, private nonprofit organizations, or participating private landowners for the purpose of protecting natural resources of units of the National Park System through collaborative efforts on land inside and outside of National Park System units (16 U.S.C. § 1j); and with any State or local government, public or private agency, organization, institution, corporation, individual, or other entity for the purpose of sharing costs or services in carrying out authorized functions and responsibilities of the Secretary of the Interior with respect to any unit or program of the National Park System (per 16 U.S.C. § 1c(a)), any affiliated area, or any designated National Scenic or Historic Trail (16 U.S.C. § 1f). NPS is also authorized to provide conservation, recreation, and disaster assistance to partners to help them achieve goals of mutual interest (16 U.S.C. § 460l(1), 16 U.S.C. § 1723(c)). In accordance with the aforementioned authorities, the NPS is authorized to enter into this Agreement to continue the Rocky Mountains CESU to assist in providing research, technical assistance and education.

G. The U.S. Fish and Wildlife Service (hereinafter called USFWS), working with others, is responsible for conserving, protecting, and enhancing fish, wildlife, plants and their habitats for the continuing benefit of the American people through federal programs related to migratory birds, endangered species, interjurisdictional fish and marine mammals, inland sport fisheries, and the National Wildlife Refuge System. In accordance with 16 U.S.C. § 661, 16 U.S.C. § 742(f), and 16 U.S.C. § 753(a), the USFWS is authorized to cooperate with other agencies to assist in providing research, technical assistance, and education; and is thereby authorized to enter into this cooperative agreement to continue the Rocky Mountains CESU.

H. The U.S. Department of Agriculture Forest Service (hereinafter called USFS) mission is to achieve quality land management under the sustainable multiple-use management concept to meet the diverse needs of the people (16 U.S.C. § 1641-1646). In accordance with 7 U.S.C. § 3318 (b) the USFS is authorized to enter into this joint venture agreement to continue the Rocky Mountains CESU to assist in providing research, technical assistance, and education.

I. The Natural Resources Conservation Service (hereinafter called NRCS) improves the health of our Nation's natural resources while sustaining and enhancing the productivity of American agriculture (16 U.S.C. §§ 590(a)-(f)). We achieve this by providing voluntary assistance through strong partnerships with private landowners, managers, and communities to protect, restore, and enhance the lands and waters upon which people and the environment depend. NRCS scientists and technical specialists identify appropriate technologies in research, development, and transfer them to field staff for recommending the technologies to America's farmers and ranchers. Under Section 714 of Pub. L. 106-387, 7 U.S.C. § 6962(a), NRCS is authorized to enter into this cooperative agreement to continue the Rocky Mountains CESU to assist in providing research, studies, technical assistance, and educational services consistent with the mission of the NRCS and the CESU Network.

J. The U.S. Army Corps of Engineers' Civil Works Program (hereinafter called USACE) provides assistance in the development and management of the nation's water resources. The main missions of USACE, i.e., the Corps, are 1) to facilitate commercial navigation, 2) to protect citizens and their property from flood and storm damages, and 3) to protect and restore environmental resources. The Corps carries out most of its work in partnership with Tribal, state, and local governments and other nonfederal entities. The Corps must rely upon using the best available science in the evaluation of water resources needs and in the development of recommendations for water resources management. The university and scientific institutions that comprise the CESU Network have knowledge and expertise of the latest scientific advances that will assist the Corps in reaching sound, scientifically based decisions. In addition, by participating in the CESU, scientists within the Corps will have access to university resources within the CESU Network and be able to interact with colleagues in various scientific disciplines, and thereby further their own professional development. Corps field offices may avail themselves of support from the regional CESUs by collaborating with the Engineer Research and Development Center, who has the authority to enter into cooperative agreements with such CESUs, thus enabling these Corps offices to receive scientific support from regional CESU members. USACE is authorized to cooperate with other agencies in accordance with Title 33 U.S.C. § 2323(a) and 10 U.S.C. § 3036(d). Additionally, USACE may enter into transactions under the authority of 10 U.S.C. § 2371 in carrying out basic, applied, and advanced research projects. In accordance with 10 U.S.C. § 2358, USACE is authorized to enter into this cooperative agreement continuing the Rocky Mountains CESU, under agreement number #W912HZ-08-2-0006 for a cumulative amount not-to-exceed $25,000,000.00.

K. The U.S. Department of Defense Office of the Deputy Under Secretary of Defense (Installations and Environment) (hereinafter called DOD) manages nearly 30 million acres of land, and the natural and cultural resources found there, and for this Agreement includes the Office of the Secretary of Defense, the Military Services, the Defense Logistics Agency, the National Guard Bureaus, and the Military Reserve Components. DOD's primary mission is national defense. DOD's conservation program supports this mission by ensuring realistic training areas, and managing its resources in ways that maximize available land, air, and water training opportunities. DOD environmental stewardship activities are authorized under the Sikes Act, as amended. In accordance with one or more of the following: 16 U.S.C. § 670(c)(1), 10

U.S.C. § 2358, 10 U.S.C. § 2694, 10 U.S.C. § 2684, and Pub. L. 103-139 (FY 94 NDAA, page 107 Stat. 1422), DOD is authorized to enter into cooperative agreements with States, nonprofit organizations, academic institutions, and other partners to support research, technical assistance, and educational services consistent with the mission of the DOD and the CESU Network. In accordance with the aforementioned authorities, the DOD is authorized to enter into this Agreement to continue the Rocky Mountains CESU.

L. The University of Montana – Missoula (hereinafter called Host University) is a comprehensive university emphasizing the liberal arts and professional education in business, education, fine arts, forestry (natural resources), journalism, law, pharmacy and related health sciences, and vocational technical education. Programs in natural resources focus on conservation, forestry, range, recreation, wilderness, and wildlife. BS, MS, and PhD degrees are offered. The university has a growing research program, significantly in cooperation with several federal partners, and it houses a very active continuing education program. Other campuses of the university are Montana Tech at Butte, University of Montana Western at Dillon, and Helena College at Helena. Governance of The University of Montana is provided by the Montana University System Board of Regents.

M. The partner institutions to the Host University include Colorado State University, Montana State University, Salish Kootenai College, University of Colorado at Boulder, University of Colorado Denver, University of Idaho, University of Wyoming, Utah State University, Washington State University, University of Northern Colorado, The Governors of the University of Calgary, Metropolitan State University of Denver, Little Big Horn College, Northwest College, University of Utah, Blackfeet Community College, Chief Dull Knife College, University of Waterloo, and Wildlife Conservation Society (hereinafter called Partner Institutions).

ARTICLE II. STATEMENT OF WORK

A. Each Federal Agency agrees to:
   1. Provide administrative assistance, as appropriate, necessary to execute this Agreement and subsequent modifications;
   2. Conduct, with the Host University and Partner Institutions, a program of research, technical assistance and education related to the Rocky Mountains CESU objectives to the extent allowed by each Federal Agencies' authorizing legislation;
   3. Provide opportunities for research on federal lands or using federal facilities in cooperation with Federal Agencies, as appropriate, and according to all applicable laws, regulations and Federal Agencies' policies;
   4. Provide funds for basic support and salary for participating Host University and Partner Institution faculty, as appropriate;
   5. Provide project funds and/or collaboration to support specific research, technical assistance and education projects, as appropriate;

6. Make available managers to serve on the Rocky Mountains CESU Manager's Committee;
7. Comply with the Host University's and Partner Institutions' rules, regulations, and policies regarding professional conduct, health, safety, use of services and facilities, use of animals, recombinant DNA, infectious agents or radioactive substances, as well as other policies generally applied to Host University and Partner Institution personnel;
8. Ensure its employees follow the Code of Ethics for Government Service (Pub. L. 96-303) and Standards of Ethical Conduct (5 C.F.R. Part 2635);
9. Allow Federal Agency employees to participate in the activities of the Host University and Partner Institutions, including serving on graduate committees and teaching courses, as appropriate, and as specifically determined in modifications to the Agreement; and
10. Be individually responsible for their agency's role in administering the Agreement, transferring funds, and supervision of agency employees, as appropriate.

B. The Host University agrees to:

1. Continue, in consultation with the Federal Agencies and Partner Institutions, the Rocky Mountains CESU;
2. Conduct, with participating Federal Agencies and Partner Institutions, a program of research, technical assistance and education related to the Rocky Mountains CESU objectives;
3. Allow and encourage faculty to engage in participating Federal Agencies' research, technical assistance and education activities related to the Rocky Mountains CESU objectives, as appropriate;
4. Provide basic administrative and clerical support as appropriate;
5. Provide access for Federal Rocky Mountains CESU staff to campus facilities, including library, laboratories, computer facilities on the same basis or costs as other faculty members of the Host University to the maximum extent allowable under state laws and regulations;
6. Provide suitable office space, furniture and laboratory space, utilities, computer network access and basic telephone service for Federal Agencies' personnel to be located at the Host University, as appropriate;
7. Offer educational and training opportunities to participating Federal Agency employees, in accordance with the respective policies of the Federal Agencies and the Host University;
8. Encourage its students to participate in the activities of the Rocky Mountains CESU;
9. Coordinate activities, as appropriate, with the Partner Institutions and develop administrative policies for such coordination; and
10. Maintain a Rocky Mountains CESU Manager's Committee and convene a meeting of this committee, at least annually, to provide advice and guidance, review of the annual work and multi-year strategic plans, and assist in evaluating the Rocky Mountains CESU.

C. Each Partner Institution agrees to:
   1. Conduct, with participating Federal Agencies and the Host University, a program of research, technical assistance, and education related to the Rocky Mountains CESU objectives and allow and encourage faculty to participate in the program as appropriate;
   2. Offer educational and training opportunities to participating Federal Agency employees, as appropriate; and
   3. Encourage students and employees to participate in the activities of the Rocky Mountains CESU.

D. All Federal Agencies, the Host University and Partner Institutions agree to:
   1. Maintain the Rocky Mountains CESU closely following the mission and goals of the CESU Network as described in the *CESU Network Strategic Plan*, adapting key elements to local and regional needs, as appropriate;
   2. Maintain a Rocky Mountains CESU role and mission statement;
   3. Operate under a multi-year strategic plan;
   4. Issue individual funding documents, in accordance with each agency's procedures, to this Agreement that individually include a specific "scope of work" statement and a brief explanation of the following:
      (a) the proposed work;
      (b) the project contribution to the objectives of the CESU;
      (c) the methodology of the project;
      (d) the substantial involvement of each party;
      (e) the project budget and schedule;
      (f) the specific project outputs or products.

      Note: For BLM, FWS, USFS, and other agencies as appropriate, this Agreement is neither a fiscal nor a funds obligation document. Any endeavor to transfer anything of value involving reimbursement or contribution of funds between the parties to this Agreement will be handled in accordance with applicable laws, regulations, and procedures including those for government procurement and printing. Such endeavors will be outlined in separate task agreements that shall be made in writing by representatives of the parties and shall be independently authorized by appropriate statutory authority. This Agreement does not provide such authority. Specifically, this Agreement does not establish authority for noncompetitive award to the cooperator of any contract or other agreement.
   5. Coordinate in obtaining all necessary state, federal, and tribal permits and/or permissions from private landowners in order to conduct projects occurring under this Agreement;
   6. Engage in collaborative activities consistent with federal scientific and scholarly integrity directives and policies (e.g., Presidential and OSTP Scientific Integrity Memoranda; DOD Instruction 3200.20; DOI 305 DM 3; USDA DR 1074-001), as appropriate;
   7. Follow OMB Circulars: A-21, "Cost Principles for Educational Institutions," as codified at 2 CFR 220; A-87, "Cost Principles for State, Local, and Indian Tribal Governments;" as codified at 2 CFR Part 225; A-102, "Grants and

Cooperative Agreements with State and Local Governments;" 2 CFR Part 215, "Uniform Administrative Requirements for Grants and Other Agreements with Institutions of Higher Education, Hospitals and Other Non-Profit Organizations;" A-122, "Cost Principles for Non-Profit Organizations;" as codified at 2 CFR Part 230; A-133, "Audits of States, Local Governments and Non-Profit Organizations;" as appropriate; and the related federal agency regulations, as applicable, specifically 43 CFR Part 12 (Department of the Interior), and 7 CFR Parts 3015- 3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 32 CFR Parts 21, 22, 32, 33, and 34 (Department of Defense), 10 USC 2358, 33 USC 2323a, 10 USC 3036(d), and DoD 3210.6-R, Department of Defense Grant and Agreement Regulations (Department of Defense); and these documents are incorporated into this Agreement by reference.

ARTICLE III. TERM OF AGREEMENT

A. This Agreement shall continue for a period of five (5) years from the effective date of execution. The effective date of this Agreement shall be 29 May 2014. Parties will have until 29 May 2014 to sign this Agreement and thereby express their intent to continue participation in the Rocky Mountains CESU; parties that do not sign this Agreement by 29 May 2014 will not be participants in the Rocky Mountains CESU; such parties will remain in "inactive" status and ineligible to process projects under this Agreement until their official signature page has been received.

B. By mutual consent and at the end of this Agreement, a new Agreement, for a separate and distinct five (5) year period, can be entered into to continue the activities of the Rocky Mountains CESU.

C. Amendments to this Agreement shall be made according to the following provisions:

1. For the purposes of this Agreement, amendments are changes (edits, deletions, or additions) to the Agreement that do not involve the transfer of funds. Amendments may be proposed by any of the Federal Agencies, the Host University or by the Host University on behalf of any of the Partner Institutions. Amendments shall be in writing, signed and agreed to by all signatories to this Agreement, except in cases described in Article III.C.2. (below).

2. For amendments whose sole purpose is to add a Partner Institution and/or Federal Agency to this Agreement, each Partner Institution and Federal Agency currently participating in this Agreement will have forty-five (45) days from receipt of the amendment to either sign the amendment or object in writing to the Host University. If a Partner Institution or Federal Agency has not responded after forty-five (45) days from receipt of the amendment, its signature will not be required to make the amendment effective. The Partner

Institution and/or Federal Agency being added to the Agreement and the Host University shall sign the amendment.

D. For the purposes of this Agreement, modifications or task agreements are specific two-party Agreements between one of the Federal Agencies and the Host University and/or a Partner Institution in support of the goals of this broad Agreement. Modifications or task agreements will be issued by a Federal Agency, will transfer funds to support the statement of work, and will conform to each Federal Agency's respective procedures.

E. A separate Interagency Agreement is required to facilitate transfer of funds from one federal agency to another federal agency.

F. The expiration of this Agreement will not affect the validity or duration of projects which have been initiated under this Agreement prior to such expiration.

ARTICLE IV. KEY OFFICIALS

A. The technical representatives for the Federal Agencies are as follows:

1. Bureau of Land Management

Kate Kitchell
Associate State Director, BLM-Montana
5001 Southgate Drive
Billings, MT 59101
Phone: (406) 896-5012
kkitchell@blm.gov

Scott Davis
Central Regional Science Coordinator
BLM National Science and Technology Center
PO Box 25047
Building Fifty
Lakewood, CO 80225-0047
Phone: (303) 236-6646
s2davis@blm.gov

2. Bureau of Reclamation

Lindsey Nafts
Grants and Cooperative Agreements Specialist
Bureau of Reclamation
PO Box 36900
Billings, MT 59107

Phone: (406) 247-7684
lnafts@usbr.gov

3. U.S. Geological Survey

Zack Bowen
USGS Fort Collins Science Center
2150 Centre Avenue, Building C
Fort Collins, CO 80526-8118
Phone: (970) 226-9218
zack_bowen@usgs.gov

4. National Park Service

Pei-Lin Yu
Acting NPS CESU Research Coordinator
College of Forestry and Conservation
University of Montana
Missoula, MT 59812
Phone: (406) 243-2660
peilin_yu@nps.gov

5. U.S. Fish and Wildlife Service

Greg Watson
Chief, Office of Landscape and Conservation
USFWS Mountain-Prairie Region
134 Union Blvd.
Lakewood, CO 80228
Phone: (303) 236-8155
greg_watson@fws.gov

6. USDA Forest Service

Jan Engert
Assistant Director, Science Application and Integration
U.S. Forest Service
Rocky Mountain Research Station
240 West Prospect
Fort Collins, CO 80526
Phone: (970) 498-1377
jengert@fs.fed.us

Claudia Regan
Regional Vegetation Ecologist, Region 2
U.S. Forest Service

740 Simms Street or PO Box 25127
Lakewood, CO 80225
Phone: (303) 275-5004
cregan@fs.fed.us

7. Natural Resources Conservation Service

Doris Washington
National Coordinator, Cooperative Ecosystems Study Units (CESU) & Center of Excellence (COE)
USDA Natural Resources Conservation Service
Science and Technology Deputy Area
101 East Capitol Avenue, Suite B-100
Little Rock, AR 72201-3811
Phone: (501) 210-8910
doris.washington@ar.usda.gov

8. U.S. Army Corps of Engineers-Civil Works

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9. Department of Defense, Office of the Deputy Under Secretary for Defense (Installations and Environment)

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B. The technical representatives for the Host University, University of Montana, are:

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C. The technical representatives for the Partner Institutions are:

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3. Salish Kootenai College

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11. The Governors of the University of Calgary

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15. University of Utah

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18. University of Waterloo

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19. Wildlife Conservation Society

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ARTICLE V. AWARD

A. Upon signature of all parties and upon satisfactory submission of a budget and related documentation from the Host University, any newly joining Federal Agency partner shall obligate $10,000 to award to the Host University to carry out this Agreement. For the Federal Agency partners listed under Article I. A., no further financial obligation is required.

B. Payments will be made by the Federal Agencies for work in accordance with 2 CFR Part 215 and OMB Circular A-21, A-87, A-102, A-122, A-133, as appropriate, and the related federal agency regulations, as applicable, specifically, 43 CFR Part 12 (Department of the Interior), 7 CFR Parts 3015-3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 10 U.S.C. § 2358, 33 U.S.C. § 2323(a), 10 U.S.C. § 3036(d), and DOD 3210.6-R, Department of Defense Grant and Agreement Regulations (U.S. Army Corps of Engineers-Civil Works).

C. A 17.5% indirect cost rate will be paid on work covered by the Agreement and all its modifications or task agreements, with exceptions listed in Article V. paragraphs C.1., C.2., and C.3. (below).

   1. One exception is that the USFS cannot reimburse "state cooperative

institutions" for indirect costs, pursuant to 7 U.S.C. § 3103(16) and 7 U.S.C. § 3319. Indirect costs may be used to satisfy USFS cost sharing requirements of at least a minimum of 20% of total project costs. It is recommended that cost-sharing is greater than 20% in accordance with the Forest Service Handbook FSH1509.11, Chapter 70.

2. An additional exception is that for NRCS, the indirect cost rate is limited to 10% of total direct costs for colleges, universities, and other nonprofit organizations pursuant to Section 708 of Pub. L. 107-76.

3. No indirect cost will be charged by the Host University for funds transferred directly from a participating Federal Agency to a Partner Institution via a modification to the Agreement.

D. Award of additional funds or in-kind resources will be made through modifications to the Agreement subject to the rules, regulations, and policies of the individual Federal Agency proposing the modification.

E. Nothing herein shall be construed as obligating the Federal Agencies to expend, or as involving the Federal Agencies in any contract or other obligation for the future payment of money, in excess of appropriations authorized by law and administratively allocated for specific work.

ARTICLE VI. PRIOR APPROVAL

Prior approvals are in accordance with 2 CFR Part 215 and OMB Circular A-102, as appropriate, and the related federal agency regulations, as applicable, specifically 43 CFR Part 12 (Department of the Interior), 7 CFR Parts 3015-3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 10 U.S.C. § 2358, 33 U.S.C. § 2323(a), 10 U.S.C. § 3036(d), and DOD 3210.6-R, Department of Defense Grant and Agreement Regulations (U.S. Army Corps of Engineers-Civil Works).

ARTICLE VII. REPORTS AND/OR DELIVERABLES

A. Reports in accordance with 2 CFR Part 215 and OMB Circular A-102, as appropriate, and the related federal agency regulations, as applicable, specifically 43 CFR Part 12 (Department of the Interior) and 7 CFR Parts 3015-3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 10 U.S.C. § 2358, 33 U.S.C. § 2323(a), 10 U.S.C. § 3036(d), and DOD 3210.6-R, Department of Defense Grant and Agreement Regulations (U.S. Army Corps of Engineers-Civil Works) establish uniform reporting procedures for financial and technical reporting.

B. As appropriate, the Host University will convene periodic meetings of Rocky Mountains CESU Federal Agencies and Partner Institutions for the purpose of collaboration and coordination of CESU activities. Copies of the meeting minutes will be available to all parties to the Agreement.

C. A current role and mission statement for the Rocky Mountains CESU will be agreed to and maintained by all Rocky Mountains CESU cooperators. Copies of the role and mission statement will be available to all parties to the Agreement.

D. Annual work plans will be developed to guide the specific activities of the Rocky Mountains CESU and will:
   1. Describe the Rocky Mountains CESU's ongoing and proposed research, technical assistance, and education activities;
   2. Describe anticipated projects and products; and
   3. Identify faculty, staff, and students involved in the Rocky Mountains CESU during the year.

   Copies of the annual work plan will be available to all parties to the Agreement.

E. A current multi-year strategic plan will be maintained to generally guide the Rocky Mountains CESU. Copies of the strategic plan will be available to all parties to the Agreement.

ARTICLE VIII. PROPERTY UTILIZATION AND DISPOSITION

Property utilization and disposition is in accordance with 2 CFR Part 215 and OMB Circular A-102, as appropriate, and the related federal agency regulations, as applicable, specifically 43 CFR Part 12 (Department of the Interior), 7 CFR Parts 3015-3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 10 U.S.C. § 2358, 33 U.S.C. § 2323(a), 10 U.S.C. § 3036(d), and DOD 3210.6-R, Department of Defense Grant and Agreement Regulations (U.S. Army Corps of Engineers-Civil Works).

ARTICLE IX. TERMINATION

Termination of this Agreement is in accordance with 2 CFR Part 215 and OMB Circular A-102, as appropriate, and the related federal agency regulations, as applicable, specifically 43 CFR Part 12 (Department of the Interior), 7 CFR Parts 3015-3052 (Department of Agriculture), 22 CFR Part 518 (Department of Defense), 10 U.S.C. § 2358, 33 U.S.C. § 2323(a), 10 U.S.C. § 3036(d), and DOD 3210.6-R, Department of Defense Grant and Agreement Regulations (U.S. Army Corps of Engineers–Civil Works). Any party to this Agreement may terminate its participation by delivery of thirty (30) days advance written notice to each of the Federal Agencies and the Host University.

ARTICLE X: REQUIRED/SPECIAL PROVISIONS

A. Required Provisions:

1. NON-DISCRIMINATION: All activities pursuant to this Agreement and the provisions of Executive Order 11246; shall be in compliance with applicable requirements of Title VI of the Civil Rights Act of 1964 (78 Stat. 252 42 USC § 2000d et seq.); Title V, Section 504 of the Rehabilitation Act of 1973 (87 Stat. 394; 29 U.S.C. § 794); the Age Discrimination Act of 1975 (89 Stat. 728; 42 U.S.C. § 6101 et seq.); and with all other applicable Federal laws and regulations prohibiting discrimination on grounds of race, color, national origin, handicap, religious or sex in providing of facilities and service to the public.

2. CONSISTENCY WITH PUBLIC LAWS: Nothing herein contained shall be deemed to be inconsistent with or contrary to the purpose of or intent of any Act of Congress establishing, affecting, or relating to the Agreement.

3. APPROPRIATIONS (Anti-Deficiency Act, 31 U.S.C. § 1341): Nothing herein contained in this Agreement shall be construed as binding the Federal Agencies to expend in any one fiscal year any sum in excess of appropriations made by Congress, for the purposes of this Agreement for that fiscal year, or other obligation for the further expenditure of money in excess of such appropriations.

4. OFFICIALS NOT TO BENEFIT: No Member of, Delegate to, or Resident Commissioner in, Congress shall be admitted to any share or part of this Agreement or to any benefit to arise therefrom.

5. LOBBYING PROHIBITION: The parties will abide by the provisions of 18 U.S.C. § 1913 (Lobbying with Appropriated Moneys), which states:

   No part of the money appropriated by any enactment of Congress shall, in the absence of express authorization by Congress, be used directly or indirectly to pay for any personal service, advertisement, telegram, telephone, letter, printed or written matter, or other device, intended or designed to influence in any manner a Member of Congress, a jurisdiction, or an official of any government, to favor, adopt, or oppose, by vote or otherwise, any legislation, law, ratification, policy or appropriation, whether before or after the introduction of any bill, measure, or resolution proposing such legislation, law, ratification, policy, or appropriation; but this shall not prevent officers or employees of the United States or of its departments or agencies from communicating to any such Member or official, at his request, or to Congress or such official, through the proper official channels, requests for any legislation, law, ratification, policy, or appropriations which they deem necessary for the efficient conduct of the public business, or from making any communication whose prohibition by this section might, in the opinion of the Attorney General, violate the Constitution or interfere with the conduct of foreign policy, counter-intelligence, intelligence, or national security activities.

6. LIABILITY PROVISION:

a) Governmental Parties

(1) The Federal Agencies (excluding the U.S. Forest Service), Host University, and Partner Institutions which are governmental parties, each accept responsibility for any property damage, injury, or death caused by the acts or omissions of their respective employees, acting within the scope of their employment, to the fullest extent permitted by their respective applicable laws, including laws concerning self-insurance.

(2) To the extent work by governmental parties is to be performed through sub-contract by non-governmental entities or persons, the governmental party sub-contracting work will require that subcontracted entity or person to meet provisions (1), (2), and (3) for non-governmental parties stated below.

(3) This provision is applicable to the U.S. Forest Service acting by and through the Forest Service, USDA does hereby recognize potential liability for payment of claims for injury or loss of property of personal injury or death caused by the Government, or any officer, agent or employee thereof, while acting within the scope of his/her office of employment under circumstances when the United States, if a private person, would be liable to the claimant in accordance with the law of the place where the act or omission occurred (28 U.S.C. §§1346 (b), 2672 et seq.).

b) Non-governmental Parties: Work provided by non-governmental entities or persons, will require that entity or person to:

(1) Have public and employee liability insurance from a responsible company or companies with a minimum limitation of one million dollars ($1,000,000) per person for any one claim, and an aggregate limitation of three million dollars ($3,000,000) for any number of claims arising from any one incident. In subsequent modifications, the parties may negotiate different levels of liability coverage, as appropriate. The policies shall name the United States as an additional insured, shall specify that the insured shall have no right of subrogation against the United States for payments of any premiums or deductibles due thereunder, and shall specify that the insurance shall be assumed by, be for the account of, and be at the insured's sole risk; and

(2) Pay the United States the full value for all damages to the lands or other property of the United States caused by such person or organization, its representatives, or employees; and

(3) Indemnify, save and hold harmless, and defend the United States against all fines, claims, damages, losses, judgments, and expenses arising out of, or from, any omission or activity of such person or organization, its representatives, or employees.

(4) Non-governmental Partner Institutions shall provide the Federal Agencies confirmation of such insurance coverage, prior to beginning specific work authorized herein and specified in subsequent modifications.

7. TRAFFICKING IN PERSONS: This Agreement and its subsequent modifications and task agreements are subject to requirements of section 106(g) of the Trafficking Victims Protection Act of 2000, as amended (22 U.S.C. § 7104); now located at 2 CFR Part 175: Trafficking in Persons.

    a) Provisions applicable to a recipient that is a private entity.

    (1) You as the recipient, your employees, subrecipients under this award, and subrecipients' employees may not—

    i. Engage in severe forms of trafficking in persons during the period of time that the award is in effect;

    ii. Procure a commercial sex act during the period of time that the award is in effect; or

    iii. Use forced labor in the performance of the award or subawards under the award.

    (2) We as the Federal awarding agency may unilaterally terminate this award, without penalty, if you or a subrecipient that is a private entity—

    i. Is determined to have violated a prohibition in paragraph (a) (1) of this award term; or

    ii. Has an employee who is determined by the agency official authorized to terminate the award to have violated a prohibition in paragraph (a) (1) of this award term through conduct that is either—

    a. Associated with performance under this award; or

    b. Imputed to you or the subrecipient using the standards and due process for imputing the conduct of an individual to an organization that are provided in 2 CFR part 180, "OMB Guidelines to Agencies on Governmentwide Debarment and Suspension (Nonprocurement)," as implemented by each respective federal agency partner at: 2 CFR Part 1125 (Department of Defense), 2 CFR Part 1326 (Department of Commerce), 2 CFR 1400 (Department of the Interior), 2 CFR Part 1880 (NASA), 7 CFR Part 3017 (Department of Agriculture).

    b) Provision applicable to a recipient other than a private entity. We as the Federal awarding agency may unilaterally terminate this award, without penalty, if a subrecipient that is a private entity—

(1) Is determined to have violated an applicable prohibition in paragraph (a) (1) of this award term; or

(2) Has an employee who is determined by the agency official authorized to terminate the award to have violated an applicable prohibition in paragraph (a) (1) of this award term through conduct that is either—

i. Associated with performance under this award; or

ii. Imputed to the subrecipient using the standards and due process for imputing the conduct of an individual to an organization that are provided in 2 CFR part 180, "OMB Guidelines to Agencies on Governmentwide Debarment and Suspension (Nonprocurement)," as implemented by our agency at 2 CFR Part 1125 (Department of Defense), 2 CFR Part 1326 (Department of Commerce), 2 CFR 1400 (Department of the Interior), 2 CFR Part 1880 (NASA), 7 CFR Part 3017 (Department of Agriculture).

c) Provisions applicable to any recipient.

(1) You must inform us immediately of any information you receive from any source alleging a violation of a prohibition in paragraph (a) (1) of this award term.

(2) Our right to terminate unilaterally that is described in paragraph (a) (2) or (b) of this section:

i. Implements section 106(g) of the Trafficking Victims Protection Act of 2000 (TVPA), as amended (22 U.S.C. § 7104(g)), and

ii. Is in addition to all other remedies for noncompliance that are available to us under this award.

(3) You must include the requirements of paragraph (a) (1) of this award term in any subaward you make to a private entity.

d) Definitions. For purposes of this award term:

(1) "Employee" means either:

i. An individual employed by you or a subrecipient who is engaged in the performance of the project or program under this award; or

ii. Another person engaged in the performance of the project or program under this award and not compensated by you including, but not limited to, a volunteer or individual whose services are contributed by a third party as an in-kind contribution toward cost sharing or matching requirements.

(2) “Forced labor” means labor obtained by any of the following methods: the recruitment, harboring, transportation, provision, or obtaining of a person for labor or services, through the use of force, fraud, or coercion for the purpose of subjection to involuntary servitude, peonage, debt bondage, or slavery.

(3) “Private entity” means any entity other than a State, local government, Indian tribe, or foreign public entity, as those terms are defined in 2 CFR 175.25. Includes:

i. A nonprofit organization, including any nonprofit institution of higher education, hospital, or tribal organization other than one included in the definition of Indian tribe at 2 CFR 175.25(b).

ii. A for-profit organization.

(4) “Severe forms of trafficking in persons,” “commercial sex act,” and “coercion” have the meanings given at section 103 of the TVPA, as amended (22 U.S.C. § 7102).

8. PROHIBITION ON TEXT MESSAGING AND USING ELECTRONIC EQUIPMENT SUPPLIED BY THE GOVERNMENT WHILE DRIVING (Included pursuant to Department of the Interior Guidance Release – DIG-2010-04):

   Executive Order 13513, Federal Leadership on Reducing Text Messaging While Driving, was signed by President Barack Obama on October 1, 2009 (http://edocket.access.gpo.gov/2009/pdf/E9-24203.pdf). This Executive Order introduces a Federal Government-wide prohibition on the use of text messaging while driving on official business or while using Government-supplied equipment. Additional guidance enforcing the ban will be issued at a later date. In the meantime, please adopt and enforce policies that immediately ban text messaging while driving company-owned or-rented vehicles, government-owned or leased vehicles, or while driving privately owned vehicles when on official government business or when performing any work for or on behalf of the government. The Government reserves the right to cancel this announcement and/or the solicitation. This announcement does not constitute solicitation.

B. <u>SPECIAL PROVISIONS:</u>

1. Joint publication of results is encouraged; however, no party will publish any results of joint effort without consulting the other. This is not to be construed as applying to popular publication of previously published technical matter. Publication may be joint or independent as may be agreed upon, always giving due credit to the cooperation of participating Federal Agencies, the Host University, and Partner Institutions, and recognizing within proper limits the rights of individuals doing the work. In the case of failure to agree as to the manner of publication or interpretation of results, either party may publish data after due

notice (not to exceed 60 days) and submission of the proposed manuscripts to the other. In such instances, the party publishing the data will give due credit to the cooperation but assume full responsibility of any statements on which there is a difference of opinion. Federal agencies reserve the right to issue a disclaimer if such a disclaimer is determined to be appropriate.

2. The results of any cooperative studies may be used in developing theses in partial fulfillment of requirements for advanced degrees and nothing herein shall delay publication of theses.

3. Individual modifications shall include specific plans for data management, sharing, and archiving, as appropriate.

ARTICLE XI: DOCUMENTS INCORPORATED BY REFERENCE

The following are to be incorporated into this Agreement:

A. SF-LLL, Disclosure of Lobbying Activities or Grants.gov Lobbying Form certification, identified in the agencies Funding Opportunity Announcement.

B. Specific project award documents will incorporate the required Standard Forms for Application for Financial Assistance:

1. SF-424 – Application for Financial Assistance
2. SF-424a – Budget for Non-Construction
3. SF-424b – Assurances for Non-Construction
4. SF-424c – Budget for Construction
5. SF-424d – Assurances for Construction

ARTICLE XII. ATTACHMENTS

A. The following documents are attached for use per agency requirements, as appropriate:

ATTACHMENT 1 – Request for Advance or Reimbursement, SF-270
ATTACHMENT 2 – Federal Financial Report, SF-425
ATTACHMENT 3 – ACH Payment Enrollment, SF-3881
ATTACHMENT 4 – Example Modification Template

ARTICLE XIII. AUTHORIZING SIGNATURES

The following authorizing signatures are attached to this Agreement:

U.S. DEPARTMENT OF THE INTERIOR
A. Bureau of Land Management

B. Bureau of Reclamation
C. U.S. Geological Survey
D. National Park Service
E. U.S. Fish and Wildlife Service

U.S. DEPARTMENT OF AGRICULTURE
F. U.S. Forest Service
G. Natural Resources Conservation Service

U.S. DEPARTMENT OF DEFENSE
H. U.S. Army Corps of Engineers – Civil Works
I. Office of the Deputy Under Secretary of Defense (Installations and Environment),

J. The University of Montana – Missoula (HOST)
K. Colorado State University
L. Montana State University
M. Salish Kootenai College
N. University of Colorado at Boulder
O. University of Colorado Denver
P. University of Idaho
Q. University of Wyoming
R. Utah State University
S. Washington State University
T. University of Northern Colorado
U. The Governors of the University of Calgary
V. Metropolitan State University of Denver
W. Little Big Horn College
X. Northwest College
Y. University of Utah
Z. Blackfeet Community College
AA. Chief Dull Knife College
BB. University of Waterloo
CC. Wildlife Conservation Society

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

A. Bureau of Land Management

For ______________________________ 5/9/14
Jamie E. Connell Date
State Director

______________________________ 5/8/14
Lori J. Anderson Date
Grant Management Officer

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

B. U.S. Bureau of Reclamation

Michelle Maher
Grants and Cooperative Agreements Specialist

5/27/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

C. U.S. Geological Survey

Sherri Ly Bredesen
Contracting Officer

05/13/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

D. National Park Service

Andrew E. Lubner
Contracting Officer

5/14/14
Date

Kelvin A. Delaney
Financial Assistance Officer

5. 6. 14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

E. U.S. Fish and Wildlife Service

_______________________________ 5/20/2014
[Print Name]: Greg Watson Date
[Print Title]: Chief, Office of Landscape Conservation

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

F. U.S. Forest Service

G. Sam Foster
Station Director, Rocky Mountain Research Station

5/16/14
Date

The authority and format of this instrument has been reviewed and approved for signature.

Linda Marsh
Grants and Agreements Specialist

5-13-14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

G. Natural Resources Conservation Service

Gayle N. Barry
Deputy Chief for Management

May 22, 2014
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

H. U.S. Army Corps of Engineers – Civil Works

Deannda Sontag

Digitally signed by SONTAG.DEANNDA.S.1230791909
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=SONTAG.DEANNDA.S.1230791909
Date: 2014.05.21 08:19:32 -05'00'

21 May 2014

Deannda Sontag
Grants Officer

Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

I. Office of the Deputy Under Secretary of Defense (Installations and Environment)

ROBICHEAUX.TRACI.
D.1260353990

Digitally signed by
ROBICHEAUX.TRACI.D.1260353990
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI,
ou=USA, cn=ROBICHEAUX.TRACI.D.1260353990
Date: 2014.05.29 07:21:46 -05'00'

Traci Robicheaux
Grants Officer
Representing ODUSD (I&E)

Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

J. THE UNIVERSITY OF MONTANA – MISSOULA (HOST)

Judy Fredenberg Director, Research & Sponsored Programs	5/14/14 Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

K. Colorado State University

David B. Doty
Associate Director, Sponsored Programs

5/19/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

L. Montana State University

Renee A. Reijo Pera, Ph.D.
Vice President for Research

5.2.14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

M. Salish Kootenai College

Robert DePoe, III
President

5-20-14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

N. University of Colorado at Boulder

Digitally signed by Denitta Ward
DN: cn=Denitta Ward, o=Office of Contracts and Grants, ou=OCG, email=denitta.ward@colorado.edu, c=US
Date: 2014.05.19 16:18:42 -06'00'

May 19, 2014

Patricia Rankin
Associate Vice Chancellor for Research

Date

Denitta D. Ward, JD
Deputy Director, Office of Contracts and Grants

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

O. University of Colorado Denver

Adelita J. DeHerrera, JD
Contracts Manager, Office of Grants and Contracts

5/23/2014
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

P. University of Idaho

Polly J. Knutson — 5/9/14
Polly J. Knutson
Director, Office of Sponsored Programs — Date

AH

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

Q. University of Wyoming

William A. Gern
Vice President for Research and Economic Development

May 6/2014
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

R. Utah State University

Kevin Peterson, JD
Executive Director, Sponsored Programs

5/19/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

S. Washington State University

Dan Nordquist
Director of OGRD

5/23/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

T. University of Northern Colorado

Michele S. Schwietz

Michele S. Schwietz, Ph.D.
Director, Office of Sponsored Programs

5/9/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

U. The Governors of the University of Calgary

John Reynolds
Director, Research Services

MAY 14 2014
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

V. Metropolitan State University of Denver

Jason Janke
Associate Professor, MSU Denver's CESU representative

5/1/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

W. Little Big Horn College

David Small
Dean of Administration

5-28-14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

X. Northwest College

Ronda Peer (signature) — 5-28-14

Ronda Peer
Dean of Extended Campus

Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

Y. University of Utah

Brent K. Brown, Esq.
Director, Office of Sponsored Projects

5/7/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

Z. Blackfeet Community College

Dr. Billie Jo Kipp
President

5-27-14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

AA. Chief Dull Knife College

Dr. Richard Littlebear
President

05/20/14
Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

BB. University of Waterloo

MAY 0 6 2014

D.G. Dixon
Vice President, University Research

Date

ARTICLE XIII. AGREEMENT AUTHORIZING SIGNATURES (cont.)

CC. Wildlife Conservation Society

Amanda Hardy
Assistant Director, North American Program

5/21/2014
Date

REQUEST FOR ADVANCE OR REIMBURSEMENT

(See instructions on back)

OMB APPROVAL NO. 0348-0004

PAGE ___ OF ___ PAGES

1. TYPE OF PAYMENT REQUESTED
   - a. *"X" one or both boxes*: ☐ **ADVANCE** ☐ **REIMBURSE-MENT**
   - b. *"X" the applicable box*: ☐ **FINAL** ☐ **PARTIAL**

2. BASIS OF REQUEST: ☐ **CASH** ☐ **ACCRUAL**

3. FEDERAL SPONSORING AGENCY AND ORGANIZATIONAL ELEMENT TO WHICH THIS REPORT IS SUBMITTED

4. FEDERAL GRANT OR OTHER IDENTIFYING NUMBER ASSIGNED BY FEDERAL AGENCY

5. PARTIAL PAYMENT REQUEST NUMBER FOR THIS REQUEST

6. EMPLOYER IDENTIFICATION NUMBER

7. RECIPIENT S ACCOUNT NUMBER OR IDENTIFYING NUMBER

8. **PERIOD COVERED BY THIS REQUEST**
   FROM *(month, day, year)*
   TO *(month, day, year)*

9. RECIPIENT ORGANIZATION

Name:

Number and Street:

City, State and ZIP Code:

10. PAYEE *(Where check is to be sent if different than item 9)*

Name:

Number and Street:

City, State and ZIP Code:

11. **COMPUTATION OF AMOUNT OF REIMBURSEMENTS/ADVANCES REQUESTED**

PROGRAMS/FUNCTIONS/ACTIVITIES ►		(a)	(b)	(c)	**TOTAL**
a. Total program outlays to date	*(As of date)*	$	$	$	$ 0.00
b. *Less:* Cumulative program income					0.00
c. Net program outlays *(Line a minus line b)*		0.00	0.00	0.00	0.00
d. Estimated net cash outlays for advance period					0.00
e. Total *(Sum of lines c & d)*		0.00	0.00	0.00	0.00
f. Non-Federal share of amount on line e					0.00
g. Federal share of amount on line e					0.00
h. Federal payments previously requested					0.00
i. Federal share now requested *(Line g minus line h)*		0.00	0.00	0.00	0.00
j. Advances required by month, when requested by Federal grantor agency for use in making prescheduled advances	1st month				0.00
	2nd month				0.00
	3rd month				0.00

12. **ALTERNATE COMPUTATION FOR ADVANCES ONLY**

a. Estimated Federal cash outlays that will be made during period covered by the advance	$
b. *Less:* Estimated balance of Federal cash on hand as of beginning of advance period	
c. Amount requested *(Line a minus line b)*	$ 0.00

(Continued on Reverse)

13.	CERTIFICATION	
I certify that to the best of my knowledge and belief the data on the reverse are correct and that all outlays were made in accordance with the grant conditions or other agreement and that payment is due and has not been previously requested.	SIGNATURE OR AUTHORIZED CERTIFYING OFFICIAL	DATE REQUEST SUBMITTED May 31, 2018
	TYPED OR PRINTED NAME AND TITLE	TELEPHONE (AREA CODE, NUMBER, EXTENSION)

This space for agency use

Public reporting burden for this collection of information is estimated to average 60 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Office of Management and Budget, Paperwork Reduction Project (0348-0004), Washington, DC 20503.

PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE OFFICE OF MANAGEMENT AND BUDGET. SEND IT TO THE ADDRESS PROVIDED BY THE SPONSORING AGENCY.

INSTRUCTIONS

Please type or print legibly. Items 1, 3, 5, 9, 10, 11e, 11f, 11g, 11i, 12 and 13 are self-explanatory; specific instructions for other items are as follows:

Item	Entry
2	Indicate whether request is prepared on cash or accrued expenditure basis. All requests for advances shall be prepared on a cash basis.
4	Enter the Federal grant number, or other identifying number assigned by the Federal sponsoring agency. If the advance or reimbursement is for more than one grant or other agreement, insert N/A; then, show the aggregate amounts. On a separate sheet, list each grant or agreement number and the Federal share of outlays made against the grant or agreement.
6	Enter the employer identification number assigned by the U.S. Internal Revenue Service, or the FICE (institution) code if requested by the Federal agency.
7	This space is reserved for an account number or other identifying number that may be assigned by the recipient.
8	Enter the month, day, and year for the beginning and ending of the period covered in this request. If the request is for an advance or for both an advance and reimbursement, show the period that the advance will cover. If the request is for reimbursement, show the period for which the reimbursement is requested.
Note:	The Federal sponsoring agencies have the option of requiring recipients to complete items 11 or 12, but not both. Item 12 should be used when only a minimum amount of information is needed to make an advance and outlay information contained in item 11 can be obtained in a timely manner from other reports.
11	The purpose of the vertical columns (a), (b), and (c) is to provide space for separate cost breakdowns when a project has been planned and budgeted by program, function, or activity. If additional columns are needed, use as many additional forms as needed and indicate page number in space provided in upper right; however, the summary totals of all programs, functions, or activities should be shown in the "total" column on the first page.
11a	Enter in "as of date," the month, day, and year of the ending of the accounting period to which this amount applies. Enter program outlays to date (net of refunds, rebates, and discounts), in the appropriate columns. For requests prepared on a cash basis, outlays are the sum of actual cash disbursements for goods and services, the amount of indirect expenses charged, the value of in-kind contributions applied, and the amount of cash advances and payments made to subcontractors and subrecipients. For requests prepared on an accrued expenditure basis, outlays are the sum of the actual cash disbursements, the amount of indirect expenses incurred, and the net increase (or decrease) in the amounts owed by the recipient for goods and other property received and for services performed by employees, contracts, subgrantees and other payees.
11b	Enter the cumulative cash income received to date, if requests are prepared on a cash basis. For requests prepared on an accrued expenditure basis, enter the cumulative income earned to date. Under either basis, enter only the amount applicable to program income that was required to be used for the project or program by the terms of the grant or other agreement.
11d	Only when making requests for advance payments, enter the total estimated amount of cash outlays that will be made during the period covered by the advance.
13	Complete the certification before submitting this request.

Reset Form

FEDERAL FINANCIAL REPORT

(Follow form instructions)

1 Federal Agency and Organizational Element to Which Report is Submitted	2 Federal Grant or Other dentifying Number Assigned by Federal Agency (To report multiple grants use FFR Attachment)	Page 1	of pages

3 Recipient Organization (Name and complete address including Zip code)

4a DUNS Number	4b E N	5 Recipient Account Number or dentifying Number (To report multiple grants use FFR Attachment)	6 Report Type	7 Basis of Accounting
			○ Quarterly ☐ Semi Annual ○ Annual ☐ Final	☐ Cash ☐ Accrual

8 Project/Grant Period From (Month Day Year)	To (Month Day Year)	9 Reporting Period End Date (Month Day Year)

10 **Transactions**	Cumulative
(Use lines a-c for single or multiple grant reporting)	
Federal Cash (To report multiple grants, also use FFR Attachment):	
a Cash Receipts	
b Cash Disbursements	
c Cash on Hand (line a minus b)	
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d Total Federal funds authorized	
e Federal share of expenditures	
f Federal share of unliquidated obligations	
g Total Federal share (sum of lines e and f)	
h Unobligated balance of Federal funds (line d minus g)	
Recipient Share:	
i Total recipient share required	
j Recipient share of expenditures	
k Remaining recipient share to be provided (line i minus j)	
Program Income:	
l Total Federal program income earned	
m Program income expended in accordance with the deduction alternative	
n Program income expended in accordance with the addition alternative	
o Unexpended program income (line l minus line m or line n)	

11 ndirect Expense	a Type	b Rate	c Period From	Period To	d Base	e Amount Charged	f Federal Share
				g Totals			

12 *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*

13. Certification: By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and intent set forth in the award documents. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 18, Section 1001)

a Typed or Printed Name and Title of Authorized Certifying Official	c Telephone (Area code number and extension)
	d Email address
b Signature of Authorized Certifying Official	e Date Report Submitted (Month Day Year)
	14 Agency use only

Standard Form 425
OMB Approval Number 0348-0061
Expiration Date 10/31/2011

Paperwork Burden Statement

According to the Paperwork Reduction Act, as amended, no persons are required to respond to a collection o in ormation unless it displays a valid OMB Control Number he valid OMB control number or this in ormation collection is 0348-0061 Public reporting burden or this collection o in ormation is estimated to average 1 5 hours per response, including time or reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection o in ormation Send comments regarding the burden estimate or any other aspect o this collection o in ormation, including suggestions or reducing this burden, to the O ice o Management and Budget, Paperwork Reduction Project (0348-0061), Washington, DC 20503

OMB No. 1510 0056

ACH VENDOR/MISCELLANEOUS PAYMENT ENROLLMENT FORM

This form is used for Automated Clearing House (ACH) payments with an addendum record that contains payment-related information processed through the Vendor Express Program. Recipients of these payments should bring this information to the attention of their financial institution when presenting this form for completion. See reverse for additional instructions.

PRIVACY ACT STATEMENT

The following information is provided to comply with the Privacy Act of 1974 (P.L. 93-579). All information collected on this form is required under the provisions of 31 U.S.C. 3322 and 31 CFR 210. This information will be used by the Treasury Department to transmit payment data, by electronic means to vendor's financial institution. Failure to provide the requested information may delay or prevent the receipt of payments through the Automated Clearing House Payment System.

AGENCY INFORMATION

FEDERAL PROGRAM AGENCY		
AGENCY IDENTIFIER:	AGENCY LOCATION CODE (ALC):	ACH FORMAT: ☐ CCD+ ☐ CTX
ADDRESS:		
CONTACT PERSON NAME:		TELEPHONE NUMBER: ( )
ADDITIONAL INFORMATION:		

PAYEE/COMPANY INFORMATION

NAME	SSN NO. OR TAXPAYER ID NO.
ADDRESS	
CONTACT PERSON NAME:	TELEPHONE NUMBER: ( )

FINANCIAL INSTITUTION INFORMATION

NAME:	
ADDRESS:	
ACH COORDINATOR NAME:	TELEPHONE NUMBER: ( )
NINE DIGIT ROUTING TRANSIT NUMBER: ___ ___ ___ ___ ___ ___ ___ ___ ___	
DEPOSITOR ACCOUNT TITLE:	
DEPOSITOR ACCOUNT NUMBER:	LOCKBOX NUMBER:
TYPE OF ACCOUNT: ☐ CHECKING ☐ SAVINGS ☐ LOCKBOX	
SIGNATURE AND TITLE OF AUTHORIZED OFFICIAL: (Could be the same as ACH Coordinator)	TELEPHONE NUMBER: ( )

Instructions for Completing SF 3881 Form

Make three copies of form after completing. Copy 1 is the Agency Copy; copy 2 is the Payee/ Company Copy; and copy 3 is the Financial Institution Copy.

1. Agency Information Section - Federal agency prints or types the name and address of the Federal program agency originating the vendor/miscellaneous payment, agency identifier, agency location code, contact person name and telephone number of the agency. Also, the appropriate box for ACH format is checked.

2. Payee/Company Information Section - Payee prints or types the name of the payee/company and address that will receive ACH vendor/miscellaneous payments, social security or taxpayer ID number, and contact person name and telephone number of the payee/company. Payee also verifies depositor account number, account title, and type of account entered by your financial institution in the Financial Institution Information Section.

3. Financial Institution Information Section - Financial institution prints or types the name and address of the payee/company's financial institution who will receive the ACH payment, ACH coordinator name and telephone number, nine-digit routing transit number, depositor (payee/ company) account title and account number. Also, the box for type of account is checked, and the signature, title, and telephone number of the appropriate financial institution official are included.

Burden Estimate Statement

The estimated average burden associated with this collection of information is 15 minutes per respondent or recordkeeper, depending on individual circumstances. Comments concerning the accuracy of this burden estimate and suggestions for reducing this burden should be directed to the Financial Management Service, Facilities Management Division, Property and Supply Branch, Room B-101, 3700 East West Highway, Hyattsville, MD 20782 and the Office of Management and Budget, Paperwork Reduction Project (1510-0056), Washington, DC 20503.

[*Agency Partner Name*] – Project Summary

[*CESU Name*] Cooperative Ecosystem Studies Unit
Agreement Modification Form

FUNDING AGENCY:		
SUB-AGREEMENT/MODIFICATION NUMBER: [CESU USE ONLY]	COOPERATIVE AGREEMENT NUMBER:	FUNDING AMOUNT:
PROJECT TITLE:		
EFFECTIVE PROJECT DATES:		
PROJECT PURPOSE:		
STATEMENT OF MUTUAL BENEFIT AND INTEREST:		
Key Words:		

Federal Agency Contact(s) and Signature(s)		Partner Signature(s)	
[*Agency*] Project Technical Representative & Project Leader: Technical Rep: Address: Phone: Fax: Email: Project Leader: Phone: Email: No Signature Needed	[*Agency*] Administrator: Signature Date	Principal Investigator: Signature Date	Agreement / Grant Administrator: Signature Date

Project Type: Research ____ Technical Assistance ____ Education ____

Project Discipline(s): Biological ____ Cultural ____ Physical ____ Social ____ Interdisciplinary ____

Annual Performance Report Required:

Report(s) Received:

Publications on File:

This Modification is subject to all the provisions included in the CESU Agreement [*Insert Agency Agreement Number*]	[*CESU Name*] CESU Tracking #:

56 Fwd_ NPS-Caffery email string.pdf

From:	Moynahan, Brendan
To:	Cat Hoffman
Subject:	Fwd: NPS-Caffery email string
Date:	Tuesday, April 03, 2018 12:13:39 PM
Attachments:	NPS Caffery email thread.docx

Would you call when you're able? Can update you on my discussion with UCB admin leads.

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell   406.241.7581

Rocky Mountains CESU

---------- Forwarded message ----------
From: **Moynahan, Brendan** <brendan_moynahan@nps.gov>
Date: Tue, Apr 3, 2018 at 12:12 PM
Subject: NPS-Caffery email string
To: denitta.ward@colorado.edu

As discussed…

Thanks so much for helping us work through this - I really appreciate our call just now.

Will stand by to hear from you and/or Joe.

Regards,

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell   406.241.7581

Rocky Mountains CESU

56 1 Attachment NPS Caffery email thread.pdf

On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To: Maria Caffrey, Rebecca Beavers, Patrick Gonzalez,

Hi all --

My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.

It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while(b) (6) [redacted]

I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.

this remains a priority and I will work on it as necessary while I'm on annual leave.

Cat

On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
To; Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez

Cat,

I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.

On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus Hurricane Sandy information on parks instead of on New York City.

The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.

The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.

However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.

On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
To; Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Cat,

Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Maria,

In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "greater than in any preceding century in at least 2,800 years" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report. It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park. Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."

I know you haven't agreed with my point on this but wanted to say again the suggested revision here isn't about "anthropogenic."

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:
To: Maria Caffrey, Rebecca Beavers, Cat Hawkins Hoffman
Cc: Larry Perez

Folks,

I read the comments and emails below very carefully, and here are my opinions on the changes.

First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.

Page Viii:

As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.

Page 1:

I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “…, recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like “… with the greatest rates occurring since 1970.” This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO2 emissions. I think a more important issue in this paragraph is that it simply says "Further warming of the atmosphere will cause sea levels to continue to rise", when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.

Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.

Page 2:

This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn't adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it's not critical and it does not alter the key results of the report.

So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.

Respectfully,
John Gross

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

John -- Thanks for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

Maria, Rebecca, Patrick -- I've attached for your consideration a revision of the introductory text removing "pre-industrial" and adding information (and citation) regarding the greatly accelerated rate of sea level rise since 1993.

I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and in (b) (6) [redacted] but I will continue to make this a priority and can make time for a call if needed.

Cat

From: **Caffrey, Maria** <maria_caffrey@partner.nps.gov>
Date: Mon, Apr 2, 2018 at 8:34 AM
To: Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez

Hi Cat,

Thanks for taking the time to make these edits. I really appreciate all the time you have put into this. I spent some time last week looking over the things we discussed and here are a few of my thoughts:

1) The Knutson and Lin references should stay. The Knutson text you had highlighted was in reference to the data that included past storms, not anthropogenic climate change. Knutson's projections use IPCC scenarios that are based on CO2 emissions, so I think it is a good thing to keep the references. (note from Cat: done; 4.1.2018 draft retains the Knutson and Lin references; removes the)

2) The Alaska issue is related to the DEMs we used to map the scenarios, it is not related to the scenarios themselves, so it is fine to include the Alaska information. (note from Cat: done)

Unfortunately, I've been asked by the University of Colorado to not make any further changes to the document. They feel that with the Reveal article that this could result in more media interest and possibly more CORA/FOIA requests in the future. I spent a good chunk of last Friday consulting with various staff at the University of Colorado to find out what this means for the report. The master agreement for the CESU lays out that this report is my intellectual property. You are welcome to publish what I sent you on 3/21 without making any edits to it. According to the master agreement, you can attach a disclaimer to the front stating that this report does not represent the views of the NPS. You also have the option to not publish it, which is fine. I have already spoken to Patrick about possibly releasing this as a journal article, although this would undoubtedly further slow down getting this information out to the parks.

I'd be happy to setup a call with Denitta Ward at the University of Colorado if you would like to discuss this further.

57 [EXTERNAL] Publishing the report in a journal.pdf

From: Maria Caffrey
To: Patrick Gonzalez NPS
Subject: [EXTERNAL] Publishing the report in a journal
Date: Tuesday, April 03, 2018 1:42:17 PM

Patrick,

Thought you might be interested to hear what I learned regarding giving notice to publish the SLR/SS report; here is what the master agreement says:

SPECIAL PROVISIONS:
1. Joint publication of results is encouraged; however, no party will publish any results of joint effort without consulting the other. This is not to be construed as applying to popular publication of previously published technical matter. Publication may be joint or independent as may be agreed upon, always giving due credit to the cooperation of participating Federal Agencies, the Host University, and Partner Institutions, and recognizing within proper limits the rights of individuals doing the work. **In the case of failure to agree as to the manner of publication or interpretation of results, either party may publish data after due notice (not to exceed 60 days) and submission of the proposed manuscripts to the other. In such instances, the party publishing the data will give due credit to the cooperation but assume full responsibility of any statements on which there is a difference of opinion. Federal agencies reserve the right to issue a disclaimer if such a disclaimer is determined to be appropriate.**

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

58 Re_ [EXTERNAL] Re_ Request for Consultation wit....pdf

From:	Moynahan, Brendan
To:	Maria Caffrey
Cc:	Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject:	Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Tuesday, April 03, 2018 2:26:49 PM

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell 406.241.7581

Rocky Mountains CESU

On Tue, Apr 3, 2018 at 2:02 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:

> Hi Brendan,
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> I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.
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Web: mariacaffrey.com

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

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Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
National Park Service | Geologic Resources Division
303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

59 Re_ [EXTERNAL] Re_ Request for Consultation wit...(1).pdf

From:	Denitta Ward
To:	Maria Caffrey; Moynahan, Brendan; Joseph G Rosse
Cc:	Beavers, Rebecca; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject:	Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Tuesday, April 03, 2018 2:29:53 PM

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

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University of Colorado Boulder

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>> 303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

60 Re_ Request for Consultation with Rocky Mountai....pdf

From: Patrick Gonzalez NPS
To: Maria Caffrey U Colorado; Maria Caffrey; Rebecca Beavers; Cat Hoffman; Brendan Moynahan; Joseph Rosse; Denitta Ward
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: Tuesday, April 03, 2018 3:10:09 PM

Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

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303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

61 Out of the Office Re_ Request for Consultation ....pdf

From: Hoffman, Cat
To: patrick_gonzalez@nps.gov
Subject: Out of the Office Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: Tuesday, April 03, 2018 3:10:14 PM

I will be out of the office March 20, 2018 through April 8, 2018. Please call my cell phone if you need to reach me (970-631-5634). I'll do my best to catch up with e-mail, but you may need to re-send your message after April 8.

If you need assistance from the NPS Climate Change Response Program, please contact Larry Perez at larry_perez@nps.gov or 970-267-2136.

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

62 Re_ Request for Consultation with Rocky Mountai...(1).pdf

From:	Caffrey, Maria
To:	Moynahan, Brendan
Cc:	Maria Caffrey U Colorado; Cat Hoffman; Joseph Rosse; Denitta Ward; Patrick Gonzalez; Rebecca Beavers
Subject:	Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Wednesday, April 04, 2018 11:21:52 AM

Brendan,

I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Thanks for the quick reply, Maria. We are in full agreement that all all authors must be on the call. Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions. I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I wanted to keep the simple (!) scheduling question to the smallest group possible. It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.
>
> I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. **So I'd ask Maria and Cat to reply all with specific times for Friday**. I will make myself available any time Friday. I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.
>
> Kind regards,
>
> Brendan
>
> --
> *Brendan J. Moynahan, Ph.D.*
>
> *Research Coordinator and Science Advisor*
> *National Park Service*
> *Rocky Mountains Cooperative Ecosystems Studies Unit*
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> *The University of Montana*
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> *c/o* Forestry 109
> *Missoula, MT 59812*
>
> *Office 406.243.4449*
> *Cell 406.241.7581*
> --
>
> 
>
> Rocky Mountains CESU
>
> On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Good morning, all-
>
> Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less.   Would it be possible for you two - Joe and Maria - to identify a time slot this week?
>
> Thanks much -
>
> Brendan
>
> --
> *Brendan J. Moynahan, Ph.D.*
>
> *Research Coordinator and Science Advisor*
> *National Park Service*
> *Rocky Mountains Cooperative Ecosystems Studies Unit*
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University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

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131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
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Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

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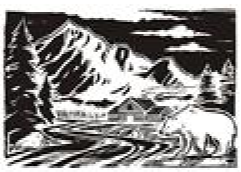

Rocky Mountains CESU

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Maria Caffrey, Ph.D.
NPS Water Resources Division
PO Box 25287
Denver CO 80225

Office: 303-969-2097
Cell: 303-518-3419

www.nps.gov/subjects/wetlands

--
Maria Caffrey, Ph.D.
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PO Box 25287
Denver CO 80225

Office: 303-969-2097
Cell: 303-518-3419

www.nps.gov/subjects/wetlands

63 [EXTERNAL] RE_ Request for Consultation with Ro....pdf

From: Joseph G Rosse
To: Caffrey, Maria; Moynahan, Brendan
Cc: Maria Caffrey; Cat Hoffman; Denitta Ward; Patrick Gonzalez; Rebecca Beavers
Subject: [EXTERNAL] RE: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: Wednesday, April 04, 2018 1:47:28 PM

Greetings, all. I'm not sure what time zones everyone is in; I'm available from 9 am on **Mountain Daylight Time** Friday.

Joe Rosse, Ph.D.
Associate Vice Chancellor of Research Integrity & Compliance
Research Integrity Officer
University of Colorado at Boulder (303) 735-5809
99 UCB/324 Regent Administrative Center Joseph.Rosse@colorado.edu
Boulder, CO 80309 http://colorado.edu/researchinnovation/ori

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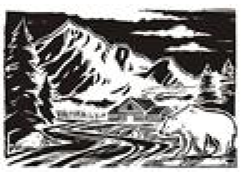

Rocky Mountains CESU

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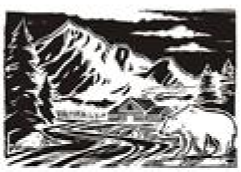

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https://ourenvironment.berkeley.edu/people/patrick-gonzalez

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>
> Office: (303) 969-2097
> Cell: (303) 518-3419
> Web: mariacaffrey.com
>
> ---
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> **Sent:** Tuesday, April 3, 2018 1:56:42 PM

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As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
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www.nps.gov/subjects/wetlands

64 Re_ Please respond.pdf

From: Rebecca Beavers
To: Hoffman, Cat
Cc: Patrick Gonzalez
Subject: Re: Please respond
Date: Wednesday, April 04, 2018 1:58:07 PM

I will make anytime work on Friday.

Sent from my iPhone

On Apr 4, 2018, at 1:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Rebecca and Patrick -- I do not assert command of your calendars, but I did let Brendan know that I have access to see your calendars and that Friday looked "do-able."
>
> Could you please let me know your availability during the times that Maria indicates in her response to Brendan.
>
> I will make myself available at any time.
>
> Cat
>
> ---------- Forwarded message ----------
> From: **Caffrey, Maria** <maria_caffrey@partner.nps.gov>
> Date: Wed, Apr 4, 2018 at 11:21 AM
> Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
> To: "Moynahan, Brendan" <brendan_moynahan@nps.gov>
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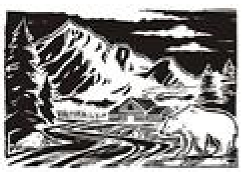

Rocky Mountains CESU

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Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
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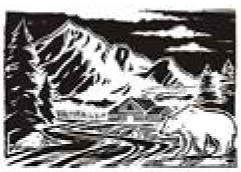

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Cat Hawkins Hoffman
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office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

65 Re_ Request for Consultation with Rocky Mountai...(2).pdf

From:	Patrick Gonzalez NPS
To:	Moynahan, Brendan
Cc:	Caffrey, Maria; Maria Caffrey U Colorado; Cat Hoffman; Joseph Rosse; Denitta Ward; Rebecca Beavers
Subject:	Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Wednesday, April 04, 2018 3:00:23 PM

Hi Brendan,

The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)

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I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.

Many thanks,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419

Web: mariacaffrey.com
From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

Thanks,

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office: 406.243.4449
Cell: 406.241.7581

Rocky Mountains CESU

On Tue, Apr 3, 2018 at 12:45 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Resending with Maria's updated NPS partner email.

On Tue, Apr 3, 2018 at 12:37 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
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In response to your email on April 2, it is my duty as the Agreement Technical Representative on Task Agreement P13AC01778 to consult with the Rocky Mountains CESU about the Master Cooperative Agreement P14AC00728.

Brendan:

As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator

National Park Service | Geologic Resources Division
303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

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Denver CO 80225

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--
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Office: 303-969-2097
Cell: 303-518-3419

www.nps.gov/subjects/wetlands

66 Re_ Request for Consultation with Rocky Mountai...(3).pdf

From:	Hoffman, Cat
To:	Patrick Gonzalez NPS
Cc:	Moynahan, Brendan; Caffrey, Maria; Maria Caffrey U Colorado; Joseph Rosse; Denitta Ward; Rebecca Beavers
Subject:	Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Wednesday, April 04, 2018 3:13:55 PM

Thanks Patrick.

Rebecca responded that she can be available anytime.

I'm available anytime on Friday.

Cat

On Wed, Apr 4, 2018 at 3:00 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Brendan,
>
> The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)
>
> Patrick
>
> ....
> Patrick Gonzalez, Ph.D.
>
> Principal Climate Change Scientist
> Natural Resource Stewardship and Science
> U.S. National Park Service
>
> Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
> Affiliate, Institute for Parks, People, and Biodiversity
> University of California, Berkeley
>
> https://ourenvironment.berkeley.edu/people/patrick-gonzalez
>
> patrick_gonzalez@nps.gov
> +1 (510) 643-9725
> 131 Mulford Hall, Berkeley, CA 94720-3114 USA
> ……………………………………………
>
> On April 4, 2018, at 10:21 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
>
> Brendan,
>
> I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Thanks for the quick reply, Maria. We are in full agreement that all all authors must be on the call. Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions. I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I wanted to keep the simple (!) scheduling question to the smallest group possible. It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.

I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. So I'd ask Maria and Cat to reply all with specific times for Friday. I will make myself available any time Friday. I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.

Kind regards,

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

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c/o Forestry 109
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Office: 406.243.4449
Cell: 406.241.7581

Rocky Mountains CESU

On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Good morning, all-

Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less. Would it be possible for you two - Joe and Maria - to identify a time slot this week?

Thanks much -

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
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32 Campus Drive
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Office: 406.243.4449
Cell: 406.241.7581

Rocky Mountains CESU

On Tue, Apr 3, 2018 at 3:10 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
Cc: "Beavers, Rebecca" <rebecca_beavers@nps.gov>, Maria Caffrey <maria_caffrey@partner.nps.gov>, Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

Assistant Vice Chancellor for Research and Director, Office of Contracts and Grants
University of Colorado Boulder

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 2:26:27 PM
To: Maria Caffrey
Cc: Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
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Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
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--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

67 Invitation_ UCBoulder - NPS coordination call @....pdf

From: brendan_moynahan@nps gov
To: rosse@colorado.edu; patr ck_gonzalez@nps.gov; rebecca_beavers@nps.gov; cat_hawkins_hoffman@nps.gov; maca2740@colorado.edu; Denitta Ward; maria_caffrey@partner.nps.gov
Subject: Invitation: UCBoulder - NPS coordination call @ Fri Apr 6, 2018 1pm - 2pm (MDT) (maria_caffrey@partner.nps.gov)
Attachments: inv te.ics

HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MTk4YjIwYmM5OTU1ZDhmMjhiYTE4OWIxMDRhNjZmYjg1OGY4N2FjYg&ctz America%2FDenver&hl en&es 1" more details »

UCBoulder - NPS coordination call
Conf Line [redacted]
Passcod [redacted]
When Fri Apr 6, 2018 1pm – 2pm Mountain Time
Video call HYPERLINK "https://hangouts.google.com/hangouts/_/doi.gov/brendan-moynaha?hceid YnJlbmRhbl9tb3luYWhhbkBucHMuZ292.34hi1oaius3578htouqmu8iksr" https://hangouts.google.com/hangouts/_/doi.gov/brendan-moynaha
Calendar maria_caffrey@partner.nps.gov
Who • brendan_moynahan@nps.gov - organizer
• rosse@colorado.edu
• patrick_gonzalez@nps gov
• rebecca_beavers@nps.gov
• cat_hawkins_hoffman@nps.gov
• maca2740@colorado.edu
• Denitta Ward
• maria_caffrey@partner.nps.gov

Going? HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y&rst 1&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MTk4YjIwYmM5OTU1ZDhmMjhiYTE4OWIxMDRhNjZmYjg1OGY4N2FjYg&ctz America%2FDenver&hl en&es 1"
Yes - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y&rst 3&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MTk4YjIwYmM5OTU1ZDhmMjhiYTE4OWIxMDRhNjZmYjg1OGY4N2FjYg&ctz America%2FDenver&hl en&es 1"
Maybe - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y&rst 2&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MTk4YjIwYmM5OTU1ZDhmMjhiYTE4OWIxMDRhNjZmYjg1OGY4N2FjYg&ctz America%2FDenver&hl en&es 1"
No HYPERLINK "https://www.google.com/calendar/event?action VIEW&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MTk4YjIwYmM5OTU1ZDhmMjhiYTE4OWIxMDRhNjZmYjg1OGY4N2FjYg&ctz America%2FDenver&hl en&es 1" more options »

68 Invitation_ UCBoulder - NPS coordination call @...(1).pdf

From:	brendan_moynahan@nps.gov
To:	maca2740@colorado edu; maria_caffrey@partner nps gov; patrick_gonzalez@nps gov; rosse@colorado edu; cat_hawk ns_hoffm_n@nps gov; Denitta Ward; rebecca_beavers@nps gov
Subject:	Invitation: UCBoulder - NPS coordination call @ Fri Apr 6, 2018 12pm - 1pm (PDT) (patrick_gonzalez@nps.gov)
Attachments:	invite.ics

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UCBoulder - NPS coordination call
Conf Line [redacted]
Passcod [redacted]
When Fri Apr 6, 2018 12pm – 1pm Pacific Time
Video call HYPERLINK "https://hangouts.google.com/hangouts/_/doi gov/brendan-moynaha?hceid YnJlbmRhbl9tb3luYWhhbkBucHMuZ292.34hi1oaius3578htouqmu8iksr" https://hangouts.google.com/hangouts/_/doi.gov/brendan-moynaha
Calendar patrick_gonzalez@nps gov
Who • brendan_moynahan@nps gov - organizer
• maca2740@colorado.edu
• maria_caffrey@partner.nps.gov
• patrick_gonzalez@nps.gov
• rosse@colorado.edu
• cat_hawkins_hoffman@nps.gov
• Denitta Ward
• rebecca_beavers@nps.gov

Going? HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgcGF0cmlja19nb2 6YWxlekBucHMuZ292&rst 1&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MWUyMTNhZjNlMDkxM2Q5ZWEzMWI1NGYxNWEzMTVkMWVkYjEzMmE3Nw&ctz America%2FLos_Angeles&hl en&es 1"
Yes - HYPERLINK "https://www.google.com/calendar/event?action RESPOND&eid MzRoaTFvYWl1czM1NzhodG91cW11OGlrc3IgcGF0cmlja19nb2 6YWxlekBucHMuZ292&rst 3&tok MjQjYnJlbmRhbl9tb3luYWhhbkBucHMuZ292MWUyMTNhZjNlMDkxM2Q5ZWEzMWI1NGYxNWEzMTVkMWVkYjEzMmE3Nw&ctz America%2FLos_Angeles&hl en&es 1"
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69 Re_ [EXTERNAL] RE_ Request for Consultation wit..._1.pdf

From:	Caffrey, Maria
To:	Joseph G Rosse
Subject:	Re: [EXTERNAL] RE: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Wednesday, April 04, 2018 4:18:04 PM
Attachments:	Instructions to Reviewers.docx Caffrey SLR Consolidated reviewer comments.xlsx Gonzalez co-authorsip 100516.pdf Manuscript_Submittal_Form 2017_SL_SS.docx Caffrey et al Sea Level Change Report_Final version_without pics .docx

Hi Joe,

I'm attaching a copy of the report from 3/21. This is the version of the report that I insist they should use (sorry it's missing the pictures, but it's too large to email otherwise). I'm also including a few files that you might be interested in. The report was originally planned to be released in May, then it got pushed to September. Note in the reviewer comments files that Cat Hoffman has submitted comments. In fact, that document hasn't been updated to reflect that she has submitted comments on multiple occasions. Cat also verbally offered to remove her name as a co-author over a phone call on March 9. Boy, I wish I had taken her up on that. There have been emails in the past, but I don't have access to my NPS emails prior to March 2018 because they deleted my account while I was (b) (6) [redacted].

On Wed, Apr 4, 2018 at 3:55 PM, Joseph G Rosse <Joseph.Rosse@colorado.edu> wrote:

> Dear Brendan, Cat and Maria,
>
> In preparation for the call on Friday, I am bringing myself up to speed by reviewing the Cooperative Agreement (H2370094000) and Task Agreement (P13AC01178). I have a couple basic questions that I'm hoping you can address in your roles as CESU representative, NPS Tech Rep, and PI, respectively.
>
> I should add that I have not seen any of the drafts of the report; I presume that Maria is first author and I saw a reference to Patrick Gonzales being the third author. Can someone explain who the other authors are? I also noted that the *Reveal* article claims that some of the edits in question were made by a Larry Perez, NPS Public Information Officer; is that correct? Am I correct in assuming that he is not a co-author?
>
> Did the co-authors reach any agreement—verbal or written—regarding such things as order of authorship and who would make final decisions regarding the report content and form? I could find no reference to any of that in the Task Agreement, and the only reference I found in the Cooperative Agreement was this:
>
> Article X.B. SPECIAL PROVISIONS:

1. Joint publication of results is encouraged; however, no party will publish any results of joint effort without consulting the other. This is not to be construed as applying to popular publication of previously published technical matter. Publication may be joint or independent as may be agreed upon, always giving due credit to the cooperation of participating Federal Agencies, the Host University, and Partner Institutions, and recognizing within proper limits the rights of individuals doing the work. In the case of failure to agree as to the manner of publication or interpretation of results, either party may publish data after due notice (not to exceed 60 days) and submission of the proposed manuscripts to the other. In such instances, the party publishing the data will give due credit to the cooperation but assume full responsibility of any statements on which there is a difference of opinion. Federal agencies reserve the right to issue a disclaimer if such a disclaimer is determined to be appropriate.

I infer that the joint parties are the PI (Maria) and the National Park Service, but if so it's not clear to me who represents NPS in that regard.

I also reviewed NPS Director's Order #79: Integrity of Scientific and Scholarly Activities. Among other things, it says that:

- Scientists and scholars "will welcome constructive criticism of my scientific and scholarly activities and will be responsive to peer review" (IV.B.5)

- Decision makers "will offer respectful, constructive, and objective review of my employees' scientific and scholarly activities and will encourage their obtaining appropriate peer reviews of their work." (IV.C.2)

Can anyone explain to me how peer review is normally done in this context? Are there any NPS guidelines on this?

Sorry if these questions seem basic, but you are all way ahead of me and I need to catch up on some basics.

Joe Rosse, Ph.D.

Associate Vice Chancellor of Research Integrity & Compliance

Research Integrity Officer

University of Colorado at Boulder (303) 735-5809

99 UCB/324 Regent Administrative Center Joseph.Rosse@colorado.edu

Boulder, CO 80309 http://colorado.edu/researchinnovation/ori

From: Hoffman, Cat <cat_hawkins_hoffman@nps.gov>
Sent: Wednesday, April 4, 2018 3:13 PM
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Cc: Moynahan, Brendan <brendan_moynahan@nps.gov>; Caffrey, Maria <maria_caffrey@partner.nps.gov>; Maria Caffrey <maria.caffrey@colorado.edu>; Joseph G Rosse <Joseph.Rosse@Colorado.EDU>; Denitta Ward <Denitta.Ward@colorado.edu>; Rebecca Beavers <Rebecca_Beavers@nps.gov>

Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Thanks Patrick.

Rebecca responded that she can be available anytime.

I'm available anytime on Friday.

Cat

On Wed, Apr 4, 2018 at 3:00 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Brendan,
>
> The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)
>
> Patrick
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> ....
> Patrick Gonzalez, Ph.D.
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> Principal Climate Change Scientist
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University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

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………………………………………….

On April 4, 2018, at 10:21 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Brendan,

I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Thanks for the quick reply, Maria.   We are in full agreement that all all authors must be on the call.   Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions.   I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I wanted to keep the simple (!) scheduling question to the smallest group possible.   It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.

I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. So I'd ask Maria and Cat to reply all with specific times for Friday.   I will make myself available any time Friday.   I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.

Kind regards,

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Good morning, all-

Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less. Would it be possible for you two - Joe and Maria - to identify a time slot this week?

Thanks much -

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 3:10 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU

re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
Cc: "Beavers, Rebecca" <rebecca_beavers@nps.gov>, Maria Caffrey <maria_caffrey@partner.nps.gov>, Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

Assistant Vice Chancellor for Research and Director, Office of Contracts and Grants
University of Colorado Boulder

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 2:26:27 PM
To: Maria Caffrey
Cc: Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 2:02 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:
Hi Brendan,

I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.

Many thanks,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com
From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

Thanks,

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 12:45 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Resending with Maria's updated NPS partner email.

On Tue, Apr 3, 2018 at 12:37 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Maria:

In response to your email on April 2, it is my duty as the Agreement Technical Representative on Task Agreement P13AC01778 to consult with the Rocky Mountains CESU about the Master Cooperative Agreement P14AC00728.

Brendan:

As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
National Park Service | Geologic Resources Division
303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

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Maria Caffrey, Ph.D.
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Denver CO 80225

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www.nps.gov/subjects/wetlands

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Cat Hawkins Hoffman

National Park Service

Chief, NPS Climate Change Response Program

1201 Oakridge Drive

Fort Collins, CO 80525

cat_hawkins_hoffman@nps.gov

office: 970-225-3567

cell: 970-631-5634

Adaptation websites: public, NPS managers

Climate Change Response Resources

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Cell: 303-518-3419

www.nps.gov/subjects/wetlands

69 1 Attachment Instructions to Reviewers.pdf

Instructions to Reviewers:

You have been asked to review the "Sea Level and Storm Surge Projections for 118 National Park Service Units". This report will be released as part of a three year project with the University of Colorado. The aim of the report is to combine sea level and storm surge estimates for 118 coastal park units. These sea level and storm surge estimates were generated by the Intergovernmental Panel on Climate Change (IPCC) and the NOAA. You have been chosen as a reviewer because of your expertise in this matter; you are not expected to review to whether using these datasets was an appropriate choice for this project, but we would like you to assess whether there are any technical errors in how these datasets have been applied and discussed.

Some of the data can be viewed using an online viewer: http://nps.maps.arcgis.com/apps/webappviewer/index.html?id=b0089512f1ee4117bc57224b97f74ecc

The report itself can be downloaded from: https://www.dropbox.com/sh/scfiwntlliasfh0/AAAOMFgFZLoS1jL9_vonekjha?dl=0

The online viewer will undergo separate review. ArcGIS is currently available by request. Use the attached excel spreadsheet to record your comments/suggested edits. Do not make edits in word.

Please return your review to us by COB December 16th.

Thank you for agreeing to review this important dataset.

69 2 Attachment Caffrey SLR Consolidated reviewer comments.pdf

Page Number(s)	Line Number Beginning	Line Number Ending
Overall		
Overall		
Overall		
Overall		
Overall		
no page number	2	17
4	19	19
4	21	21
5	5	7
5	11	12
7	5	5
7	5	5
7	18	18
9	11	38
11	Fig. 4	
11	14	19
12	3	3
12	Fig. 5	
12	27	29
12	37	37
14	22	22
General grammar		
12	Fig. 5 caption	
14	1	2
14	3	
14	8	9
14	10	10
14	29	29
9	9	9
16	3	3
16	10	20
17	3	5
16	3	3
16	2	2
16	16	20
Big picture		
17	9	9
16	10	11
17	23	23
17	25	25
18	6	10
18	17	17
19	16	17
19	20	20
20	15	15
20	17	17

21	5	15
22	2	2
23	19	19
23	23	23
23	25	26
23	14	16
3	Fig. 1	
23	34	36
23	36	40
24	25	25
24	26	31
24	32	32
25	2	3
A-1	8	
B-1	9	
C-1	7	
C-2	2	
C-2	15	
C-2	20	24
C-2	26	32
C-3	7	11
C-4	1	
C-4	1	5
C-4	2	
D-1		
E-1		
Overall		
1	22	24
1	31	31
2	4	4
2	Figure 1	
3	23	23
4	3	4
4	1	7
4	Table 1	
8	7	15
8	25	
9	32	33
9	34	35
12	2	
12	3	
13-Dec		
15	13	14
16	5	
16	6	7
23	17	
23	35	

24	3	
24	7	
viii	3	3
viii	5	5
viii	19	19
viii	24	24
ix	24	25
1	5	
1	8	8
1	22	22
1	23	23
1	38	1
2	11	12
3	3	3
4	3	3
4	4	5
4	8	8
Overall		
3	18	20
5	23	24
3	33	whole section
3	33	whole section
3	33	whole section

6	15	whole section
6	15	whole section
9	9	10
9	16	16
10	31	36
12	11	27
22	12	whole section
6	15	mapping
Datums		
Overall		

viii	3	3
viii	5	5
viii	19	19
viii	24	24
ix	24	25
1	5	
1	8	8
1	22	22
1	23	23
1	38	1
2	11	12
3	3	3
4	3	3
4	4	5
4	8	8
1 (Introduction)	1	
2	18 (Figure caption)	18
2	19 (Figure caption)	19
4	6	6
4	19	28
21	37	40
Overall		
Overall		
Overall		
Overall		
Overall		
Appendix B		

Reviewer Comment
See word doc
See PDF
See PDF
See PDF
See PDF
First paragraph of Introduction needs to have at least one sentence introducing this is a report about parks. Mayb
Suggest adding "potentially" before "vulnerable".
Is this rates of sea level change or is it sea level change projections?
Suggest revising to: While the melting of sea ice is problematic from an oceanographic and heat budget perspecti
Suggest moving first sentence of paragraph into previous paragraph. 2nd sentence: not sure if getting into density
Missing word "in" or "for" between "inundation" and "all"
Suggest adding a a sentence explaining choice of RCPs (e.g. These two represent a plausible range of scenarios be
Need to make it clear that SLOSH is at current sea level. I would suggest adding to end of first sentence, but you m
Need to add limitations on vertical accuracy of DEMs.
Personal pet peeve - this pie chart conveys remarkably little information. The same point could more effectively b
Can you give a range of the land level change values you got from the available tide gauges so for places where or
Word choice: "per" doesn't totally fit, I guess it's definitionally correct, but would "by" work better? See also subs
Change to "National Capital" region
Suggest adding a clause that indicates that it will likely be more than that because of what is known about directio
The "above waterline" made me realize that the question of which datums the rise is relative to had not been disc
grammar - is how an extra word?
I would suggest a re-write of how you use average as a verb in a lot of places. If I was doing it in track changes, I su
Need to clarify the difference between the standard deviation and the range, you explain it but I didn't have quite
Methodologically, this is unsound. I raised this early on, and I thought you were not doing this. Since this has been
Good idea
It's not just classified differently, it that the storm surge behaves highly differently and SLOSH is only designed to
I suggest using "hurricanes" instead of "storms" unless the database captures extratropical storms, then it's ok.
Delete "so". Good explanation in following sentence.
Suggest adding a sentence (could be here or it could be the first time you should one of the maps) explaining that
Word choice: although, suggest deleting
I'm confused about whether/how you combined SLR and storm surge (maybe my comment on line 20 isn't about
Need a sentence with the explanation that these things aren't additive because storm surge will propagate differe
storms should be plural
Capitalize Southeast Region
This is a great example, would be even better if it included the numbers you estimate that do not include land lev
In Introduction, it would be helpful to explain types of planning sea level rise info and storm surge info can inform
I have trouble with talking about "ranking". I think your point here is a good one, but by raising that term it makes
Here I am confused again. The way this is written I expect the figure (or something) to show combined SLR & stor
Because it's now so developed? And/or because sea level is higher?
I suggest adding a sentence that states what the SLR projections are for NCR parks.
This seems like an awful lot of text to devote to a park that shouldn't have been included as coastal in the first pla
Suggest changing from "could be nominated for a study of this nature" to are subject to sea level change.
Really interesting point - it may be worth mentioning that in the front section, that SLOSH does not look at impact
Figure 12 caption: should this be Intermountain Region?
I'm confused about standard deviation again (could be fixed by clarification of my comment on row 19
See my earlier comment about "tied"

Can you say something in the first sentence that's less about modeling and more about whether parks in the Paci
Change do to does
word choice: results section does not back up "catastrophic"
Instead of "if combined with a storm surge", I suggest "if the dynamic landforms are not able to keep pace with su
Also p. 13 line 1: What are the sea level rise maps? Is Fig. 2 an example of these and the whole slate of them is lin
Really key sentence - I'd suggest bringing that up to the start of the discussion. Word choice on regions - it may be
One summary figure that would be amazing and important to have is your own equivalent of Fig. 1, make a dot fo
I read the Sallenger paper differently than you are describing it here. The storm surge is not what's causing the ho
Here's my confusion again - if you've mapped these things, why aren't you including the figure? If I knew what you
Re-write to clarify so that storm surge is not before due to anthropogenic climate change. Do the same p.25, line
To follow up on my previous comment about "ranking", I think you want to highlight conclusions about how most
Word choice: instead of "unique" I suggest "locally-specific"
This may be incorrect due to confusion on this issue, but is it possible what you mean to say is "by providing both
Need to include an explanation of the the various layers and key meta-data here.
Need to include an explanation of the categories of hurricane, methods on mean and high tide and key meta-data
Suggest adding a sentence about guidance provided to include parks that have a shoreline as well as within a non-
See earlier comment about datums, at that point and here needs an explantation of what NAVD88 is. Here (and p
after factors, I suggest adding: including risk tolerance and expected time horizon of the project
Need to add a discussion on the accuracy of the vertical data that is the base of the maps (here as well as where I
I thought MOMs are maximums, not average. Isn't it a worst case scenario? Or is it an average of worst case scen
This is so important, but it was not clear in body of report that you do not recommend adding them together, sinc
word choice: change destroyed to damaged
Suggest adding: increased erosion
did you mean "buried"?
General thought on the waysides: I expected to have the waysides include the SLR projections and storm surge m
Great to see that you have rates of subsidence for all parks but two. Text in the Methods needs to be clear that su
This is a very well-written report: your methods and results are easy to follow, and appropriate "side boards" are
It should be noted that estimates from Aerts et al. are specific to NYC. Also, this sentence is a bit wonky: t sets up
Reword 2 to read something like "show how storm surge generated by hurricanes…"
Change page number to "ix"
Recommend increasing the size of the figure enough to make the credit line in the lower left corner legible
From "...find out more information..." to "learn"
To keep the subject of both paragraphs cosistent and clear, consider swapping the final phrase of line 3 with the c
Consider shortening statements regarding the implication of sea-ice into a single, succinct paragraph, and move m
Unless this table is reference elsewhere (perhaps to demonstrate the increasing rate of rise) it is a poor tool for ill
The question could be asked (and probably should be addressed): why did we filter historic storm intensity using
inputted or "imported", perhaps?
Recommend rewording to: "Changes in various land-based loadings on the continents—such as ice sheets during
This line is also a bit confusing: post-glacial isostatic rebound is the result of pressure being removed from the ear
Currently, it looks like this is being made available only in Appendix A.
Appendix D?
Currently, the sea level change data for regions is rolled out/discussed in this order: 2100, 2030, 2050. For reader
recommend: "…path passed present-day Boston National…"
recommend: "…indicate the potential height and extend of storm surge generated by…"
In reading this, it occurs to me that additional caveats might be necessary (i.e. a nod to the influence of storm dire
Change "then" to "the"
I defer to better knowledge, but would suspect that it is more accurate to say: "…discussed how changes in ocean

change "regions" to "region"
change "as energy" to "energy"
and the potential for
present ~~many~~ challenges
bathtub - should be defined in the abstract for readers who never go further
Region is ~~also~~ projected
The North American land surface is still returning to equilibrium after the melting of this continental ice.
"If human" - even if we don't stop we will continue to warm but if we do stop then the warming will not be as ext
sea levels to continue to rise
amount change to cost and end the sentence with "be extreme; extreme storms have extreme costs.
Concern: Will the general reader know that 1/100 is rare while 1/500 is even more rare? Maybe a modifier here w
Funding change to "The scope of this project was limited to sea levels. Even though interior waterways and lakes,
Furthermore, sea-level rise refers only to rising water levels resulting..."
Alaska is ~~also very~~ tectonically...
I'm not sure the general reader is familiar with albedo - please define
If you write: Melting sea ice is not a cause of sea-level rise. The volume of water in the sea remains the same whe
As ocean waters warm, the density of these waters - clarify density here. The warmer waters have a lower density
See PDF
Mentions the SLOSH modeling used but not the Tebaldi et al, 2012 data that is mentioned later for West Coast.
Is this the NOAA method used for their SLR viewer? Potenially site the mapping method used. Marcy, D., Brooks, W., Draganov, K., Hadley, B., Haynes, C., Herold, N., McCombs, J., Pendleton, M., Ryan, S., Schmid, K., Sutherland, M., and Waters, K. (2011) New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts. Solutions to Coastal Disasters 2011: pp. 474-490. doi: 10.1061/41185(417)42
Im sure you may get this question from other reviewers. Why use the lower IPCC estimates of SLR that really don't take into account more aggressive ice melt scenarios. Most Federal Agencies are/or have agreed to use the Parris et al, 2012 (input to the 3rd National Climate Assessment) scenarios or at least other similar scenarios such as the NRC west coast scenarios or the USACE scenarios. Also these have been used by DOD more recently and updated in their Coastal Assessment Regional Scenario Working Group (CARSWG). https://www.serdp-estcp.org/content/download/38961/375873/version/3/file/CARSWG+SLR+FINAL+April+2016.pdf The FEMA TMAC future conditions mapping report points to these scnenarios as does the E.O. 13690 - Federal Flood Risk Management Standard (FFRMS) - Climate Informed Science Approach.
It is not very clear if local subsidence was taken into account for all of these sites? The SLR scenarios should be based on locals relative sea level rise. At the very least, choosing closest tide gauge and using the USACE SLR Calculator would result in more accurate local scenarios if you were to use the NCA scenarios, or just use the subsidence values in the equations to extrapolate future sea level rise. I fear not taking into account local subsidence will result in number too low for the future scenarios.
The highest SLR scenario used is the RCP 8.5 by 2100 which only estimates ~0.8m of Sea Level Rise. The upper end of the NCA3 scenarios was 2.0m and the NCA4 range is likley to go up to 2.5m for the 2100 worse case RCP 8.5 scenario. I think your SLR estimates are too low for future planning.

Please check the descriptions of the P-Surge, MEOWS, and MOMs. P-Surge is used for probabalistic real-time runs during landfalling storms and produces an exceedence probablilty. The MEOWS and MOMS in the SLOSH display program were not derived from P-Surge and have no probability associated with them. The MEOWS are a worst case basin snapshot for a particular storm category, forward speed, trajectory, and initial tide level, incorporating uncertainty in forecast landfall location. These products are compiled when a SLOSH basin is developed or updated. MEOWs are not storm specific and are available to view in the SLOSH display program for all operational basins. No single hurricane will produce the regional flooding depicted in the MEOWs. Instead, the product is intended to capture the worst case high water value at a particular location for hurricane evacuation planning. MOMS provide a worst case snapshot for a particular storm category under "perfect" storm conditions. Each MOM considers combinations of forward speed, trajectory, and initial tide level. These products are compiled when a SLOSH basin is developed or updated. As with MEOWs, MOMs are not storm specific and are available to view in the SLOSH display program for all operational basins. No single hurricane will produce the regional flooding depicted in the MOMs. Instead, the product is intended to capture the worst case high water value at a particular location for hurricane evacuation planning. The MOMs are also used to develop the nation's evauation zones.   Long story short is that MOMS are used for worse case evacuation planning and are not in any way
Using MOMs can be problematic because in the SLOSH display program there are often mean tide and high tide runs, but the various basins ran different amounts of tide and different tide scenarios, based on what the State Partners wanted modeled for their state Hurricane Evacuation Study. Also where basins overlap there will be non-matching values. Choosing the correct basin value is often a judgement call. NHC has recently put out a National MOM product and they are working on a version 2 and they plan to make the GIS data available. I suggest you contact NHC and try to access this data to improve your study results. http://noaa.maps.arcgis.com/apps/StorytellingTextLegend/index.html?appid=b1a20ab5eec149058bafc059635a82ee   http://www.nhc.noaa.gov/news/20141106_pa_natlSurgeMap.pdf
Tebaldi uses MHW to reference the extreme surge values…and the mapping for the SLR projections was relateive to MHHW. Make sure datums are consistent.
SLOSH uses a multiple scenario approach…not probabalistic.
The Storm surge layers were not in the map viewer. I could not find where to download the GIS data. Also I noticed the maps for the high SLR scenario for RCP 8.5 are comparible to the NOAA SLR viewer maps for around 2FT above MHHW. I think this is too low of a scenario for 2100 planning. We have reached 2FT above MHHW during high frequency king tide / perigean tide events in Charleston, SC.
Figure 4. Does this include the Gulf Coast? Seems like the number should be much higher in the Gulf based on the very high SLR trends in Louisiana vs. the East Coast.
Discussion: need to add a description of the difference between using SLOSH MOMs worse case scenarios and Tebaldi numbers for West Coast. These really are not comparible. The Tebaldi numbers are based on the work of NOAA (Zervis) which are based on 1% water levels at the tide gauges. These numbers will also not match FEMA coastal flood studies because wave effects are not included. The SLOSH MOMs are often way higher than the 1% flood. For example, in Charleston, SC the 1% chance water level at the Charleston tide gauge is ~7.5FT. The category 1 MOM is that high. Going out to Cat 2-5 will produce surge value way above the 1% chance. So comparing SLOSH vs. Tebaldi numbers isn't really valid. One is based on probalistic analysis of historical data and the other is on 4500 or so scenario runs and having a cumlative peek value. In many cases in the east and gulf coast the 1% chance FEMA BFE is only a Cat 1 to Cat 2 MOM value.
How were the SLOSH results mapped? There are methods out there from the USACE for doing this for HES studies. http://www.northerngulfinstitute.org/impact/resources/inundationWorkshop/scott.pdf
SLR mapping was done using MHHW but was that converted to NAVD88 to match the DEMs? Just wanting to make sure all the map legend values are showing correct height relative to the same datum for both sets of
See PDF

and the potential for
present many challenges
bathtub - should be defined in the abstract for readers who never go further
Region is also projected
The North American land surface is still returning to equilibrium after the melting of this continental ice.
If human - even if we don't stop we will continue to warm but if we do stop then the warming will not be as extre
sea levels to continue to rise
amount change to cost and end the sentence with "be extreme; extreme storms have extreme costs.
Concern: Will the general reader know that 1/100 is rare while 1/500 is even more rare? Maybe a modifier here w
Funding change to "The scope of this project was limited to sea levels. Even though interior waterways and lakes,
Furthermore, sea-level rise refers only to rising water levels resulting..."
Alaska is also very tectonically...
I'm not sure the general reader is familiar with albedo - please define
If you write: Melting sea ice is not a cause of sea-level rise. The volume of water in the sea remains the same whe
As ocean waters warm, the density of these waters - clarify density here. The warmer waters have a lower density
Since you have chosen the IPCC projections over the semi-empirical approach, you should probably briefly mentic
Substitute 'for 2015' with 'using all available data including 2015'
Cross out 'relative to global mean sea level'. A trend is not relative to any level.
Substitute 'ice wholly contained within water and not supported by land' with 'ice wholly supported by water'
This paragraph is another place to note that the semi-empirical approach can result in projected levels over twice
This is an important point. Most of southern Alaska is rising rapidly with spatially and temporally variable rates. T
See PDF
See word doc
Multiple edits suggested over google drive
Hi Rebecca, I know you love 12th hour typo edits, but I was just looking at the report and noticed that Stanton's n
See PDF
My only comment this time around applies to this question and answer. Q. Why don’t you recommend that I add storm surge numbers on top of the sea level change numbers? A. Higher sea level and permanent inundation will change the way waves propagate within a basin in the future. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. This is not something NOAA takes into account in their SLOSH model.

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69 3 Attachment Gonzalez co-authorsip 100516.pdf

Caffrey, Maria <maria_a_caffrey@partner.nps.gov>

Sea level and storm surge report co-author

Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> Wed, Oct 5, 2016 at 11:36 AM
To: Maria Caffrey <maria_a_caffrey@partner.nps.gov>
Cc: Maria Caffrey <maria.caffrey@colorado.edu>, Patrick Gonzalez UC <patrickgonzalez@berkeley.edu>

Hi Maria,

Thank you for the offer to be a co-author. I would be honored to be included.

Please include my two affiliations:

National Park Service
Climate Change Response Program
130 Mulford Hall
Berkeley, CA 94720-3114

University of California, Berkeley
Department of Environmental Science, Policy, and Management
130 Mulford Hall
Berkeley, CA 94720-3114

Thanks,

Patrick

....

From: "Caffrey, Maria" <maria_a_caffrey@partner.nps.gov>
Subject: Re: Comments on sea level and storm surge report
Date: October 5, 2016 at 7:47:11 AM PDT
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

Hi Patrick,

Thanks for getting this back to me. I really appreciate you taking the time to review this. I know you're very busy at the moment. I'm looking forward to getting this report out and then turning my attention to putting this into an academic publication.

With regards to authorship, would you like to be co-author on this? You've spent so much time working on this giving me advice throughout the life of the project and helping with text.

Cheers,

Maria Caffrey, PhD

Research Associate, University of Colorado
NPS Partner, Geologic Resources Division
Office: (303) 969-2097
Cell: (b) (6) [redacted]

NPS Geologic Resources Division http://nature.nps.gov/geology
Energy and Minerals * Active Processes and Hazards * Geologic Heritage

On Tue, Oct 4, 2016 at 10:26 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Maria,

Congratulations on finishing the draft of your technical report! It represents a lot of hard work.

You'll find attached the document with recommended edits tracked in Word. I found no major issues. You'll see that most of the edits related to using the word "projected" for future estimates that are dependent on emissions scenarios and use of the conditional voice (could, might) when talking about the future. I did not have time to add explanatory comments for each edit - I know that you'll easily grasp the rationale behind individual edits. You can call me on my personal cell phone (b) (6) [redacted] for any questions.

All the best,

Patrick

....
Patrick Gonzalez, Ph.D.
Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Department of Environmental Science, Policy, and Management
University of California, Berkeley
130 Mulford Hall, Berkeley, CA 94720-3114 USA

patrick_gonzalez@nps.gov
patrickgonzalez@berkeley.edu
@pgonzaleztweet
http://www.patrickgonzalez.net
....

....
From: "Caffrey, Maria" <maria_a_caffrey@partner.nps.gov>
Subject: Re: Sea level and storm surge report
Date: October 3, 2016 at 3:09:30 PM PDT
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

No worries. Thanks for taking the time to do this.

Maria Caffrey, PhD

Research Associate, University of Colorado
NPS Partner, Geologic Resources Division
Office: (303) 969-2097
Cell: (b) (6) [redacted]

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On Mon, Oct 3, 2016 at 4:06 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Maria - I'm going through the report and will get to you before too long. Thanks for your patience.
>
> Patrick
>
> _____
>
> **From:** "Caffrey, Maria" <maria_a_caffrey@partner.nps.gov>
> **Subject: Re: Sea level and storm surge report**
> **Date:** September 28, 2016 at 10:02:19 AM PDT
> **To:** Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
>
> Patrick,

No problem. You don't need to hurry it. I can wait until Monday. I'm attending the Geological Society of America meeting this week, so I have other things I can do with my time. I just thought I might take a poke at some edits during my downtime between papers.

Maria Caffrey, PhD

Research Associate, University of Colorado
NPS Partner, Geologic Resources Division
Office: (303) 969-2097
Cell: [redacted]

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On Wed, Sep 28, 2016 at 11:00 AM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

Hi Maria,

I'm sorry for the delay in reviewing your report. I travelled, then gave two presentations, then was on leave. If you can wait until tomorrow, I can make suggestions to the Word document though track changes.

Patrick

——

From: "Caffrey, Maria" <maria_a_caffrey@partner.nps.gov>
Subject: Re: Sea level and storm surge report
Date: September 28, 2016 at 9:01:10 AM PDT
To: Patrick Gonzalez <patrick_gonzalez@nps.gov>

Hi Patrick,

Do you have any edits you would like to suggest for the final report? I'm starting to make changes based on Amanda's comments, but I wanted to see if you have anything to add before I start going through it.

Cheers,

Maria Caffrey, PhD

Research Associate, University of Colorado
NPS Partner, Geologic Resources Division
Office: (303) 969-2097
Cell: [redacted]

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On Fri, Sep 2, 2016 at 3:04 PM, Caffrey, Maria <maria_a_caffrey@partner.nps.gov> wrote:

Amanda, Patrick,

Here is the draft report. I have included an excel spreadsheet for your comments so I don't have to try and combine four versions of track changes from everyone (I'll be emailing Rob and Steve for their comments separately). Please try to get your reviews back to me by 9/16/16.

Have a great labor day weekend!

Maria Caffrey, PhD

Research Associate, University of Colorado
NPS Partner, Geologic Resources Division
Office: (303) 969-2097
Cell: [redacted]

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69 4 Attachment Manuscript_Submittal_Form 2017_SL_SS.pdf

Manuscript Submittal Form and Checklist

Fields marked by an asterisk are required

SECTION 1.

1. Manuscript submitter - the person submitting this manuscript for publication, e.g., project manager, author, editor

* **Name: Rebecca Beavers**

* **Mailing Address (street, city, state, zip): National Park Service, Geologic Resources Division, 12795 West Alameda Parkway, Lakewood, CO 80228**

* **Phone:** 303-987-6945

* **Email: Rebecca_beavers@nps.gov**

2. Title and author(s)

* **Title of manuscript:** Sea level rise and storm surge projections for the National Park Service

* **Authors (complete table)**

Author List Order	First Name	Middle Initial (optional)	Last Name
First	**Maria**	**A.**	**Caffrey**
Second	**Rebecca**	**L.**	**Beavers**
Third	**Patrick**	Click here to enter text.	**Gonzalez**
Fourth	**Cat**	Click here to enter text.	**Hawkins-Hoffman**
Fifth	Click here to enter text.	Click here to enter text.	Click here to enter text.
Sixth	Click here to enter text.	Click here to enter text.	Click here to enter text.
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3. * Report Series - select series that is appropriate for the manuscript

☐ **Natural Resource Data Series (NRDS) (proceed to sections 2 and 4 below)**

Intended for the timely release of basic data sets and routine data summaries that are based on data collection and data management methods documented in established, peer-reviewed protocols. While QA procedures have been completed to assure the accuracy of raw data values, *analysis or interpretation of the data has not been completed and should not be included in NRDS manuscripts.* (see NRDS guidance and tips)

☒ **Natural Resource Report (NRR) series (proceed to sections 3 and 4 below)**

Intended for comprehensive information and analysis about natural resources and related topics concerning lands managed by NPS. NRR manuscripts may include quantitative data that are accompanied by analysis and/or interpretation; procedural documents such as protocols and standard operating procedures; planning or policy information; and/or resource management information.

Note: If the manuscript meets criteria for 'Highly Influential Scientific or Scholarly Information' as defined by the OMB Peer Review Bulletin (i.e., provides the sole or major component of information used in decision-making; or, by itself, leads to a change in the direction of decision-making or to a decision that creates a clear and substantial impact on important public policies or private sector decisions), publication should not occur in the NRR.

SECTION 2. NRDS Manuscript

This section applies only if you are publishing in the **Natural Resource Data Series**.

No peer review is required for these reports; however, program management review is recommended.

*** Citation or link (preferred) to protocol associated with report:**

n/a

SECTION 3. NRR Manuscript

This section applies only if you are publishing in the **Natural Resource Report** *series*. This series requires peer review.

This section should be completed by the program manager who is assuming responsibility for the content of the manuscript. **Note**: Authors can never hold the role of Program Manager or Peer Review Manager for a manuscript.

Current NPS peer review guidance requires that NPS scientific and scholarly activities comply with OMB Final Information Quality Bulletin for Peer Review (2004; 70 FR 2664-2677), and NPS Director's Order (DO) #11B: Ensuring Quality of Information Disseminated by the National Park Service.

Peer review of the manuscript must comply with the NPS Interim Guidance on Peer Review. If the manuscript is submitted by or on behalf of the Inventory and Monitoring Division, it must also adhere to IMD-specific guidance

3.1. Peer Review Manager

The peer review manager oversees the peer review process of this report, and assumes responsibility for the manuscript fully meeting NPS peer review guidance. Manuscripts submitted by the Inventory and Monitoring Division must also meet the latest version of the IMD Peer Review Policy (NPS-only).

The peer review manager recommends, to the program manager, the technical acceptance of the manuscript in a written record documenting the process. The peer review manager is also responsible for maintaining all records associated with the peer review process, including correspondence, comments, and responses.

*** Peer Review Manager Name: John Gross**

*** Title: Climate Change Ecologist**

3.2. Peer Review Summary

Briefly describe the major review comments addressed, and areas of the report that were revised during the peer review conducted by the Peer Review Manager.

Peer review was carried out using both internal and external reviewers. Reviewers were selected based on their expertise in one or more fields relating to coastal climate change, sea level change, or storm surge. The following people reviewed the document: Amanda Babson (NPS), Ann Gallagher (NPS), Larry Perez (NPS), Steve Nerem (University of Colorado), Bob Glahn (emeritus, NOAA), Doug Marcy (NOAA), Chris Zervas (NOAA), Rob Thieler (USGS), and Claudia Tebaldi (Climate Central). All peer review comments have been compiled in either spreadsheets or as PDFs. Desciptions of how each comment was addressed are included in the spreadsheets. Comments covered the entire report. Peer reviewers were not supplied the GIS data referenced in this report. The GIS data will undergo a separate review.

Provide confirmation that peer and management review comments have been adequately incorporated into the final manuscript.

The report authors were responsible for the incorporation of peer and management comments into the final manuscript. These edits were reviewed by peer review manager John Gross to ensure that their edits adequately addressed the peer and management comments.

☐ Yes
☒ No

Does the manuscript include any sensitive or commercially valuable information that may potentially jeopardize a park resource or that might justify a management review by a qualified individual? If yes, please explain

Click here to enter text.

☐ Yes
☒ No

Is there policy-sensitive material in the manuscript that might justify a management review by an appropriate reviewer who can verify consistency with or clear and appropriate relation to NPS policy? A management review should be conducted if any material might not be consistent with NPS policy. If one of the reviewers is qualified to conduct such a review and has already done so, please explain.

Click here to enter text.

SECTION 4. Approval and Publication

4.1 Program Manager Approval

The NPS program manager has final authority to approve publication of the manuscript, and assumes responsibility for this report's adherence to scientific integrity, administrative and policy standards.

*** Program Manager Name: Cat Hawkins-Hoffman**

*** Title: Chief, Climate Change Response Program**

*** Date Approved for Publication: 4/14/2017**

4.2. Report Numbers and Data Store Record Owners

Provide the name and email address of additional NPS employees who should receive the final publication review notice from the series manager, and who should review the associated NPS Data Store record.

Name: Rebecca Beavers

Email: Rebecca_Beavers@nps.gov

Name: Patrick Gonzalez

Email: Patrick_Gonzalez@nps.gov

The following information is completed by the publication series manager.

Report Series Number: NPS/NRSS/NRR—2017/1425

Technical Information Center (TIC) number: 999/137852

NPS Data Store Reference Code: 2239974

Comments:
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This completed form is archived through the Natural Resource Publication Series. Archived forms are available to NPS management and other U.S. Government oversight entities upon request.

Series Manager – Fagan Johnson (Fagan_johnson@nps.gov, 970-267-2190)

69 5 Attachment Caffrey et al Sea Level Change Report_Final v_1.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

Maria A. Caffrey[1], Rebecca L. Beavers[2], Patrick Gonzalez[3], Cat Hawkins-Hoffman[4]

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Lakewood, CO 80235

[3]National Park Service
Climate Change Response Program
131 Mulford Hall
University of California
Berkeley, CA 94720-3114

[4]National Park Service
Climate Change Response Program
1201 Oakridge Drive, #150
Fort Collins, CO 80525

May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate’s Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside

for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

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[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or “perfect storm”). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA’s SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor’easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the “Labor Day Hurricane” that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand,

Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of

using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by

explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site[‡]	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site[‡]	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument[‡]	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*[‡]	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*[‡]	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield[‡]	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve[‡]	Fernandina Beach, FL (8720030)	N	110	0.600

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Southeast Region (continued)	Virgin Islands Coral reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial‡	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve‡	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park‡	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

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Pacific West Region	American Memorial Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park[‡]	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve[‡]	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site[‡]	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*[‡]	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park[‡]	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*[‡]	Seattle, WA (9447130)	N	109	0.540

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Pacific West Region (continued)	Point Reyes National Seashore[‡]	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial[‡]	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*[‡]	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument[‡]	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*[‡]	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve[‡]	No data	No data	No data	No data

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument[‡]	No data	No data	No data	No data
	Glacier Bay National Park*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park[‡]	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park[‡]	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park[‡]	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park[‡]	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve[‡]	Cordova, AK (9454050)	N	43	3.450

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore[§]	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Saugus Iron Works National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve§	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14[‡]	0.13	0.12	0.12
		2050	0.24[‡]	0.23	0.21	0.24
		2100	0.47[‡]	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14[‡]	0.13	0.13[‡]	0.12
		2050	0.25[‡]	0.24	0.24[‡]	0.24
		2100	0.50[‡]	0.54	0.59[‡]	0.68
	Cape Hatteras National Seashore	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.26[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Cape Lookout National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore[§]	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve[†§]	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway[§]	2030	0.15[‡]	0.15	0.15[‡]	0.14
		2050	0.26[‡]	0.27	0.26[‡]	0.28
		2100	0.53[‡]	0.62	0.66[‡]	0.79
	Harpers Ferry National Historical Park*[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park[§]	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park[§]	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park[§]	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu’uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve§	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument§	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park†§	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve†	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve†§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

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Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President's Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

70 Accepted_ UCBoulder - NPS coordination call @ F....pdf

From:	Google Calendar on behalf of Patrick Gonzalez
To:	brendan_moynahan@nps.gov
Subject:	Accepted: UCBoulder - NPS coordination call @ Fri Apr 6, 2018 1pm - 2pm (MDT) (brendan_moynahan@nps.gov)
Attachments:	invite.ics

Patrick Gonzalez has accepted this invitation.
UCBoulder - NPS coordination call
Conf Line: [redacted]
Passcode [redacted]
When Fri Apr 6, 2018 1pm – 2pm Mountain Time
Video call HYPERLINK "https://hangouts.google com/hangouts/_/doi.gov/brendan-moynaha?hceid=YnJlbmRhbl9tb3luYWhhbkBucHMuZ292.34hi1oaius3578htouqmu8iksr" https://hangouts.google.com/hangouts/_/doi.gov/brendan-moynaha
Calendar brendan_moynahan@nps.gov
Who • brendan_moynahan@nps.gov - organizer
• maca2740@colorado.edu
• rebecca_beavers@nps.gov
• maria_caffrey@partner.nps.gov
• rosse@colorado.edu
• Denitta Ward
• cat_hawkins_hoffman@nps.gov
• patrick_gonzalez@nps.gov

71 Re_ [EXTERNAL] RE_ Request for Consultation wit...(1)_1.pdf

From:	Moynahan, Brendan
To:	Joseph G Rosse
Cc:	Hoffman, Cat; Caffrey, Maria; Denitta Ward
Subject:	Re: [EXTERNAL] RE: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date:	Thursday, April 05, 2018 8:52:47 AM
Attachments:	NPS Caffery email thread.docx

Forgive the missing attachment - it's here...

Brendan J. Moynahan, Ph.D.

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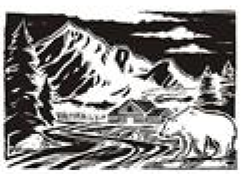

Rocky Mountains CESU

On Thu, Apr 5, 2018 at 8:49 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Hi Joe,
>
> Good questions. Thanks for the effort to come up to speed. I'll try to reply to your questions in order.
>
> You're right that Larry Perez is not a co-author. Larry is the Communications Coordinator for the NPS Climate Change Response Program (a national level Program). He commonly reviews and is involved in production of reports provided by the Program to parks. As discussed further below, the current report is a part of the NPS Natural Resource Report series specifically developed for NPS managers; Larry and his staff assist with production of these, and other reports. As with other reviewer comments, the response to Larry's suggestions and ultimate disposition is up to the collective best judgement of the authors and the NPS Peer Review Manager. I'll come back to that person and role in a moment.
>
> The authors on the draft report are (in order) Maria Caffrey, Rebecca Beavers, Patrick Gonzalez, and Cat Hawkins Hoffman. Of course, other than Maria, the other three are NPS employees. To my knowledge, there were no verbal or written agreements about an author or authors having authority to make final decisions on report content. It is nearly always the case – particularly with CESU projects – that our Partner PI is first author for two reasons: first, they often lead analysis, coordinate the team, and contribute greatly to the first draft of such a complex report; second, we understand that first-authorship is particularly important to our PIs at academic institutions. Form is a different beast in this case, because of the intent all along to publish the report as an NPS Natural Resource Report in our agency's Natural Resource Publication Series. That Series has requirements for form and has guidance, too, on the peer review process and the role of the peer review manager.

Which brings me back to your peer review question. Dr. John Gross, one of our most accomplished and respected scientists in NPS, was tapped to be Peer Review Manager for this report. He coordinated reviews from 6 external reviewers (in addition to 3 additional [non-author] NPS reviewers) and also verified documentation of the authors' handling of review comments. Cat also requested John's review to address Maria's concerns over some of Cat's recommended revisions to the draft report; specifically to consider Maria's concern that incorporating these changes would require a fresh peer review. Partly due to the nature of the comments and partly due to them pertaining nearly entirely to the Executive Summary (and not the analysis or conclusions) Dr. Gross saw no need to consider additional peer review. He did encourage the coauthors to move toward Maria's position on a couple points, and also for Cat's suggested comments to stand on a couple of points. I've attached the email string in that regard here.

I hope this helps with your questions. You're right that the "Special Provisions" section you shared is the ultimate guidance for moving forward if we can't reach agreement among the authors. We can talk about that if needed, but I honestly think we'll solve this on Friday.

Best,

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 3:55 PM, Joseph G Rosse <Joseph.Rosse@colorado.edu> wrote:

> Dear Brendan, Cat and Maria,
>
> In preparation for the call on Friday, I am bringing myself up to speed by reviewing the Cooperative Agreement (H2370094000) and Task Agreement (P13AC01178). I have a couple basic questions that I'm hoping you can address in your roles as CESU representative, NPS Tech Rep, and PI, respectively.

I should add that I have not seen any of the drafts of the report; I presume that Maria is first author and I saw a reference to Patrick Gonzales being the third author. Can someone explain who the other authors are? I also noted that the *Reveal* article claims that some of the edits in question were made by a Larry Perez, NPS Public Information Officer; is that correct? Am I correct in assuming that he is not a co-author?

Did the co-authors reach any agreement—verbal or written—regarding such things as order of authorship and who would make final decisions regarding the report content and form? I could find no reference to any of that in the Task Agreement, and the only reference I found in the Cooperative Agreement was this:

Article X.B. SPECIAL PROVISIONS:

1. Joint publication of results is encouraged; however, no party will publish any results of joint effort without consulting the other. This is not to be construed as applying to popular publication of previously published technical matter. Publication may be joint or independent as may be agreed upon, always giving due credit to the cooperation of participating Federal Agencies, the Host University, and Partner Institutions, and recognizing within proper limits the rights of individuals doing the work. In the case of failure to agree as to the manner of publication or interpretation of results, either party may publish data after due notice (not to exceed 60 days) and submission of the proposed manuscripts to the other. In such instances, the party publishing the data will give due credit to the cooperation but assume full responsibility of any statements on which there is a difference of opinion. Federal agencies reserve the right to issue a disclaimer if such a disclaimer is determined to be appropriate.

I infer that the joint parties are the PI (Maria) and the National Park Service, but if so it's not clear to me who represents NPS in that regard.

I also reviewed NPS Director's Order #79: Integrity of Scientific and Scholarly Activities. Among other things, it says that:

- Scientists and scholars "will welcome constructive criticism of my scientific and scholarly activities and will be responsive to peer review" (IV.B.5)

- Decision makers "will offer respectful, constructive, and objective review of my employees' scientific and scholarly activities and will encourage their obtaining appropriate peer reviews of their work." (IV.C.2)

Can anyone explain to me how peer review is normally done in this context? Are there any NPS guidelines on this?

Sorry if these questions seem basic, but you are all way ahead of me and I need to catch up on some basics.

Joe Rosse, Ph.D.

Associate Vice Chancellor of Research Integrity & Compliance

Research Integrity Officer

University of Colorado at Boulder (303) 735-5809

99 UCB/324 Regent Administrative Center Joseph.Rosse@colorado.edu

Boulder, CO 80309 http://colorado.edu/researchinnovation/ori

From: Hoffman, Cat <cat_hawkins_hoffman@nps.gov>
Sent: Wednesday, April 4, 2018 3:13 PM
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>
Cc: Moynahan, Brendan <brendan_moynahan@nps.gov>; Caffrey, Maria <maria_caffrey@partner.nps.gov>; Maria Caffrey <maria.caffrey@colorado.edu>; Joseph G Rosse <Joseph.Rosse@Colorado.EDU>; Denitta Ward <Denitta.Ward@colorado.edu>; Rebecca Beavers <Rebecca_Beavers@nps.gov>

Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Thanks Patrick.

Rebecca responded that she can be available anytime.

I'm available anytime on Friday.

Cat

On Wed, Apr 4, 2018 at 3:00 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

Hi Brendan,

The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
…………………………………………….

On April 4, 2018, at 10:21 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Brendan,

I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Thanks for the quick reply, Maria.   We are in full agreement that all all authors must be on the call.   Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions.   I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I

wanted to keep the simple (!) scheduling question to the smallest group possible.   It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.

I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. So I'd ask Maria and Cat to reply all with specific times for Friday.   I will make myself available any time Friday.   I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.

Kind regards,

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Good morning, all-

Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less.   Would it be possible for you two - Joe and Maria - to identify a time slot this week?

Thanks much -

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 3:10 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....

Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science

U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
Cc: "Beavers, Rebecca" <rebecca_beavers@nps.gov>, Maria Caffrey <maria_caffrey@partner.nps.gov>, Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

Assistant Vice Chancellor for Research and Director, Office of Contracts and Grants
University of Colorado Boulder

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 2:26:27 PM
To: Maria Caffrey
Cc: Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 2:02 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:
Hi Brendan,

I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.

Many thanks,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com
From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative

Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

Thanks,

Brendan

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 12:45 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Resending with Maria's updated NPS partner email.

On Tue, Apr 3, 2018 at 12:37 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Maria:

In response to your email on April 2, it is my duty as the Agreement Technical Representative on Task Agreement P13AC01778 to consult with the Rocky Mountains CESU about the Master Cooperative Agreement P14AC00728.

Brendan:

As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
National Park Service | Geologic Resources Division
303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

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--

Cat Hawkins Hoffman

National Park Service

Chief, NPS Climate Change Response Program

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cat_hawkins_hoffman@nps.gov

office: 970-225-3567

cell: 970-631-5634

Adaptation websites: public, NPS managers

Climate Change Response Resources

71 1 Attachment NPS Caffery email thread_1.pdf

On Tue, Mar 27, 2018 at 9:41 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To: Maria Caffrey, Rebecca Beavers, Patrick Gonzalez,

Hi all --

My last revisions to the report are attached. I suggest these changes in order to strengthen the focus on parks (recognizing our responsibilities out of this program to parks), and to emphasize this not just as a set of projections, but as a broader reference for park managers on sea level change and the science behind understanding it.

It looks like our schedules have us going in different directions for a few more days, and I know at least Patrick and I are still nose-to-grindstone in working sessions for NCA4 for much of tomorrow. Per Patrick's suggestion, we may be able to get this to the finish line through e-mail correspondence. Otherwise, I can be available next week while (b) (6) [redacted].

I would welcome your thoughts on these revisions. I removed photos and graphics to reduce the size for transmission, and because my computer kept locking up within the document for some reason. I tried to set this up as a google doc so that everyone could contribute to one document, but it would not convert to a google doc, so please share your comments with all. When we're satisfied with the language, Larry, would you mind reassembling the full document and please get it to Fagan who is ready and waiting to push this through final formatting and 508 compliance.

this remains a priority and I will work on it as necessary while I'm on annual leave.

Cat

On Wed, Mar 28, 2018 at 11:07 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
To; Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez

Cat,

I feel that these are really extensive revisions that really change the tone of the document. I'm wondering if we should resend it out for review or get approval from the existing reviewers if we make these changes. I know this goes way beyond the type of edits an editor would allow me to make once one of my journal articles has passed review and is being prepared for publication.

On Wed, Mar 28, 2018 at 12:35 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Maria -- There are essentially two new "context setting" paragraphs, and one paragraph that combines the essence of two longer paragraphs -- the purpose of that is to refocus Hurricane Sandy information on parks instead of on New York City.

The recommended changes do not alter any scientific analyses, results, discussion, or conclusions, but strengthen the focus on (1) the importance of this information for park managers, and (2) the provision of the report as a reference for managers to better understand contemporary sea level rise, and the basis for scientific understanding of it.

The additional text validates why it was important for NPS to fund the work -- this is appropriate context as part of the Natural Resources Report Series for national parks. It does not require approval from reviewers in my view.

However, this is one reason we have an independent peer review manager; I would ask John to provide his perspective on this. John, please see my e-mail from last night (below). I've attached my final recommendations on this report to get it to the finish line. Would you please review my recommended changes, and let us know if you think these are substantive and warrant going back to the peer review scientists. Thank you.

On Wed, Mar 28, 2018 at 2:01 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
To; Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Cat,

Thanks for bringing in John. I would appreciate hearing his opinion on it. One thing I do want to point out though is that I feel this is more than providing more than context. The edits remove the term "anthropogenic." In the introductory chapter for example, you have replaced it with the term"post-industrial era" which, as I explained over the phone last week, includes a natural as well as human-caused component to climate change, so I feel it is inaccurate to replace the term anthropogenic with "post-industrial." So I think some of these changes might have unintended implications for the science.

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

Hi Maria,

In previous conversations I've described my perspective on this section in particular; I prefer language that makes an impact -- language that helps readers to "see" and really grasp the point. The purpose of my recommended change has nothing to do with the word anthropogenic. A sentence stating that the rate of sea level rise since the industrial era began (i.e. post-industrial) is "greater than in any preceding century in at least 2,800 years" is more illustrative and powerful than "anthropogenic climate change has significantly increased the rate of global sea level rise". We want NPS staff to use this report. It's far more likely that our interpreters and educators will use the first statement in their programs, as would a superintendent of a coastal park speaking at a rotary club about what we know about sea level rise and how sea level rise is affecting his/her park. Additionally, for any park staff or visitors who contend that we're in some normal cycle of sea level "always changing," this provides information to counter that erroneous view; it gives more detail about, and substantiates that the rate of contemporary sea level rise is not "normal."

I know you haven't agreed with my point on this but wanted to say again the suggested revision here isn't about "anthropogenic."

On Wed, Mar 28, 2018 at 3:59 PM, Gross, John <john_gross@nps.gov> wrote:
To: Maria Caffrey, Rebecca Beavers, Cat Hawkins Hoffman
Cc: Larry Perez

Folks,

I read the comments and emails below very carefully, and here are my opinions on the changes.

First, in my opinion the suggested changes are far too insubstantial to merit sending this back out for review.

Page Viii:

As Cat stated, the key issues here are SLR and storm surge, for whatever reason. The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations.

Page 1:

I agree with Maria that replacing “anthropogenic” with “post-industrial” on page 1 is not advisable, although my reasons differ from Maria’s. My recommendation is to simply state the relevant time period over which the rate of SLR was higher than for the previous 2,800 years. E.g., “…, recent analyses reveal that the rate of SLR during the last century was greater than during any preceding century in at least 2,800 years”. If there’s a good citation, you could add something like “… with the greatest rates occurring since 1970.” This simple statement is most consistent with the quotation that Cat provided. The following sentences in the paragraph clearly lay out the role of climate change and they articulate the role of human activities leading to CO_2 emissions. I think a more important issue in this paragraph is that it simply says "Further warming of the atmosphere will cause sea levels to continue to rise", when the real story is about the incredibly large portion of anthropogenic global warming that has, so far, been absorbed by the oceans as compared to the atmosphere.

Also, the importance of GHG emissions is again articulated in the first paragraph of the discussion.

Page 2:

This information sets the context and perhaps facilitates interpretation. Since this report specifically targets NPS units it seems much more relevant to discuss impacts to park resources rather than city infrastructure. Paragraph A dropped the information about more frequent return intervals as a result of the combined effects of change in sea level, storm surge, and more intense storms. While an understanding of these dynamics is important, this extremely brief introduction doesn't adequate describe the many considerations, or geographical contexts, in sufficient detail for this to be a stand-alone reference on these dynamics. The information is beneficial, but it's not critical and it does not alter the key results of the report.

So these are all issues that the report authors need to resolve. None of them influence, in any meaningful way, the results or conclusions that one would draw from the data or analyses that were conducted.

Respectfully,
John Gross

On Wed, Mar 28, 2018 at 3:16 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
To; Maria Caffrey, Rebecca Beavers, Patrick Gonzalez
Cc: John Gross, Larry Perez

John -- Thanks for giving your time to this on short notice and for your prompt review and comments. It's helpful to have your perspective from a "fresh look."

Maria, Rebecca, Patrick -- I've attached for your consideration a revision of the introductory text removing "pre-industrial" and adding information (and citation) regarding the greatly accelerated rate of sea level rise since 1993.

I know Rebecca and Patrick are still traveling and/or off. I'm hoping we can complete this by early next week and move it over to Fagan so that it might be formatted and available by the end of the week. I'll be on a plane and driving tomorrow, and in (b) (6) [redacted] but I will continue to make this a priority and can make time for a call if needed.

Cat

From: **Caffrey, Maria** <maria_caffrey@partner.nps.gov>
Date: Mon, Apr 2, 2018 at 8:34 AM
To: Cat Hawkins Hoffman, Rebecca Beavers, Patrick Gonzalez

Hi Cat,

Thanks for taking the time to make these edits. I really appreciate all the time you have put into this. I spent some time last week looking over the things we discussed and here are a few of my thoughts:

1) The Knutson and Lin references should stay. The Knutson text you had highlighted was in reference to the data that included past storms, not anthropogenic climate change. Knutson's projections use IPCC scenarios that are based on CO_2 emissions, so I think it is a good thing to keep the references. (note from Cat: done; 4.1.2018 draft retains the Knutson and Lin references; removes the)

2) The Alaska issue is related to the DEMs we used to map the scenarios, it is not related to the scenarios themselves, so it is fine to include the Alaska information. (note from Cat: done)

Unfortunately, I've been asked by the University of Colorado to not make any further changes to the document. They feel that with the Reveal article that this could result in more media interest and possibly more CORA/FOIA requests in the future. I spent a good chunk of last Friday consulting with various staff at the University of Colorado to find out what this means for the report. The master agreement for the CESU lays out that this report is my intellectual property. You are welcome to publish what I sent you on 3/21 without making any edits to it. According to the master agreement, you can attach a disclaimer to the front stating that this report does not represent the views of the NPS. You also have the option to not publish it, which is fine. I have already spoken to Patrick about possibly releasing this as a journal article, although this would undoubtedly further slow down getting this information out to the parks.

I'd be happy to setup a call with Denitta Ward at the University of Colorado if you would like to discuss this further.

72 Re_ SCHEDULED_ Friday April 6, 1PM Mountain (No....pdf

From:	Moynahan, Brendan
To:	Hoffman, Cat
Cc:	Patrick Gonzalez NPS; Caffrey, Maria; Maria Caffrey U Colorado; Joseph Rosse; Denitta Ward; Rebecca Beavers
Subject:	Re: SCHEDULED: Friday April 6, 1PM Mountain (Noon Pacific) -- UCB-NPS conference call re: sea level/storm surge report
Date:	Thursday, April 05, 2018 10:11:31 AM
Attachments:	Caffrey et al Sea Level Change Report_no pics.4.01.2018 BJM highlights.docx

All,

Given our time limit tomorrow and my role as facilitator of the call, I'd like your help with detailing exactly the areas of disagreement. After many conversations and review of email strings and the marked-up draft report, I want to propose that we focus on two specific paragraphs that seem to be the crux of impasse.

The first is the opening paragraph of the Executive Summary (page viii). The second is the last paragraph on page 1, in the Introduction, beginning with "Global sea level is rising. ..."

So we're all working from the same slate, I've attached the 4/1/18 version of the report that, based on the 3/21/18 version, shows Cat's suggested edits. I've highlighted the two paragraphs in this file.

I would appreciate hearing if the co-authors agree with my proposed focus. Also, if there are other essential points that we must discuss tomorrow, please let me know.

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 3:48 PM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Thanks, all, for your replies.
>
> Please lock in 1pm-2pm Mountain (12-1pm Pacific) on Friday, 4/6. Let's plan for 1 hour.
>
> Our objectives are: (1) to clearly define and mutually understand the specific points of

disagreement, and (2) identify language that will all us to proceed with publication with full representation of the four authors. If needed, we can also identify and describe report and project completion in the absence of consensus.

I'll facilitate the call as needed and be able to speak to specific terms of CESU Agreements, etc.

Thank you for bringing your best ideas, understanding, and maximum flexibility!

Best,

Brendan

Conference Line: (b) (5) [redacted]

Passcode: (b) (5) [redacted]

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 3:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Thanks Patrick.
>
> Rebecca responded that she can be available anytime.
>
> I'm available anytime on Friday.
>
> Cat
>
> On Wed, Apr 4, 2018 at 3:00 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
>
>> Hi Brendan,
>>
>> The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)
>>
>> Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
…………………………………………….

On April 4, 2018, at 10:21 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Brendan,

I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Thanks for the quick reply, Maria. We are in full agreement that all all authors must be on the call. Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions. I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I wanted to keep the simple (!) scheduling question to the smallest group possible. It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.

I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. So I'd ask Maria and Cat to reply all with specific times for Friday. I will make myself available any time Friday. I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.

Kind regards,

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:
Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Good morning, all-

Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less.   Would it be possible for you two - Joe and Maria - to identify a time slot this week?

Thanks much -

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 3:10 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
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patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
Cc: "Beavers, Rebecca" <rebecca_beavers@nps.gov>, Maria Caffrey <maria_caffrey@partner.nps.gov>, Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

Assistant Vice Chancellor for Research and Director, Office of Contracts and Grants
University of Colorado Boulder

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 2:26:27 PM
To: Maria Caffrey
Cc: Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 2:02 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:
Hi Brendan,

I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.

Many thanks,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com
From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

Thanks,

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 12:45 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:

Resending with Maria's updated NPS partner email.

On Tue, Apr 3, 2018 at 12:37 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:

Maria:

In response to your email on April 2, it is my duty as the Agreement Technical Representative on Task Agreement P13AC01778 to consult with the Rocky Mountains CESU about the Master Cooperative Agreement P14AC00728.

Brendan:

As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
National Park Service | Geologic Resources Division
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Adaptation websites: public, NPS managers
Climate Change Response Resources

72 1 Attachment Caffrey et al Sea Level Change Report_no pics_4.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—~~2017/1425~~ ←premature; will need new NRR number

Starting document is 3/21/2018 draft.

Photos, graphics, and appendices are removed from this draft to reduce size of the document for e-mail transmission among authors while working on final text in the body of the report.

Recommended changes are only to text in the body of the report, and do not remove or affect existing photos or graphics in the report. Suggest adding one photo of the Statute of Liberty (see text).

There are no changes or alterations to the appendices, analyses, or results. Modifications are intended to better focus on NPS, the importance of this work to parks, and the provision of explanatory scientific information regarding sea level rise and storm surge.

Removal of photos and graphics changed pagination, thus created errors in the table of contents. This will be fixed when the document is "reassembled" to include the original photos and graphics.

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—~~2017/1425~~

Maria A. Caffrey[1], Rebecca L. Beavers[2], Patrick Gonzalez[3], Cat Hawkins Hoffman[4]

Comment [HCH1]: No hyphen

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—~~2017/1425~~. National Park Service, Fort Collins, Colorado.

Comment [HCH2]: Premature; will need a new number

NPS 999/137852, May 2017

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Photo 1. Looking ~~out~~ towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Comment [HCH3]: Strike "out" – not needed grammatically

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers understand these changes and their implications so we may better steward the resources under our care and provide for visitor use. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, the report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Comment [HCH4]: Executive summary answers the "why" – why is this important to parks .this should be a succinct statement of the reason NPS invested in this work, focused on parks I E we have an affirmative responsibility to address the threat of sea level rise (change) and storm surge in order to protect resources and visitor opportunities The drivers that cause sea level change and the science behind it are included in the document as a reference for our managers Recommended text for tighter focus on parks in keeping with NPS core messages

A note from John Gross (independent peer review coordinator): "The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations."

Comment [HCH5]: Redundant with first sentence

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration ~~for~~ and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth

receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Comment [HCH6]: The report is about sea level rise and storm surge It provides definitions for sea level, sea level change, and sea level rise, but never defines storm surge We need to include a definition recommended definition provided here from NOAA

Source:
https://www nhc noaa gov/surge/surge_intro pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009, ~~anthropogenic climate change has significantly increased the rate of global sea level rise~~ Grinsted et al. 2010, Church and White 2011); ~~; Slangen et al. 2016, Fasullo et al. 2016~~). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20[th] century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet, et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect many national parks. ~~how we protect and manage our national parks.~~ The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

Comment [HCH7]: Added these two introductory paragraphs to provide better context stressing the importance of the work for national park managers

Comment [HCH8]: This is an important point that I suggest including here from the Methods section (in summary form) The same statement remains in Methods section

Comment [HCH9]: I moved this statement from lower in the document to provide it here as part of early introduction b/c it is a succinct statement of what the report provides

Comment [HCH10]: Added this subheading to better frame the significance of recent, rapid rates of sea level rise

Comment [HCH11]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19[th] century began To me this is much more clear than "anthropogenic climate change has significantly increased the rate of global sea level rise" – it's an effective, impactful statement that negates any perceptions that some may have of "well, sea level is always changing "

Source: From USGCRP Climate Science Special Report, 2017 (Sea level rise chapter, Sweet et al 2017): "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32 The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Source from which the CSSR derived this information:
Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016: Temperature-driven global sea-level variability in the Common Era *Proceedings of the National Academy of Sciences*, **113**, E1434-E1441 http://dx doi org/10 1073/pnas 1517056113

Comment [HCH12]: Titus, J.G., E.K. Anderson D.R. Cahoon S. Gill R.E. Thieler and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research https //downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms) affecting infrastructure and ecosystems, including those of national parks. Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

~~**Suggest using paragraph "A" below as a substitute for this paragraph and the next one:**~~
~~For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

~~**Suggest deleting this paragraph; part of it is combined below and is more specific to parks**Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).~~

~~"A"~~ The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, ~~Ting et al. 2015~~), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

Comment [HCH13]: Moved this text earlier in the document

Comment [HCH14]: Relation of temperature increase to rising sea level already noted above No need to say "we'll tell you more about it below"

Comment [HCH15]: The text needs to be more directly relevant to parks In a report about parks, it would be more useful to discuss the cost of damage in parks from Sandy, vs the cost of damage in New York City (which has infrastructure far beyond anything in parks) We could get reasonable ballpark figures from Rich Turk regarding damage caused in parks (GATE, FIIS, STLI, etc) from Sandy

Followup: I obtained the cost figures for Hurricane Sandy damage to national park units from Tim Hudson Tim worked on the Sandy recovery effort for NPS; now Superintendent at Katahdin Woods and Waters National Monument This information is in the paragraph labeled "A"

We also need to update the text to recognize the recent, 2017 hurricanes: Harvey, Irma, Maria Paragraph "A" mentions these hurricanes in addition to Sandy

Comment [HCH16]: Retained; use in paragraph below that discusses impacts of Hurricane Sandy on national parks, instead of on New York City

Comment [HCH17]: This would need a citation

Comment [HCH18]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS

This information is more relevant to national parks than the cost of damage to New York City infrastructure

Comment [BJM19]: Anthropogenic retained here

Comment [HCH20]: Check whether this reference is relevant to the point; from my (cursory) reading of it, it appears inconclusive on attribution Update (4 2 2018): Maria says the reference does substantiate the point We will retain

Comment [HCH21]: Similar to Knutson et al – not sure this reference substantiates the point about models projecting increasing storm intensities under scenarios of increasing GHG emissions Seems focused on managing risks of climate change, including GHG mitigation Update (4/2/2018): per Maria, the reference does substantiate the point We will retain

Comment [HCH22]: Not sure this reference substantiates the point

Conclusions include "the model simulations indicate that aerosol forcing has been more effective in causing potential intensity (PI) than the corresponding GHG forcing: the decrease in PI due to aerosols and increase due to GHG largely cancel each other Thus, PI increases in the recent 30 years appears to be dominated by multidecadal natural variability associated with the positive phase of th ...

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

~~Sea Level Rise Data~~ Understanding Sea Level Rise and Storm Surge

Comment [HCH23]: Moved this below as a subheading in this section

Numerous factors cause ~~S~~sea level rise~~. is caused by numerous factors.~~ As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

Need to add explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise – 2-3 sentences would suffice.

Comment [HCH24]: As of 4/2/2018, do not have anything from Maria or others on this Delete

Sea Level Rise Data

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The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are

reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are

shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and 2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

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NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; ae is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the

nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix ~~D~~C. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane str king the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane str king the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington’s Olympic Peninsula and in the San Juan Islands, affecting Ebey’s Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea

level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved

towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

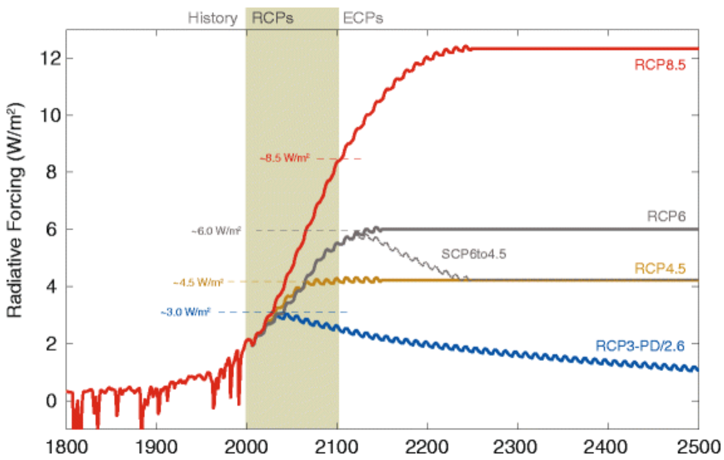

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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73 summary; exerpts.pdf

From:	Hoffman, Cat
To:	Brendan Moynahan
Subject:	summary; exerpts
Date:	Thursday, April 05, 2018 3:26:11 PM
Attachments:	excerpts for Brendan.docx

attached.

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Adaptation websites: public, NPS managers
Climate Change Response Resources

73 1 Attachment excerpts for Brendan.pdf

REGARDING "ANTHROPOGENIC"

(1) List of Figures after Table of Contents

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011. Retain; no change was or is suggested here

(2) Executive Summary

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges present challenges to national park managers, and compel the NPS to help our managers understand these changes and their implications so we may better steward the resources under our care and provide for visitor use. ~~due to anthropogenic climate change present challenges to national park managers.~~ This report summarizes work ~~done by~~of ~~the~~ University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC), and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, the report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

John Gross' recommendation: "The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations." **Cat's perspective:** Concur with John Gross. Implying that relative sea level rise is due to anthropogenic change is wrong - there are always a number of factors related to relative (i.e. local) SLR so this statement is disingenuous. In my/Cat's view the point to make in the Exec Summary is: (1) changes that are occurring in sea levels and storm surge potential present challenges to our coastal park managers; (2) we have a responsibility to help park managers address these challenges; (3) towards meeting that responsibility, this report provides sea level rise projections and augments two earlier NRR series reports (the Handbook and Case Studies)

- Scientific rationale for retaining "anthropogenic" in Exec Summary is lacking; retention is not scientifically defensible as currently worded, and would require additional explanation/analyses not performed in this study.
- Not essential to an explanation of why this report supports and is important to national parks.

(3) Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009, ~~anthropogenic climate change has significantly increased the rate of global sea level rise~~ Grinsted et al. 2010, Church and White 2011)~~.;~~ ~~Slangen et al. 2016~~, ~~Fasullo et al. 2016~~). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet, et al. 2017).

Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016

- Purpose of suggested revision was not aimed at the word anthropogenic. Purpose was to focus on providing more impactful, illustrative language that relates to context of the timeline.
- But it's fine to include this: "anthropogenic climate change has significantly increased the rate of global sea level rise" (this phrase could be added following a semi-colon after the citations).

(4) Introduction

~~**Suggest using paragraph "A" below as a substitute for this paragraph and the next one:**~~

~~For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

- Regarding the sentence: "This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change" -- totally fine to include this sentence within paragraph A below
- Removal of the sentence was not aimed at "anthropogenic" (though I certainly should've recognized that would be the perception)…the intent was to talk about effects of Sandy in context of national parks, not New York City, and this sentence was a victim of too-swift editing on my/Cat's part to refocus on parks

~~**Suggest deleting this paragraph; part of it is combined below and is more specific to parks**Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).~~

- In this paragraph, the sentence "Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities" is already included in paragraph A below….i.e. retained.

The sentence "Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities" is included in the new paragraph focusing on parks.

~~**"A"**~~ The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive damage to infrastructure and resources in numerous coastal national park units. The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, ~~Ting et al. 2015~~), and rising sea levels increase the potential for damage from storm surge. Management decisions and investments in coastal national park units can benefit from understanding projections for the future in conjunction with lessons learned from past storm events.

REGARDING GREENHOUSE GASES, HUMAN CAUSES, ETC.

Retain; no changes recommended to any.

Executive Summary, p. viii: Results illustrate potential future inundation and storm surge under four greenhouse gas emissions scenarios.

Introduction, p. 1 last paragraph: Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014).

Introduction, p. 1 last paragraph: Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013).

Introduction, p. 2: Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010), and rising sea levels increase the potential for damage from storm surge.

Methods, p. 5 middle of page: As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013).

Discussion, first paragraph: Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1)

Discussion, second paragraph: The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100.

OTHER

Methods, p. 6 middle of page: "Need to add explanation here about storm surge; we talk a lot about why sea level is rising and what sea level change is, but don't really define storm surge….what is storm surge and why is it a problem for parks in addition to sea level rise – 2-3 sentences would suffice." Still think this would be beneficial to add, but not imperative, and developing this text myself likely to produce additional resistance; will drop it.

74 Re_ SCHEDULED_ Friday April 6, 1PM Mountain (No...(1).pdf

From:	Moynahan, Brendan
To:	Hoffman, Cat
Cc:	Patrick Gonzalez NPS; Caffrey, Maria; Maria Caffrey U Colorado; Joseph Rosse; Denitta Ward; Rebecca Beavers
Subject:	Re: SCHEDULED: Friday April 6, 1PM Mountain (Noon Pacific) -- UCB-NPS conference call re: sea level/storm surge report
Date:	Thursday, April 05, 2018 5:40:33 PM

Thanks, Cat. That's helpful. I believe everyone got this as intended on the first go-round, but I appreciate you ensuring that.

Talk to you tomorrow-

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Thu, Apr 5, 2018 at 2:45 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Brendan and all -- I see this is addressed to me, but I think you meant this query for all? (Maria, Rebecca, Patrick, me)
>
> For my part, my desire is to complete the report with all authors, provide it to park managers, post it on our NPS/CCRP website for the public -- within all standard protocols of course... scientifically accurate/sound, relevant to parks, supports park managers with information to protect resources. I expect the components you flagged from my recommended edits are concerns to other co-authors, but may not be the only areas others wish to discuss, and I'm open to discussion of any concerns.
>
> Cat
>
> On Thu, Apr 5, 2018 at 10:02 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
>
>> All,
>>
>> Given our time limit tomorrow and my role as facilitator of the call, I'd like your help with detailing exactly the areas of disagreement. After many conversations and review

of email strings and the marked-up draft report, I want to propose that we focus on two specific paragraphs that seem to be the crux of impasse.

The first is the opening paragraph of the Executive Summary (page viii). The second is the last paragraph on page 1, in the Introduction, beginning with "Global sea level is rising. ..."

So we're all working from the same slate, I've attached the 4/1/18 version of the report that, based on the 3/21/18 version, shows Cat's suggested edits. I've highlighted the two paragraphs in this file.

I would appreciate hearing if the co-authors agree with my proposed focus. Also, if there are other essential points that we must discuss tomorrow, please let me know.

Brendan

Brendan J. Moynahan, Ph.D.

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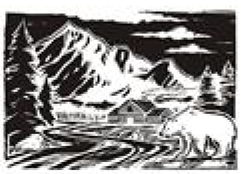

Rocky Mountains CESU

On Wed, Apr 4, 2018 at 3:48 PM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Thanks, all, for your replies.
>
> Please lock in 1pm-2pm Mountain (12-1pm Pacific) on Friday, 4/6. Let's plan for 1 hour.
>
> Our objectives are: (1) to clearly define and mutually understand the specific points of disagreement, and (2) identify language that will all us to proceed with publication with full representation of the four authors. If needed, we can also identify and describe report and project completion in the absence of consensus.
>
> I'll facilitate the call as needed and be able to speak to specific terms of CESU Agreements, etc.
>
> Thank you for bringing your best ideas, understanding, and maximum flexibility!

Best,

Brendan

Conference Line: (b) (5) [redacted]

Passcode: (b) (5) [redacted]

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Wed, Apr 4, 2018 at 3:13 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Thanks Patrick.
>
> Rebecca responded that she can be available anytime.
>
> I'm available anytime on Friday.
>
> Cat
>
> On Wed, Apr 4, 2018 at 3:00 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:
>
>> Hi Brendan,
>>
>> The best period for me on Friday is 12-2 PM MDT (11 AM - 1 PM PDT)
>>
>> Patrick
>>
>> ....
>> Patrick Gonzalez, Ph.D.
>>
>> Principal Climate Change Scientist
>> Natural Resource Stewardship and Science
>> U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
…………………………………………

On April 4, 2018, at 10:21 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

Brendan,

I am available from 8:30-10 am, 10:45 am -2 pm, and 2:45-3:30 pm on Friday.

On Wed, Apr 4, 2018 at 10:53 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:
Thanks for the quick reply, Maria.   We are in full agreement that all all authors must be on the call.   Furthermore, it's not just desirable, but essential, that this team lead resolution of the current questions.   I feel I ought to clarify that the only reason that I limited my email this morning to you, Joe, me, and Kat is that we are the four that are in the position to schedule the call. Cat can bring both Rebecca and Patrick to the call, so I wanted to keep the simple (!) scheduling question to the smallest group possible.   It's fine that you added Patrick to this string; I've likewise now added Rebecca so we all can see the full discussion.

I see that Joe just wrote that Friday is workable for him. That's great - I had misunderstood and thought that you (Maria) were away at a conference this week, not next. So I'd ask Maria and Cat to reply all with specific times for Friday.   I will make myself available any time Friday.   I'm sure you'll all forgive the added email clutter as we schedule this - I'd like to avoid any miscommunication or perception of exclusion.

Kind regards,

Brendan

Brendan J. Moynahan, Ph.D.

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On Wed, Apr 4, 2018 at 10:04 AM, Caffrey, Maria
<maria_caffrey@partner.nps.gov> wrote:
Hi Brendan,

I might have some time tomorrow or Friday, although I really must insist that all authors attend the meeting. I am also not comfortable discussing this without a representative from CU present. I consider the removal of the word "anthropogenic" and attempts to hide the human causes of climate change from my report to be very serious and so I don't want to discuss this in the lobby of the New Orleans Sheraton hotel where I'll be attending my conference next week. I'm afraid I am going to have to insist that we put this off until I get back if we can't find a time before I leave.

Many thanks,

On Wed, Apr 4, 2018 at 9:42 AM, Moynahan, Brendan
<brendan_moynahan@nps.gov> wrote:
Good morning, all-

Joe and Maria, is it possible we could find a time this week to meet by phone, rather than Monday? Maria - I understand you're in a conference - the four of us in NPS are able and would be pleased to prioritize a call this week, and it would be very helpful if you could find an opportunity to step out of your conference for perhaps an hour, probably less. Would it be possible for you two - Joe and Maria - to identify a time slot this week?

Thanks much -

Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 3:10 PM, Patrick Gonzalez NPS
<patrick_gonzalez@nps.gov> wrote:
Hi,

Thanks to Maria for including me on discussing this added stage in the process.

Best regards,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728
Date: April 3, 2018 at 1:29:48 PM PDT
To: Maria Caffrey <maria.caffrey@colorado.edu>, "Moynahan, Brendan" <brendan_moynahan@nps.gov>, Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
Cc: "Beavers, Rebecca" <rebecca_beavers@nps.gov>, Maria Caffrey <maria_caffrey@partner.nps.gov>, Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

I am sending this poll to Joe Rosse of Research Integrity who will participate for CU.

Best regards,

Denitta Ward
Denitta.Ward@colorado.edu

Assistant Vice Chancellor for Research and Director, Office of Contracts and Grants
University of Colorado Boulder

From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 2:26:27 PM
To: Maria Caffrey
Cc: Beavers, Rebecca; Denitta Ward; Maria Caffrey; Cat Hawkins Hoffman; Patrick Gonzalez NPS
Subject: Re: [EXTERNAL] Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Great - thanks, Maria.

All - please use this doodle poll to find a time on Monday. If successful in getting us all together, I'll follow with an email and a conference line. If at all possible, please complete the poll by COB tomorrow, Wednesday, 4/3.

-Brendan

Brendan J. Moynahan, Ph.D.

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Rocky Mountains CESU

On Tue, Apr 3, 2018 at 2:02 PM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:
Hi Brendan,

I'm free all day on Monday. I'm afraid I'm attending a conference the rest of the week, so I am unavailable the rest of the time. I would also like to invite Denitta Ward (assistant vice chancellor for research at the University of Colorado) who has already been assisting me in this matter. I'm also copying Patrick Gonzalez. He is third author on the report and should also be included in any conversations regarding this matter.

Many thanks,

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com
From: Moynahan, Brendan <brendan_moynahan@nps.gov>
Sent: Tuesday, April 3, 2018 1:56:42 PM
To: Beavers, Rebecca
Cc: Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject: Re: Request for Consultation with Rocky Mountains CESU re:Cooperative Agreement P14AC00728

Hi Rebecca and Maria -

I'm happy to lend a hand with this collaboration. We have so much progress and effort under our belts, and I agree that the objective is to complete the final report with all authors on board. I'm very hopeful that we can get this back on track and uncross some of these wires. Maria - would you suggest a few times over the next couple days that would work for you, so we can try to get all of us on the phone?

Thanks,

Brendan

Brendan J. Moynahan, Ph.D.

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On Tue, Apr 3, 2018 at 12:45 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Resending with Maria's updated NPS partner email.

On Tue, Apr 3, 2018 at 12:37 PM, Beavers, Rebecca <rebecca_beavers@nps.gov> wrote:
Maria:

In response to your email on April 2, it is my duty as the Agreement Technical Representative on Task Agreement P13AC01778 to consult with the Rocky Mountains CESU about the Master Cooperative Agreement P14AC00728.

Brendan:

As Research Coordinator and Science Advisor for the Rocky Mountains CESU, I request consultation with you re: the Master Cooperative Agreement P14AC00728.

Our objective is to complete a final version of the report "Sea Level and Storm Surge Projections for the National Park Service" and associated products.

Rebecca Beavers, Ph.D.| Coastal Geology & Adaptation Coordinator
National Park Service | Geologic Resources Division
303-987-6945 (Office) | 720-519-5085 (mobile) | rebecca_beavers@nps.gov

--
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--
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--
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Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
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Adaptation websites: public, NPS managers
Climate Change Response Resources

--
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Adaptation websites: public, NPS managers
Climate Change Response Resources

75 3-21-2018 document.pdf

From:	Hoffman, Cat
To:	Brendan Moynahan
Cc:	Joseph Rosse; Denitta Ward; Rebecca Beavers; Caffrey, Maria; Patrick Gonzalez
Subject:	3-21-2018 document
Date:	Friday, April 06, 2018 3:03:18 PM
Attachments:	Caffrey et al Sea Level Change Report_no pics_3.21.2018.docx

Hi Brendan -- here is the 3-21-2018 document (sans pictures, graphics).

Thank you for your work and contributions to help us with this.

Cat

--
Cat Hawkins Hoffman
National Park Service

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1201 Oakridge Drive
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cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

75 1 Attachment Caffrey et al Sea Level Change Report_no pics_5.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

Maria A. Caffrey[1], Rebecca L. Beavers[2], Patrick Gonzalez[3], Cat Hawkins-Hoffman[4]

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate’s Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside

for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or “perfect storm”). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA’s SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/-20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$\mathrm{a}e = E_0 - e_i + R$$

Where; ae is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand,

Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of

using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by

explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site[‡]	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site[‡]	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument[‡]	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*[‡]	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*[‡]	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield[‡]	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve[‡]	Fernandina Beach, FL (8720030)	N	110	0.600

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Southeast Region (continued)	Virgin Islands Coral reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial‡	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve‡	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park‡	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

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Pacific West Region	American Memorial Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park[‡]	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve[‡]	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site[‡]	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*[‡]	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park[‡]	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*[‡]	Seattle, WA (9447130)	N	109	0.540

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Pacific West Region (continued)	Point Reyes National Seashore‡	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial‡	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*‡	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*‡	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument‡	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*‡	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve‡	No data	No data	No data	No data

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument[‡]	No data	No data	No data	No data
	Glacier Bay National Park*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*[‡]	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park[‡]	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park[‡]	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park[‡]	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park[‡]	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve[‡]	Cordova, AK (9454050)	N	43	3.450

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14[‡]	0.13	0.12	0.12
		2050	0.24[‡]	0.23	0.21	0.24
		2100	0.47[‡]	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14[‡]	0.13	0.13[‡]	0.12
		2050	0.25[‡]	0.24	0.24[‡]	0.24
		2100	0.50[‡]	0.54	0.59[‡]	0.68
	Cape Hatteras National Seashore	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.26[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Cape Lookout National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park[§]	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park[§]	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve†§	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway[§]	2030	0.15[‡]	0.15	0.15[‡]	0.14
		2050	0.26[‡]	0.27	0.26[‡]	0.28
		2100	0.53[‡]	0.62	0.66[‡]	0.79
	Harpers Ferry National Historical Park*[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14[‡]	0.12	0.12[‡]	0.12
		2050	0.23[‡]	0.23	0.22[‡]	0.23
		2100	0.47[‡]	0.51	0.55[‡]	0.66
	Palo Alto Battlefield National Historical Park*[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park[§]	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

[*] Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†] Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu'uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve§	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument§	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park†§	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve†	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve†§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

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Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President’s Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

76 Next steps and timeline for NPS-UCBoulder Sea L....pdf

From:	Moynahan, Brendan
To:	Caffrey, Maria; Rebecca Beavers; Patrick Gonzalez NPS; Cat Hoffman; Joseph Rosse; Denitta Ward; Maria Caffrey; John Gross
Subject:	Next steps and timeline for NPS-UCBoulder Sea Level Project
Date:	Friday, April 06, 2018 3:52:31 PM

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to all with what they prefer, what they could accept, and what they will not accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer review manager (John Gross) as to whether the differences are resolved by any one of the three options. If so, the selected option will be incorporated into the report and the report will be submitted to the Natural Resource Publication Series manager for acceptance, formatting, and publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder (Joe Rosse) to proceed with publication and appropriately acknowledge contributions.

Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

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77 Fwd_ Next steps and timeline for NPS-UCBoulder ....pdf

From: Hoffman, Cat
To: Guy Adema; Jennifer Wyse
Subject: Fwd: Next steps and timeline for NPS-UCBoulder Sea Level Project
Date: Friday, April 06, 2018 8:17:42 PM
Attachments: Caffrey et al Sea Level Change Report_no pics_3.21.2018.docx

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Also, attached is the 3.21.2018 version (without photos and graphics, to make it smaller for transmission). This is the version that preceded our discussion among authors and with Ray. After that discussion, Maria and Patrick did not retain any points of agreement from the discussion with Ray.

Brendan is going to use this version as the starting point and create 3 different options for the Executive Summary and Introduction, working with my recommended changes and what he heard from Maria and Patrick in discussion today.

Cat

---------- Forwarded message ----------
From: **Hoffman, Cat** <cat_hawkins_hoffman@nps.gov>
Date: Fri, Apr 6, 2018 at 8:12 PM
Subject: Fwd: Next steps and timeline for NPS-UCBoulder Sea Level Project
To: Guy Adema <guy_adema@nps.gov>, Jennifer Wyse <jennifer_wyse@nps.gov>

FYI -- can discuss more next week. Heading back to Fort Collins from N.C. on Sunday; back in the office on Monday.

---------- Forwarded message ----------
From: **Moynahan, Brendan** <brendan_moynahan@nps.gov>
Date: Fri, Apr 6, 2018 at 3:52 PM
Subject: Next steps and timeline for NPS-UCBoulder Sea Level Project
To: "Caffrey, Maria" <maria.caffrey@colorado.edu>, Rebecca Beavers <Rebecca_Beavers@nps.gov>, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>, Cat Hoffman <cat_hawkins_hoffman@nps.gov>, Joseph Rosse <joseph.rosse@colorado.edu>, Denitta Ward <denitta.ward@colorado.edu>, Maria Caffrey <maria_caffrey@partner.nps.gov>, John Gross <john_gross@nps.gov>

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

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Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

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Adaptation websites: public, NPS managers
Climate Change Response Resources

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77 1 Attachment Caffrey et al Sea Level Change Report_no pics_6.pdf

National Park Service
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Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

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May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

Please cite this publication as:

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NPS 999/137852, May 2017

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Photo 1. Looking out towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside

for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

---

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or “perfect storm”). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA’s SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$\mathrm{a}e = \mathrm{E}_0 - e_\mathrm{i} + \mathrm{R}$$

Where; ae is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand,

Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of

using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by

explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and
www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site‡	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*[‡]	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument[‡]	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park[‡]	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument[‡]	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site‡	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument‡	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*‡	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*‡	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve‡	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield‡	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park‡	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve‡	Fernandina Beach, FL (8720030)	N	110	0.600

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial[‡]	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve‡	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park‡	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park[‡]	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve[‡]	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site[‡]	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*[‡]	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park[‡]	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*[‡]	Seattle, WA (9447130)	N	109	0.540

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore[‡]	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial[‡]	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*[‡]	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument[‡]	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*[‡]	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve[‡]	No data	No data	No data	No data

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument‡	No data	No data	No data	No data
	Glacier Bay National Park*‡	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*‡	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park‡	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park‡	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park‡	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park‡	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve‡	Cordova, AK (9454050)	N	43	3.450

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Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore[§]	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14[‡]	0.13	0.12	0.12
		2050	0.24[‡]	0.23	0.21	0.24
		2100	0.47[‡]	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14[‡]	0.13	0.13[‡]	0.12
		2050	0.25[‡]	0.24	0.24[‡]	0.24
		2100	0.50[‡]	0.54	0.59[‡]	0.68
	Cape Hatteras National Seashore	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.26[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Cape Lookout National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore[§]	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve[†§]	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway§	2030	0.15‡	0.15	0.15‡	0.14
		2050	0.26‡	0.27	0.26‡	0.28
		2100	0.53‡	0.62	0.66‡	0.79
	Harpers Ferry National Historical Park*§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*] Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†] Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡] No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14[‡]	0.12	0.12[‡]	0.12
		2050	0.23[‡]	0.23	0.22[‡]	0.23
		2100	0.47[‡]	0.51	0.55[‡]	0.66
	Palo Alto Battlefield National Historical Park*[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore[§]	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu'uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area[§]	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve[§]	2030	0.09[‡]	0.09	0.09	0.09
		2050	0.15[‡]	0.17	0.16	0.18
		2100	0.31[‡]	0.38	0.4	0.51

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve[§]	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument[§]	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park[†§]	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve[†]	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park[§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve[†§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President's Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

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78 Re_ Upholding scientific integrity on anthropog....pdf

From:	Hoffman, Cat
To:	Patrick Gonzalez
Cc:	Maria Caffrey; Rebecca Beavers; Brendan Moynahan; Joseph Rosse; Denitta Ward
Subject:	Re: Upholding scientific integrity on anthropogenic climate change
Date:	Friday, April 06, 2018 11:19:54 PM

Hi Patrick -- thank you for the summary of your perspective.

There is no arguing the scientific basis for the human cause of climate change and no question that the NPS and the NPS Climate Change Response Program stand on that science, and that is where I stand.

The report clearly acknowledges the human causes of climate change and contemporary sea level rise. My recommended changes are to improve the context for park managers; I'm not focused or hung up on "anthropogenic."

I regret that this has become divisive and polarized. Our responsibility is to serve the needs of national parks by providing actionable science to help resolve issues and protect park resources and I know we can do that with this report. I advocate that we abide by the process agreed to today.

On Fri, Apr 6, 2018 at 8:44 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote:

> Dear Colleagues,
>
> The central issue with the sea level rise report by Maria Caffrey is the attempted deletions by National Park Service staff of the terms "anthropogenic climate change" or "human-caused climate change" or text on how greenhouse gas emissions from human activities are the cause of climate change. I consider those attempts contrary to scientific integrity.
>
> I have appreciated the times when people have discussed this in a respectful and professional manner and have deplored the times when it has not. I wish to summarize for you what I said on the telephone call today and have said previously.
>
> The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.
>
> Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S. national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate

Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.

Because both the scientific and policy bases for anthropogenic climate change are sound, attempts to delete or alter the term or related text are for non-science and non-policy reasons. The repeated attempts over the past year to delete or alter scientific content or meaning for non-science and non-policy reasons and halting the report unless Maria accepted the deletions possess characteristics of suppressing science that would apparently violate the policy on scientific integrity of the U.S. Department of the Interior.

I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.

Thank you for your consideration,

Patrick

....
Patrick Gonzalez, Ph.D.

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Natural Resource Stewardship and Science
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....

References

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Adaptation websites: public, NPS managers
Climate Change Response Resources

79 Re_ Upholding scientific integrity on anthropog...(1).pdf

From:	Moynahan Brendan
To:	Gonzalez Patric
Cc:	Maria Caffrey; Mar a Caffrey; Rebecca Beavers; Cat Hawkins Hoffman; Joseph Rosse; Denitta Ward
Subject:	Re: Upholding scientific integrity on anthropogen c climate change
Date:	Monday Apr l 09 2018 12:25:10 PM

Hi Patrick,

Your email is received and your position understood. Given the strength of your support for what you see as the central issue - that the word 'anthropogenic' not be removed from the report - I appreciate your interest in articulating your position as a point-in-time documentation of having made that case. Given that this string serves that purpose, I want to honor your message with a full reply; please forgive the length. Of course, my involvement with this issue dates back only to last Monday.

Your email Friday evening came on the heels of our group discussion that afternoon with the four coauthors, Joe Rosse (the Associate Vice Chancellor for Scientific Integrity at UC Boulder), and me, in the role of facilitator. That afternoon's discussion is exceptionally important context for your written assertions, and I feel compelled to offer a few points here so the written record of this individual email string fully represents where we are in the process. For reference, I've pasted below the email on points of agreement and next steps that I sent as a summary of our call yesterday. There are four items I'd like to have included.

First, your position seems to be encapsulated in the first paragraph of your email - that you see the central issue with the present impasse as being the 'attempted deletion" of certain terms - with particular focus on "anthropogenic" (or "human-caused") as a descriptor for greenhouse gases and climate change. As discussed yesterday - and reiterated by Cat in her reply to you - I can verify that there is no requirement, demand, effort, or request by your coauthors or the peer review manager that those terms or the intended message be removed from the report. I also made it clear last week that the coauthors and peer review manager are the final authority on disposition of reviewer comments. The word "anthropogenic" and message of human-caused-climate change as a principal driver of seal level change, are, in fact, retained in the document; they would be retained even if all of of the 4.1.18 suggested edits were accepted. On Friday, all authors agreed on at least one additional place in the Introduction where one coauthor's suggestion to strike a sentence in which "anthropogenic" occured will be withdrawn without objection, and the word will be retained. To be clear, the characterization of attempted deletion has not, does not, and will not equate to actual deletion. The phrase will be retained in the final report, as will the original language on page 1 (Introduction) that explicitly draws a straight-line connection between anthropogenic emissions and sea level rise (as you are aware, that line was not suggested for edit or deletion).

Second, I thank you for directing our attention again to the policy and scientific underpinnings for the authors' inclusion of 'anthropogenic' and related points. The offered citations are exceptionally well-vetted and relevant. All coauthors agree that they and their scientific underpinnings are foundational to the report.

Third, you make the accusation of willful actions that substantially impact the scientific integrity of the report, although it is not clear to me to whom this accusation is directed. I myself see no indication of scientific misconduct or diminishment of scientific integrity. I understand that Joe Rosse of UC-Boulder is in agreement with me on this point. In response to your making this same point on our Friday group call, I and others noted then that none of our points of discussion touch or approach the data, analysis, findings, conclusions, or recommendations of the report. Our present discussion is focused exclusively on the specific wording of several sentences in the Executive Summary and the Introduction, along with the location (and not content) of two suggested introductory paragraphs. That these points rest squarely in the realm of editorial disagreement is all the more clear given the retention of the words and phrases of concern discussed above. Just as scientific integrity must certainly be guarded and protected - and your role in that regard is deeply valued - so must the professional reputation of the members of our group. Although I myself see nothing to support a claim of damage to scientific integrity, the charge is serious and I am not in a position to dismiss your concerns. I would, if you wish, facilitate an introduction for you to Dr. Sara Newman, our NPS Scientific Integrity Officer. As you weigh whether to submit a formal complaint with Dr. Newman, I would encourage consideration of retention of the words central to your objection, as well as the important distinction between (a) objectionable suggestions that may have pre-dated my involvement and (b) actual or realized changes that damaged scientific integrity of the report.

Finally, I wish to document our discussion Friday on the prospect for future analysis, reports, or manuscripts that Maria may wish to pursue. Led by Cat's comments, Maria was explicitly encouraged to pursue additional academic or technical works with the data products generated by the project. Maria has made a remarkable investment in this project and her work with these data and results need not end with this NPS report; I am certain that NPS and the CESU program would be deeply pleased to see these data and analyses put to further use. There are limitless opportunities for Maria to do so, in an outlet of her choosing and fully outside the scope and purview of this particular Cooperative Agreement. While the federal government has a clear right to full use, application, and distribution of the products of this project, it is certainly not an exclusive right, nor one that would stand in conflict with additional work by Maria or others.

Thank you once again for your participation in our group call yesterday, as well as our one-on-one call a bit earlier in the day - in which you delivered the very same message as presented in your email. NPS deserves only the best work of our internal and partner scientists, as well as every sincere effort to resolve editorial disagreement. The strength of your conviction to protect scientific integrity is exceptional and very much appreciated.

Best regards,

Brendan

>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

Next steps and timeline for NPS-UCBoulder Sea Level Project

Moynahan, Brendan <brendan moynahan@nps.gov> Apr 6 (3 days ago)

to Maria, Rebecca, Patrick, Cat, Joseph, Denitta, Maria, John

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to all with what they prefer, what they could accept, and what they will not accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer review manager (John Gross) as to whether the differences are resolved by any one of the three options. If so, the selected option will be incorporated into the report and the report will be submitted to the Natural Resource Publication Series manager for acceptance, formatting, and publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder (Joe Rosse) to proceed with publication and appropriately acknowledge contributions.

Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

B endan J Moynahan PhD

Resea ch Coo d nato and Science Advisor
National Pa k Se vice
R k M C R S d U

The Un ve s ty of Montana
32 Campus D ve
c/o Forestry 109
Missoula MT 59812

Office 406 243 4449
Cell 406 241 7581

On Fri, Apr 6, 2018 at 8 44 PM, Gonzalez, Patrick <patrick gonzalez@nps.gov> wrote

> Dear Colleagues,
>
> The central issue with the sea level rise report by Maria Caffrey is the attempted deletions by National Park Service staff of the terms "anthropogenic climate change" or "human-caused climate change" or text on how greenhouse gas emissions from human activities are the cause of climate change. I consider those attempts contrary to scientific integrity.
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> I have appreciated the times when people have discussed this in a respectful and professional manner and have deplored the times when it has not. I wish to summarize for you what I said on the telephone call today and have said previously.
>
> The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.
>
> Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S.

national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.

Because both the scientific and policy bases for anthropogenic climate change are sound, attempts to delete or alter the term or related text are for non-science and non-policy reasons. The repeated attempts over the past year to delete or alter scientific content or meaning for non-science and non-policy reasons and halting the report unless Maria accepted the deletions possess characteristics of suppressing science that would apparently violate the policy on scientific integrity of the U.S. Department of the Interior.

I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.

Thank you for your consideration,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

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References

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013 The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC.

80 [EXTERNAL] Fwd_ today’s call.pdf

From:	Maria Caffrey
To:	patrick_gonzalez@nps.gov
Subject:	[EXTERNAL] Fwd: today"s call
Date:	Monday, April 09, 2018 1:06:24 PM

FYI

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

Begin forwarded message:

> **From:** Joseph G Rosse <Joseph.Rosse@Colorado.EDU>
> **Date:** April 6, 2018 at 3:49:44 PM MDT
> **To:** Maria Caffrey <maria.caffrey@colorado.edu>
> **Subject: today's call**

Dear Maria,

I thought it might be helpful to provide my reactions to the conference call. First, I do not believe the issue is one of integrity of the research. There seems to be general agreement that the methods, analyses, and findings are all accurate. What initially seemed to be the issue was the framing of these results in terms of anthropogenic causes, yet in the discussion today I heard general agreement that (a) the effects are human-caused and (b) the report in toto adequately describes that. There even appeared to be near-consensus on use of the word anthropogenic to state that (I say "near" because the discussion of the Executive Summary was cut short.)

Rather, it seemed to me that the bulk of the discussion had to do with identifying the target audience, and then the appropriate way to frame the message for that audience. As an outsider, and without poring over all of the agreements, it seems unfortunate that this was not resolved at a much earlier point. To be honest, I found the argument from Brendan, Cat and Rebecca to be compelling that the report should "speak to" park managers, as well as a larger audience. I suppose I'm part of that larger audience, in a way, and I personally found the added paragraphs to be effective in creating a context. But personal impressions aside, it strikes me as analogous to the difference between submitting a paper to a specialty journal in your field versus to a more generalist journal, such as *Nature* or *Science*. Certainly there would be differences in papers submitted to each, and the editor would be within his or her bounds to stipulate what is or is not acceptable. I know have certainly experienced situations in which a journal or book editor wanted things worded, or ordered, differently. I might or might not agree, but I understand that he or she is calling the shots.

The journal/editor analogy isn't perfect because if I don't agree with the editor, I can withdraw the paper and go to a different journal. In a sense they did offer that option —Cat and Brendan both repeatedly said that you are completely free to publish the paper in different venues (in fact, I heard that you could publish for BOTH a general audience and scientific audience.)

What did surprise me a bit was Brendan's ultimatum that if you all cannot reach agreement, NPS will proceed to publish the report without specific authors. While I think that may have been a bit of a negotiating tactic, I can also see the logic. I believe

NPS really wants this to be a report authored by you (and Rebecca, Patrick and Cat), we can all appreciate that ultimately NPS needs to get some return on their $500K investment. I (and, I'm convinced, NPS) doesn't want to go to that nuclear option, but if we do end up there we can talk with Denitta about strategies. As Patrick suggested, there may be other avenues; at the very least, you might argue that you should have the same right as a Federal agency to include a disclaimer if you disagree with the report. (Since that's not explicit, I don't know if you would prevail, but I'm not an attorney.) I'm willing to hope that Brendan can craft language that will be mutually satisfactory.

Joe Rosse, Ph.D.
Associate Vice Chancellor of Research Integrity & Compliance
Research Integrity Officer
University of Colorado at Boulder (303) 735-5809
99 UCB/324 Regent Administrative Center Joseph.Rosse@colorado.edu
Boulder, CO 80309 http://colorado.edu/researchinnovation/ori

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81 [EXTERNAL] RE_ Upholding scientific integrity o....pdf

From: Joseph G Rosse
To: Moynahan Brendan; Gonzalez Patrick
Cc: Maria Caffrey; Maria Caffrey; Rebecca Beavers; Cat Hawkins Hoffman; Denitta Ward
Subject: [EXTERNAL] RE: Upholding scientif c integrity on anthropogenic climate change
Date: Tuesday Apr l 10 2018 10:26:08 AM

Hello Brendan

I would like to provide additional clarity in regards to your emails.

First you stated that the federal government owns copyright in the product of our Cooperative Agreement. This is incorrect; in fact the university owns copyright. Article II.D.6 of our Cooperative Agreement #H237009400 identifies some of the Park Service obligations including the obligation to follow 43 CFR Part 12. Under those regulations the award recipient holds copyright. See 43 CFR Section 12.936.

Secondly you stated that NPS could at your discretion "proceed to publish the report without specific authors." In fact this would violate Article X.B.1 of the Cooperative Agreement. Each party is required to "always" give due credit to the university and to recognize the rights of the individual authors. This would be the case unless you obtained agreement otherwise.

Finally I would like to clarify your comment below regarding conclusions that you believe I made regarding the scientific integrity of this process and efforts by NPS and Dr. Caffrey to come to mutual agreement with respect to the publication of her work. I suspect that this misunderstanding arose because I did opine that there have been no allegations that would trigger jurisdiction of or investigation by my office here at the university. That said I have not been asked to investigate or reach conclusions regarding whether scientific integrity is or has been threatened or compromised by NPS nor would it be appropriate for me to do so.

The university is interested in seeing publication of Maria Caffrey s report but does not want any undue pressure to publish promptly to negatively impact your collaboration and the relationship between the National Park Service and lead researcher Maria Caffrey. Thank you for the opportunity to clarify these points. I encourage you to work with Dr. Caffrey in good faith to finalize a product that meets the needs of the National Park Service and fully respects the scientific independence and quality of Dr. Caffrey s work. I appreciate your attention to these matters.

Joe Rosse Ph.D.
Associate Vice Chancellor for Research Integrity & Compliance
Professor of Management
University of Colorado at Boulder (30) 735-5809
26 UCB/331 Regent Administrative Center Joseph.Rosse@colorado.edu
Boulder CO 80309 http://colorado edu/vcr/ori

From: Moynahan Brendan <brendan_moynahan@nps.gov>
Sent: Monday April 09 2018 12 25 PM
To: Gonzalez Patrick <patrick_gonzalez@nps.gov>
Cc: Maria Caffrey <maria.caffrey@colorado.edu>; Maria Caffrey <maria_caffrey@partner.nps.gov>; Rebecca Beavers <rebecca_beavers@nps.gov>; Cat Hawkins Hoffman <cat_hawkins_hoffman@nps.gov>; Joseph G Rosse <Joseph.Rosse@Colorado.EDU>; Denitta Ward <Denitta.Ward@colorado.edu>
Subject: Re Upholding scientific integrity on anthropogenic climate change

Hi Patrick,

Your email is received and your position understood. Given the strength of your support for what you see as the central issue - that the word 'anthropogenic' not be removed from the report - I appreciate your interest in articulating your position as a point-in-time documentation of having made that case. Given that this string serves that purpose, I want to honor your message with a full reply; please forgive the length. Of course, my involvement with this issue dates back only to last Monday.

Your email Friday evening came on the heels of our group discussion that afternoon with the four coauthors, Joe Rosse (the Associate Vice Chancellor for Scientific Integrity at UC Boulder), and me, in the role of facilitator. That afternoon's discussion is exceptionally important context for your written assertions, and I feel compelled to offer a few points here so the written record of this individual email string fully represents where we are in the process. For reference, I've pasted below the email on points of agreement and next steps that I sent as a summary of our call yesterday. There are four items I'd like to have included.

First, your position seems to be encapsulated in the first paragraph of your email - that you see the central issue with the present impasse as being the 'attempted deletion" of certain terms - with particular focus on "anthropogenic" (or "human-caused") as a descriptor for greenhouse gases and climate change. As discussed yesterday - and reiterated by Cat in her reply to you - I can verify that there is no requirement, demand, effort, or request by your coauthors or the peer review manager that those terms or the intended message be removed from the report. I also made it clear last week that the coauthors and peer review manager are the final authority on disposition of reviewer comments. The word "anthropogenic" and message of human-caused-climate change as a principal driver of seal level change, are, in fact, retained in the document; they would be retained even if all of of the 4.1.18 suggested edits were accepted. On Friday, all authors agreed on at least one additional place in the Introduction where one coauthor's suggestion to strike a sentence in which "anthropogenic" occured will be withdrawn without objection, and the word will be retained. To be clear, the characterization of attempted deletion has not, does not, and will not equate to actual deletion. The phrase will be retained in the final report, as will the original language on page 1 (Introduction) that explicitly draws a straight-line connection between anthropogenic emissions and sea level rise (as you are aware, that line was not suggested for edit or deletion).

Second, I thank you for directing our attention again to the policy and scientific underpinnings for the authors' inclusion of 'anthropogenic' and related points. The offered citations are exceptionally well-vetted and relevant. All coauthors agree that they and their scientific underpinnings are foundational to the report.

Third, you make the accusation of willful actions that substantially impact the scientific integrity of the report, although it is not clear to me to whom this accusation is directed. I myself see no indication of scientific misconduct or diminishment of scientific integrity. I understand that Joe Rosse of UC-Boulder is in agreement with me on this point. In response to your making this same point on our Friday group call, I and others noted then that none of our points of discussion touch or approach the data, analysis, findings, conclusions, or recommendations of the report. Our present discussion is focused exclusively on the specific wording of several sentences in the Executive Summary and the Introduction, along with the location (and not content) of two suggested introductory paragraphs. That these points rest squarely in the realm of editorial disagreement is all the more clear given the retention of the words and phrases of concern discussed above. Just as scientific integrity must certainly be guarded and protected - and your role in that regard is deeply valued - so must the professional reputation of the members of our group. Although I myself see nothing to support a claim of damage to scientific integrity, the charge is serious and I am not in a position to dismiss your concerns. I would, if you wish, facilitate an introduction for you to Dr. Sara Newman, our NPS Scientific Integrity Officer. As you weigh whether to submit a formal complaint with Dr. Newman, I would encourage consideration of retention of the words central to your objection, as well as the important distinction between (a) objectionable suggestions that may have pre-dated my involvement and (b) actual or realized changes that damaged scientific integrity of the report.

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Best regards,

Brendan

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Next steps and timeline for NPS-UCBoulder Sea Level Project

Apr 6 (3 days ago)

Moynahan, Brendan <brendan_moynahan@nps.gov>

to Maria, Rebecca, Patrick, Cat, Joseph, Denitta, Maria, John

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

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Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

B endan J Moynahan Ph D

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Cell 406 241 7581

On Fri, Apr 6, 2018 at 8 44 PM, Gonzalez, Patrick <patrick gonzalez@nps.gov> wrote

> Dear Colleagues,
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> The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.
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> Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S. national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.
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> I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.
>
> Thank you for your consideration,
>
> Patrick
>
> ....
> Patrick Gonzalez, Ph.D.
>
> Principal Climate Change Scientist
> Natural Resource Stewardship and Science
> U.S. National Park Service
>
> Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
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>
> U.S. Global Change Research Program (USGCRP). 2017. Climate Science

Special Report Fourth National Climate Assessment, Volume I
[Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart,
and T.K. Maycock (eds.)]. U.S. Global Change Research Program,
Washington, DC.

82 Re_ [EXTERNAL] RE_ Upholding scientific integri....pdf

From:	Moynahan Brendan
To:	Joseph G Rosse
Cc:	Gonzalez Patrick; Maria Caffrey; Maria Caffrey; Rebecca Beavers; Cat Hawk ns Hoffman; Denitta Ward
Subject:	Re: [EXTERNAL] RE: Upho ding sc entific integr ty on anthropogenic climate change
Date:	Tuesday April 10 2018 11:11:31 AM
Attachments:	C1 - CESU Master Agreement pdf

Thank you Joe.

I am in full agreement on our shared interest to work through the impasse and to assist the coauthors with reaching consensus on publication as planned.

I wish to make it clear that I have not spoken to copyright at all – I don t believe I ve ever used that term. However I have felt it important to respond to several instances in writing and on the phone of Maria s claim of the report and data being her individual intellectual property. I have consulted on this specific issue with our Washington Office lead for Financial Assistance and an analyst with our Washington Office of Financial Assistance Policy. Both concur with my interpretation of that Article X.B.1 that you cite. While I intentionally did not suggest the federal government retains copyright I did speak to a specific non-exclusive right to use apply and distribute data products (including publication under the allowances and steps in Article X.B.1). Intellectual property rights were not specifically addressed in the older Master Agreement under which this Task Agreement was awarded but development of the issue has since led to standard language that applies to all Cooperative Agreements. Specifically our present Master Agreement with UCBoulder (executed just a few months ago; attached) specifically addresses "Rights in Data" in Section XII.B.3 (pasted below for ease of reference). You are correct that the federal government's rights in data products produced under cooperative agreement does not equate to copyright; however I understand that those rights are broad and quite well established.

To reiterate my earlier email (on our process for the next couple weeks) if agreement between the coauthors is not reached I would be happy to work with you (or other appropriate representative of the University) to ensure that UCBoulder contributions are thoroughly and appropriately acknowledged – in the spirit of not only that formal language but also of our broader positive relationship with UCBoulder.

The present discussion is important but somewhat regrettable in that I remain quite optimistic that the coauthors can resolve the stated and documented disagreements. In my role as facilitator and science advisor (and not a lawyer) I am focused on the next steps on which we reached consensus on Friday. By COB tomorrow I will send the three versions of the Executive Summary and Introduction as I ve been asked to do by all four coauthors.

Thank you for your email - you are certainly right that clarity in terms and understanding the decision space available is critically important.

Kind regards,

Brendan

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3. Rights in Data. The Cooperator must grant the United States of America a royalty-free, non-exclusive and irrevocable license to publish, reproduce and use, and dispose of in any manner and for any purpose without limitation, and to authorize or ratify publication, reproduction or use by others, of all copyrightable material first produced or composed under this Agreement by the Cooperator, its employees or any individual or concern specifically employed or assigned to originate and prepare such material.
>>>>>>>>>>>>>>>>>>>>>>>>

B endan J Moynahan Ph D

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Joe Rosse Ph.D.

Associate Vice Chancellor for Research Integrity & Compliance

Professor of Management

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From: Moynahan Brendan <brendan moynahan@nps.gov>
Sent: Monday April 09 2018 12 25 PM
To: Gonzalez Patrick <patrick gonzalez@nps.gov>
Cc: Maria Caffrey <maria.caffrey@colorado.edu>; Maria Caffrey <maria caffrey@partner.nps.gov>; Rebecca Beavers <rebecca beavers@nps.gov>; Cat Hawkins Hoffman <cat hawkins hoffman@nps.gov>; Joseph G Rosse <Joseph.Rosse@Colorado.EDU>; Denitta Ward <Denitta Ward@colorado edu>
Subject: Re Upholding scientific integrity on anthropogenic climate change

Hi Patrick,

Your email is received and your position understood. Given the strength of your support for what you see as the central issue - that the word 'anthropogenic' not be removed from the report - I appreciate your interest in articulating your position as a point-in-time documentation of having made that case. Given that this string serves that purpose, I want to honor your message with a full reply; please forgive the length. Of course, my involvement with this issue dates back only to last Monday.

Your email Friday evening came on the heels of our group discussion that afternoon with the four coauthors, Joe Rosse (the Associate Vice Chancellor for Scientific Integrity at UC Boulder), and me, in the role of facilitator. That afternoon's discussion is exceptionally important context for your written assertions, and I feel compelled to offer a few points here so the written record of this individual email string fully represents where we are in the process. For reference, I've pasted below the email on points of agreement and next steps that I sent as a summary of our call yesterday. There are four items I'd like to have included.

First, your position seems to be encapsulated in the first paragraph of your email - that you see the central issue with the present impasse as being the 'attempted deletion" of certain terms - with particular focus on "anthropogenic" (or "human-caused") as a descriptor for greenhouse gases and climate change. As discussed yesterday - and reiterated by Cat in her reply to you - I can verify that there is no requirement, demand, effort, or request by your coauthors or the peer review manager that those terms or the intended message be removed from the report. I also made it clear last week that the coauthors and peer review manager are the final authority on disposition of reviewer comments. The word "anthropogenic" and message of human-caused-climate change as a principal driver of seal level change, are, in fact, retained in the document; they would be retained even if all of of the 4.1.18 suggested edits were accepted. On Friday, all authors agreed on at least one additional place in the Introduction where one coauthor's suggestion to strike a sentence in which "anthropogenic" occured will be withdrawn without objection, and the word will be retained. To be clear, the characterization of attempted deletion has not, does not, and will not equate to actual deletion. The phrase will be retained in the final report, as will the original language on page 1 (Introduction) that explicitly draws a straight-line connection between anthropogenic emissions and sea level rise (as you are aware, that line was not suggested for edit or deletion).

Second, I thank you for directing our attention again to the policy and scientific underpinnings for the authors' inclusion of 'anthropogenic' and related points. The offered citations are exceptionally well-vetted and relevant. All coauthors agree that they and their scientific underpinnings are foundational to the report.

Third, you make the accusation of willful actions that substantially impact the scientific integrity of the report, although it is not clear to me to whom this accusation is directed. I myself see no indication of scientific misconduct or diminishment of scientific integrity. I understand that Joe Rosse of UC-Boulder is in agreement with me on this point. In response to your making this same point on our Friday group call, I and others noted then that none of our points of discussion touch or approach the data, analysis, findings, conclusions, or recommendations of the report. Our present discussion is focused exclusively on the specific wording of several sentences in the Executive Summary and the Introduction, along with the location (and not content) of two suggested introductory paragraphs. That these points rest squarely in the realm of editorial disagreement is all the more clear given the retention of the words and phrases of concern discussed above. Just as scientific integrity must certainly be guarded and protected - and your role in that regard is deeply valued - so must the professional reputation of the members of our group. Although I myself see nothing to support a claim of damage to scientific integrity, the charge is serious and I am not in a position to dismiss your concerns. I would, if you wish, facilitate an introduction for you to Dr. Sara Newman, our NPS Scientific Integrity Officer. As you weigh whether to submit a formal complaint with Dr. Newman, I would encourage consideration of retention of the words central to your objection, as well as the important distinction between (a) objectionable suggestions that may have pre-dated my involvement and (b) actual or realized changes that damaged scientific integrity of the report.

Finally, I wish to document our discussion Friday on the prospect for future analysis, reports, or manuscripts that Maria may wish to pursue. Led by Cat's comments, Maria was explicitly encouraged to pursue additional academic or technical works with the data products generated by the project. Maria has made a remarkable investment in this project and her work with these data and results need not end with this NPS report; I am certain that NPS and the CESU program would be deeply pleased to see these data and analyses put to further use. There are limitless opportunities for Maria to do so, in an outlet of her choosing and fully outside the scope and purview of this particular Cooperative Agreement. While the federal government has a clear right to full use, application, and distribution of the products of this project, it is certainly not an exclusive right, nor one that would stand in conflict with additional work by Maria or others.

Thank you once again for your participation in our group call yesterday, as well as our one-on-one call a bit earlier in the day - in which you delivered the very same message as presented in your email. NPS deserves only the best work of our internal and partner scientists, as well as every sincere effort to resolve editorial disagreement. The strength of your conviction to protect scientific integrity is exceptional and very much appreciated.

Best regards,

Brendan

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Next steps and timeline for NPS-UCBoulder Sea Level Project

Moynahan, Brendan <brendan_moynahan@nps.gov>

Apr 6 (3 days ago)

to Maria, Rebecca, Patrick, Cat, Joseph, Denitta, Maria, John

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to all with what they prefer, what they could accept, and what they will not accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer review manager (John Gross) as to whether the differences are resolved by any one of the three options. If so, the selected option will be incorporated into the report and the report will be submitted to the Natural Resource Publication Series manager for acceptance, formatting, and publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder (Joe Rosse) to proceed with publication and appropriately acknowledge contributions.

Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

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On Fri, Apr 6, 2018 at 8 44 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote

Dear Colleagues,

The central issue with the sea level rise report by Maria Caffrey is the attempted deletions by National Park Service staff of the terms "anthropogenic climate change" or "human-caused climate change" or text on how greenhouse gas emissions from human activities are the cause of climate change. I consider those attempts contrary to scientific integrity.

I have appreciated the times when people have discussed this in a respectful and professional manner and have deplored the times when it has not. I wish to summarize for you what I said on the telephone call today and have said previously.

The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.

Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S. national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.

Because both the scientific and policy bases for anthropogenic climate change are sound, attempts to delete or alter the term or related text are for non-science and non-policy reasons. The repeated attempts over the past year to delete or alter scientific content or meaning for non-science and non-policy reasons and halting the report unless Maria accepted the deletions possess characteristics of suppressing science that would apparently violate the policy on scientific integrity of the U.S. Department of the Interior.

I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.

Thank you for your consideration,

Patrick

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Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

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References

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013 The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program,

Washington, DC.

82 1 Attachment C1 - CESU Master Agreement.pdf

Cooperative Ecosystem Studies Unit
Cooperative Agreement No. P17AC01142
Between
THE UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
AND
THE REGENTS OF THE UNIVERSITY OF COLORADO (THE COOPERATOR)
DUNS No: 007431505
3100 Marine Street, Room 467
Boulder, CO 80309-0572

CFDA: 15.945 Cooperative Research and Training Programs Resources of the National Park System
Project Title: **Provide research, technical assistance and education for resource management and research**
Federal Funds Obligated by this action: N/A
Total Amount of Award: $0
Period of Performance: July 21, 2017 – July 21, 2022

This Agreement is made and entered into between the United States Department of the Interior, National Park Service (NPS) and the Regents of the University of Colorado (the Cooperator).

ARTICLE I – BACKGROUND AND OBJECTIVES

The partnership proposed by the Cooperator was selected due to merit review evaluations from the 2017 Notice of Funding Opportunity P17AS00037. The Cooperator demonstrated expertise in disciplines and subject areas of relevance to cooperative research and training. The Cooperator met the program interests of NPS with expertise, facilities, experience, diversity of programs, and history of collaborative research projects.

The Cooperator helps the NPS-CESU to meet its objectives to:

- Provide research, technical assistance and education to NPS for land management, and research;
- Develop a program of research, technical assistance and education that involves the biological, physical, social, and cultural sciences needed to address resources issues and interdisciplinary problem-solving at multiple scales and in an ecosystem context at the local, regional, and national level; and
- Place special emphasis on the working collaboration among NPS, universities, and their related partner institutions.

Title: Provide research, technical assistance and education for resource management and research

The CESU network seeks to provide scientifically-based information on the nature and status of selected biological, physical, and cultural resources occurring within the parks in a form that increases its utility for making management decisions, conducting scientific research, educating the public, developing effective monitoring programs, and developing management strategies for resource protection.

Studying the resources present in NPS parks benefits the Cooperator's goal of advancing knowledge through scientific discovery, integration, application, and teaching, which lead toward a holistic understanding of our environmental and natural resources.

The Cooperator is a public research university, sharing research, educational, and technological strengths with other institutions. Through inter-institutional collaboration, combined with the unique contributions of each constituent institution, the Cooperator strives to contribute substantially to the cultural, economic, environmental, scientific, social and technological advancement of the nation.

The NPS expects there to be substantial involvement between itself and the Cooperator in carrying out the activities contemplated in this Agreement.

The primary purpose of this study is not the acquisition of property or services for the direct benefit or use by the Federal Government, but rather to accomplish a public purpose of support or stimulation authorized the Legislative Authorities in ARTICLE II.

This agreement fulfills a Public Purpose of support and economic stimulation by:

- Projects will engage recipients, partners, communities, and/or visitors in shared environmental stewardship.
- Projects will promote greater public and private participation in historic preservation programs and activities. The project builds resource stewardship ethics in its participants.
- The information, products and/or services identified or developed by projects will be shared through a variety of strategies to increase public awareness, knowledge and support for historic preservation and stewardship of the nation's cultural and historical heritage.
- Projects will support the Government's objective to provide opportunities for youth to learn about the environment by spending time working on projects in National Parks. The NPS receives the indirect benefit of completing conservation projects.
- Projects will motivate youth participants to become involved in the natural, cultural and /or historical resource protection of their communities and beyond.
- Students gain "real world" or hands-on experience outside of the classroom of natural, cultural and/or historical resource projects.
- The scientific community and/or researchers external to NPS gains by new knowledge provided through research and related results dissemination of natural, cultural and/or historical resource information.
- Projects assist in the creation, promotion, facilitation, and/or improvement of the public's understanding of natural, cultural, historic, recreational and other aspects of areas such as ecological conservation areas, and state and local parks.

For performance under this cooperative agreement, the regulations set forth in 2 CFR, Part 200, supersedes OMB Circulars A–21 (2 CFR 220), A–87 (2 CFR 225), A–110, and A–122 (2 CFR

230); Circulars A–89, A–102, and A–133; and the guidance in Circular A–50 on Single Audit Act follow–up apply. The Cooperator shall adhere to 2 CFR, Part 200 in its entirety in addition to any terms and conditions of the master agreement not superseded by 2 CFR 200, as well as the terms and conditions set forth in this agreement. In the event of a conflict between the original terms of the master agreement and 2 CFR, Part 200, relating to this task agreement, 2 CFR, Part 200 shall take precedence.

ARTICLE II - AUTHORITY

NPS enters into this Agreement pursuant to the following authorities, to assist in providing research, technical assistance, and education.

a. 54 U.S.C. § 100703 - Agreements with Educational Institutions to Study National Park System Resources and Non-Park Service Resources: The NPS is authorized and directed to enter into cooperative agreements with colleges and universities in partnership with other Federal and State agencies, to establish cooperative study units to conduct multi-disciplinary research and develop integrated information products on the resources of the National Park System or the larger region of which parks are a part.

b. 54 U.S.C. § 101702(b) – Cooperative Research and Training Programs:
The NPS is authorized to enter into cooperative agreements with public or private educational institutions, States, and their political subdivisions, for the purpose of developing adequate, coordinated, cooperative research and training activities concerning the resources of the NPS.

c. 54 U.S.C. § 101702(a) – Agreements for the Transfer of Appropriated Funds to Carry out NPS Programs: The NPS is authorized to enter into cooperative agreements that involve the transfer of National Park Service appropriated funds to State, local and tribal governments, other public entities, educational institutions, and private nonprofit organizations for the public purpose of carrying out National Park Service programs.

d. 54 U.S.C. § 101702(d)(1) – Cooperative Agreements for National Park Natural Resource Protection: The NPS is authorized to enter into cooperative agreements with State, local, or tribal governments, other Federal agencies, other public entities, educational institutions, private nonprofit organizations, or participating private landowners for the purpose of protecting natural resources of units of the National Park System through collaborative efforts on land inside and outside of National Park System units.

e. 54 U.S.C. § 200103(g)(1) - Outdoor Recreation of Programs, Research and Education: The NPS is authorized to sponsor, engage in, and assist in research relating to outdoor recreation, directly or by contract or cooperative agreements, and make payments for such purposes without regard to the limitations of section 3324(a) and (b) of title 31 concerning advances of funds when he considers such action in the public interest, (2) undertake studies and assemble information concerning outdoor recreation, directly or by contract or cooperative agreement, and disseminate such information without regard to the provisions of section 3204 of title 39, and (3) cooperate with educational institutions and others in order to assist in establishing education programs and activities and to encourage public use and benefits from outdoor recreation.

ARTICLE III – STATEMENT OF WORK

A. The Cooperator agrees to:

1. Conduct, a program of research, technical assistance, and education related to the CESU objectives and allow and encourage faculty to participate in the program as appropriate;
2. Promote the application of biological, physical, and cultural information to the conservation, restoration, and management of NPS's resources;
3. Encourage students and employees to participate in the activities of the CESU;
4. Allow and encourage faculty to engage in NPS research, technical assistance and education activities related to the CESU objectives, as appropriate;
5. Encourage its students to participate in the activities of the CESU;
6. Attend the CESU Manager's Committee meeting, at least annually, to provide advice and guidance, review of the annual work and multi-year strategic plans, and assist in evaluating the CESU;
7. Obtain research collecting permits through the appropriate NPS administrative unit for work accomplished through this Agreement;
8. Participate in symposiums, conferences, or workshops to promote the understanding and use of biodiversity information on NPS parks;
9. Support professional development for youth and visitors, whenever possible, with projects under this Agreement;
10. Provide to the NPS expert consultation in support of environmental policy and management of natural and cultural resources;
11. Assist the NPS in outreach to national and international audiences with information about the resources that are supported by national parks;
12. Provide the NPS with reports, manuscripts, popular-press articles, monographs, and research data generated by personnel conducting projects under this Agreement.

B. NPS agrees to:

1. Provide administrative assistance, as appropriate, necessary to execute this Agreement and subsequent modifications;
2. Participate in project activity research, technical assistance and education related to the CESU objectives to the extent allowed by NPS authorizing legislation;
3. Provide opportunities for research on national park lands or using federal facilities in cooperation with NPS, as appropriate, and according to all applicable laws, regulations, and policies;

4. Provide project funds and/or collaboration to support specific research, technical assistance and education projects, as appropriate;
5. Make available managers to serve on the CESU Manager's Committee;
6. Comply with the Cooperator's rules, regulations, and policies regarding professional conduct, health, safety, use of services and facilities, use of animals, recombinant DNA, infectious agents or radioactive substances, as well as other policies generally applied to the Cooperator's personnel;
7. Ensure its employees follow the Code of Ethics for Government Service (Pub. L. 96-303) and Standards of Ethical Conduct (5 CFR Part 2635);
8. Allow NPS employees to participate in the activities of the Cooperator, including serving on graduate committees and teaching courses, as appropriate, and as specifically determined in modifications to the Agreement; and
9. Provide substantial guidance and consultation to the Cooperator in connection with projects, as appropriate.
10. Familiarize the Cooperator with parks and park resources.
11. Provide the Cooperator with timely information on changes to park boundaries or land ownership.
12. Provide access to and use of the natural and cultural resources of units of the National Park System for appropriate research, monitoring, and educational activities of the Cooperator, except for those activities which may conflict with the values and purposes of the area as stated in Federal law or policy.

C. The Cooperator and NPS jointly agree to:

1. Maintain the CESU closely following the mission and goals of the CESU Network as described in the *CESU Network Strategic Plan*, adapting key elements to local and regional needs, as appropriate;
2. Maintain a CESU role and mission statement;
3. Operate under a multi-year strategic plan;
4. Issue individual funding documents, in accordance with NPS procedures, developed cooperatively between the NPS and Cooperator that individually include a specific "scope of work" statement and a brief explanation of the following:
    a. the proposed work;
    b. the project contribution to the objectives of the CESU;
    c. the methodology of the project;
    d. the substantial involvement of each party;
    e. the project budget and schedule;
    f. the specific project outputs or products.

    Unless otherwise specified, the terms and conditions of this Cooperative Agreement will apply to Task Agreements written under it.
5. Provide data on CESU projects to the CESU Network National Office and/or host institution in accordance with CESU Network Council guidelines as posted on the CESU Network National Office website (www.cesu.org);
6. Engage in collaborative activities consistent with federal scientific and scholarly integrity directives and policies (e.g., Presidential and OSTP Scientific Integrity Memoranda, as appropriate. The Code of Scientific and Scholarly Conduct for

the Department of the Interior can be found at: https://www.doi.gov/sites/doi.gov/files/migrated/scientificintegrity/upload/DOI-Code-of-Scientific-and-Scholarly-Conduct-Poster-December-2014.pdf

ARTICLE IV – TERM OF AGREEMENT

A. The Agreement will become effective July 21, 2017 and extend through July 21, 2022, unless terminated earlier per Article XI. The period from the Effective Date to the Expiration Date is the period of performance for the Agreement (Agreement Term).

B. For the purposes of this Agreement, amendments are changes (edits, deletions, or additions) to the Agreement that do not involve the transfer of funds. Amendments may be proposed by NPS or the Cooperator. Amendments shall be in writing, signed, and agreed to by NPS and the Cooperator.

C. The expiration of this Agreement will not affect the validity or duration of projects which have been initiated under this Agreement prior to such expiration.

ARTICLE V – KEY OFFICIALS

A. Key officials are essential to ensure maximum coordination and communications between the parties and the work being performed. They are:

1. **For the NPS:**

a. **Financial Assistance Awarding Officer (AO)**
Katie Gaertner
Grants Management Specialist
National Park Service
Intermountain Region
12795 W. Alameda Parkway
Lakewood, CO 80228
Phone: (303) 969-2909
Email: katie_gaertner@nps.gov

b. **Agreement Technical Representative (ATR)**
Brendan Moynahan
Research Coordinator
National Park Service
32 Campus Drive, c/o Forestry 109
NPS-CESU
Missoula, MT 59812
Phone: (406) 243-4449
Email: Brendan_moynahan@nps.gov

2. **For the Cooperator:**

a. **Principal Investigator**
Timothy Seastedt
Professor of Ecology and Evolutionary Biology
Fellow INSTAAR
Institute of Arctic and Alpine Research
University of Colorado
4001 Discovery Drive
Boulder, CO 80303
Phone: (303) 492-3302
Email: timothy.seastedt@coloardo.edu

b. **Authorizing Official**
Gary Henry
Director of Contracts
Office of Contracts and Grants, 572 UCB
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3100 Marine Street, Room 467
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Phone: (303) 735-8905
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Authorized Representative
Michael J. Spires
Principal Proposal Analyst
Office of Contracts and Grants, 572 UCB
3100 Marine Street, Room 467
Boulder, CO 80309-0572
Phone: (303) 492-6646
Email: michael.spires@coloardo.edu

B. **Communications.** Cooperator shall address any communication regarding this Agreement to the ATR with a copy to the AO. Communications that relate solely to technical matters may be sent only to the ATR.

C. **Changes in Key Officials.** Neither the NPS nor Cooperator may make any permanent change in a key official without written notice to the other party reasonably in advance of the proposed change. The notice will include a justification with sufficient detail to permit evaluation of the impact of such a change on the scope of work specified within this Agreement. Any permanent change in key officials will be made only by modification to this Agreement.

ARTICLE VI – AWARD AND PAYMENT

A. The commitment of funds in furtherance of this Agreement will be authorized by individual Task Agreements issued against this Cooperative Agreement identifying each project or group of projects, the amount of financial assistance and any other special terms or conditions applicable to the project tasks.

B. A 17.5% indirect cost rate will be paid on work covered by the Agreement and all its modifications or task agreements. Non-CESU sub-recipients may be asked to follow the rate, but may not be required.

C. Cooperator shall request payment in accordance with the following:

1. **Method of Payment.** Payment will be made by advance and/or reimbursement through the Department of Treasury's Automated Standard Application for Payments (ASAP) system.

2. **Requesting Advances.** Requests for advances must be submitted via the ASAP system. Requests may be submitted as frequently as required to meet the needs of the Financial Assistance (FA) Cooperator to disburse funds for the Federal share of project costs. If feasible, each request should be timed so that payment is received on the same day that the funds are dispersed for direct project costs and/or the proportionate share of any allowable indirect costs. If same-day transfers are not feasible, advance payments must be as close to actual disbursements as administratively feasible.

3. **Requesting Reimbursement.** Requests for reimbursements must be submitted via the ASAP system. Requests for reimbursement should coincide with normal billing patterns. Each request must be limited to the amount of disbursements made for the Federal share of direct project costs and the proportionate share of allowable indirect costs incurred during that billing period.

4. **Adjusting Payment Requests for Available Cash.** Funds that are available from repayments to, and interest earned on, a revolving fund, program income, rebates, refunds, contract settlements, audit recoveries, credits, discounts, and interest earned on any of those funds must be disbursed before requesting additional cash payments.

5. **Bank Accounts.** All payments are made through electronic funds transfer to the bank account identified in the ASAP system by the FA Cooperator.

6. **Supporting Documents and Agency Approval of Payments.** Additional supporting documentation and prior NPS approval of payments may be required when/if a FA Cooperator is determined to be "high risk" or has performance issues. If prior Agency payment approval is in effect for an award, the ASAP system will notify the FA Cooperator when they submit a request for payment. The Cooperator must then notify the NPS AO that a payment request has been submitted. The NPS AO may request additional information from the Cooperator

to support the payment request prior to approving the release of funds, as deemed necessary. The FA Cooperator is required to comply with these requests. Supporting documents may include invoices, copies of contracts, vendor quotes, and other expenditure explanations that justify the reimbursement requests.

D. **System for Award Management (SAM)**. In order to receive a financial assistance award and to ensure proper payment, it is required that Cooperator maintain their registration with SAM, accessed at http://www.sam.gov. Failure to maintain registration can impact obligations and payments under this Agreement and/or any other financial assistance or procurements documents the Cooperator may have with the Federal government.

E. **Anti-Deficiency Act.** Any award beyond the current fiscal year is subject to availability of funds; funds may be provided in subsequent fiscal years if project work is satisfactory and funding is available.

F. **Allowable and Eligible Costs.** Expenses charged against awards under the Agreement may not be incurred prior to the beginning of the Agreement, and may be incurred only as necessary to carry out the approved objectives, scope of work and budget with prior approval from the NPS AO. The Cooperator shall not incur costs or obligate funds for any purpose pertaining to the operation of the project, program, or activities beyond the expiration date stipulated in the award.

G. **Travel Costs.** For travel costs charged against awards under the Agreement, costs incurred must be considered reasonable and otherwise allowable only to the extent such costs do not exceed charges normally allowed by the Cooperator in its regular operations as the result of the Cooperator's written travel policy. If the Cooperator does not have written travel policies established, the Cooperator and its contractors shall follow the travel policies in the Federal Travel Regulation, and may not be reimbursed for travel costs that exceed the standard rates. All charges for travel must conform to the applicable cost principles.

H. **Indirect Costs.** Indirect costs will not be allowable charges against the award unless specifically included as a line item in the approved budget incorporated into the award.

I. **Cooperator Cost Share or Match.** Any non-Federal share, whether in cash or in-kind, is expected to be paid out at the same general rate as the Federal share. Exceptions to this requirement may be granted by the AO based on sufficient documentation demonstrating previously determined plans for or later commitment of cash or in-kind contributions. In any case, the Cooperator must meet their cost share commitment over the life of the award.

J. Nothing herein shall be construed as obligating the NPS to expend, or as involving the NPS in any contract or other obligation for the future payment of money, in excess of appropriations authorized by law and administratively allocated for specific work.

ARTICLE VII – PRIOR APPROVAL

The Cooperator shall obtain prior approval for budget and program revisions, in accordance with 2 CFR 200.308.

ARTICLE VIII – INSURANCE AND LIABILITY

A. **Insurance.** The Cooperator shall be required to (1) obtain liability insurance or (2) demonstrate present financial resources in an amount determined sufficient by NPS to cover claims brought by third parties for death, bodily injury, property damage, or other loss resulting from one or more identified activities carried out in connection with this agreement.

B. **Indemnification.** The Cooperator hereby agrees to be responsible for the negligent acts and omissions of the Cooperator, its officers, employees, or agents. This obligation shall survive the termination of this Agreement but not violate any of the immunities, rights, benefits or other protections provided the Cooperator under the provisions of the Colorado Governmental Immunity Act, C.R.S. §§24-10-101 et seq., as amended (“Act”).

The Cooperator hereby agrees to maintain general, automobile, workers compensation and employee liability insurance at its own expense from a responsible company or companies with a general aggregate limitation of *one million dollars ($1,000,000)* for any number of claims arising from any one incident, in accordance with the limits of the “Act.”

The Cooperator hereby agrees to compensate the United States for damage to the lands or other property of the United States caused by the Cooperator’s negligent acts as allowed by the “Act.”

The Cooperator hereby agrees to provide workers' compensation protection to the Cooperator, its officers, employees, and agents.

The Cooperator hereby agrees to cooperate with NPS in the investigation and defense of any claims that may be filed with NPS arising out of the activities of the Cooperator, its agents, and employees.

In the event of damage to or destruction of the buildings and facilities assigned for the use of the Cooperator in whole or in part by any cause whatsoever, nothing herein contained shall be deemed to require NPS to replace or repair the buildings or facilities. If NPS determines in writing, after consultation with the Cooperator that damage to the buildings or portions thereof renders such buildings unsuitable for continued use by the Cooperator, NPS shall assume sole control over such buildings or portions thereof. If the buildings or facilities rendered unsuitable for use are essential for conducting operations authorized under this Agreement, then failure to substitute and assign other facilities acceptable to the Cooperator will constitute termination of this Agreement by NPS.

D. **Flow-down**: For the purposes of this Article VIII, "Cooperator" includes such sub-Cooperators, contractors, or subcontractors as, in the judgment of the Cooperator and subject to the NPS's determination of sufficiency, have sufficient resources and/or maintain adequate and appropriate insurance to achieve the purposes of this Article VIII.

ARTICLE IX – REPORTS AND/OR DELIVERABLES

A. Specific projects, tasks or activities for which funds are advanced will be tracked and reported by **annual** submission of a SF-425 Federal Financial Report (FFR) and narrative Performance Report. A final SF-425 and Performance Report shall be submitted at the completion of the Agreement. The following reporting period end dates shall be used for interim reports: 12/31. For final the SF-425 and Performance Report, the reporting period end date shall be the end date of the agreement. Interim reports shall be submitted no later than 30 days after the end of each reporting period. Annual and final reports shall be submitted no later than 90 days after the end period date. All reports shall be submitted via email to the NPS AO at FA-IMR@nps.gov with a copy to the NPS Agreements Technical Representative via email.

B. The Secretary of the Interior and the Comptroller General of the United States, or their duly authorized representatives, will have access, for the purpose of financial or programmatic review and examination, to any books, documents, papers, and records that are pertinent to the Agreement at all reasonable times during the period of retention in accordance with 2 CFR 200.333.

C. An electronic version of the final report and separate abstract suitable for public distribution will be submitted by the Recipient to the ATR. The ATR will send the final report electronically to NPS's Technical Information Center and carbon-copy the CESU Research Coordinator. Please send the Technical Information Center (TIC) one hard copy and one digital copy of the final report and abstract. Mail the hard copy to: NPS Denver Service Center- Technical Information Center (TIC) 12795 West Alameda Parkway, Lakewood, Colorado 80228 and email the digital version to tic-requests@nps.gov and cc the CESU Research Coordinator.

ARTICLE X – PROPERTY UTILIZATION

All equipment and facilities furnished by NPS will be on a loan basis. Equipment and facilities will be returned in the same condition received except for normal wear and tear in project use. Property management standards set forth in 2 CFR 200.310 through 200.316 apply to this Agreement.

ARTICLE XI – MODIFICATION, REMEDIES FOR NONCOMPLIANCE TERMINATION

A. This Agreement may be modified only by a written instrument executed by the parties. Modifications will be in writing and approved by the NPS AO and the authorized representative of Cooperator.

B. Additional conditions may be imposed by NPS if it is determined that the Cooperator is non-compliant to the terms and conditions of this agreement. Remedies for Noncompliance can be found in 2 CFR 200.338.

C. This Agreement may be terminated consistent with applicable termination provisions for Agreements found in 2 CFR 200.339 through 200.342.

ARTICLE XII – GENERAL AND SPECIAL PROVISIONS

A. **General Provisions**

1. **OMB Circulars and Other Regulations.** The following Federal regulations are incorporated by reference into this Agreement (full text can be found at http://www.ecfr.gov:

   a. **Administrative Requirements:** *2 CFR, Part 200 – Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards, in its entirety;*

   b. **Determination of Allowable Costs**: *2 CFR, Part 200 – Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards, Subpart E;* and

   c. **Audit Requirements**: *2 CFR, Part 200 – Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards, Subpart F.*

   d. **Code of Federal Regulations/Regulatory Requirements:** *2 CFR Part 182 & 1401*, “Government-wide Requirements for a Drug-Free Workplace”;

   2 CFR 180 & 1400, “Non-Procurement Debarment and Suspension”, previously located at 43 CFR Part 42, “Governmentwide Debarment and Suspension (NonProcurement)”;

   43 CFR 18, “New Restrictions on Lobbying”;

   2 CFR Part 175, “Trafficking Victims Protection Act of 2000”;

   FAR Clause 52.203-12, Paragraphs (a) and (b), Limitation on Payments to Influence Certain Federal Transactions;

   2 CFR Part 25, System for Award Management (www.SAM.gov) and Data Universal Numbering System (DUNS); and

   2 CFR Part 170, “Reporting Subawards and Executive Compensation”.

2. **Non-Discrimination.** All activities pursuant to this Agreement shall be in compliance with the requirements of Executive Order 11246, as amended; Title VI of the Civil Rights Act of 1964, as amended, (78 Stat. 252; 42 U.S.C. §§2000d et seq.); Title V, Section 504 of the Rehabilitation Act of 1973, as amended, (87 Stat. 394; 29 U.S.C. §794); the Age Discrimination Act of 1975 (89 Stat. 728; 42

U.S.C. §§6101 et seq.); and with all other federal laws and regulations prohibiting discrimination on grounds of race, color, sexual orientation, national origin, disabilities, religion, age, or sex.

3. **Lobbying Prohibition.** 18 U.S.C. §1913, Lobbying with Appropriated Moneys, as amended by Public Law 107-273, Nov. 2, 2002 - No part of the money appropriated by any enactment of Congress shall, in the absence of express authorization by Congress, be used directly or indirectly to pay for any personal service, advertisement, telegram, telephone, letter, printed or written matter, or other device, intended or designed to influence in any manner a Member of Congress, a jurisdiction, or an official of any government, to favor, adopt, or oppose, by vote or otherwise, any legislation, law, ratification, policy, or appropriation, whether before or after the introduction of any bill, measure, or resolution proposing such legislation, law, ratification, policy, or appropriation; but this shall not prevent officers or employees of the United States or of its departments or agencies from communicating to any such Members or official, at his request, or to Congress or such official, through the proper official channels, requests for legislation, law, ratification, policy, or appropriations which they deem necessary for the efficient conduct of the public business, or from making any communication whose prohibition by this section might, in the opinion of the Attorney General, violate the Constitution or interfere with the conduct of foreign policy, counter-intelligence, intelligence, or national security activities. Violations of this section shall constitute violations of section 1352(a) of title 31. In addition to the above, the related restrictions on the use of appropriated funds found in Div. F, § 402 of the Omnibus Appropriations Act of 2008 (P.L. 110-161) also apply.

4. **Anti-Deficiency Act.** Pursuant to 31 U.S.C. §1341 nothing contained in this Agreement shall be construed as binding the NPS to expend in any one fiscal year any sum in excess of appropriations made by Congress, for the purposes of this Agreement for that fiscal year, or other obligation for the further expenditure of money in excess of such appropriations.

5. **Minority Business Enterprise Development.** Pursuant to Executive Order 12432 it is national policy to award a fair share of contracts to small and minority firms. NPS is strongly committed to the objectives of this policy and encourages all Cooperators of its Cooperative Agreements to take affirmative steps to ensure such fairness by ensuring procurement procedures are carried out in accordance with the Executive Order.

6. **Assignment.** No part of this Agreement shall be assigned to any other party without prior written approval of the NPS and the Assignee.

7. **Member of Congress.** Pursuant to 41 U.S.C. § 22, no Member of Congress shall be admitted to any share or part of any contract or agreement made, entered into, or adopted by or on behalf of the United States, or to any benefit to arise thereupon.

8. **Agency.** The Cooperator is not an agent or representative of the United States, the Department of the Interior, NPS, or the Park, nor will the Cooperator represent its self as such to third parties. NPS employees are not agents of the Cooperator and will not act on behalf of the Cooperator.

9. **Non-Exclusive Agreement.** This Agreement in no way restricts the Cooperator or NPS from entering into similar agreements, or participating in similar activities or arrangements, with other public or private agencies, organizations, or individuals.

10. **Survival.** Any and all provisions which, by themselves or their nature, are reasonably expected to be performed after the expiration or termination of this Agreement shall survive and be enforceable after the expiration or termination of this Agreement. Any and all liabilities, actual or contingent, which have arisen during the term of and in connection with this Agreement shall survive expiration or termination of this Agreement.

11. **Partial Invalidity.** If any provision of this Agreement or the application thereof to any party or circumstance shall, to any extent, be held invalid or unenforceable, the remainder of this Agreement or the application of such provision to the parties or circumstances other than those to which it is held invalid or unenforceable, shall not be affected thereby and each provision of this Agreement shall be valid and be enforced to the fullest extent permitted by law.

12. **Captions and Headings**: The captions, headings, article numbers and paragraph numbers appearing in this Agreement are inserted only as a matter of convenience and in no way shall be construed as defining or limiting the scope or intent of the provision of this Agreement nor in any way affecting this Agreement.

13. **No Employment Relationship.** This Agreement is not intended to and shall not be construed to create an employment relationship between NPS and Cooperator or its representatives. No representative of Cooperator shall perform any function or make any decision properly reserved by law or policy to the Federal government.

14. **No Third-Party Rights.** This Agreement creates enforceable obligations between only NPS and Cooperator. Except as expressly provided herein, it is not intended nor shall it be construed to create any right of enforcement by or any duties or obligation in favor of persons or entities not a party to this Agreement.

15. **Foreign Travel.** The Cooperator shall comply with the provisions of the Fly America Act (49 USC 40118). The implanting regulations of the Fly America Act are found at 41 CFR 301-10.131 through 301-10.143.

B. Special Provisions

1. **Public Information and Endorsements.**
    a. Cooperator shall not publicize or otherwise circulate promotional material (such as advertisements, sales brochures, press releases, speeches, still and motion pictures, articles, manuscripts or other publications) which states or implies governmental, Departmental, bureau, or government employee endorsement of a business, product, service, or position which the Cooperator represents. No release of information relating to this award may state or imply that the Government approves of the Cooperator's work products, or considers the Cooperator's work product to be superior to other products or services.
    b. All information submitted for publication or other public releases of information regarding this project shall carry the following disclaimer.
    c. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.
    d. Cooperator must obtain prior Government approval for any public information releases concerning this award which refer to the Department of the Interior or any bureau or employee (by name or title). The specific text, layout photographs, etc. of the proposed release must be submitted with the request for approval.
    e. Cooperator further agrees to include this provision in a subaward to a subrecipient, except for a subaward to a State government, a local government, or to a federally recognized Indian tribal government.

2. **Publications of Results of Studies.** No party will unilaterally publish a joint publication without consulting the other party. This restriction does not apply to popular publications of previously published technical matter. Publications pursuant to this Agreement may be produced independently or in collaboration with others; however, in all cases proper credit will be given to the efforts of those parties contribution to the publication. In the event no agreement is reached concerning the manner of publication or interpretation of results, either party may publish data after due notice and submission of the proposed manuscripts to the other. In such instances, the party publishing the data will give due credit to the cooperation but assume full responsibility for any statements on which there is a difference of opinion.

3. **Rights in Data.** The Cooperator must grant the United States of America a royalty-free, non-exclusive and irrevocable license to publish, reproduce and use, and dispose of in any manner and for any purpose without limitation, and to authorize or ratify publication, reproduction or use by others, of all copyrightable material first produced or composed under this Agreement by the Cooperator, its employees or any individual or concern specifically employed or assigned to originate and prepare such material.

4. **Retention and Access Requirements for Records.** All Cooperator financial and programmatic records, supporting documents, statistical records, and other grants-related records shall be maintained and available for access in accordance with 2 CFR Part 200.333-200.337.

5. **Audit Requirements.**
   a. Non-Federal entities that expend $750,000 or more during a year in Federal awards shall have a single or program-specific audit conducted for that year in accordance with the Single Audit Act Amendments of 1996 (31 U.S.C. 7501-7507) and2 CFR Part 200, Subpart F , which is available at http://www.ecfr.gov/cgi-bin/text-idx?SID=fd6463a517ceea3fa13e665e525051f4&node=sp2.1.200.f&rgn=div6
   b. Non-Federal entities that expend less than $750,000 for a fiscal year in Federal awards are exempt from Federal audit requirements for that year, but records must be available for review or audit by appropriate officials of the Federal agency, pass-through entity, and General Accounting Office (GAO).
   c. Audits shall be made by an independent auditor in accordance with generally accepted government auditing standards covering financial audits. Additional audit requirements applicable to this agreement are found at 2 CFR Part 200, Subpart F, as applicable. Additional information on single audits is available from the Federal Audit Clearinghouse at http://harvester.census.gov/sac/.

6. **Procurement Procedures.** It is a national policy to place a fair share of purchases with minority business firms. The Department of the Interior is strongly committed to the objectives of this policy and encourages all Cooperators of its grants and cooperative agreements to take affirmative steps to ensure such fairness. Positive efforts shall be made by Cooperators to utilize small businesses, minority-owned firms, and women's business enterprises, whenever possible. Cooperators of Federal awards shall take all of the following steps to further this goal:
   a. Ensure that small businesses, minority-owned firms, and women's business enterprises are used to the fullest extent practicable.
   b. Make information on forthcoming opportunities available and arrange time frames for purchases and contracts to encourage and facilitate participation by small businesses, minority-owned firms, and women's business enterprises.
   c. Consider in the contract process whether firms competing for larger contracts intend to subcontract with small businesses, minority-owned firms, and women's business enterprises.
   d. Encourage contracting with consortiums of small businesses, minority-owned firms and women's business enterprises when a contract is too large for one of these firms to handle individually.

e. Use the services and assistance, as appropriate, of such organizations as the Small Business Development Agency in the solicitation and utilization of small business, minority-owned firms and women's business enterprises.

7. **Prohibition on Text Messaging and Using Electronic Equipment Supplied by the Government while Driving.** Executive Order 13513, Federal Leadership On Reducing Text Messaging While Driving, was signed by President Barack Obama on October 1, 2009. This Executive Order introduces a Federal Government-wide prohibition on the use of text messaging while driving on official business or while using Government-supplied equipment. **Additional guidance enforcing the ban will be issued at a later date.** In the meantime, please adopt and enforce policies that immediately ban text messaging while driving company-owned or –rented vehicles, government-owned or leased vehicles, or while driving privately owned vehicles when on official government business or when performing any work for or on behalf of the government.

8. **Seat Belt Provision.** The Cooperator is encouraged to adopt and enforce on-the-job seat belt use policies and programs for their employees when operating company-owned, rented, or personally owned vehicles. These measures include, but are not limited to, conducting education, awareness, and other appropriate programs for their employees about the importance of wearing seat belts and the consequences of not wearing them.

9. **Trafficking in Persons.** This term of award is pursuant to paragraph (g) of Section 106 of the Trafficking Victims Protections Act of 2000, as amended (2 CFR §175.15).
   a. Provisions applicable to a Cooperator that is a private entity.
      1. You as the Cooperator, your employees, subCooperators under this award, and subrecipients' employees may not-
         i. Engage in severe forms of trafficking in persons during the period of time that the award is in effect;
         ii. Procure a commercial sex act during the period of time that the award is in effect; or
         iii. Use forced labor in the performance of the award or subawards under the award.
      2. We as the Federal awarding agency may unilaterally terminate this award, without penalty, if you or a subrecipient that is a private entity-
         i. Is determined to have violated a prohibition in paragraph a.1 of this award term; or
         ii. Has an employee who is determined by the agency official authorized to terminate the award to have violated a prohibition in paragraph a.1 of this award term through conduct that is either:
            a. Associated with performance under this award; or

b. Imputed to you or the subrecipient using the standards and due process for imputing the conduct of an individual to an organization that are provided in 2 CFR part 180, "OMB Guidelines to Agencies on Governmentwide Debarment and Suspension (NonProcurement)," as implemented by our agency at 2 CFR part 1400.

b. Provision applicable to a Cooperator other than a private entity. We as the Federal awarding agency may unilaterally terminate this award, without penalty, if a subrecipient that is a private entity-
   1. Is determined to have violated an applicable prohibition in paragraph a.1 of this award term; or
   2. Has an employee who is determined by the agency official authorized to terminate the award to have violated an applicable prohibition in paragraph a.1 of this award term through conduct that is either:
      i. Associated with performance under this award; or
      ii. Imputed to the subrecipient using the standards and due process for imputing the conduct of an individual to an organization that are provided in 2 CFR part 180, "OMB Guidelines to Agencies on Governmentwide Debarment and Suspension (NonProcurement)," as implemented by our agency at 2 CFR part 1400.

c. Provisions applicable to any Cooperator.
   1. You must inform us immediately of any information you receive from any source alleging a violation of a prohibition in paragraph a.1 of this award term.
   2. Our right to terminate unilaterally that is described in paragraph a.2 or b of this section:
      i. Implements section 106(g) of the Trafficking Victims Protection Act of 2000 (TVPA), as amended (22 USC 7104(g)), and
      ii. Is in addition to all other remedies for noncompliance that are available to us under this award.
   3. You must include the requirements of paragraph a.1 of this award term in any subaward you make to a private entity.

d. Definitions. For purposes of this award term:
   1. "Employee" means either:
      i. An individual employed by you or a subrecipient who is engaged in the performance of the project or program under this awards; or
      ii. Another person engaged in the performance of the project or program under this award and not compensated by you including, but not limited to, a volunteer or individual whose services are contributed by a third party as an in-

kind contribution toward cost sharing or matching requirements.

2. "Forced labor" means labor obtained by any of the following methods: The recruitment, harboring, transportation, provision, or obtaining of a person for labor or services, through the use of force, fraud, or coercion for the purpose of subjection to involuntary servitude, peonage, debt bondage, or slavery.
3. "Private entity" means:
    - i. Any entity other than a State, local government, Indian tribe, or foreign public entity, as those terms are defined in 2 CFR 175.25; and
    - ii. Includes:
        - a. A nonprofit organization, including any nonprofit institution of higher education, hospital, or tribal organization other than one included in the definition of Indian tribe at 2 CFR 175.25(b).
        - b. A for-profit organization.
4. "Severe forms of trafficking in persons," "commercial sex act," and "coercion" have the meanings given at section 103 of the TVPA, as amended (22 USC 7102).

10. Cooperator Employee Whistleblower Rights and Requirement to Inform Employees of Whistleblower Rights.

a. This award and employees working on this financial assistance agreement will be subject to the whistleblower rights and remedies in the pilot program on Award Cooperator employee whistleblower protections established at 41 U.S.C. 4712 by section 828 of the National Defense Authorization Act for Fiscal Year 2013 (Pub. L. 112-239).

b. The Award Cooperator shall inform its employees in writing, in the predominant language of the workforce, of employee whistleblower rights and protections under 41 U.S.C. 4712.

c. The Award Cooperator shall insert the substance of this clause, including this paragraph (c), in all subawards or subcontracts over the simplified acquisition threshold, 42 CFR § 52.203-17 (as referenced in 42 CFR § 3.908-9).

11. Reporting Subawards and Executive Compensation

a. Reporting of first-tier subawards.

1. Applicability. Unless you are exempt as provided in paragraph D. of this award term, you must report each action that obligates $25,000 or more in Federal funds that does not include Recovery Act funds (as defined in section 1512(a)(2) of the American Recovery and Reinvestment Act of 2009, Pub. L. 111–5) for a subaward to an entity (see definitions in paragraph E. of this award term).
2. Where and when to report.

i. You must report each obligating action described in paragraph A.1. of this award term to http://www.fsrs.gov.

ii. For subaward information, report no later than the end of the month following the month in which the obligation was made. (For example, if the obligation was made on November 7, 2014, the obligation must be reported by no later than December 31, 2014.)

3. What to report. You must report the information about each obligating action that the submission instructions posted at http://www.fsrs.gov specify.

b. Reporting Total Compensation of Cooperator Executives.

1. Applicability and what to report. You must report total compensation for each of your five most highly compensated executives for the preceding completed fiscal year, if—

i. The total Federal funding authorized to date under this award is $25,000 or more;

ii. In the preceding fiscal year, you received—

a. 80 percent or more of your annual gross revenues from Federal procurement contracts (and subcontracts) and Federal financial assistance subject to the Transparency Act, as defined at 2 CFR 170.320 (and subawards); and

b. $25,000,000 or more in annual gross revenues from Federal procurement contracts (and subcontracts) and Federal financial assistance subject to the Transparency Act, as defined at 2 CFR 170.320 (and subawards); and

iii. The public does not have access to information about the compensation of the executives through periodic reports filed under section 13(a) or 15(d) of the Securities Exchange Act of 1934 (15 U.S.C. 78m(a), 78o(d)) or section 6104 of the Internal Revenue Code of 1986. (To determine if the public has access to the compensation information, see the U.S. Security and Exchange Commission total compensation filings at http://www.sec.gov/answers/execomp.htm.)

2. Where and when to report. You must report executive total compensation described in paragraph A.1. of this award term:

i. As part of your registration profile at https://www.sam.gov.

ii. By the end of the month following the month in which this award is made, and annually thereafter.

c. Reporting of total compensation of subrecipient executives.

1. Applicability and what to report. Unless you are exempt as provided in paragraph D. of this award term, for each first-tier subrecipient under this award, you shall report the names and total compensation of each of the subrecipient’s five most highly

compensated executives for the subrecipient's preceding completed fiscal year, if—

i. In the subrecipient's preceding fiscal year, the subrecipient received—
   a. 80 percent or more of its annual gross revenues from Federal procurement contracts (and subcontracts) and Federal financial assistance subject to the Transparency Act, as defined at 2 CFR 170.320 (and subawards); and
   b. $25,000,000 or more in annual gross revenues from Federal procurement contracts (and subcontracts), and Federal financial assistance subject to the Transparency Act (and subawards); and
ii. The public does not have access to information about the compensation of the executives through periodic reports filed under section 13(a) or 15(d) of the Securities Exchange Act of 1934 (15 U.S.C. 78m(a), 78o(d)) or section 6104 of the Internal Revenue Code of 1986. (To determine if the public has access to the compensation information, see the U.S. Security and Exchange Commission total compensation filings at http://www.sec.gov/answers/execomp.htm.)

2. Where and when to report. You must report subrecipient executive total compensation described in paragraph c.1. of this award term:
   i. To the Cooperator.
   ii. By the end of the month following the month during which you make the subaward. For example, if a subaward is obligated on any date during the month of October of a given year (i.e., between October 1 and 31), you must report any required compensation information of the subrecipient by November 30 of that year.

d. Exemptions.
   1. If, in the previous tax year, you had gross income, from all sources, under $300,000, you are exempt from the requirements to report:
      i. Subawards, and
      ii. The total compensation of the five most highly compensated executives of any subrecipient.

e. Definitions. For purposes of this award term:
   1. Entity means all of the following, as defined in 2 CFR part 25:
      i. A Governmental organization, which is a State, local government, or Indian tribe;
      ii. A foreign public entity;
      iii. A domestic or foreign nonprofit organization;
      iv. A domestic or foreign for-profit organization;
      v. A Federal agency, but only as a subrecipient under an award or subaward to a non-Federal entity.

2. Executive means officers, managing partners, or any other employees in management positions.
3. Subaward:
    i. This term means a legal instrument to provide support for the performance of any portion of the substantive project or program for which you received this award and that you as the Cooperator award to an eligible subrecipient.
    ii. The term includes your procurement of property and services needed to carry out the project or program. The term does not include procurement of incidental property and services needed to carry out the award project or program.
    iii. A subaward may be provided through any legal agreement, including an agreement that you or a subrecipient considers a contract.
4. Subrecipient means an entity that:
    i. Receives a subaward from you (the Cooperator) under this award; and
    ii. Is accountable to you for the use of the Federal funds provided by the subaward.
5. Total compensation means the cash and noncash dollar value earned by the executive during the Cooperator's or subrecipient's preceding fiscal year and includes the following (for more information see 17 CFR 229.402(c)(2)):
    i. Salary and bonus.
    ii. Awards of stock, stock options, and stock appreciation rights. Use the dollar amount recognized for financial statement reporting purposes with respect to the fiscal year in accordance with the Statement of Financial Accounting Standards No. 123 (Revised 2004) (FAS 123R), Shared Based Payments.
    iii. Earnings for services under non-equity incentive plans. This does not include group life, health, hospitalization or medical reimbursement plans that do not discriminate in favor of executives, and are available generally to all salaried employees.
    iv. Change in pension value. This is the change in present value of defined benefit and actuarial pension plans.
    v. Above-market earnings on deferred compensation which is not tax-qualified.
    vi. Other compensation, if the aggregate value of all such other compensation (e.g. severance, termination payments, value of life insurance paid on behalf of the employee, perquisites or property) for the executive exceeds $10,000.

12. Conflict of Interest

a. The Cooperator must establish safeguards to prohibit its employees and Subrecipients from using their positions for purposes that constitute or present the appearance of a personal or organizational conflict of interest. The Cooperator is responsible for notifying the Awarding Officer in writing of any actual or potential conflicts of interest that may arise during the life of this award. Conflicts of interest include any relationship or matter which might place the Cooperator or its employees in a position of conflict, real or apparent, between their responsibilities under the agreement and any other outside interests. Conflicts of interest may also include, but are not limited to, direct or indirect financial interests, close personal relationships, positions of trust in outside organizations, consideration of future employment arrangements with a different organization, or decision-making affecting the award that would cause a reasonable person with knowledge of the relevant facts to question the impartiality of the Cooperator and/or Cooperator's employees and Subrecipients in the matter.

b. The Awarding Officer and the servicing Ethics Counselor will determine if a conflict of interest exists. If a conflict of interest exists, the Awarding Officer will determine whether a mitigation plan is feasible. Mitigation plans must be approved by the Awarding Officer in writing.

c. Failure to resolve conflicts of interest in a manner that satisfies the government may be cause for termination of the award. Failure to make required disclosures may result in any of the remedies described in 2 CFR § 200.338, Remedies/or Noncompliance, including suspension or debarment (see also 2 CFR Part 180).

13. **Minimum Wages Under Executive Order 13658 (January 2015)**

a. *Definitions.* As used in this clause—

"United States" means the 50 states and the District of Columbia.

"Worker"—

1. Means any person engaged in performing work on, or in connection with, an agreement covered by Executive Order 13658, and
    i. Whose wages under such agreements are governed by the Fair Labor Standards Act (29 U.S.C. chapter 8), the Service Contract Labor Standards statute (41 U.S.C. chapter 67), or the Wage Rate Requirements (Construction) statute (40 U.S.C. chapter 31, subchapter IV),
    ii. Other than individuals employed in a bona fide executive, administrative, or professional capacity, as those terms are defined in 29 C.F.R. § 541,
    iii. Regardless of the contractual relationship alleged to exist between the individual and the employer.
2. Includes workers performing on, or in connection with, the agreement whose wages are calculated pursuant to special certificates issued under 29 U.S.C. § 214(c).

3. Also includes any person working on, or in connection with, the agreement and individually registered in a bona fide apprenticeship or training program registered with the Department of Labor's Employment and Training Administration, Office of Apprenticeship, or with a State Apprenticeship Agency recognized by the Office of Apprenticeship.

b. *Executive Order Minimum Wage rate.*

1. The Cooperator shall pay to workers, while performing in the United States, and performing on, or in connection with, this agreement, a minimum hourly wage rate of $10.10 per hour beginning January 1, 2015.
2. The Cooperator shall adjust the minimum wage paid, if necessary, beginning January 1, 2016 and annually thereafter, to meet the Secretary of Labor's annual E.O. minimum wage. The Administrator of the Department of Labor's Wage and Hour Division (the Administrator) will publish annual determinations in the Federal Register no later than 90 days before the effective date of the new E.O. minimum wage rate. The Administrator will also publish the applicable E.O. minimum wage on *www.wdol.gov* (or any successor Web site) and on all wage determinations issued under the Service Contract Labor Standards statute or the Wage Rate Requirements (Construction) statute. The applicable published E.O. minimum wage is incorporated by reference into this agreement.
3.
   i. The Cooperator may request a price adjustment only after the effective date of the new annual E.O. minimum wage determination. Prices will be adjusted only if labor costs increase as a result of an increase in the annual E.O. minimum wage, and for associated labor costs and relevant subaward costs. Associated labor costs shall include increases or decreases that result from changes in social security and unemployment taxes and workers' compensation insurance, but will not otherwise include any amount for general and administrative costs, overhead, or profit.
   ii. Subrecipients may be entitled to adjustments due to the new minimum wage, pursuant to paragraph (b)(2). Cooperators shall consider any Subrecipient requests for such price adjustment.
   iii. The Awarding Officer will not adjust the agreement price under this clause for any costs other than those identified in paragraph (b)(3)(i) of this clause, and will not provide duplicate price adjustments with any price adjustment under clauses implementing the Service Contract Labor

Standards statute or the Wage Rate Requirements (Construction) statute.

4. The Cooperator warrants that the prices in this agreement do not include allowance for any contingency to cover increased costs for which adjustment is provided under this clause.
5. The Cooperator shall pay, unconditionally to each worker, all wages due free and clear without subsequent rebate or kickback. The Cooperator may make deductions that reduce a worker's wages below the E.O. minimum wage rate only if done in accordance with 29 C.F.R. § 10.23, Deductions.
6. The Cooperator shall not discharge any part of its minimum wage obligation under this clause by furnishing fringe benefits or, with respect to workers whose wages are governed by the Service Contract Labor Standards statute, the cash equivalent thereof.
7. Nothing in this clause shall excuse the Cooperator from compliance with any applicable Federal or State prevailing wage law or any applicable law or municipal ordinance establishing a minimum wage higher than the E.O. minimum wage. However, wage increases under such other laws or municipal ordinances are not subject to price adjustment under this subpart.
8. The Cooperator shall pay the E.O. minimum wage rate whenever it is higher than any applicable collective bargaining agreement(s) wage rate.
9. The Cooperator shall follow the policies and procedures in 29 C.F.R. § 10.24(b) and 10.28 for treatment of workers engaged in an occupation in which they customarily and regularly receive more than $30 a month in tips.

c.

1. This clause applies to workers as defined in paragraph (a). As provided in that definition—
   i. Workers are covered regardless of the contractual relationship alleged to exist between the Cooperator or Subrecipient and the worker;
   ii. Workers with disabilities whose wages are calculated pursuant to special certificates issued under 29 U.S.C. § 214(c) are covered; and
   iii. Workers who are registered in a bona fide apprenticeship program or training program registered with the Department of Labor's Employment and Training Administration, Office of Apprenticeship, or with a State Apprenticeship Agency recognized by the Office of Apprenticeship, are covered.
2. This clause does not apply to—
   i. Fair Labor Standards Act (FLSA) – covered individuals performing in connection with contracts covered by the E.O., *i.e.* those individuals who perform duties necessary to

the performance of the agreement, but who are not directly engaged in performing the specific work called for by the agreement, and who spend less than 20 percent of their hours worked in a particular workweek performing in connection with such agreements;

ii. Individuals exempted from the minimum wage requirements of the FLSA under 29 U.S.C. § 213(a) and 214(a) and (b), unless otherwise covered by the Service Contract Labor Standards statute, or the Wage Rate Requirements (Construction) statute. These individuals include but are not limited to—

A. Learners, apprentices, or messengers whose wages are calculated pursuant to special certificates issued under 29 U.S.C. § 214(a).

B. Students whose wages are calculated pursuant to special certificates issued under 29 U.S.C. § 214(b).

C. Those employed in a bona fide executive, administrative, or professional capacity (29 U.S.C. § 213(a)(1) and 29 C.F.R. § part 541).

d. *Notice.* The Cooperator shall notify all workers performing work on, or in connection with, this agreement of the applicable E.O. minimum wage rate under this clause. With respect to workers covered by the Service Contract Labor Standards statute or the Wage Rate Requirements (Construction) statute, the Contractor may meet this requirement by posting, in a prominent and accessible place at the worksite, the applicable wage determination under those statutes. With respect to workers whose wages are governed by the FLSA, the Cooperator shall post notice, utilizing the poster provided by the Administrator, which can be obtained at *www.dol.gov/whd/govcontracts*, in a prominent and accessible place at the worksite. Cooperators that customarily post notices to workers electronically may post the notice electronically provided the electronic posting is displayed prominently on any Web site that is maintained by the Cooperator, whether external or internal, and customarily used for notices to workers about terms and conditions of employment.

e. *Payroll Records.*

1. The Cooperator shall make and maintain records, for three years after completion of the work, containing the following information for each worker:

i. Name, address, and social security number;

ii. The worker's occupation(s) or classification(s);

iii. The rate or rates of wages paid;

iv. The number of daily and weekly hours worked by each worker;

v. Any deductions made; and

vi. Total wages paid.

2. The Cooperator shall make records pursuant to paragraph (e)(1) of this clause available for inspection and transcription by authorized representatives of the Administrator. The Cooperator shall also make such records available upon request of the Contracting Officer.
3. The Cooperator shall make a copy of the agreement available, as applicable, for inspection or transcription by authorized representatives of the Administrator.
4. Failure to comply with this paragraph (e) shall be a violation of 29 C.F.R. § 10.26 and this agreement. Upon direction of the Administrator or upon the Awarding Officer's own action, payment shall be withheld until such time as the noncompliance is corrected.
5. Nothing in this clause limits or otherwise modifies the Cooperator’s payroll and recordkeeping obligations, if any, under the Service Contract Labor Standards statute, the Wage Rate Requirements (Construction) statute, the Fair Labor Standards Act, or any other applicable law.

f. *Access.* The Cooperator shall permit authorized representatives of the Administrator to conduct investigations, including interviewing workers at the worksite during normal working hours.

g. *Withholding.* The Awarding Officer, upon his or her own action or upon written request of the Administrator, will withhold funds or cause funds to be withheld, from the Cooperator under this or any other Federal agreement with the same Cooperator, sufficient to pay workers the full amount of wages required by this clause.

h. *Disputes.* Department of Labor has set forth in 29 C.F.R. § 10.51, Disputes concerning Cooperator compliance, the procedures for resolving disputes concerning an Cooperator’s compliance with Department of Labor regulations at 29 C.F.R. § 10. Such disputes shall be resolved in accordance with those. This includes disputes between the Cooperator (or any of its Subrecipients) and the contracting agency, the Department of Labor, or the workers or their representatives.

i. *Antiretaliation.* The Cooperator shall not discharge or in any other manner discriminate against any worker because such worker has filed any complaint or instituted or caused to be instituted any proceeding under or related to compliance with the E.O. or this clause, or has testified or is about to testify in any such proceeding.

j. *Subcontractor compliance.* The Cooperator is responsible for Subrecipient compliance with the requirements of this clause and may be held liable for unpaid wages due Subrecipient workers.

i. *Subawards.* The Cooperator shall include the substance of this clause, including this paragraph (k) in all subawards, regardless of dollar value, that are subject to the Service Contract Labor Standards statute or the Wage Rate Requirements (Construction) statute, and are to be performed in whole or in part in the United States.

(End of clause)

3. All other provisions remain unchanged**.**

ARTICLE XIII - CESU COOPERATIVE AND JOINT VENTURE AGREEMENT COMPLIANCE

In addition to the terms and conditions of this agreement, the Recipient shall also comply with the terms and conditions of the Rocky Mountain Cooperative Ecosystem Studies Unit, Document Number: NPS# P14AC00749. In the instance of conflicting terms and conditions, the terms and conditions of this agreement shall apply.

ARTICLE XIV – ATTACHMENTS

The following completed documents are attached to and made a part of this Agreement:
Attachment A. SF424 - Application for Federal Assistance
Attachment B. SF424B - Assurances
Attachment C. ATR designation

ARTICLE XV – SIGNATURES

IN WITNESS WHEREOF, the parties hereto have executed this Agreement on the date(s) set forth below.

FOR THE REGENTS OF THE UNIVERSITY OF COLORADO

Name Date
Title

FOR THE NATIONAL PARK SERVICE

Katie Gaertner July 21, 2017

Katie Gaertner Date
Financial Assistance Awarding Officer

83 Re_ Next steps and timeline for NPS-UCBoulder S....pdf

From:	Moynahan, Brendan
To:	Caffrey, Maria; Rebecca Beavers; Patrick Gonzalez NPS; Cat Hoffman; Joseph Rosse; Denitta Ward; Maria Caffrey; John Gross
Subject:	Re: Next steps and timeline for NPS-UCBoulder Sea Level Project
Date:	Wednesday, April 11, 2018 3:32:59 PM
Attachments:	Introduction_A.docx Introduction_B.docx Introduction_C.docx Executive Summary_A.docx Executive Summary_B.docx Executive Summary_C.docx

All,

As promised, attached are three track-change versions of the Executive Summary and three of the Introduction.

For both sections, Version A is very close to Maria's 3.21.18 draft, with the inclusion of the consensus changes agreed to on Friday (and detailed in the email below). Version B is close to Cat's 4.1.18 track-changes version, but also including the changes agreed to Friday (retaining 'anthropogenic' in 2 locations- one we discussed on Friday, and one that Cat had been uncomfortable with striking but was included in a paragraph that was suggested for striking). Version C is my best effort to find a space between A and B.

Note on the central suggestion for the Executive Summary:
To resolve the technical problem with the sentence that happened to also include "anthropogenic climate change," I needed to rework that sentence and try to preserve the language, the point, and resolve the clarity issue noted by the Peer Review Manager. I did that by crafting two sentences that first ID sea level rise and storm surge as the two challenges to managers, and then links storm surge, sea level rise, and anthropogenic climate change in the second sentence.

Note on the central suggestion for the Introduction:
There were 2 big challenges in the Introduction versions. The first was the difficulty resolving both the addition the agreed-upon content of the suggested introduction paragraphs, and still making the transition to the more direct, science-focused introduction that Maria had drafted.   Also, the *Introduction* needed to state a specific context and purpose for the report that linked NPS information need and the challenge highlighted by the science on sea level rise and storm surge. I had a moment of realization that one way to do that was to address that transition from the more 'thematic' language offered by Cat and the more direct, well-supported language offered by Maria. Strangely enough, I think the way to do that is to specifically cite the Secretary's priorities for DOI. Specifically, priority 1A calls for DOI to "Utilize science to identify best practices to manage land and water resources and adapt to changes in the environment."   It struck me that that priority - the first on the list - could be seen as if it had written specifically for this report and body of work.

So I used it. Doing so, I think, directly links the NPS interest with the science and scientific principles, speaks directly to the now-engaged audiences at DOI, and also sets a stage for retention of all references to anthropogenic climate change in both the *Executive Summary* and the *Introduction*.

Per our agreement, you all now have up to a week to consider these options. You're likely getting tired of me saying this, but I believe there is consensus to be had that communicates the NPS purpose and value that is important to Cat and Rebecca, preserves some specific language that is of particular importance to Maria and Patrick, and still preserves clear message, value, and scientific integrity that you all have been so committed to.

Please respond to me by COB next Wednesday, April 18 with your take on each of the three options for both sections: identify each as preferred, acceptable, or not acceptable. Some may find multiple versions to be acceptable or not (no need to force yourself to rate all three versions differently).

Thank you you for your continued efforts.

Brendan

P.S. Of course, please don't share these files outside of your group of coauthors. Any individual one out of context of this group effort may be misinterpreted and could further complicate the likelihood of success.

Brendan J. Moynahan, Ph.D.

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Cell   406.241.7581

On Fri, Apr 6, 2018 at 3:52 PM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> All,
>
> Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:
>
> Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the

introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to all with what they prefer, what they could accept, and what they will not accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer review manager (John Gross) as to whether the differences are resolved by any one of the three options. If so, the selected option will be incorporated into the report and the report will be submitted to the Natural Resource Publication Series manager for acceptance, formatting, and publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder (Joe Rosse) to proceed with publication and appropriately acknowledge contributions.

Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

Brendan J. Moynahan, Ph.D.

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83 1 Attachment Introduction_A.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. In this way, this report speaks directly to the first priority of the Secretary of the Interior: to utilize science to identify best practices to manage land and water resources and adapt to changes in the environment.

Perhaps the most significant environmental change facing coastal parks is that gGlobal sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to

Comment [BJM1]: I note that our Friday discussion had consensus that the content of these paragraphs should be included. There was disagreement among placement.

I've thought a lot about how to place these somewhere else that met 2 goals: first, a relevant introduction for the reader, including but not limited to park managers; second, a flow from a broader, more general point of introduction/purpose to a more specific one.

Given that all coauthors agreed to retain the content, I took that to mean that these paragraphs should be included in all three options I'd present to the coauthors, and the only decision to be made had to do with location. I propose keeping them at the outset because I believe this location is the only place that achieves the two goals.

Comment [BJM2]: Given above point, I did add a sentence that I think makes the transition from broad introduction to the specific scientific issues the report addresses. I think it transitions to the next paragraph more cleanly. I'm hopeful that this added sentence and the phrase now leading the next paragraph may be a very effective way to resolve several of the coauthors core concerns and to speak directly to agency considerations of ensuring maximum relevance across science and agency audiences.

Sec. Priorities for Financial Assistance, 2018. (includes CESU projects). Cited priority is 1(a). Can supply if needed.

climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost \$2–5 billion and a 500 year storm surge could cost \$5–11 billion (Aerts et al. 2013).

Comment [BJM3]: I agree that this paragraph doesn't speak to parks and doesn't contribute much to the introduction. But I've left it in this Version A.

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks

Comment [BJM4]: This is an excellent, concise statement of purpose. Could be moved up front, but will leave here Version A for our present purposes.

83 2 Attachment Introduction_B.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009);~~,~~ anthropogenic climate change has significantly increased the rate of global sea level rise Grinsted et al. 2010, Church and White 2011).~~,~~ ~~Slangen et al. 2016, Fasullo et al. 2016~~). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect many national parks.~~how we protect and manage our national parks~~. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

Comment [HCH1]: Added these two introductory paragraphs to provide better context stressing the importance of the work for national park managers.

Comment [BJM2]: Please note that I worked on this entirely independently; Cat did not make edits to this document directly. Comments below that look like hers result from me copy/pasting from the 4.1.18 Word Document that held her suggestions and comments.

Comment [HCH3]: This is an important point that I suggest including here from the Methods section (in summary form). The same statement remains in Methods section.

Comment [HCH4]: I moved this statement from lower in the document to provide it here as part of early introduction b/c it is a succinct statement of what the report provides.

Comment [HCH5]: Added this subheading to better frame the significance of recent, rapid rates of sea level rise.

Comment [HCH6]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19th century began. To me this is much more clear than "anthropogenic climate change has significantly increased the rate of global sea level rise" – it's an effective, impactful statement that negates any perceptions that some may have of "well, sea level is always changing."

Source: From USGCRP Climate Science Special Report, 2017 (Sea level rise chapter, Sweet et al 2017): "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches) ...

Comment [HCH7]: Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee ...

Comment [BJM8]: This change represents coauthor agreement on Friday that 'anthropogenic' is retained here.

Comment [BJM9]: Maria asked last Friday about adding a new instance of "anthropogenic" to this sentence. Cat hesitated, based on the reliance of that sentence on the citation. I reviewed the ...

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, but associated storm surges occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Comment [BJM10]: Stricken here because Cat suggested moving it up to highlight it earlier in the section.

Comment [BJM11]: Cat comment: Relation of temperature increase to rising sea level already noted above. No need to say "we'll tell you more about it below."

Comment [BJM12]: Retained and moved below to next paragraph.

Comment [BJM13]: Paragraph deleted and replaced with suggestion below that Cat feels speaks more directly to NPS units but still retains those important events as reference for the reader.

Comment [BJM14]: Added by Brendan

Comment [HCH15]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS.

This information is more relevant to national parks than is the cost of damage to New York City infrastructure.

Comment [BJM16]: Retained as always.

83 3 Attachment Introduction_C.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This analysis applies a unified approach to identify how sea level change may affect coastal park units ofacross the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. In this way, this report speaks directly to the first priority of the Secretary of the Interior: to utilize science to identify best practices to manage land and water resources and adapt to changes in the environment.

Perhaps the most significant environmental change facing coastal parks is that global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century in the post-industrial era was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009). aAnthropogenic climate change has significantly increased the rate of global sea level rise, with observed rates almost doubling since 1993 (Titus et al. 2009, Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea

Comment [BJM1]: I note that our Friday discussion had consensus that the content of these paragraphs should be included. There was disagreement among placement.

I've thought a lot about how to place these somewhere else that met 2 goals: first, a relevant introduction for the reader, including but not limited to park managers; second, a flow from a broader, more general point of introduction/purpose to a more specific one.

Given that all coauthors agreed to retain the content, I took that to mean that these paragraphs should be included in all three options I'd present to the coauthors, and the only decision to be made had to do with location. I propose keeping them at the ...

Comment [BJM2]: Please note that I worked on all these versions entirely independently; Cat did not make edits to th ...

Comment [HCH3]: This is an important point that I suggest including here from the ...

Comment [BJM4]: I agree, but I don't think it worked well floating out on its own. For t ...

Comment [HCH5]: I moved this statement from lower in the document to provide it he ...

Comment [BJM6]: Agree – same comment as above.

Comment [BJM7]: Given above point, I did add a sentence that I think makes the transition from broad introduction to the ...

Comment [HCH8]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise sin ...

Comment [BJM9]: I agree that this framing is a more effective timeline for the reader.

Comment [HCH10]: Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coasta ...

Comment [BJM11]: I also agree that this is a strong place to follow up that timeline with the specifics of this Maria's language on the ...

Comment [BJM12]: Double-check retention of these references... I haven't checked them, but rejected the deletion in this Version C.

Comment [BJM13]: Maria asked last Friday about adding a new instance of "anthropogenic" to this sentence. Cat ...

Comment [BJM14]: Rejected Cat's suggested edit per our discussion Friday.

levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

~~For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, but associated storm surges occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Comment [BJM15]: Stricken here because Cat suggested moving it up to highlight it earlier in the section. The sentence is retained but moved up in the section.

Comment [BJM16]: I agree with Cat comment: Relation of temperature increase to rising sea level already noted above. No need to say "we'll tell you more about it below."

Comment [BJM17]: Rejected Cat's suggestion and retained Maria's original language for this sentence; but moved below to next paragraph. In this way, the new paragraph speaks to NPS more directly as Cat wished, but keeps the linkage to 'anthropogenic climate change' that Maria originally drafted (and that fits particularly well and appropriately in this context)

Comment [BJM18]: Paragraph deleted and replaced with suggestion from Cat (below) that speaks more directly to NPS units but still retains those important events as reference for the reader.

Comment [BJM19]: Added by Brendan

Comment [HCH20]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS.

This information is more relevant to national parks than is the cost of damage to New York City infrastructure.

Comment [BJM21]: Retained as always.

83 4 Attachment Executive Summary_A.pdf

Executive Summary

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

83 5 Attachment Executive Summary_B.pdf

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges ~~due to anthropogenic climate change~~ present challenges to national park managers, and compel the National Park Service (NPS) to help our managers understand these changes and their implications so we may better steward the resources under our care. This report summarizes work ~~done by~~ of the University of Colorado scientists in partnership with the ~~National Park Service (~~NPS~~)~~ to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, this report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Comment [BJM1]: Proposed for revision in *response to comment from the Peer Review Manager (J. Gross):*

"The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations."

Comment [BJM2]: Retained as always.

Comment [BJM3]: Redundant with first sentence

83 6 Attachment Executive Summary_C.pdf

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Managers of coastal park units are challenged by rising sea levels and increasing frequency and intensity of storm surges. Increasing storm surges are directly influenced by degradation of coastal and estuarine habitats, and are indirectly influenced by anthropogenic climate change, which drives sea level rise through melting of land-fast ice and thermal expansion of water. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. The National Park Service (NPS) is committed to helping our managers understand these changes and their implications so we may better steward the resources under our care. This report summarizes work done by of the University of Colorado scientists in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, this report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Comment [BJM1]: Is this accurate?

Comment [BJM2]: Stricken and replaced with above to parse the technical issue with the sentence. Anthropogenic climate change retained.

Comment [BJM3]: Retained as always.

Comment [BJM4]: Redundant with first sentence

84 Re_ Next steps and timeline for NPS-UCBoulder S...(1).pdf

From:	Moynahan, Brendan
To:	Caffrey, Maria; Rebecca Beavers; Patrick Gonzalez NPS; Cat Hoffman; Joseph Rosse; Denitta Ward; Maria Caffrey; John Gross
Subject:	Re: Next steps and timeline for NPS-UCBoulder Sea Level Project
Date:	Friday, April 13, 2018 11:22:53 AM

Maria, Rebecca, Patrick, and Cat -

To be clear, I'd request that each of you respond to me independently. I'd like to avoid (1) the reality or perception that one person's response influenced another, or (2) any one feeling the need to respond to another's statements or preferences before we have all responses in.

Thank you,

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell 406.241.7581

On Wed, Apr 11, 2018 at 3:32 PM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> All,
>
> As promised, attached are three track-change versions of the Executive Summary and three of the Introduction.
>
> For both sections, Version A is very close to Maria's 3.21.18 draft, with the inclusion of the consensus changes agreed to on Friday (and detailed in the email below). Version B is close to Cat's 4.1.18 track-changes version, but also including the changes agreed to Friday (retaining 'anthropogenic' in 2 locations- one we discussed on Friday, and one that Cat had been uncomfortable with striking but was included in a paragraph that was suggested for striking). Version C is my best effort to find a space between A and B.
>
> **Note on the central suggestion for the Executive Summary:**
> To resolve the technical problem with the sentence that happened to also include "anthropogenic climate change," I needed to rework that sentence and try to preserve the language, the point, and resolve the clarity issue noted by the Peer Review Manager. I did that by crafting two sentences that first ID sea level rise and storm surge as the two

challenges to managers, and then links storm surge, sea level rise, and anthropogenic climate change in the second sentence.

Note on the central suggestion for the Introduction:

There were 2 big challenges in the Introduction versions. The first was the difficulty resolving both the addition the agreed-upon content of the suggested introduction paragraphs, and still making the transition to the more direct, science-focused introduction that Maria had drafted. Also, the *Introduction* needed to state a specific context and purpose for the report that linked NPS information need and the challenge highlighted by the science on sea level rise and storm surge. I had a moment of realization that one way to do that was to address that transition from the more 'thematic' language offered by Cat and the more direct, well-supported language offered by Maria. Strangely enough, I think the way to do that is to specifically cite the Secretary's priorities for DOI. Specifically, priority 1A calls for DOI to "Utilize science to identify best practices to manage land and water resources and adapt to changes in the environment." It struck me that that priority - the first on the list - could be seen as if it had written specifically for this report and body of work. So I used it. Doing so, I think, directly links the NPS interest with the science and scientific principles, speaks directly to the now-engaged audiences at DOI, and also sets a stage for retention of all references to anthropogenic climate change in both the *Executive Summary* and the *Introduction*.

Per our agreement, you all now have up to a week to consider these options. You're likely getting tired of me saying this, but I believe there is consensus to be had that communicates the NPS purpose and value that is important to Cat and Rebecca, preserves some specific language that is of particular importance to Maria and Patrick, and still preserves clear message, value, and scientific integrity that you all have been so committed to.

Please respond to me by COB next Wednesday, April 18 with your take on each of the three options for both sections: identify each as preferred, acceptable, or not acceptable. Some may find multiple versions to be acceptable or not (no need to force yourself to rate all three versions differently).

Thank you you for your continued efforts.

Brendan

P.S. Of course, please don't share these files outside of your group of coauthors. Any individual one out of context of this group effort may be misinterpreted and could further complicate the likelihood of success.

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell 406.241.7581

On Fri, Apr 6, 2018 at 3:52 PM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

All,

Thank you, sincerely, for your efforts this afternoon. While we came up short on full resolution, I'm certain we made a few important points of progress and identified our last best effort to see this through to publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript. This will be the basis for an effort to accomodate the remaining points of disagreement and the points we agreed to today. I noted that we reached agreement today on three points (1) that the introduction will retain of the "anthropogenic" phrase on page 1, (2) restore of "how we protect and manage our national parks" on page 1, and (3) include the content (if not the placement) of the introductory language offered by Cat in her 4.1.2018 mark-up file. We had very little time to propose resolution for the Executive Summary, but I believe I understand the competing thoughts on it's form and content.

By next Wednesday, April 11, I will send to the group three track-changes versions of the Executive Summary and the Introduction. All will include the changes that we agreed to today (i.e., those three points above). The three versions will include one that is inline with what I understand to be Maria's and Patrick's preference; one will be inline with what I understand to be Cat's and Rebecca's preference; one will be my honest best effort to find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to all with what they prefer, what they could accept, and what they will not accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer review manager (John Gross) as to whether the differences are resolved by any one of the three options. If so, the selected option will be incorporated into the report and the report will be submitted to the Natural Resource Publication Series manager for acceptance, formatting, and publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder (Joe Rosse) to proceed with publication and appropriately acknowledge contributions.

Again, thank you for your participation today. This is an exceptionally valuable, important, and relevant body of work.

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service

Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
32 Campus Drive
c/o Forestry 109
Missoula, MT 59812

Office 406.243.4449
Cell 406.241.7581
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85 [EXTERNAL] Telephone today.pdf

From: Patrick Gonzalez
To: Maria Caffrey
Cc: Patrick Gonzalez
Subject: [EXTERNAL] Telephone today
Date: Monday, April 16, 2018 8:59:20 AM

Hi Maria,

Do you have time at 12 PM MDT (11 AM PDT). I might have time 10:30-11 MDT, but 12 PM is open in my schedule.

Thanks,

Patrick

86 [EXTERNAL] Re_ Telephone today.pdf

From:	Maria Caffrey
To:	Patrick Gonzalez
Cc:	Patrick Gonzalez
Subject:	[EXTERNAL] Re: Telephone today
Date:	Monday, April 16, 2018 9:00:22 AM

Great. Let's plan to talk at 11 am PST/12 MST.

Maria Caffrey, Ph.D.

Office: (303) 969-2097
Cell: (303) 518-3419
mariacaffrey.com

> On Apr 16, 2018, at 8:58 AM, Patrick Gonzalez <patrickgonzalez@berkeley.edu> wrote:
>
> Hi Maria,
>
> Do you have time at 12 PM MDT (11 AM PDT). I might have time 10:30-11 MDT, but 12 PM is open in my schedule.
>
> Thanks,
>
> Patrick

87 text options.pdf

From:	Hoffman, Cat
To:	Brendan Moynahan
Subject:	text options
Date:	Monday, April 16, 2018 7:21:19 PM
Attachments:	Executive Summary_B_CHH.docx Introduction_C_CHH.docx Kemp&Horton_2013_Contrib of relative SLR to hurricane flooding-New York City.pdf

Hi Brendan,

here are my preferences among the options you provided.

Executive summary: I prefer Option B.

I feel that this version as written is the strongest Executive Summary in my opinion, clearly states that this is an analysis of sea level rise and storm surge projections for NPS under climate change, and thus is my preference. The Executive Summary Option C contains helpful explanatory text, but since the report doesn't explicitly discuss (for example) estuarine habitat degradation, my guess is that some of the other authors will reject Option C due to changes in the second sentence as potentially incomplete or alternatively, too detailed for an Executive Summary.

That said, I can live with any of the options as long as we resolve the second sentence in the first paragraph in Option A in a way that is accurate. As John Gross noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that are attributed to anthropogenic climate change present issues to our managers. This is not correct. There are many other sources of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change.

If we go with Option A for the Executive Summary I would request/recommend one addition to the second sentence:

> "Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers."

In Option A, I still advocate the addition of this sentence at the end of the paragraph:

> As a reference for NPS staff, this report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

Introduction: I prefer Introduction Option C, and provided a suggested change. With modifications to the paragraph that once solely focused on Hurricane Sandy, the second sentence needs some edits to make sense and to be more widely applicable to parks (not just Sandy and New York City). I provided a suggested change in the attachment, and also attached the article cited in this paragraph should any of the other authors need to validate the changes I recommend here...this is the same article cited in the March 21, 2018 version).

I can live with Introduction Option B, but would suggest that the same change be made to the Hurricane Sandy, Harvey, Irma, Maria paragraph.

I can also live with Introduction Option A, although I would advocate using the same hurricane paragraph as developed in the Option C attached here to focus on parks, and not exclusively on New York City. But if that becomes a huge sticking point then leave as is.

Thanks for all you are doing to help the authors resolve this Brendan.

Cat

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

87 1 Attachment Executive Summary_B_CHH.pdf

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges ~~due to anthropogenic climate change~~ present challenges to national park managers, and compel the National Park Service (NPS) to help our managers understand these changes and their implications so we may better steward the resources under our care. This report summarizes work ~~done by~~ of the University of Colorado scientists in partnership with the ~~National Park Service (~~NPS~~)~~ to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. As a reference for NPS staff, this report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Comment [BJM1]: Proposed for revision in *response to comment from the Peer Review Manager (J. Gross):*

"The revised statement is both clearer and more technically correct. If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations."

Comment [BJM2]: Retained as always.

Comment [BJM3]: Redundant with first sentence

* *

Comments from Cat: This version as written is the strongest Executive Summary in my opinion, clearly states that this is an analysis of sea level rise and storm surge projections for NPS under climate change, and thus is my preference. The Executive Summary Option C contains helpful explanatory text, but since the report doesn't explicitly discuss (for example) estuarine habitat degradation, my guess is that some of the other authors will reject Option C due to changes in the second sentence as potentially incomplete or alternatively, too detailed for an Executive Summary.

If there are continued concerns from other authors regarding making any change whatsoever to the second sentence in any of the options, then we must resolve this in a way that is accurate. As John Gross noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that may be attributed to anthropogenic climate change present issues to our managers. This is not correct. There are many other sources of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change.

As noted, I favor Option B for the Executive Summary. That said, I can support any of the other versions as long as the statement made in the second sentence is not misleading. If we go with Option A, I would request revision of the second sentence as follows (this can also be used with any of the options).

> "Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers, and compel the National Park Service (NPS) to help our managers understand these changes and their implications so we may better steward the resources under our care."

87 2 Attachment Introduction_C_CHH.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. In this way, this report speaks directly to the first priority of the Secretary of the Interior: to utilize science to identify best practices to manage land and water resources and adapt to changes in the environment.

Perhaps the most significant environmental change facing coastal parks is that global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet~~,~~ et al. 2017)~~, with rates almost doubling since 1993 (Titus, et al. 2009~~. ~~a~~Anthropogenic climate change has significantly increased the rate of global sea level rise, with observed rates almost doubling since 1993 (Titus et al. 2009, ~~–~~Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea

Comment [BJM1]: I note that our Friday discussion had consensus that the content of these paragraphs should be included. There was disagreement among placement.

I've thought a lot about how to place these somewhere else that met 2 goals: first, a relevant introduction for the reader, including but not limited to park managers; second, a flow from a broader, more general point of introduction/purpose to a more specific one.

Given that all coauthors agreed to retain the content, I took that to mean that these paragraphs should be included in all three options I'd present to the coauthors, and the only decision to be made had to do with location. I propose keeping them at the ...

Comment [BJM2]: Please note that I worked on all these versions entirely independently; Cat did not make edits to th ...

Comment [HCH3]: This is an important point that I suggest including here from the ...

Comment [BJM4]: I agree, but I don't think it worked well floating out on its own. For t ...

Comment [HCH5]: I moved this statement from lower in the document to provide it he ...

Comment [BJM6]: Agree – same comment as above.

Comment [BJM7]: Given above point, I did add a sentence that I think makes the transition from broad introduction to the ...

Comment [HCH8]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise sin ...

Comment [BJM9]: I agree that this framing is a more effective timeline for the reader.

Comment [HCH10]: Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coasta ...

Comment [BJM11]: I also agree that this is a strong place to follow up that timeline with the specifics of this Maria's language on the ...

Comment [BJM12]: Double-check retention of these references… I haven't checked them, but rejected the deletion in this Version C.

Comment [BJM13]: Maria asked last Friday about adding a new instance of "anthropogenic" to this sentence. Cat ...

Comment [BJM14]: Rejected Cat's suggested edit per our discussion Friday.

levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

~~For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, associated storm surges occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

****

Suggested revisions to the Hurricane Sandy paragraph (this could also be used with Introduction Option B):

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change and other factors intensify the effects of associated storm surges,

Comment [BJM15]: Stricken here because Cat suggested moving it up to highlight it earlier in the section. The sentence is retained but moved up in the section.

Comment [BJM16]: I agree with Cat comment: Relation of temperature increase to rising sea level already noted above. No need to say "we'll tell you more about it below."

Comment [BJM17]: Rejected Cat's suggestion and retained Maria's original language for this sentence; but moved below to next paragraph. In this way, the new paragraph speaks to NPS more directly as Cat wished, but keeps the linkage to 'anthropogenic climate change' that Maria originally drafted (and that fits particularly well and appropriately in this context)

Comment [BJM18]: Paragraph deleted and replaced with suggestion from Cat (below) that speaks more directly to NPS units but still retains those important events as reference for the reader.

Comment [BJM19]: Added by Brendan

Comment [HCH20]: SINCE THIS CAME FROM THE PARAGRAPH THAT ONCE SOLELY FOCUSED ON HURRICANE SANDY, ADDITIONAL TEXT IS NEEDED TO MAKE THIS MORE WIDELY APPLICABLE TO PARKS (NOT JUST SANDY AND NEW YORK CITY). SUGGESTED REVISIONS ARE BELOW, AND THE KEMP AND HORTON ARTICLE ATTACHED IN CASE ANYONE NEEDS TO VALIDATE MY SUGGESTED CHANGES TO THIS PARAGRAPH AS SHOWN BELOW.

Comment [HCH21]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS.

This information is more relevant to national parks than is the cost of damage to New York City infrastructure.

Comment [BJM22]: Retained as always.

Comment [HCH23]: This must be included b/c there are numerous causes for changes in sea level in addition to climate change which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline (NEED A CITATION), and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Comment [HCH24]: Stating "permanent loss of land across much of the United States coastline" warrants a citation. Suggest checking with Maria or Patrick for this.

Comment [HCH25]: Content from the March 21, 2018 draft.

87 3 Attachment Kemp&Horton_2013_Contrib of relative SLR to hu.pdf

 ISSN 0267 8179. DOI: 10.1002/jqs.2653

Rapid Communication

Contribution of relative sea-level rise to historical hurricane flooding in New York City

ANDREW C. KEMP[1*,†] and BENJAMIN P. HORTON[2]
[1]School of Forestry and Environmental Studies, Yale University, New Haven, USA
[2]Sea Level Research, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, USA

Received 13 March 2013; Revised 20 June 2013; Accepted 5 July 2013

ABSTRACT: Flooding during hurricanes is a hazard for New York City. Flood height is determined by storm surge characteristics, timing (high or low tide) and relative sea level (RSL) change. The contribution from these factors is estimated for seven historical hurricanes (1788 2012) that caused flooding in New York City. Measurements from The Battery tide gauge and historical accounts are supplemented with a RSL reconstruction from Barnegat Bay, New Jersey. RSL was reconstructed from foraminifera preserved in salt marsh sediment that was dated using marker horizons of lead and copper pollution and ^{137}Cs activity. Between the 1788 hurricane and Hurricane Sandy in 2012, RSL rose by 56 cm, including 15 cm from glacio isostatic adjustment. Storm surge characteristics and timing with respect to astronomical tides remain the dominant factors in determining flood height. However, RSL rise will raise the base level for flood heights in New York City and exacerbate flooding caused by future hurricanes.

KEYWORDS: Hurricane Sandy; New Jersey; salt marsh; storm surge; tide gauge.

Introduction

Flooding during hurricanes is a hazard and economic burden to New York City (Coch, 1994; Gornitz *et al.*, 2001; Colle *et al.*, 2008). In October 2012, Hurricane Sandy caused an estimated $50 billion of damage, making it the second costliest hurricane (after Katrina in 2005) to hit the United States (Blake *et al.*, 2013). In New York City, coastal New Jersey, and elsewhere along the US north east Atlantic coast, this damage was caused predominantly by flooding. Notable historical flooding from hurricanes in New York City also occurred in 1985 (Hurricane Gloria), 1960 (Hurricane Donna), 1938, 1893, 1821, and 1788 (unnamed; Coch, 1994; Scileppi and Donnelly, 2007).

The height of flooding attained during a hurricane is the product of storm surge height, timing in the astronomical tidal cycle and relative sea level (RSL) change. Storm surge height is unique to each hurricane, being governed by meteorological conditions and coastal geomorphology (Irish *et al.*, 2008; Lin *et al.*, 2010). Worse flooding occurs when a hurricane's impact is coincident with higher tides. Conversely, lower tides provide vertical space to accommodate a storm surge and to lessen, or prevent, flooding. RSL changes through time and is ultimately the base level on which astronomical tides and storm surges are superimposed. Consequently, the flood height reached at a particular location in New York City (e.g. a building or landmark) during one hurricane compared with another is partly attributed to RSL change. In the 21st century, RSL rise will impact New York City by augmenting the height of storm surges and tides (Bindoff *et al.*, 2007; Yin *et al.*, 2009).

The contribution of RSL change to flooding in New York City during Hurricane Sandy compared with earlier historical events is unknown. We reconstruct RSL for the past ~230 years from salt marsh sediment in northern New Jersey and show that RSL rose by 56 ± 4 cm between the 1788 hurricane and Hurricane Sandy in 2012. Ongoing glacio isostatic adjustment accounted for an estimated 15 cm of this change. These results demonstrate that future RSL rise will add to flood heights attained during hurricanes, but that variability among storm surges and timing remain the dominant controls on flooding in New York City.

Historical hurricane flooding in New York City

The National Hurricane Center defines a storm tide as the water level reached from the combined effects of astronomical tides and storm surge and expressed relative to a contemporary tidal datum. Storm surge height at a tide gauge is the difference between the observed water level and the predicted astronomical tide for that time. Tide level reflects the daily rising and falling of the tides and also position in the astronomical cycle of spring and neap tides. Great diurnal tidal range at The Battery tide gauge in New York City is currently 1.54 m. Wave heights are excluded from these definitions because they are filtered out by tide gauge measurements. RSL is the height of the ocean surface relative to the land at a given location, where zero commonly refers to present (Shennan *et al.*, 2012). It is what an observer on a coast would experience and the net effect of many processes acting simultaneously, including glacio isostatic adjustment. RSL rise between hurricanes raises the base level on which tides and storm surges are superimposed.

The digitized instrumental record of individual hurricane flooding events in New York City is available from the National Ocean Survey since 1920, although archival data from as early as 1835 exist (Talke and Jay, 2013). Tide gauge data from The Battery on the southern tip of Manhattan (Fig. 1) show that Hurricane Sandy (October 2012) generated a 2.81 m storm surge that occurred with a high astronomical tide (0.67 m above mean tide level; MTL) resulting in a storm tide of 3.48 m MTL (Fig. 2). The King's Point tide gauge in

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E-mail: andrew.kemp@tufts.edu
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(b) (4)

[redacted]

(b) (4)

[redacted]

(b) (4)

(b) (4)

88 Re_ text options.pdf

From: Brendan Moynahan
To: Hoffman, Cat
Subject: Re: text options
Date: Monday, April 16, 2018 8:20:34 PM

Received... thanks Cat.

Brendan

Sent from my mobile device

On Apr 16, 2018, at 7:20 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Brendan,
>
> here are my preferences among the options you provided.
>
> **Executive summary**: I prefer Option B.
>
> I feel that this version as written is the strongest Executive Summary in my opinion, clearly states that this is an analysis of sea level rise and storm surge projections for NPS under climate change, and thus is my preference. The Executive Summary Option C contains helpful explanatory text, but since the report doesn't explicitly discuss (for example) estuarine habitat degradation, my guess is that some of the other authors will reject Option C due to changes in the second sentence as potentially incomplete or alternatively, too detailed for an Executive Summary.
>
> That said, I can live with any of the options as long as we resolve the second sentence in the first paragraph in Option A in a way that is accurate. As John Gross noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that are attributed to anthropogenic climate change present issues to our managers. This is not correct. There are many other sources of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change.
>
> If we go with Option A for the Executive Summary I would request/recommend one addition to the second sentence:
>
> > "Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers."
>
> In Option A, I still advocate the addition of this sentence at the end of the paragraph:

> As a reference for NPS staff, this report summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *Coastal Adaptation Strategies: Case Studies*.

Introduction: I prefer Introduction Option C, and provided a suggested change. With modifications to the paragraph that once solely focused on Hurricane Sandy, the second sentence needs some edits to make sense and to be more widely applicable to parks (not just Sandy and New York City). I provided a suggested change in the attachment, and also attached the article cited in this paragraph should any of the other authors need to validate the changes I recommend here...this is the same article cited in the March 21, 2018 version).

I can live with Introduction Option B, but would suggest that the same change be made to the Hurricane Sandy, Harvey, Irma, Maria paragraph.

I can also live with Introduction Option A, although I would advocate using the same hurricane paragraph as developed in the Option C attached here to focus on parks, and not exclusively on New York City. But if that becomes a huge sticking point then leave as is.

Thanks for all you are doing to help the authors resolve this Brendan.

Cat

--
Cat Hawkins Hoffman
National Park Service

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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

<Executive Summary_B_CHH.docx>

<Introduction_C_CHH.docx>

<Kemp&Horton_2013_Contrib of relative SLR to hurricane flooding-New York City.pdf>

89 Re_ Upholding scientific integrity on anthropog...(2).pdf

From:	Hoffman, Cat
To:	Gonzalez, Patrick
Cc:	Maria Caffrey; Maria Caffrey; Rebecca Beavers; Brendan Moynahan; Joseph Rosse; Denitta Ward; John Dennis
Subject:	Re: Upholding scientific integrity on anthropogenic climate change
Date:	Tuesday, April 17, 2018 12:34:32 AM

Hello Patrick – As you know, I was on annual leave when you sent this message and then was out of the office in meetings all last week. Absence from the office only amplifies my chronic burial by e-mail; I did my best to process some e-mail very late at night (b) (6) [redacted], but ran out of time and left much of it unanswered. Thus, I've spent some of the last few evenings trying to work through hundreds of messages.

Although others responded to your message, I don't recall if I responded and do not wish for you or others copied here to interpret my lack of response as concurrence with statements in your message. Patrick, I certainly respect your right to your perspective, although I disagree with your portrayal of our work on final edits for this report.

I can unequivocally state that I, and the NPS Climate Change Response Program, stand on the science of climate change and its human attribution as documented through the findings of the IPCC as well as the USGCRP through the National Climate Assessment. The draft sea level change report acknowledges the human cause of climate change as a driver for sea level rise as I know the final version will (as Brendan hears back from co-authors), which I fully support. As a co-author of the report, my suggested edits to the text are not for "non-science" or "non-policy" or "suppressing science" reasons as you assert, but to improve the report for use by park managers, interpreters, and other park staff.

I respect and abide by the process we agreed to with Brendan and Joe to resolve editorial views among the authors. I also wanted to let you, Rebecca, and Maria know that should there still be disagreement among the co-authors after all respond to Brendan, I've asked Brendan to work with Joe on behalf of UC-Boulder, and also with John Dennis (in his capacity as the Deputy Chief Scientist for the NPS) to resolve the editorial differences. As a co-author, I should not be part of that process.

Cat

On Fri, Apr 6, 2018 at 8:44 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote:

> Dear Colleagues,
>
> The central issue with the sea level rise report by Maria Caffrey is the attempted deletions by National Park Service staff of the terms "anthropogenic climate change" or "human-caused climate change" or text on how greenhouse gas emissions from human activities are the cause of climate change. I consider those attempts contrary to scientific integrity.

I have appreciated the times when people have discussed this in a respectful and professional manner and have deplored the times when it has not. I wish to summarize for you what I said on the telephone call today and have said previously.

The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.

Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S. national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.

Because both the scientific and policy bases for anthropogenic climate change are sound, attempts to delete or alter the term or related text are for non-science and non-policy reasons. The repeated attempts over the past year to delete or alter scientific content or meaning for non-science and non-policy reasons and halting the report unless Maria accepted the deletions possess characteristics of suppressing science that would apparently violate the policy on scientific integrity of the U.S. Department of the Interior.

I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.

Thank you for your consideration,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science,

Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
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+1 (510) 643-9725
....

References

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC.

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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

90 Re_ SLR Report Scientific Integrity Discussion.pdf

From:	Caffrey, Maria
To:	Sara Newman
Subject:	Re: SLR Report Scientific Integrity Discussion
Date:	Tuesday, April 17, 2018 12:30:49 PM
Attachments:	Timeline for Caffrey et al.docx

Sara,

It just occurred to me that this document might help our discussion today.

Thanks,

On Tue, Apr 17, 2018 at 9:40 AM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

> Sara,
>
> That would be great. I'll update the invite.
>
> On Tue, Apr 17, 2018 at 5:51 AM, Sara Newman <sara_newman@nps.gov> wrote:
>
>> Maria,
>>
>> My schedule freed up and I can talk today after 2pm. Does 2:30pm work for you? Or we can keep our time tomorrow. Cheers, Sara
>>
>> Sara B. Newman, DrPH, MCP
>> Captain, USPHS
>> Director, Office of Public Health
>> Bureau Scientific Integrity Officer
>> National Park Service
>> 1849 C Street NW, Room 2542
>> Washington DC 20240
>> Office: 202-513-7225
>> Cell: 202-222-8608
>> Fax: 202-371-1349
>>
>> On Apr 16, 2018, at 2:01 PM, Maria Caffrey <maria_caffrey@partner.nps.gov> wrote:
>>
>>> You have been invited to the following event.
>>>
>>> Title: SLR Report Scientific Integrity Discussion
>>> Meeting to discuss the possible violation of the scientific integrity
>>> policy in reference to the sea level and storm surge report.
>>>
>>> Number to call: 303-969-2097
>>> When: Wed Apr 18, 2018 2pm – 3pm Eastern Time
>>> Video call: https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-s
>>> <https://hangouts.google.com/hangouts/_/doi.gov/maria-caffrey-s?hceid=bWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3Y.61tic0g76r72e910rvsiulr51f>
>>> Calendar: sara_newman@nps.gov
>>> Who:

* maria_caffrey@partner.nps.gov - organizer
* sara_newman@nps.gov

Event details:
https://www.google.com/calendar/event?action=VIEW&eid=NjF0aWMwZzc2cjcyZTkxMHJ2c2l1bHI1MWYgc2FyYV9uZXdtYW5AbnBzLmdvdg&tok=MjkjbWFyaWFfY2FmZnJleUBwYXJ0bmVyLm5wcy5nb3YxYzk5ZWE3NGU3YmIyODQzOGQ5ZjM3ZThlODVhYjRhODYzMjYwNzIx&ctz=America%2FNew_York&hl=en&es=1

Invitation from Google Calendar: https://www.google.com/calendar/

You are receiving this email at the account sara_newman@nps.gov because you
are subscribed for invitations on calendar sara_newman@nps.gov.

To stop receiving these emails, please log in to
https://www.google.com/calendar/ and change your notification settings for this calendar.

Forwarding this invitation could allow any recipient to modify your RSVP response. Learn more at
https://support.google.com/calendar/answer/37135#forwarding

<meeting.ics>

--
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www.nps.gov/subjects/wetlands

--
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www.nps.gov/subjects/wetlands

90 1 Attachment Timeline for Caffrey et al.pdf

Timeline for Caffrey et al. Sea Level and Storm Surge Report

(b) (7)(A)

[redacted]

(b) (7)(A)

[redacted]

(b) (7)(A)

[redacted]

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[redacted]

(b) (7)(A)

[redacted]

(b) (7)(A)

[redacted]

(b) (7)(A)

[redacted]

91 text options(1).pdf

From:	Hoffman, Cat
To:	Brendan Moynahan
Subject:	text options
Date:	Tuesday, April 17, 2018 7:31:36 PM
Attachments:	Executive Summary_A_w.edits.docx Introduction_A_w.edits.docx Introduction_B_w.edits.docx Introduction_C_w.edits.docx Kemp&Horton_2013_Contrib of relative SLR to hurricane flooding-New York City.pdf

Hi Brendan,

here are my preferences among the options you provided, within the parameters of the request to identify "preferred," "acceptable," or "non-acceptable."

Executive summary: Prefer Option B.
This version as written is the strongest Executive Summary in my opinion; it clearly states that this is an analysis of sea level rise and storm surge projections for the NPS under climate change, recognizes the importance of the information for meeting our responsibilities to steward/protect resources, and links the work to our previous products (Adaptation Strategies Handbook, and Case Studies) -- thus is my preference.

Option A: Not acceptable as written.
Acceptable with suggested edits shown in the attached document.

Option C: The Executive Summary Option C contains helpful explanatory text, but since the report doesn't explicitly discuss (for example) estuarine habitat degradation, my guess is that some of the other authors will reject Option C due to changes in the second sentence as potentially incomplete or alternatively, too detailed for an Executive Summary. I am willing to review and consider any suggestions other authors may wish to make for edits to the first part of the paragraph in Option C.

Common to all: Whatever version goes forward, it is important to ensure that the statement made in the second sentence of the Executive Summary is not misleading. As the peer review manager (John Gross) noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that may be attributed to anthropogenic climate change present issues to our managers. This is not correct. There are many other drivers of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change. The sentence could be corrected as follows: "Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers....."

Introduction: Prefer Option C, with a suggested change.
I'm almost equally split between Option B, and Option C. However, the language suggested in the 3rd paragraph in Option C is an improvement over Option B, in my opinion.

A revision is needed because modifications to the paragraph that once solely focused on Hurricane Sandy and New York City created a need for edits in the second sentence to make sense and to be more widely applicable to parks (not just Sandy and New York City). I provided a suggested change in the attachment, and also attached the article cited in this paragraph should any of the other authors need to validate the changes I recommend here...this is the same publication cited in the March 21, 2018 draft. I'm open to other suggestions for how to fix this paragraph.

Option A: Not acceptable as written.
Acceptable with suggested edits (to clarify the second sentence of the hurricane paragraph) shown in the attached document. I'm also open to suggestions other than those I provided.

Option B: Not acceptable as written.

Acceptable with suggested edits (to clarify the second sentence of the hurricane paragraph) shown in the attached document. I'm also open to suggestions other than those I provided.

Thank you Brendan -- I do appreciate your continued assistance to the authors in this.

Cat
--
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National Park Service

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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

91 1 Attachment Executive Summary_A_w.edits.pdf

Executive Summary (language provided by Brendan for Option A)

Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Not Preferred, but Acceptable with this Requested revision if Executive Summary Option A is used

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Comment [A1]: As John Gross noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that may be attributed to anthropogenic climate change present issues to our managers. This is not correct. There are many other sources of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast

Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *NPS Coastal Adaptation Strategies: Case Studies.*

91 2 Attachment Introduction_A_w.edits.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. In this way, this report speaks directly to the first priority of the Secretary of the Interior: to utilize science to identify best practices to manage land and water resources and adapt to changes in the environment.

Perhaps the most significant environmental change facing coastal parks is that gGlobal sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to

Comment [BJM1]: I note that our Friday discussion had consensus that the content of these paragraphs should be included. There was disagreement among placement.

I've thought a lot about how to place these somewhere else that met 2 goals: first, a relevant introduction for the reader, including but not limited to park managers; second, a flow from a broader, more general point of introduction/purpose to a more specific one.

Given that all coauthors agreed to retain the content, I took that to mean that these paragraphs should be included in all three options I'd present to the coauthors, and the only decision to be made had to do with location. I propose keeping them at the outset because I believe this location is the only place that achieves the two goals.

Comment [BJM2]: Given above point, I did add a sentence that I think makes the transition from broad introduction to the specific scientific issues the report addresses. I think it transitions to the next paragraph more cleanly. I'm hopeful that this added sentence and the phrase now leading the next paragraph may be a very effective way to resolve several of the coauthors core concerns and to speak directly to agency considerations of ensuring maximum relevance across science and agency audiences.

Sec. Priorities for Financial Assistance, 2018. (includes CESU projects). Cited priority is 1(a). Can supply if needed.

climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Comment [BJM3]: I agree that this paragraph doesn't speak to parks and doesn't contribute much to the introduction. But I've left it in this Version A.

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks

Comment [BJM4]: This is an excellent, concise statement of purpose. Could be moved up front, but will leave here Version A for our present purposes.

<u>Option A Not Preferred, but Acceptable with this (or some) revision if Option A is used</u>

Request removal of the Hurricane Sandy-New York City paragraph above, and substitute the paragraph below:

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change and other factors intensify the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline (NEED A CITATION), and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Comment [HCH5]: This must be included b/c there are numerous causes for changes in sea level in addition to climate change

Comment [HCH6]: I feel that stating "permanent loss of land across much of the United States coastline" warrants a citation, although we may proceed without it as necessary. Suggest checking with Maria or Patrick for this.

Comment [HCH7]: Content from the March 21, 2018 draft.

91 3 Attachment Introduction_B_w.edits.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units.

The Importance of Understanding Contemporary Sea Level Change for Parks

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet, et al. 2017), with rates almost doubling since 1993 (Titus, et al. 2009); ~~,~~ anthropogenic climate change has significantly increased the rate of global sea level rise Grinsted et al. 2010, Church and White 2011). ~~, Slangen et al. 2016, Fasullo et al. 2016~~). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect many national parks. ~~how we protect and manage our national parks~~. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

Comment [HCH1]: Added these two introductory paragraphs to provide better context stressing the importance of the work for national park managers.

Comment [BJM2]: Please note that I worked on this entirely independently; Cat did not make edits to this document directly. Comments below that look like hers result from me copy/pasting from the 4.1.18 Word Document that held her suggestions and comments.

Comment [HCH3]: This is an important point that I suggest including here from the Methods section (in summary form). The same statement remains in Methods section.

Comment [HCH4]: I moved this statement from lower in the document to provide it here as part of early introduction b/c it is a succinct statement of what the report provides.

Comment [HCH5]: Added this subheading to better frame the significance of recent, rapid rates of sea level rise.

Comment [HCH6]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise since the 19th century began. To me this is much more clear than "anthropogenic climate change has significantly increased the rate of global sea level rise" – it's an effective, impactful statement that negates any perceptions that some may have of "well, sea level is always changing."

Source: From USGCRP Climate Science Special Report, 2017 (Sea level rise chapter, Sweet et al 2017): "Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches) ...

Comment [HCH7]: Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee ...

Comment [BJM8]: This change represents coauthor agreement on Friday that 'anthropogenic' is retained here.

Comment [BJM9]: Maria asked last Friday about adding a new instance of "anthropogenic" to this sentence. Cat hesitated, based on the reliance of that sentence on the citation. I reviewed the ...

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail. As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, but associated storm surges occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Comment [BJM10]: Stricken here because Cat suggested moving it up to highlight it earlier in the section.

Comment [BJM11]: Cat comment: Relation of temperature increase to rising sea level already noted above. No need to say "we'll tell you more about it below."

Comment [BJM12]: Retained and moved below to next paragraph.

Comment [BJM13]: Paragraph deleted and replaced with suggestion below that Cat feels speaks more directly to NPS units but still retains those important events as reference for the reader.

Comment [BJM14]: Added by Brendan

Comment [HCH15]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS.

This information is more relevant to national parks than is the cost of damage to New York City infrastructure.

Comment [BJM16]: Retained as always.

Option B Not Preferred, but Acceptable w/ this Requested revision if Option B is used

This – or some -- revision is needed (5th paragraph above) as modifications to the paragraph regarding hurricanes created a need for edits in the second sentence to make sense, and to be more widely applicable to parks (not just Sandy and New York City).

> The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change and other factors intensify the effects of associated storm surges, which may be even further amplified during the highest

Comment [HCH17]: This must be included b/c there are numerous causes for changes in sea level in addition to climate change astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline (NEED A CITATION), and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Comment [HCH18]: I feel that stating "permanent loss of land across much of the United States coastline" warrants a citation, although we may proceed without it if necessary. Suggest checking with Maria or Patrick for this.

Comment [HCH19]: Content from the March 21, 2018 draft.

91 4 Attachment Introduction_C_w.edits.pdf

Introduction

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the national park system. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections. This analysis applies a unified approach to identify how sea level change may affect coastal park units ~~of~~across the National Park System. Results provide estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. In this way, this report speaks directly to the first priority of the Secretary of the Interior: to utilize science to identify best practices to manage land and water resources and adapt to changes in the environment.

Perhaps the most significant environmental change facing coastal parks is that global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), recent analyses reveal that the rate of sea level rise in the last century ~~in the post-industrial era~~ was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet~~,~~ et al. 2017)~~, with rates almost doubling since 1993 (Titus, et al. 2009~~. ~~, a~~Anthropogenic climate change has significantly increased the rate of global sea level rise, with observed rates almost doubling since 1993 (Titus et al. 2009, ~~-~~Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Numerous analyses indicate that elevated temperatures driven by 20th century global warming account for a substantial portion of global mean sea level rise since 1900 (Sweet et al. 2017). Further warming of the atmosphere will cause sea levels to continue to rise (Slangen et al. 2016, Grinsted et al. 2010, Fasullo et al. 2016) which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea

Comment [BJM1]: I note that our Friday discussion had consensus that the content of these paragraphs should be included. There was disagreement among placement.

I've thought a lot about how to place these somewhere else that met 2 goals: first, a relevant introduction for the reader, including but not limited to park managers; second, a flow from a broader, more general point of introduction/purpose to a more specific one.

Given that all coauthors agreed to retain the content, I took that to mean that these paragraphs should be included in all three options I'd present to the coauthors, and the only decision to be made had to do with location. I propose keeping them at the ...

Comment [BJM2]: Please note that I worked on all these versions entirely independently; Cat did not make edits to th ...

Comment [HCH3]: This is an important point that I suggest including here from the ...

Comment [BJM4]: I agree, but I don't think it worked well floating out on its own. For t ...

Comment [HCH5]: I moved this statement from lower in the document to provide it he ...

Comment [BJM6]: Agree – same comment as above.

Comment [BJM7]: Given above point, I did add a sentence that I think makes the transition from broad introduction to the ...

Comment [HCH8]: IMO, this stays in context of a timeline, and thoroughly "paints the picture" of the spike in sea level rise sin ...

Comment [BJM9]: I agree that this framing is a more effective timeline for the reader.

Comment [HCH10]: Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coasta ...

Comment [BJM11]: I also agree that this is a strong place to follow up that timeline with the specifics of this Maria's language on the ...

Comment [BJM12]: Double-check retention of these references… I haven't checked them, but rejected the deletion in this Version C.

Comment [BJM13]: Maria asked last Friday about adding a new instance of "anthropogenic" to this sentence. Cat ...

Comment [BJM14]: Rejected Cat's suggested edit per our discussion Friday.

levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

~~This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.~~ As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

~~For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).~~

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, associated storm surges occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Requested revisions if Option C is used

(1) Optional to use this between the second and third paragraphs, but I think it's helpful:
The Importance of Understanding Contemporary Sea Level Change for Parks

Comment [BJM15]: Stricken here because Cat suggested moving it up to highlight it earlier in the section. The sentence is retained but moved up in the section.

Comment [BJM16]: I agree with Cat comment: Relation of temperature increase to rising sea level already noted above. No need to say "we'll tell you more about it below."

Comment [BJM17]: Rejected Cat's suggestion and retained Maria's original language for this sentence; but moved below to next paragraph. In this way, the new paragraph speaks to NPS more directly as Cat wished, but keeps the linkage to 'anthropogenic climate change' that Maria originally drafted (and that fits particularly well and appropriately in this context)

Comment [BJM18]: Paragraph deleted and replaced with suggestion from Cat (below) that speaks more directly to NPS units but still retains those important events as reference for the reader.

Comment [BJM19]: Added by Brendan

Comment [HCH20]: SINCE THIS CAME FROM THE PARAGRAPH THAT ONCE SOLELY FOCUSED ON HURRICANE SANDY, ADDITIONAL TEXT IS NEEDED TO MAKE THIS MORE WIDELY APPLICABLE TO PARKS (NOT JUST SANDY AND NEW YORK CITY). SUGGESTED REVISIONS ARE BELOW, AND THE KEMP AND HORTON ARTICLE ATTACHED IN CASE ANYONE NEEDS TO VALIDATE MY SUGGESTED CHANGES TO THIS PARAGRAPH AS SHOWN BELOW.

Comment [HCH21]: Received this information from Tim Hudson (NPS) who helped to lead Sandy recovery effort for NPS.

This information is more relevant to national parks than is the cost of damage to New York City infrastructure.

Comment [BJM22]: Retained as always.

(2) This – or some similar -- revision is needed (5th paragraph above) as modifications to the paragraph regarding hurricanes created a need for edits in the second sentence to make sense, and to be more widely applicable to parks (not just Sandy and New York City).

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change and other factors intensify the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline (NEED A CITATION), and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Comment [HCH23]: This must be included b/c there are numerous causes for changes in sea level in addition to climate change

Comment [HCH24]: I feel that stating "permanent loss of land across much of the United States coastline" warrants a citation, although we may proceed without it if necessary. Suggest checking with Maria or Patrick for this.

Comment [HCH25]: Content from the March 21, 2018 draft.

91 5 Attachment Kemp&Horton_2013_Contrib of relative SLR to hu_1.pdf

JOURNAL OF QUATERNARY SCIENCE (2013) 28(6) 537 541 ISSN 0267 8179. DOI: 10.1002/jqs.2653

Rapid Communication

Contribution of relative sea-level rise to historical hurricane flooding in New York City

ANDREW C. KEMP[1*,†] and BENJAMIN P. HORTON[2]
[1]School of Forestry and Environmental Studies, Yale University, New Haven, USA
[2]Sea Level Research, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, USA

Received 13 March 2013; Revised 20 June 2013; Accepted 5 July 2013

ABSTRACT: Flooding during hurricanes is a hazard for New York City. Flood height is determined by storm surge characteristics, timing (high or low tide) and relative sea level (RSL) change. The contribution from these factors is estimated for seven historical hurricanes (1788 2012) that caused flooding in New York City. Measurements from The Battery tide gauge and historical accounts are supplemented with a RSL reconstruction from Barnegat Bay, New Jersey. RSL was reconstructed from foraminifera preserved in salt marsh sediment that was dated using marker horizons of lead and copper pollution and ^{137}Cs activity. Between the 1788 hurricane and Hurricane Sandy in 2012, RSL rose by 56 cm, including 15 cm from glacio isostatic adjustment. Storm surge characteristics and timing with respect to astronomical tides remain the dominant factors in determining flood height. However, RSL rise will raise the base level for flood heights in New York City and exacerbate flooding caused by future hurricanes.

KEYWORDS: Hurricane Sandy; New Jersey; salt marsh; storm surge; tide gauge.

Introduction

Flooding during hurricanes is a hazard and economic burden to New York City (Coch, 1994; Gornitz *et al.*, 2001; Colle *et al.*, 2008). In October 2012, Hurricane Sandy caused an estimated $50 billion of damage, making it the second costliest hurricane (after Katrina in 2005) to hit the United States (Blake *et al.*, 2013). In New York City, coastal New Jersey, and elsewhere along the US north east Atlantic coast, this damage was caused predominantly by flooding. Notable historical flooding from hurricanes in New York City also occurred in 1985 (Hurricane Gloria), 1960 (Hurricane Donna), 1938, 1893, 1821, and 1788 (unnamed; Coch, 1994; Scileppi and Donnelly, 2007).

The height of flooding attained during a hurricane is the product of storm surge height, timing in the astronomical tidal cycle and relative sea level (RSL) change. Storm surge height is unique to each hurricane, being governed by meteorological conditions and coastal geomorphology (Irish *et al.*, 2008; Lin *et al.*, 2010). Worse flooding occurs when a hurricane's impact is coincident with higher tides. Conversely, lower tides provide vertical space to accommodate a storm surge and to lessen, or prevent, flooding. RSL changes through time and is ultimately the base level on which astronomical tides and storm surges are superimposed. Consequently, the flood height reached at a particular location in New York City (e.g. a building or landmark) during one hurricane compared with another is partly attributed to RSL change. In the 21st century, RSL rise will impact New York City by augmenting the height of storm surges and tides (Bindoff *et al.*, 2007; Yin *et al.*, 2009).

The contribution of RSL change to flooding in New York City during Hurricane Sandy compared with earlier historical events is unknown. We reconstruct RSL for the past ~230 years from salt marsh sediment in northern New Jersey and show that RSL rose by 56 ± 4 cm between the 1788 hurricane and Hurricane Sandy in 2012. Ongoing glacio isostatic adjustment accounted for an estimated 15 cm of this change. These results demonstrate that future RSL rise will add to flood heights attained during hurricanes, but that variability among storm surges and timing remain the dominant controls on flooding in New York City.

Historical hurricane flooding in New York City

The National Hurricane Center defines a storm tide as the water level reached from the combined effects of astronomical tides and storm surge and expressed relative to a contemporary tidal datum. Storm surge height at a tide gauge is the difference between the observed water level and the predicted astronomical tide for that time. Tide level reflects the daily rising and falling of the tides and also position in the astronomical cycle of spring and neap tides. Great diurnal tidal range at The Battery tide gauge in New York City is currently 1.54 m. Wave heights are excluded from these definitions because they are filtered out by tide gauge measurements. RSL is the height of the ocean surface relative to the land at a given location, where zero commonly refers to present (Shennan *et al.*, 2012). It is what an observer on a coast would experience and the net effect of many processes acting simultaneously, including glacio isostatic adjustment. RSL rise between hurricanes raises the base level on which tides and storm surges are superimposed.

The digitized instrumental record of individual hurricane flooding events in New York City is available from the National Ocean Survey since 1920, although archival data from as early as 1835 exist (Talke and Jay, 2013). Tide gauge data from The Battery on the southern tip of Manhattan (Fig. 1) show that Hurricane Sandy (October 2012) generated a 2.81 m storm surge that occurred with a high astronomical tide (0.67 m above mean tide level; MTL) resulting in a storm tide of 3.48 m MTL (Fig. 2). The King's Point tide gauge in

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E-mail: andrew.kemp@tufts.edu
†Present address: Department of Earth and Ocean Sciences, Tufts University, Medford, MA 02155, USA.

(b) (4)

[redacted]

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(b) (4)

[redacted]

(b) (4)

[redacted]

93 Erroneous statement in NPS e-mail.pdf

From:	Gonzalez, Patrick
To:	Denitta Ward; Rosse Joseph
Cc:	Maria Caffrey; Maria Caffrey; Cat Hawkins Hoffman
Subject:	Erroneous statement in NPS e-mail
Date:	Wednesday, April 18, 2018 6:40:23 PM

Dear Denita and Joseph,

The e-mail from NPS (below) contains an inaccurate statement. The phrase in the second paragraph, last sentence "for one of four coauthors" is wrong. It is two of four coauthors. As you know, I have consistently rejected all attempts by NPS to delete "anthropogenic climate change" or otherwise alter related scientific text on the human cause of climate change.

Sincerely,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science,
Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

131 Mulford Hall, Berkeley, CA 94720-3114 USA
patrick_gonzalez@nps.gov
+1 (510) 643-9725
....

---------- Forwarded message ----------

From: Brendan Moynahan <brendan_moynahan@nps.gov>
Date: April 18, 2018 at 4:00:50 PM MDT
To: "Caffrey, Maria" <maria_caffrey@partner.nps.gov>
Cc: Denitta Ward <denitta.ward@colorado.edu>, Maria Caffrey U Colorado <maria.caffrey@colorado.edu>, Rosse Joseph <joseph.rosse@colorado.edu>
Subject: Re: Sea Level/Storm Surge Report Options

Thank you for the response.

I am in no position to unilaterally make changes. I can respond to your point about the introductory paragraphs. Because we all agreed that the introductory text could be included, it was my charge from all coauthors to find an appropriate place for it. It is broad, thematic language that introduces the report to primary intended audience (park managers). I found that it simply does not fit anywhere else. I considered additional headers to break the Section up, but I determined that doing so would unnecessarily complicate a relatively short section that would otherwise flow quite well as suggested

Respectfully, I don't understand the assertion that the location of that broad language could be perceived in any way as "burying" references to human causes, particularly when I've offered alternatives that include all mentions of "anthropogenic" and "human caused" that were the crux of earlier discussions, and worked to correct the technical problem with the sentence in the Exec Summary such that "anthropogenic" was retained there, too. Given how late we are in this last-best-effort, forgive me if this comes across as blunt; but I find it rather demanding for one of four coauthors to refuse the editorial, impartial suggestion of location of acceptable content when all the issues that we had identified for resolution on our April 6 call have been resolved — which includes all contested mentions of those words that were in your preferred 3.21 draft.

I would suggest that insistence that those paragraphs be moved elevates an actually minor and entirely editorial issue to the level of an unresolvable impasse. If, somehow, that location of introductory text were reconsidered and found acceptable to you, then I believe we would have agreement to proceed Version C with exceedingly minor adjustments cited by other coauthors in their replies to me. I believe your words that you want to find that middle ground. Based on multiple others' responses, I can assure you that Version C is the only available opportunity to secure it. This is a complicated report with 4 authors all working to preserve content, integrity, and ensure timely delivery to parks. Reasonable give and take is always a challenge in these cases. But I've never been party to one that has been unresolved due to objection of location of agreed-upon introductory content.

So, I'm urging your reconsideration of your position to accept no alternative other than what was already identified as your preference. I and many others would be so pleased to publish this report with full authorship and to demonstrate that we can work through these challenges. You're welcome to reply today and respond to my request that you reconsider. In any case, I will be consulting with UCBoulder and our NPS Chief Scientist tomorrow morning to present author responses and make my recommendation as facilitator.

Sincerely,

Brendan

Sent from my mobile device

On Apr 18, 2018, at 3:05 PM, Caffrey, Maria <maria_caffrey@partner nps.gov> wrote:

Hi Brendan,

I have taken the time to review what you sent me and have reached a decision. Version A of the executive summary appears to be an unchanged version of what I submitted on 3.21. Therefore I can accept that. I cannot accept versions B or C of the executive summary.

All three versions of the introduction you sent me include the text that I objected to being in the very front of the document. Frankly, I would prefer that the text not be in there at all because I believe it is an attempt to bury text referring to the human causes of climate change. In an effort to make provisions for what my co-authors stated regarding the need for the text I said I would be open to looking at an option that would put the text in another section that was perhaps labelled for park managers. I certainly cannot agree to the text beginning “From rocky headlands…” to “…adapt to changes in the environment” being the opening statement of the document. Please delete it or move it to another section.

I was under the impression during our meeting when you said that two of the three options you were going to present were going to be “bookends” that meant that I would at least have the option to accept one version that was mine as well as look at Cat’s version and a version that merges my document with Cat’s. That does not appear to be the case. As a result I cannot accept any of the introductions you sent me.

Brendan, I really hope that some middle ground can be found between what Cat and I want. I just believe what you sent me does not have that. I would be open to looking at other introduction options, although I would like to state for the record that all the co-authors had agreed on a version to be released in May 2017. If no agreement can be reached I would really like you to consider publishing the May 2017 version that everyone had previously accepted before politics interrupted the process.

Many thanks,

Maria

--
Maria Caffrey, Ph.D.
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Cell: 303-518-3419

www.nps.gov/subjects/wetlands

94 Re_ Remove my name from the NPS sea level rise ....pdf

From:	Caffrey, Maria
To:	Gonzalez, Patrick
Cc:	Rebecca Beavers; Cat Hoffman
Subject:	Re: Remove my name from the NPS sea level rise report
Date:	Thursday, April 19, 2018 9:04:53 AM

Thank you Patrick. For the record, I really appreciate all the input you had in this process and significant contributions you made to this report. I completely understand your position on this and look forward to working you in the future.

Many thanks,

Maria.

On Wed, Apr 18, 2018 at 6:39 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote:

> Dear Maria,
>
> I remove my name from the author list of the NPS sea level rise report.
>
> As you know, I welcome collaboration with you in the future.
>
> Sincerely,
>
> Patrick
>
> ....
> Patrick Gonzalez, Ph.D.
>
> Principal Climate Change Scientist
> Natural Resource Stewardship and Science
> U.S. National Park Service
>
> Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
> Affiliate, Institute for Parks, People, and Biodiversity
> University of California, Berkeley
>
> https://ourenvironment.berkeley.edu/people/patrick-gonzalez
>
> 131 Mulford Hall, Berkeley, CA 94720-3114 USA
> patrick_gonzalez@nps.gov
> +1 (510) 643-9725
> ....
>
> ---------- Forwarded message ----------
> From: Gonzalez, Patrick <patrick_gonzalez@nps.gov>
> Date: Fri, Apr 6, 2018 at 7:44 PM
> Subject: Upholding scientific integrity on anthropogenic climate change
> To: Maria Caffrey <maria.caffrey@colorado.edu>, Maria Caffrey

<maria_caffrey@partner.nps.gov>, Rebecca Beavers
<rebecca_beavers@nps.gov>, Cat Hawkins Hoffman
<cat_hawkins_hoffman@nps.gov>, Brendan Moynahan
<brendan_moynahan@nps.gov>, Joseph Rosse <joseph.rosse@colorado.edu>,
Denitta Ward <denitta.ward@colorado.edu>

Dear Colleagues,

The central issue with the sea level rise report by Maria Caffrey is the attempted deletions by National Park Service staff of the terms "anthropogenic climate change" or "human-caused climate change" or text on how greenhouse gas emissions from human activities are the cause of climate change. I consider those attempts contrary to scientific integrity.

I have appreciated the times when people have discussed this in a respectful and professional manner and have deplored the times when it has not. I wish to summarize for you what I said on the telephone call today and have said previously.

The Intergovernmental Panel on Climate Change (IPCC 2013) and the U.S. Global Change Research Program (USGCRP 2017) both confirm the overwhelming scientific evidence and agreement of scientists on the human cause of climate change. So, the scientific basis of the terms is robust.

Concerning U.S. Government policy, the U.S. is a party to the U.N. Framework Convention on Climate Change, which affirms the scientific findings of the human cause of climate change and seeks to reduce greenhouse gas emissions from human activities. These reductions would reduce the negative effects of climate change on places like the U.S. national parks. Also, the U.S. National Climate Assessment (USGCRP 2017), the official U.S. Government report on climate change, confirmed the human cause. Finally, the National Park Service Climate Change Response Strategy affirms the scientific findings of the human cause of climate change. So, the policy basis of the terms is solid.

Because both the scientific and policy bases for anthropogenic climate change are sound, attempts to delete or alter the term or related text are for non-science and non-policy reasons. The repeated attempts over the past year to delete or alter scientific content or meaning for non-science and non-policy reasons and halting the report unless Maria accepted the deletions possess characteristics of suppressing science that would apparently violate the policy on scientific integrity of the U.S. Department of the Interior.

I appreciate the recognition by Maria of my scientific collaboration with her and the invitation to me to serve as a co-author. If the deletions or alterations of scientific content were made, however, I would remove my name as a co-author. I hope that you can respect that I am speaking out of strong adherence to a core principal - scientific integrity.

Thank you for your consideration,

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

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....

References

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC.

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95 Fwd_ More on scientific integrity and the NPS s....pdf

From:	Brendan Moynahan
To:	cat_hawkins_hoffman@nps.gov
Cc:	patrick_gonzalez@nps.gov; Malone Patrick; john_dennis@nps.gov; Rebecca_Beavers@nps.gov
Subject:	Fwd: More on scientific integrity and the NPS sea level rise report
Date:	Thursday, April 19, 2018 9:57:04 AM

Cat,

I'm writing to you as Patrick's supervisor about a matter of what I see as an egregious breach of norms of professional conduct. As you are aware, Patrick yesterday accused me in an email to both NPS and external partners of (1) working to appropriate others' work without proper attribution, (2) threatening a partner researcher with professional retribution, and (3) politically motivated manipulation of scientific material. The pertinent email string is below.

I believe these allegations are plainly worded and beyond misinterpretation. They are also readily and incontrovertibly refuted by a complete written record of the issue. I do not take this lightly and will not let it stand. Perhaps most offensive to me is that it seems that Patrick wields "scientific integrity" as both a weapon and a shield - in the same breath that he presents himself as a warrior for scientific integrity, he levels accusations of my conduct and professional integrity that are wholly without merit, cannot be substantiated, and potentially quite damaging to me.

I have my own thoughts on his motivation for making these accusations. But the motivation matters much less at this moment than what has actually transpired, and what may very well be shared his and Maria Caffery's media contacts. I feel that this is professional bullying and defamation, plain and simple. It is particularly serious to me given my position as a senior science professional for the NPS and a liaison to scores of external science partners.

Patrick, I've cc'd you here as a professional courtesy only; I do not request any response from you directly. Cat, I'll follow up with you and others with responsibilities for investigating conduct, ethics, and scientific integrity issues.

Sincerely,

Brendan

Cc: John Dennis, NPS Deputy Chief Scientist
Rebecca Beavers, Project Lead and ATR
Patrick Malone, IMR ARD for Natural Resources

Sent from my mobile device

Begin forwarded message:

From: Brendan Moynahan <brendan_moynahan@nps.gov>
Date: April 19, 2018 at 6:36:55 AM MDT
To: "Gonzalez, Patrick" <patrick_gonzalez@nps.gov>, maria_caffrey@partner.nps.gov, maria.caffrey@colorado.edu, Cat Hoffman <cat_hawkins_hoffman@nps.gov>, Rebecca Beavers <Rebecca_Beavers@nps.gov>, Joseph Rosse <joseph.rosse@colorado.edu>, Denitta Ward <denitta.ward@colorado.edu>
Cc: john_dennis@nps.gov
Subject: Re: More on scientific integrity and the NPS sea level rise report

All,

First, let me apologize to Denitta and Joe for the tone that this email string has just taken. I am replying here only because of the serious nature of the content and the clear attention of others to this issue. This most recent email now includes some gross mischaracterizations that I am compelled to respond to for the sake of an accurate record.

Patrick - your characterizations of my role, intentions, actions, and integrity are, simply put, wrong, misleading, and damaging. On your first point, I would simply note that the resolution of this issue is specifically articulated in the parent agreement between NPS and UCBoulder that outlines resolution for precisely this type of impasse.   I'd be happy to share that again, but it's already been presented to all and discussed in earlier email strings -- notably, when Joe Rosse inquired on April 6 as to its relevance in this case. I have received concurrence on my understanding of the meaning of that language from our supporting Procurement Analyst with the NPS Financial Assistance Policy Branch and from the the NPS Chief of Financial Assistance for the Washington Contracting Office. As detailed in my April 9 email, if consensus can't be reached, NPS may publish the report (with contributions acknowledged) to inform Park management, and other authors would be free to publish/present the work as they please. It is not my determination to make; it is a process prescribed by the cooperative agreement between our institutions.

Second, your characterization of my email as a 'threat to coerce' Maria is wrong, manipulative, professionally irresponsible, and consequential. Throughout this process, I have encouraged all authors to seek common ground in a good-faith effort produce a product that maintained integrity, relevance, and respect for the significant investments of all parties. I am entirely comfortable with the entire string of communication since my involvement began, up to and including that last email to Maria.

Your third point is most difficult to respond to; it is wholly untethered from the well-documented reality of the process you and your coauthors agreed to. You cite and continue to forward your email of April 6 without the balance of the email string, its essential context, and the point-by-point refutation of the misleading nature of that email.

I must point out, again, that the versions that I prepared for consideration were in response to all 4 coauthors requesting them of me on April 6. You may recall that I asked each coauthor for verbal confirmation that you all would like me to do that. We also all understood on that call that this process was explicitly framed as our last-best-effort to resolve the outstanding issues. We openly discussed that the umbrella agreement prescribed the ultimate resolution if coauthors could not come to agreement. Finally, I would point out that candidate options I prepared as a result of our call retained all mentions of the terms of ultimate concern - specifically including “anthropogenic” and “human-caused climate change.”

I will not debate this further by group email. I have made my best good-faith effort to try to help you all work past disagreement that is quite apparently unresolvable. I’ve followed the process that all agreed to; agreement was not reached and I will make my recommendation as the Science Advisor of the Rocky Mountains CESU. I don’t believe any part of my contributions here can be reasonably characterized as anything other than honorable.

One final request - if any of our group opts to share Patrick’s email with parties outside of our group effort here - media, colleagues, anyone - please take care to include this response from me. Without full context and my reply, his allegations are potentially damaging and could be considered defamatory.

Sincerely,

Brendan

Sent from my mobile device

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor
National Park Service
Rocky Mountains Cooperative Ecosystems Studies Unit

The University of Montana
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c/o Forestry 109

Missoula, MT 59812

Office: 406.243.4449
Cell: 406.241.7581

On Apr 18, 2018, at 6:45 PM, Gonzalez, Patrick <patrick_gonzalez@nps.gov> wrote:

> Brendan, colleagues,
>
> Upon careful consideration, I have found problems with certain steps taken by Brendan. First, the plan for NPS to publish the report stripped of the names of the authors would, in effect, be publishing the work of authors without proper credit of the authors, clearly violating scientific integrity. Second, the use of that possibility as a threat to coerce Maria into changing text also violates scientific integrity. Third, deletion by Brendan of "anthropogenic climate change" and alterations of related scientific text on the human cause of climate change violate scientific integrity (as I previously wrote on April 6, 2018).
>
> If NPS attempts to publish the report without authors listed, I do not consent to the listing of my name in any note that would attempt to replace the listing of authors.
>
> I have already informed the lead author, Maria, that I remove my name
> from the author list.
>
> I recognize that others have different views and would like those who disagree to respect that my conclusions arise from careful consideration of scientific integrity.
>
> Sincerely,
>
> Patrick
>
> ....
> Patrick Gonzalez, Ph.D.
>
> Principal Climate Change Scientist
> Natural Resource Stewardship and Science
> U.S. National Park Service
>
> Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
> Affiliate, Institute for Parks, People, and Biodiversity
> University of California, Berkeley

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....

On Fri, Apr 13, 2018 at 10:22 AM, Moynahan, Brendan <brendan_moynahan@nps.gov> wrote:

> Maria, Rebecca, Patrick, and Cat -
>
> To be clear, I'd request that each of you respond to me independently. I'd
>
> like to avoid (1) the reality or perception that one person's response
>
> influenced another, or (2) any one feeling the need to respond to another's
>
> statements or preferences before we have all responses in.
>
> Thank you,
>
> Brendan
>
> --
>
> Brendan J. Moynahan, Ph.D.
>
> Research Coordinator and Science Advisor
>
> National Park Service
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On Wed, Apr 11, 2018 at 3:32 PM, Moynahan, Brendan

<brendan_moynahan@nps.gov> wrote:

All,

As promised, attached are three track-
change versions of the Executive

Summary and three of the Introduction.

For both sections, Version A is very close to
Maria's 3.21.18 draft, with

the inclusion of the consensus changes
agreed to on Friday (and detailed in

the email below). Version B is close to
Cat's 4.1.18 track-changes version,

but also including the changes agreed to
Friday (retaining 'anthropogenic'

in 2 locations- one we discussed on Friday, and one that Cat had been

uncomfortable with striking but was included in a paragraph that was

suggested for striking). Version C is my best effort to find a space

between A and B.

Note on the central suggestion for the Executive Summary:

To resolve the technical problem with the sentence that happened to also

include "anthropogenic climate change," I needed to rework that sentence and

try to preserve the language, the point, and resolve the clarity issue noted

by the Peer Review Manager. I did that by crafting two sentences that first

ID sea level rise and storm surge as the two challenges to managers, and

then links storm surge, sea level rise, and anthropogenic climate change in

the second sentence.

Note on the central suggestion for the Introduction:

There were 2 big challenges in the Introduction versions. The first was

the difficulty resolving both the addition the agreed-upon content of the

suggested introduction paragraphs, and still making the transition to the

more direct, science-focused introduction that Maria had drafted. Also, the Introduction needed to state a specific context and purpose for the

report that linked NPS information need and the challenge highlighted by the

science on sea level rise and storm surge. I had a moment of realization

that one way to do that was to address that transition from the more

'thematic' language offered by Cat and the more direct, well-supported

language offered by Maria. Strangely enough, I think the way to do that is

to specifically cite the Secretary's priorities for DOI. Specifically,

priority 1A calls for DOI to "Utilize science to identify best practices to

manage land and water resources and adapt to changes in the environment."

It struck me that that priority - the first on the list - could be seen as

if it had written specifically for this report and body of work. So I used

it. Doing so, I think, directly links the NPS interest with the science and

scientific principles, speaks directly to the now-engaged audiences at DOI,

and also sets a stage for retention of all references to anthropogenic

climate change in both the Executive Summary and the Introduction.

Per our agreement, you all now have up to a week to consider these

options. You're likely getting tired of me saying this, but I believe there is consensus to be had that communicates the NPS purpose and value that is

important to Cat and Rebecca, preserves some specific language that is of

particular importance to Maria and Patrick, and still preserves clear

message, value, and scientific integrity that you all have been so committed

to.

Please respond to me by COB next Wednesday, April 18 with your take on

each of the three options for both sections: identify each as preferred,

acceptable, or not acceptable. Some may find multiple versions to be

acceptable or not (no need to force yourself to rate all three versions

differently).

Thank you you for your continued efforts.

Brendan

P.S. Of course, please don't share these files outside of your group of

coauthors. Any individual one out of context of this group effort may be

misinterpreted and could further complicate the likelihood of success.

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor

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On Fri, Apr 6, 2018 at 3:52 PM, Moynahan, Brendan

<brendan_moynahan@nps.gov> wrote:

All,

Thank you, sincerely, for your

efforts this afternoon. While we came up

short on full resolution, I'm certain we made a few important points of

progress and identified our last best effort to see this through to

publication with all authors. That process is this:

Cat will send to the entire group the 3.21 version of the manuscript.

This will be the basis for an effort to accomodate the remaining points of

disagreement and the points we agreed to today. I noted that we reached

agreement today on three points (1) that the introduction will retain of the

"anthropogenic" phrase on page 1, (2) restore of "how we protect and manage

our national parks" on page 1, and (3) include the content (if not the

placement) of the introductory language offered by Cat in her 4.1.2018

mark-up file. We had very little time to propose resolution for the

Executive Summary, but I believe I understand the competing thoughts on it's

form and content.

By next Wednesday, April 11, I will send to the group three track-changes

versions of the Executive Summary and the Introduction. All will include

the changes that we agreed to today (i.e., those three points above). The

three versions will include one that is inline with what I understand to be

Maria's and Patrick's preference; one will be inline with what I understand

to be Cat's and Rebecca's preference; one will be my honest best effort to

find the space between the two.

All four coauthors will have until COB Wednesday, April 18 to reply to

all with what they prefer, what they could accept, and what they will not

accept.

By Friday, April 20, Brendan will advise NPS project (Cat) and peer

review manager (John Gross) as to whether the differences are resolved by

any one of the three options. If

so, the selected option will be

incorporated into the report and the report will be submitted to the Natural

Resource Publication Series manager for acceptance, formatting, and

publication. If not, the NPS (Brendan and Cat) will consult with UC Boulder

(Joe Rosse) to proceed with publication and appropriately acknowledge

contributions.

Again, thank you for your participation today. This is an exceptionally

valuable, important, and relevant body of work.

Brendan

Brendan J. Moynahan, Ph.D.

Research Coordinator and Science Advisor

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Rocky Mountains Cooperative
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99 Fwd_ Moynahan recommendations re publication of...(1).pdf

From:	Hoffman, Cat
To:	Jennifer Wyse; Guy Adema
Subject:	Fwd: Moynahan recommendations re publication of sea level report
Date:	Thursday, April 19, 2018 11:29:25 PM
Attachments:	ATT00001.htm Moynahan recommendation - UCBoulder-NPS Sea Level Storm Surge Report.docx Executive Summary_D.docx ATT00002.htm

---------- Forwarded message ----------
From: **Brendan Moynahan** <brendan_moynahan@nps.gov>
Date: Thu, Apr 19, 2018 at 6:59 PM
Subject: Moynahan recommendations re publication of sea level report
To: Dennis John <john_dennis@nps.gov>, john_gross@nps.gov
Cc: maria.caffrey@colorado.edu, Rebecca_Beavers@nps.gov, cat_hawkins_hoffman@nps.gov, Rosse Joseph <joseph.rosse@colorado.edu>, Denitta.Ward@colorado.edu

I'm writing you, John Gross as Peer Review Manager for this report, and you, John Dennis, as Deputy Chief Scientist. I have copied the three coauthors to the report and two administrators for the University of Colorado-Boulder.

I have attached my documentation of my assistance to this project since April 2, along with my recommendation for the path forward. I have also attached a file that is referenced in the first document.

Please forgive the informality of the memo; I'm presently on travel and am working across mobile devices.

Please let me know if I can provide any further assistance.

Regards and sincerely,

Brendan

Sent from my mobile device

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
Fort Collins, CO 80525
cat_hawkins_hoffman@nps.gov
office: 970-225-3567
cell: 970-631-5634

Adaptation websites: public, NPS managers

Climate Change Response Resources

99 2 Attachment Moynahan recommendation - UCBoulder-NPS Sea L_2.pdf

To: John Gross and John Dennis
From: Brendan Moynahan
Date: April 19, 2018
Re: Recommendation for publication of cooperative sea level report

This email is my documentation of my role as facilitator for completion of the sea level-storm surge report prepared by UCBoulder and NPS under a Cooperative Ecosystem Studies Unit (CESU) Task Agreement. I wish to restate that I have no authority decide any actions with the report - I myself may not edit the document or make the publication decision. My recommendation for proceeding to publication is presented at the end of this document.

I was asked by the NPS Climate Change Response Program on April 2 to consult on an impasse among coauthors and allegations of actions that impacted the scientific integrity of the report. I facilitated a call on Friday, April 6, 2018 with all four coauthors to the report: Maria Caffrey, Rebecca Beavers, Patrick Gonzales, and Cat Hawkins Hoffman. Joe Rosse of UCBoulder also attended this call. Each coauthor spoke briefly to their view of the disagreement over proposed edits. We focused our group discussion on the specific points of contention, which was initially limited to the treatment of the specific language of “anthropogenic” and “human-caused climate change.” Later in the call, Maria also noted her disagreement with the location of two suggested introductory paragraphs offered by Cat; upon further discussion we collectively came to understand that no coauthors objected to the content of the paragraphs, but rather disagreed on placement within the Introduction section. Maria and Patrick felt that leading the Introduction with them inappropriately ‘buried’ or demoted the climate change, sea level, and storm surge message; Cat and Rebecca disagreed.

In my post-call email on April 6, I noted that we did make some progress but did not fully address all the language issues. Toward the end of the call, I proposed an approach to try to find an agreeable solution for the several outstanding issues with the Executive Summary and the Introduction. That approach would be my preparation of three candidate versions of each section for consideration by all coauthors (detailed in my meeting recap email on April 6). I was to use the 3.21.18 draft of the report as a baseline. Coauthors would have one week to consider the candidates and write me independently to indicate which candidates they found to be preferred, acceptable, or not acceptable. I asked each to respond independently to me because I wanted to avoid one coauthor challenging or critiquing another as responses came in; I wanted to create space for each to freely communicate their positions free of judgement or reaction. I asked each coauthor to respond directly whether they supported this approach and my role; all responded affirmatively.

All candidates of both sections retained all instances of “anthropogenic” and “human-caused” that had been debated in the 4.1.18 draft. Candidates varied in the proposed resolution of the second sentence of the Executive Summary and several sentences in the Introduction. They all retained the accepted content of the Introductory paragraphs;

I found that I could not place them elsewhere in that section and still retain the flow of the document for readers - whether they be NPS managers, science professionals, or members of the public.

Coauthors agreed to respond by Wednesday, April 18 at close-of-business. I received responses in the agreed form from Rebecca, Cat, and Maria, in that order. Rebecca responded with the brief statement that she was “comfortable with all options because major content of the report remains unchanged.” Patrick responded but did not offer reactions to candidates. Furthermore, he withdrew his name as author on April 18. For these two reasons - nonresponse and self-removal from coauthorship, I have no responses to report for him. He did send written objections to my handling of the process. His objections and my response is detailed in an email that I sent Thursday, April 19. The following are summarized responses for Cat and Maria to the candidates as they were written.

Executive Summary:

Candidate A: Preferred by Maria. Not acceptable to Cat.
Candidate B: Preferred by Cat. Not acceptable to Maria.
Candidate C: Close to acceptable by Cat. Not acceptable to Maria.

Introduction:

Candidate A: Preferred by Maria. Not acceptable to Cat.
Candidate B: Not acceptable to either.
Candidate C: Preferred by Cat. Not acceptable to Maria as written.

Cat supplied some suggestions that could make Candidate A of the Executive Summary acceptable, and that would slightly adjust Candidate C.

I believe agreement on the Executive Summary is attainable if the three coauthors agreed to the attached Candidate D (with track changes to show suggested edits from the v3.21.18 baseline). This candidate is Maria’s preferred option with 3 edits suggested by Cat. My opinion is that these three edits are minor and entirely within the normal give-and-take of multiple-author documents.

It is my opinion that agreement on the Introduction eludes us, but only as a result of disagreement over the location of the thematic introductory paragraphs offered by Cat. I believe this because all candidates resolve the concerns about the specific terms “anthropogenic” and “human-caused.”

I worked to try to find some other placement in the Introduction that would have allowed for relocation, but I came to the conclusion that the material is so broad, thematic, introductory, and innocuous that the section flowed clearly only with those 2 paragraphs at the start of the section. As understand it, the content is acceptable to Maria, but she objects on other grounds; her emailed response stated that her preference is “that the text not be included at all because I believe that it is an attempt to bury the text referring to the human causes of climate change.” I strongly disagree. Again, the candidates all retain the originally contested language and the body of the report remains unchanged from the 3.21.18 draft.

Recommendation:

I recommend that Rebecca Beaver is identified as the editor of the report. Rebecca has been listed as second author, has contributed most of the NPS effort to the project since inception, and has been the NPS Agreement Technical Representative to the Agreement. As editor, she would be free to explore whether agreement may yet be reached on the proposed Executive Summary Candidate D and whether the location of the introductory text can be resolved.

If they are somehow resolved, the consensus Executive Summary and Introduction would be inserted into the 3.21.17 version of the report, and it would be submitted for publication with Caffrey, Beavers, and Hoffman as authors.

If those two sections remain unresolved (as they are at the time of writing), I recommend that Rebecca make the final adjustments to the 3.21.18 version based on her understanding of the (now) 3 coauthors positions that I have documented here. She alone would be cited as editor of the report. I would then ask Dr. John Dennis (in his role as NPS Deputy Chief Scientist) and Dr. Joe Rosse (in his role as UCBoulder Associate Vice Chancellor for Research Integrity and Compliance) collaborate to prepare a <1 page statement that appropriately acknowledges contributors to the report. This statement would be included in the front matter of the report, along with a statement that NPS takes responsibility for the content of the report, and a reference to the language from the Cooperative Agreement that prescribes this process in that case. As stated elsewhere in our phone calls and emails, Maria would remain free to prepare any additional analyses or publications as she chooses, per the terms of the Cooperative Agreement that requires either publishing party to supply a copy of the document to be published prior to actual publication. At her request, I would supply Rebecca with coauthors written responses and/or my view of the process since April 2.

99 3 Attachment Executive Summary_D_2.pdf

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge due to climate change under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety. This work complements the NPS *Coastal Adaptation Strategies Handbook*, and *NPS Coastal Adaptation Strategies: Case Studies.*

Comment [A1]: As John Gross (Peer Review Manager) noted, the second sentence (from the Executive Summary, *3-21-2018* draft) implies that only sea level change and storm surge that may be attributed only to anthropogenic climate change present issues to our managers. This is not correct. There are many other sources of sea level change that are pertinent at a local level. The NPS is responsible for responding to changes in sea level from any cause that affect national parks, not just climate change.

101 Re_ [EXTERNAL] Re_ Moynahan recommendations re ....pdf

From:	Hoffman, Cat
To:	Maria Caffrey; John Dennis; John Gross
Cc:	Brendan Moynahan; Rebecca_Beavers@nps.gov; Joseph G Rosse; Denitta Ward
Subject:	Re: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report
Date:	Friday, April 20, 2018 3:11:19 PM
Attachments:	Caffrey et al Sea Level Change Report_no pics_4.20.2018.docx

Maria -- I appreciate your suggested changes. I believe we can find an acceptable solution to the "two introductory paragraphs" through use of formatting with an inset text box. In addition to the introductory text, it is reasonable for the hurricane discussion in the introduction to focus on national parks. I have provided suggested text for edits in the document, attached. I would ask that you not share this outside of this group; thank you.

I sincerely want you to remain as an author on the report; please know that. It is important for you to receive due credit for this work as an author.

Cat

On Fri, Apr 20, 2018 at 9:20 AM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:

> Brendan,
>
> Thank you for letting me know about this change in circumstance. It is unfortunate that the lines of communication have broken down so much. I do feel it necessary to correct one important detail in your email regarding my voting on version preferences. In my email to you I said that executive summary A was the only executive summary I could accept, but I did not say that I found introduction A acceptable. In fact, I did not find any of the introductions acceptable.
>
> I have worked hard at trying to find a middle ground in this situation. I thought that I had made it clear that I could not accept any version of text that leads with the text that Cat wrote. I apologize if I did not emphasize that enough. I have attached an example of the kind of placement of the text that I could find acceptable.
>
> Finally, I would like to say that while I can see why you suggested Rebecca as editor, I am afraid I would have to state that I cannot follow that suggestion. I understand from your perspective based on Rebecca's voting choices that she seems to be the logical choice, but I feel she has too many conflicts of interest in this case that should remove her from consideration. I think it would be better to involve someone that all co-authors can agree to make an impartial decision. Perhaps the recently retired former editor of Park Science Jeff Selleck? I would also like to suggest that we do not use the term "editor" because that term could have a bearing on how the report is cited.
>
> Many thanks,
>
> Maria Caffrey, PhD
> Research Associate
> Geological Sciences,
> UCB 399,
> 2200 Colorado Ave,
> Boulder, CO 80309
>
> Office: (303) 969-2097
> Cell: (303) 518-3419

Web: mariacaffrey.com

From: Brendan Moynahan <brendan_moynahan@nps.gov>
Sent: Thursday, April 19, 2018 6:59:34 PM
To: Dennis John; john_gross@nps.gov
Cc: Maria Caffrey; Rebecca_Beavers@nps.gov; cat_hawkins_hoffman@nps.gov; Joseph G Rosse; Denitta Ward
Subject: Moynahan recommendations re publication of sea level report

I'm writing you, John Gross as Peer Review Manager for this report, and you, John Dennis, as Deputy Chief Scientist. I have copied the three coauthors to the report and two administrators for the University of Colorado-Boulder.

I have attached my documentation of my assistance to this project since April 2, along with my recommendation for the path forward. I have also attached a file that is referenced in the first document.

Please forgive the informality of the memo; I'm presently on travel and am working across mobile devices.

Please let me know if I can provide any further assistance.

Regards and sincerely,

Brendan

Sent from my mobile device

--
Cat Hawkins Hoffman
National Park Service

Chief, NPS Climate Change Response Program
1201 Oakridge Drive
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cat_hawkins_hoffman@nps.gov
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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

101 1 Attachment Caffrey et al Sea Level Change Report_no pics_7.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

Starting document is 3/21/2018 draft.

Photos, graphics, and appendices are removed from this draft to reduce size of the document for e-mail transmission among authors while working on final text in the body of the report.

Recommended changes are only to text in the body of the report, and do not remove or affect existing photos or graphics in the report.

There are no changes or alterations to the appendices, analyses, or results. Modifications are intended to better focus on NPS, the importance of this work to parks, and the provision of explanatory scientific information regarding sea level rise and storm surge.

Removal of photos and graphics changed pagination, thus created errors in the table of contents. This will be fixed when the document is "reassembled" to include the original photos and graphics.

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California
Photograph courtesy of Maria Caffrey, University of Colorado

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California
Photograph courtesy of Maria Caffrey, University of Colorado

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—2017/1425

Maria A. Caffrey[1], Rebecca L. Beavers[2], Patrick Gonzalez[3], Cat Hawkins-Hoffman[4]

Comment [HCH1]: Remove hyphen

[1] University of Colorado
Geological Sciences Building
UCB 399
Boulder, CO 80309

[2]National Park Service
Geologic Resources Division
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Lakewood, CO 80235

[3]National Park Service
Climate Change Response Program
131 Mulford Hall
University of California
Berkeley, CA 94720-3114

[4]National Park Service
Climate Change Response Program
1201 Oakridge Drive, #150
Fort Collins, CO 80525

May 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Caffrey, M. A., R. L. Beavers, P. Gonzalez, and C. Hawkins-Hoffman. 2017. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2017/1425. National Park Service, Fort Collins, Colorado.

Comment [HCH2]: Remove hyphen

NPS 999/137852, May 2017

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Photo 1. Looking ~~out~~ towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Comment [HCH3]: Remove "out" (grammatically unnecessary)

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge ~~due to climate change~~ under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Comment [HCH4]: Highlights the order-of-magnitude importance of this issue to the National Park Service

Comment [HCH5]: Suggested revision to respond to comment from the Peer Review Manager (J Gross):

"If you specifically include anthropogenic climate change, then you really need to include ground subsidence due to oil extraction in the Gulf, reduced sediment transport, etc. as all of these factors are very important in specific locations."

Without this addition ("and other factors") this sentence implies that only sea level change and storm surge that may be specifically attributed to anthropogenic climate change present issues to our managers The NPS is responsible for responding to changes in sea level that affect national park resources and infrastructure, from all sources, including anthropogenic climate change and other factors which are important at a local level, and also described in this report

Comment [HCH6]: Editorial *suggestion* to remove b/c is redundant with previous sentence

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Comment [HCH7]: Suggested addition, but optional if this is a stumbling block for some reason

The report is about sea level rise and storm surge It provides definitions for sea level, sea level change, and sea level rise, but never defines storm surge We should include a definition recommended definition provided here from NOAA

Source:
https://www nhc noaa gov/surge/surge_intro pdf

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Recent analyses reveal that the rate of sea level rise in the last century was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet et al. 2017). Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.

The Importance of Understanding Contemporary Sea Level Change for Parks

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite Many are living witness to our national story – true icons of our history (picture #x of Statue of Liberty) But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all

Today's managers of these parks face new challenges -- challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the National Park System Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections

Comment [HCH8]: This is an effective, impactful statement that remains in the context of the long timeline and provides useful information to park educators and interpreters

From USGCRP Climate Science Special Report, 2017 (Sea level rise chapter, Sweet et al 2017):
"Over the last 2,000 years, prior to the industrial era, GMSL exhibited small fluctuations of about ±8 cm (3 inches), with a significant decline of about 8 cm (3 inches) between
the years 1000 and 1400 CE coinciding with about 0 2°C (0 4°F) of global mean cooling 32
The rate of rise in the last century, about 14 cm/century (5 5 inches/century), was greater than during any preceding century in at least 2,800 years (Figure 12 2b) "

Source from which the CSSR derived this information:
Kopp, R E , A C Kemp, K Bittermann, B P Horton, J P Donnelly, W R Gehrels, C C Hay, J X Mitrovica, E D Morrow, and S Rahmstorf, 2016: Temperature-driven global sea-level variability in the Common Era *Proceedings of the National Academy of Sciences,* **113**, E1434-E1441

Citations for Sweet et al and Kopp et al added to Literature Cited

Comment [HCH9]: Recommend placement of this text as an inset box so that it stands apart as a highlight for managers and also does not break the flow of the rest of the text Statue of Liberty photo optional if inclusion of a photo further exacerbates Maria's concerns about "burying" text Final layout experts will do a better job: this is simply an illustration

As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

Suggested revision to these two paragraphs is below. It is appropriate for an NPS report to focus on effects of these major storms on national parks, vs infrastructure in New York City. For example, when Hurricane Sandy struck New York City in 2012 it caused an estimated $19 billion in damage to public and private infrastructure (Tollefson 2013). This single storm cannot be attributed to anthropogenic climate change, but the storm surge occurred over a sea whose level had risen due to climate change (Kemp and Horton 2013). Extreme storms such as Hurricane Sandy have extreme costs. When Hurricane Sandy struck it was estimated to have a return period between a 398 year (Lin et al. 2016) and a 1570 year storm (Sweet et al. 2013). Currently, a 100 year storm surge in New York City could cost $2–5 billion and a 500 year storm surge could cost $5–11 billion (Aerts et al. 2013).

Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding and the permanent loss of land across much of the United States coastline. Increasing sea levels increase the likelihood of another Hurricane Sandy-sized storm surge striking New York City. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

Suggested revision:

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change exacerbates the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline, and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

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[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www.nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contr butions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$\mathrm{a}e = E_0 - e_\mathrm{i} + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address: https://www.nps.gov/subjects/climatechange/sealevelchange htm

The raw IPCC (2013) data can be downloaded using the following link: http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the

respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia

National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms. Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand,

Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of

using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by

explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long "hotspot" along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region's parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents noaa.gov/stations html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www nhc noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site[‡]	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of L berty National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*[‡]	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument[‡]	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park[‡]	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*[‡]	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument[‡]	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument[‡]	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site[‡]	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument[‡]	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*[‡]	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*[‡]	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield[‡]	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve[‡]	Fernandina Beach, FL (8720030)	N	110	0.600

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial[‡]	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve[‡]	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park[‡]	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park‡	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve‡	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site‡	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*‡	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*‡	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park‡	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*‡	Seattle, WA (9447130)	N	109	0.540

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore[‡]	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial[‡]	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*[‡]	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*[‡]	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument[‡]	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*[‡]	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve[‡]	No data	No data	No data	No data

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument‡	No data	No data	No data	No data
	Glacier Bay National Park*‡	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*‡	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park‡	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park‡	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park‡	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park‡	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve‡	Cordova, AK (9454050)	N	43	3.450

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	**Park Unit**	**Year**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of L berty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14‡	0.13	0.12	0.12
		2050	0.24‡	0.23	0.21	0.24
		2100	0.47‡	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14‡	0.13	0.13‡	0.12
		2050	0.25‡	0.24	0.24‡	0.24
		2100	0.50‡	0.54	0.59‡	0.68
	Cape Hatteras National Seashore	2030	0.15‡	0.15	0.15	0.14
		2050	0.26‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Cape Lookout National Seashore§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore[§]	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve[†§]	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway§	2030	0.15‡	0.15	0.15‡	0.14
		2050	0.26‡	0.27	0.26‡	0.28
		2100	0.53‡	0.62	0.66‡	0.79
	Harpers Ferry National Historical Park*§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu'uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve§	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument§	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park†§	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve†	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve†§	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President’s Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey’s Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu’uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, May 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

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102 Re_ Agreement info.pdf

From: Cat Hoffman
To: Dennis, John
Subject: Re: Agreement info
Date: Friday, April 20, 2018 9:31:41 PM

Thanks John. I'm fairly certain that Maria has the agreement— she's mentioned it a couple times during this saga, mainly describing her view that the report was supposed to mirror IPCC.

Sent from my iPhone

On Apr 20, 2018, at 12:50 PM, Dennis, John <john_dennis@nps.gov> wrote:

> Thanks, Cat -
>
> I find noteworthy the following excerpts:
>
> From original task agreement:
>
>> Approximately 105 coastal parks are potentially affected by changing RSL; this number will be higher when potential storm surges are included. To support planning and management decisions, NPS coastal units (including Alaska and the Pacific islands) require better information on potential RSL and storm surge events over the next 40–100 years.
>>
>> NPS and the University of Colorado Boulder will collaborate to develop sea level and storm surge projections. Rising sea levels will compound effects from increased intensity, and possibly frequency, of storms, particularly hurricanes, nor'easters, and typhoons. Phase I of the project will be a service-wide assessment to project the height of relative sea level in each coastal park unit coupled with storm surge projections. Phase II will focus on three pilot parks to develop specific adaptation actions for individual park adaptation strategies. The project will assess multiple time horizons by calculating rates of sea level change by 2050 and 2100, paired with projected storm surge data.
>>
>> Design, develop, and implement sea level change projections for 105 coastal parks. The results of these projections will be detailed in a "Sea level change in the National Park System" report that follows a similar format (i.e. summary for policymakers, technical summary) to current Intergovernmental Panel on Climate Change (IPCC) reports.
>>
>> The purpose of this project is to create sea level and storm surge change projections that will enable the University of Colorado Boulder faculty and students, National Park Service (NPS) staff, as well as other researchers, educators, and the public sector to better understand the potential impact of climate change in the coastal zone in our national parks. Information and data will be collected, stored, archived, analyzed, and disseminated to help foster temporal and spatial analysis at a variety of scales and will be made readily available to the public via wayside exhibits and a University of

Colorado Boulder website. First, a document showing projected rates of sea level and storm surge change will be developed. This data will be shared within the NPS to help guide park planners and managers in 105 coastal parks

To support planning and management decisions, NPS coastal units (including Alaska and the Pacific islands) require better information on potential RSL and storm surge events over the next 40–100 years

Because models of global sea level change cannot include variability within each region, such as beach morphology, rate of isostatic (elevation of the land) change, or the types of engineered structures/barriers that exist; current sea level studies report on a mean global scale (an average rate of sea level change if calculated for the whole world). In addition to local geomorphologic controls, the rate of sea level change also varies temporally, depending on changes in global rates of carbon dioxide (CO2) emissions, ocean response (lag) time between initial warming and associated glacial melting and thermal expansion, and the weakening of ocean currents. Coastal flooding will increase over coming decades, particularly during storm seasons when projected increases in storm intensity and possibly frequency will further compound the impact of changing RSL. Using only projected rises in RSL without storm surge data misses much information required for contingency planning and sensitivity analyses. In addition to RSL rise, the scientific literature also indicates that storm (particularly hurricane) intensity has increased over the past 35 year and will likely continue to increase in the future. Given recent impacts of Hurricanes Katrina (2005), Irene (2011), and Sandy (2012) on NPS units, we aim to examine how the extent of storm surges will change when sea levels change over this century

Identify and incorporate the latest available data regarding local geomorphic controls to provide park managers with a more accurate projection of RSL. This information can support park planning (including foundation documents), as well as interpretive materials and partnership activities. The project will also canvas the literature and record data gaps where these exist regarding physiographic or isostasy information needed for each park. By combining global projections of RSL for 2050 and 2100 with more localized projections of storm surges (based on the NOAA models) we will provide coastal parks with a range of expected RSL for their area over the next century.

A comprehensive "Sea level change in the National Park System" report that follows a similar format (i.e. summary for policymakers, technical summary) to current IPCC reports. This report will not only provide guidance for natural and cultural resource managers but will also contain language for policy makers and facilities and planning. In addition to these sections the report will include the following:

I'm not going to look at the modifications at this time. I think these excerpts make clear that the focus of the work and ensuing reports and other products is park managers and that sea level rise and storm effects respond not only to climate change but to other factors not related to climate change. Do you know whether Maria has a copy of the task agreement an associated statement of work and is aware of what it says regarding these elements?

Thanks.

JGD

On Fri, Apr 20, 2018 at 2:00 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> attached
>
> --
> ***Cat Hawkins Hoffman***
> **National Park Service**
>
> **Chief, NPS Climate Change Response Program**
> **1201 Oakridge Drive**
> **Fort Collins, CO 80525**
> **cat_hawkins_hoffman@nps.gov**
> **office: 970-225-3567**
> **cell: 970-631-5634**
>
> Adaptation websites: public, NPS managers
> Climate Change Response Resources

--
John G. Dennis
Deputy Chief Scientist
National Park Service
1849 C Street, N.W. Room 2648
Washington, DC 20240
202-513-7174
john_dennis@nps.gov

104 Thanks - recommendations re publication of sea ....pdf

From:	Patrick Gonzalez NPS
To:	Maria Caffrey U Colorado
Subject:	Thanks - recommendations re publication of sea level report
Date:	Monday, April 23, 2018 11:41:20 AM

Thanks, Maria.

Patrick

....
Patrick Gonzalez, Ph.D.

Principal Climate Change Scientist
Natural Resource Stewardship and Science
U.S. National Park Service

Associate Adjunct Professor, Department of Environmental Science, Policy, and Management
Affiliate, Institute for Parks, People, and Biodiversity
University of California, Berkeley

https://ourenvironment.berkeley.edu/people/patrick-gonzalez

patrick_gonzalez@nps.gov
+1 (510) 643-9725
131 Mulford Hall, Berkeley, CA 94720-3114 USA
....

From: Maria Caffrey <maria.caffrey@colorado.edu>
Subject: Fw: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report
Date: April 23, 2018 at 10:34:43 AM PDT
To: Patrick Gonzalez NPS <patrick_gonzalez@nps.gov>

FYI - just put it in writing that your name needs to be removed.

Maria Caffrey, PhD
Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Maria Caffrey
Sent: Monday, April 23, 2018 11:28 AM
To: Hoffman, Cat
Cc: John Dennis; John Gross; Brendan Moynahan; Rebecca_Beavers@nps.gov; Joseph G Rosse
Subject: Re: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report

Ok. Great. One very important thing that needs to be done during 508 formatting is that Patrick's name and affiliation needs to be removed. I just spoke to him to let him know that we have reached a resolution. He would still like to have his name removed.

Thanks,

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UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Hoffman, Cat <cat_hawkins_hoffman@nps.gov>

Sent: Monday, April 23, 2018 10:58:32 AM
To: Maria Caffrey
Cc: John Dennis; John Gross; Brendan Moynahan; Rebecca_Beavers@nps.gov; Joseph G Rosse
Subject: Re: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report

Thanks for your response. The intent was to use a photo of Sandy-damage to STLI, but will leave it to the layout experts to see if this even fits. We'll get this into 508 formatting.

Cat

On Mon, Apr 23, 2018 at 10:20 AM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:

> Cat,
>
> I have taken the time to review what you sent. The text box was a great idea. It all works for me. One minor thing -- I don't think the statue of liberty figure is necessary unless you have a picture showing the damage done to it by Sandy or something. A regular picture of the statue of liberty seems unnecessary.
>
> Apart from that, I think it looks good.
>
> Thanks,
>
> Maria Caffrey, PhD
> Research Associate
> Geological Sciences,
> UCB 399,
> 2200 Colorado Ave,
> Boulder, CO 80309
>
> Office: (303) 969-2097
> Cell: (303) 518-3419
> Web: mariacaffrey.com
>
> ---
>
> **From:** Maria Caffrey
> **Sent:** Friday, April 20, 2018 3:19:51 PM
> **To:** Hoffman, Cat; John Dennis; John Gross
> **Cc:** Brendan Moynahan; Rebecca_Beavers@nps.gov; Joseph G Rosse; Denitta Ward
> **Subject:** Re: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report
>
> Cat,
>
> I just took a quick flick through it. I think this might work!!!
>
> I'm look at it on my phone at the moment, so is it ok if I wait until Monday to reply to you?
>
> I really appreciate you taking the time to try to make this work.
>
> Maria Caffrey, PhD
> Research Associate
> Geological Sciences,
> UCB 399,
> 2200 Colorado Ave,
> Boulder, CO 80309
>
> Office: (303) 969-2097
> Cell: (303) 518-3419
> Web: mariacaffrey.com
>
> ---
>
> **From:** Hoffman, Cat <cat_hawkins_hoffman@nps.gov>
> **Sent:** Friday, April 20, 2018 3:10:24 PM
> **To:** Maria Caffrey; John Dennis; John Gross
> **Cc:** Brendan Moynahan; Rebecca_Beavers@nps.gov; Joseph G Rosse; Denitta Ward
> **Subject:** Re: [EXTERNAL] Re: Moynahan recommendations re publication of sea level report
>
> Maria -- I appreciate your suggested changes. I believe we can find an acceptable solution to the "two introductory paragraphs" through use of formatting with an inset text box. In addition to the introductory text, it is reasonable for the hurricane discussion in the introduction to focus on national parks. I have provided suggested text for edits in the document, attached. I would ask that you not share this outside of this group; thank you.
>
> I sincerely want you to remain as an author on the report; please know that. It is important for you to receive due credit for this work as an author.
>
> Cat
>
> On Fri, Apr 20, 2018 at 9:20 AM, Maria Caffrey <maria.caffrey@colorado.edu> wrote:
>
> > Brendan,

Thank you for letting me know about this change in circumstance. It is unfortunate that the lines of communication have broken down so much. I do feel it necessary to correct one important detail in your email regarding my voting on version preferences. In my email to you I said that executive summary A was the only executive summary I could accept, but I did not say that I found introduction A acceptable. In fact, I did not find any of the introductions acceptable.

I have worked hard at trying to find a middle ground in this situation. I thought that I had made it clear that I could not accept any version of text that leads with the text that Cat wrote. I apologize if I did not emphasize that enough. I have attached an example of the kind of placement of the text that I could find acceptable.

Finally, I would like to say that while I can see why you suggested Rebecca as editor, I am afraid I would have to state that I cannot follow that suggestion. I understand from your perspective based on Rebecca's voting choices that she seems to be the logical choice, but I feel she has too many conflicts of interest in this case that should remove her from consideration. I think it would be better to involve someone that all co-authors can agree to make an impartial decision. Perhaps the recently retired former editor of Park Science Jeff Selleck? I would also like to suggest that we do not use the term "editor" because that term could have a bearing on how the report is cited.

Many thanks,

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Research Associate
Geological Sciences,
UCB 399,
2200 Colorado Ave,
Boulder, CO 80309

Office: (303) 969-2097
Cell: (303) 518-3419
Web: mariacaffrey.com

From: Brendan Moynahan <brendan_moynahan@nps.gov>
Sent: Thursday, April 19, 2018 6:59:34 PM
To: Dennis John; john_gross@nps.gov
Cc: Maria Caffrey; Rebecca_Beavers@nps.gov; cat_hawkins_hoffman@nps.gov; Joseph G Rosse; Denitta Ward
Subject: Moynahan recommendations re publication of sea level report

I'm writing you, John Gross as Peer Review Manager for this report, and you, John Dennis, as Deputy Chief Scientist. I have copied the three coauthors to the report and two administrators for the University of Colorado-Boulder.

I have attached my documentation of my assistance to this project since April 2, along with my recommendation for the path forward. I have also attached a file that is referenced in the first document.

Please forgive the informality of the memo; I'm presently on travel and am working across mobile devices.

Please let me know if I can provide any further assistance.

Regards and sincerely,

Brendan

Sent from my mobile device

--
Cat Hawkins Hoffman
National Park Service

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--
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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

105 Re_ acknowledgment for Patrick’s contribution.pdf

From:	Caffrey, Maria
To:	Patrick Gonzalez NPS
Subject:	Re: acknowledgment for Patrick''s contribution
Date:	Monday, April 23, 2018 2:13:42 PM

Great. That's what I figured, but I thought I should try to add something more seeing as Cat asked for it.

On Mon, Apr 23, 2018 at 2:10 PM, Patrick Gonzalez NPS <patrick_gonzalez@nps.gov> wrote:

> Hi Maria,
>
> The first mention (part of science advisory team) is OK.
>
> I appreciate the thought, but don't want that other sentence in red (who acted…)
>
> So, it looks like no change is needed to the existing text.
>
> Thanks,
>
> Patrick
>
> ———
>
> **From:** "Caffrey, Maria" <maria_caffrey@partner.nps.gov>
> **Subject: Re: acknowledgment for Patrick's contribution**
> **Date:** April 23, 2018 at 12:42:11 PM PDT
> **To:** Patrick Gonzalez <patrick_gonzalez@nps.gov>
>
> Hi Patrick,
>
> I have copied the acknowledgments section below. You were already acknowledged as a member of the science team. I added some extra text in red, but maybe it's overkill? Feel free to edit any way you would like.
>
> This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.
>
> We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander

designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Many thanks to Patrick Gonzalez who acted as the project's task agreement manager(?) and who spent a significant amount of time editing and reviewing the document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

On Mon, Apr 23, 2018 at 1:17 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria -- I just spoke with Patrick to ask if he would want to be included in the acknowledgments, recognizing the contributions he made to this work.
>
> He suggested that if you want to write an acknowledgment of his contribution, he would review it and advise whether he would like to include that in the report.
>
> If it's possible for the two of you to work this out and let me know this afternoon, I would very much appreciate it.
>
> thank you.
>
> Cat
>
> --
> *Cat Hawkins Hoffman*
> **National Park Service**
>
> **Chief, NPS Climate Change Response Program**
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> **Fort Collins, CO 80525**
> **cat_hawkins_hoffman@nps.gov**
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> Adaptation websites: public, NPS managers
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--
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Office: 303-969-2097
Cell: 303-518-3419

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--
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www.nps.gov/subjects/wetlands

106 Re_ acknowledgment for Patrick’s contribution(1).pdf

From: Hoffman, Cat
To: Caffrey, Maria
Cc: Patrick Gonzalez
Subject: Re: acknowledgment for Patrick''s contribution
Date: Monday, April 23, 2018 2:17:11 PM

Ah right; got it. Thanks.

Cat

On Mon, Apr 23, 2018 at 2:15 PM, Caffrey, Maria <maria_caffrey@partner.nps.gov> wrote:

> Hi Cat,
>
> Patrick and I just shared a few communications regarding the acknowledgements. He was already listed in the acknowledgments as a member of the science team. He said it's fine if we just keep it as that. So no need to make any further changes to the acknowledgments.
>
> Thanks,
>
> M.
>
> On Mon, Apr 23, 2018 at 1:17 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:
>
>> Hi Maria -- I just spoke with Patrick to ask if he would want to be included in the acknowledgments, recognizing the contributions he made to this work.
>>
>> He suggested that if you want to write an acknowledgment of his contribution, he would review it and advise whether he would like to include that in the report.
>>
>> If it's possible for the two of you to work this out and let me know this afternoon, I would very much appreciate it.
>>
>> thank you.
>>
>> Cat
>>
>> --

>> ***Cat Hawkins Hoffman***
>> **National Park Service**
>>
>> **Chief, NPS Climate Change Response Program**
>> **1201 Oakridge Drive**
>> **Fort Collins, CO 80525**
>> **cat_hawkins_hoffman@nps.gov**
>> **office: 970-225-3567**
>> **cell: 970-631-5634**

>>
>> Adaptation websites: public, NPS managers
>> Climate Change Response Resources

> --
> Maria Caffrey, Ph.D.
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> Office: 303-969-2097
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>
> www.nps.gov/subjects/wetlands

--
Cat Hawkins Hoffman
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cell: 970-631-5634

Adaptation websites: public, NPS managers
Climate Change Response Resources

107 Fwd_ acknowledgment for Patrick’s contribution.pdf

From:	Hoffman, Cat
To:	Larry Perez
Subject:	Fwd: acknowledgment for Patrick"s contribution
Date:	Monday, April 23, 2018 2:17:24 PM

---------- Forwarded message ----------
From: **Caffrey, Maria** <maria_caffrey@partner.nps.gov>
Date: Mon, Apr 23, 2018 at 2:15 PM
Subject: Re: acknowledgment for Patrick's contribution
To: "Hoffman, Cat" <cat_hawkins_hoffman@nps.gov>
Cc: Patrick Gonzalez <patrick_gonzalez@nps.gov>

Hi Cat,

Patrick and I just shared a few communications regarding the acknowledgements. He was already listed in the acknowledgments as a member of the science team. He said it's fine if we just keep it as that. So no need to make any further changes to the acknowledgments.

Thanks,

M.

On Mon, Apr 23, 2018 at 1:17 PM, Hoffman, Cat <cat_hawkins_hoffman@nps.gov> wrote:

> Hi Maria -- I just spoke with Patrick to ask if he would want to be included in the acknowledgments, recognizing the contributions he made to this work.
>
> He suggested that if you want to write an acknowledgment of his contribution, he would review it and advise whether he would like to include that in the report.
>
> If it's possible for the two of you to work this out and let me know this afternoon, I would very much appreciate it.
>
> thank you.
>
> Cat
>
> --
> ***Cat Hawkins Hoffman***
> **National Park Service**
>
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108 Unnamed.pdf attached.pdf

From:	Hoffman, Cat
To:	Jennifer Wyse
Subject:	.pdf attached
Date:	Monday, April 23, 2018 3:12:19 PM
Attachments:	2018-04-23 Caffrey et al Sea Level Change Report - Agreed Change .pdf

Hi Jen -- here is the .pdf of the report.

Content is ready for review. Two things remaining that will be done during final formatting for 508:

- Fagan will assign the NRR series numbers (now shown as XXXX/XXXX)
- Several of the figures shown as left-aligned will be centered on the page.

I am preparing the final administrative review form for Guy to sign.

Cat

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108 1 Attachment 2018-04-23 Caffrey et al Sea Level Change Repo.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

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April 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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NPS 999/137852, April 2018

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Photo 1. Looking towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Recent analyses reveal that the rate of sea level rise in the last century was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet et al. 2017) Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.

The Importance of Understanding Contemporary Sea Level Change for Parks

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (Photo 3). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges—challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the National Park System. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change exacerbates the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline, and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Photo 3. A National Park Service ranger surveys damage from the aftermath of Hurricane Sandy at Statue of Liberty National Monument, NY. Photo credit: National Park Service.

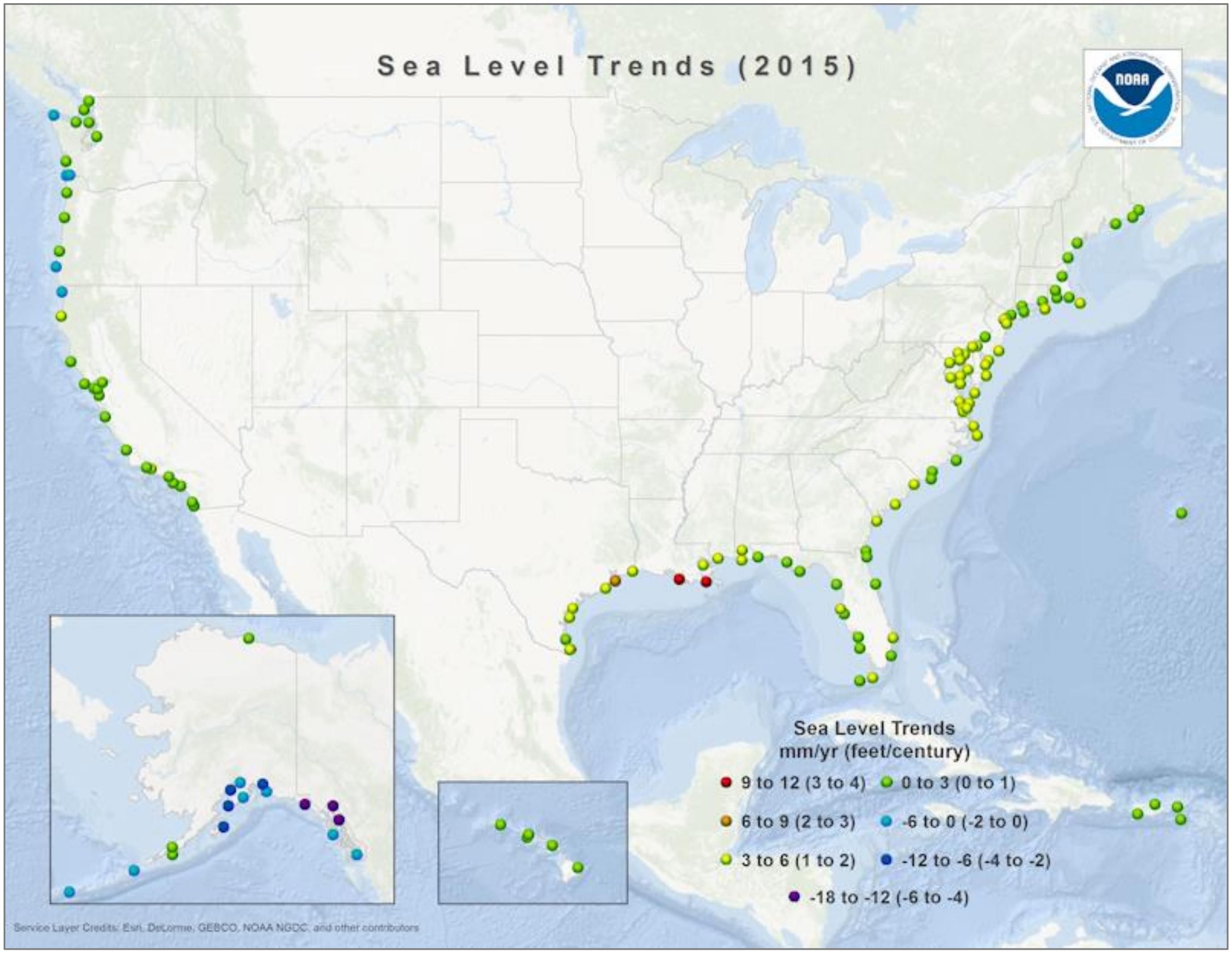

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

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[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of

maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

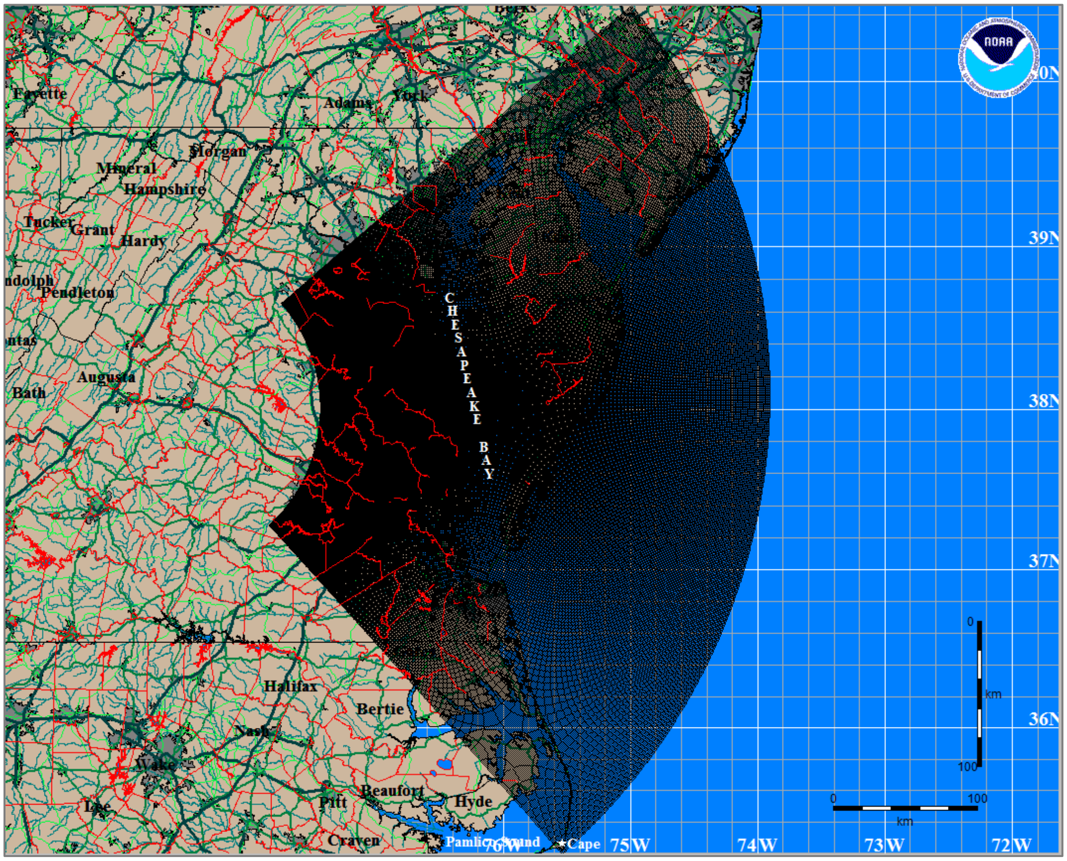

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; ae is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address: https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link: http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

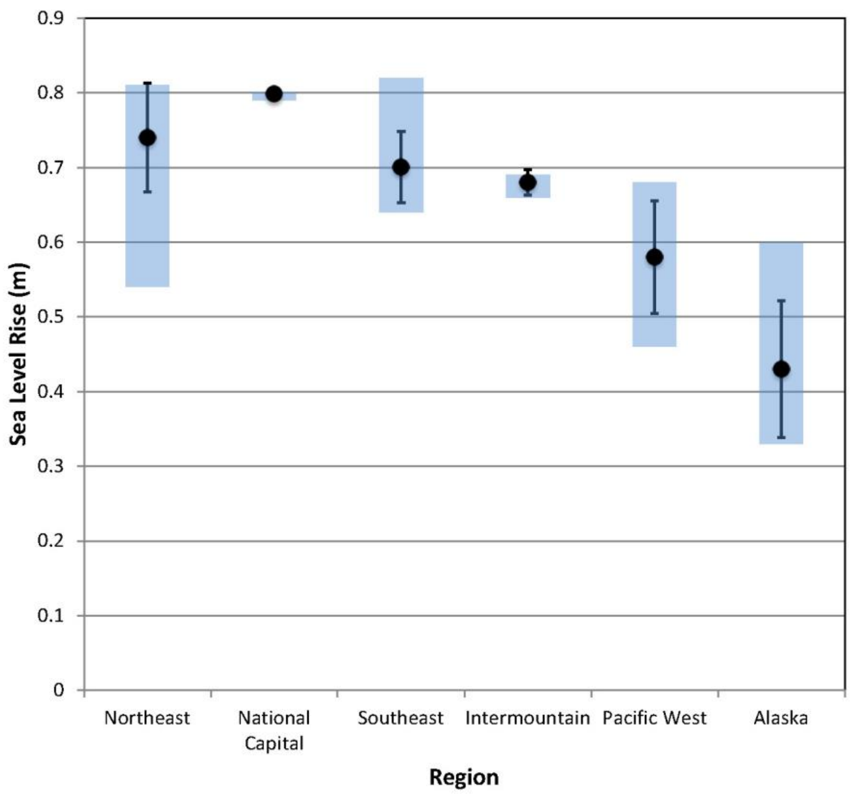

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National

Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

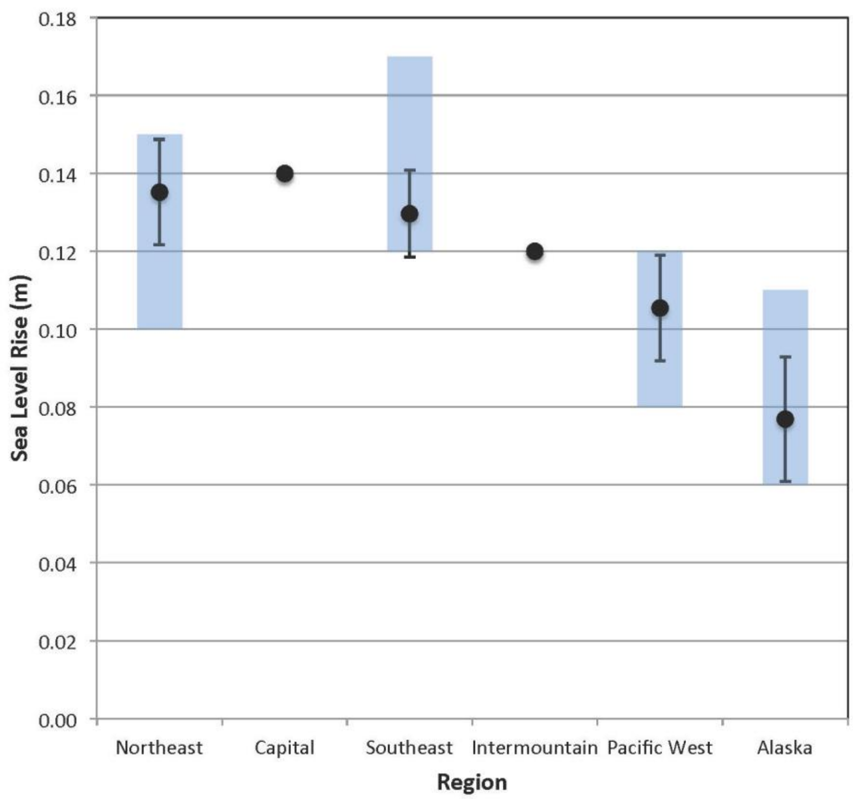

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

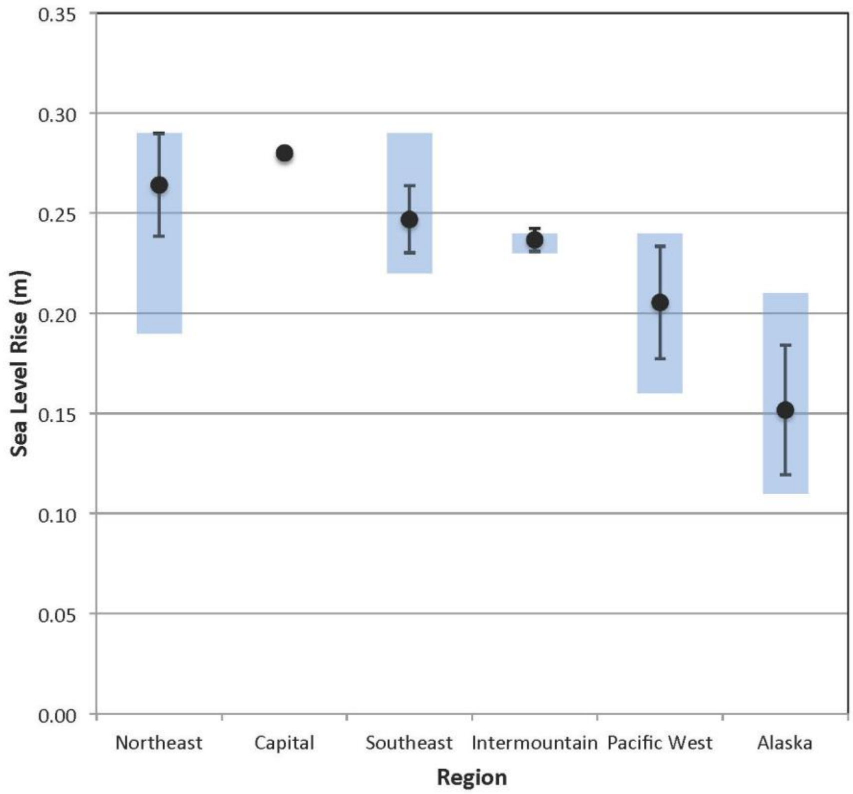

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

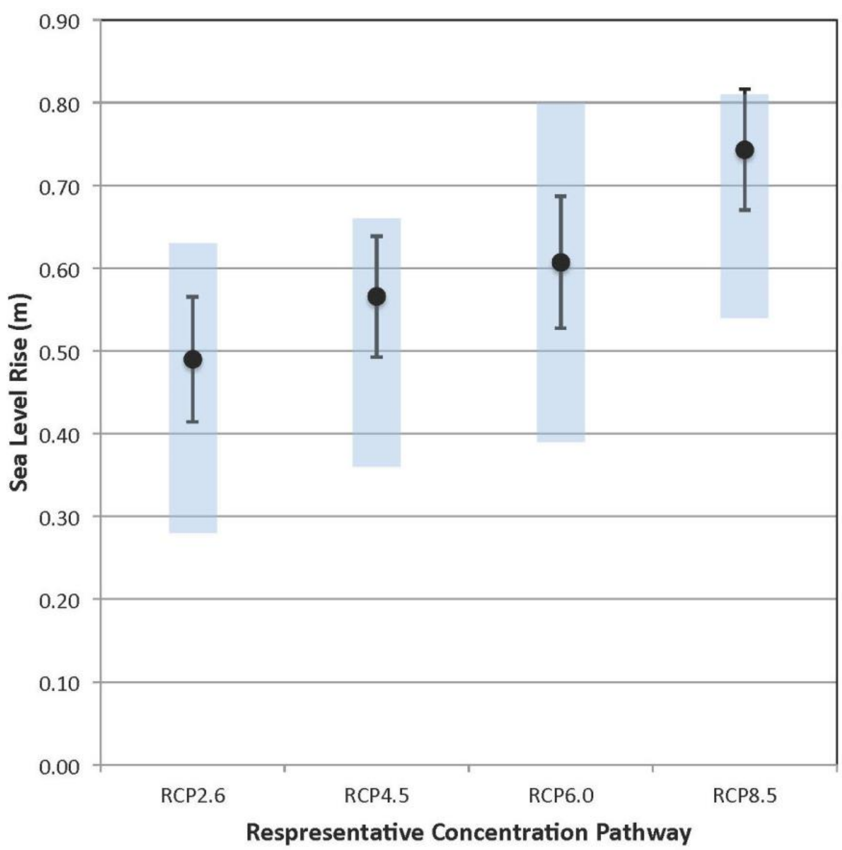

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

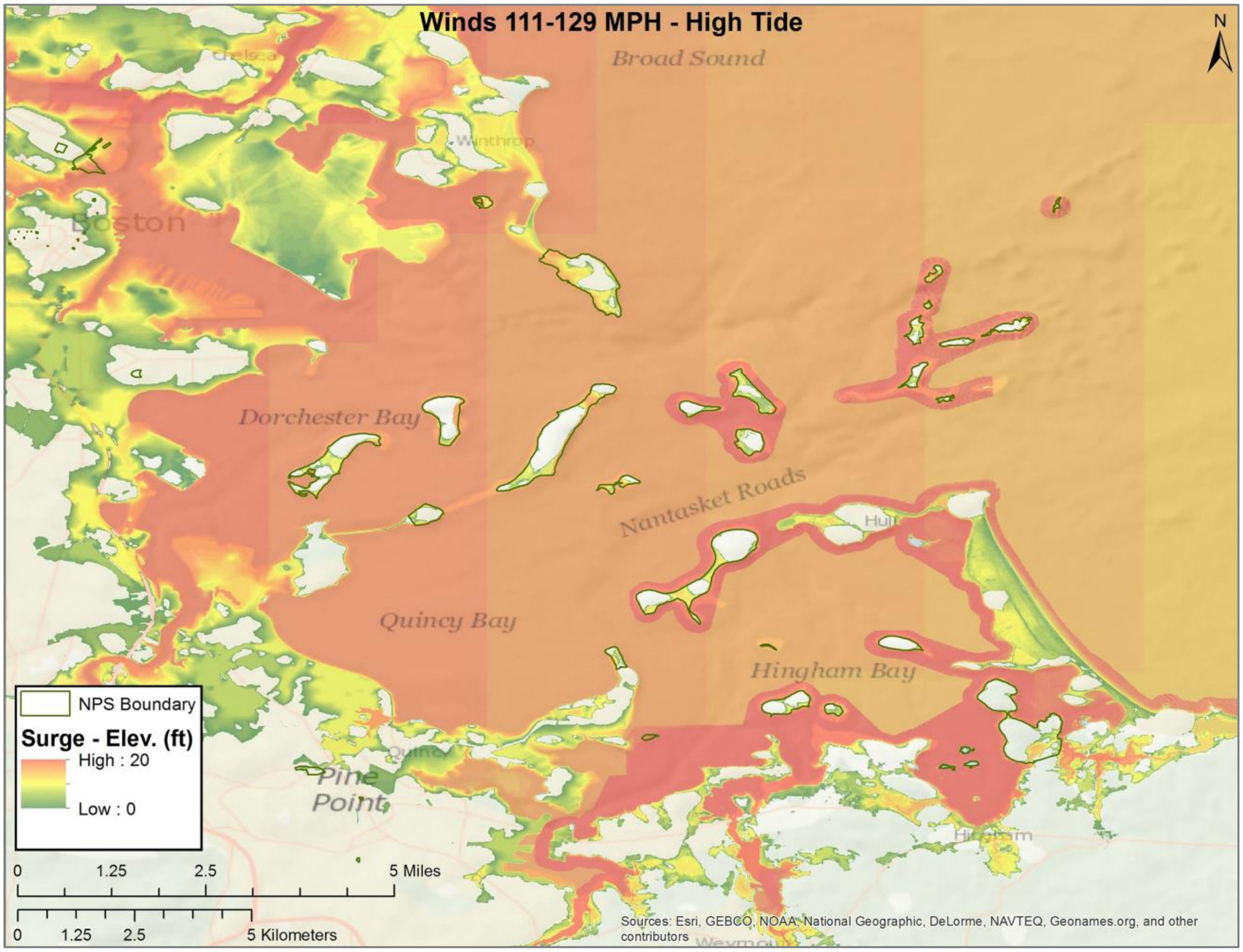

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms.

Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

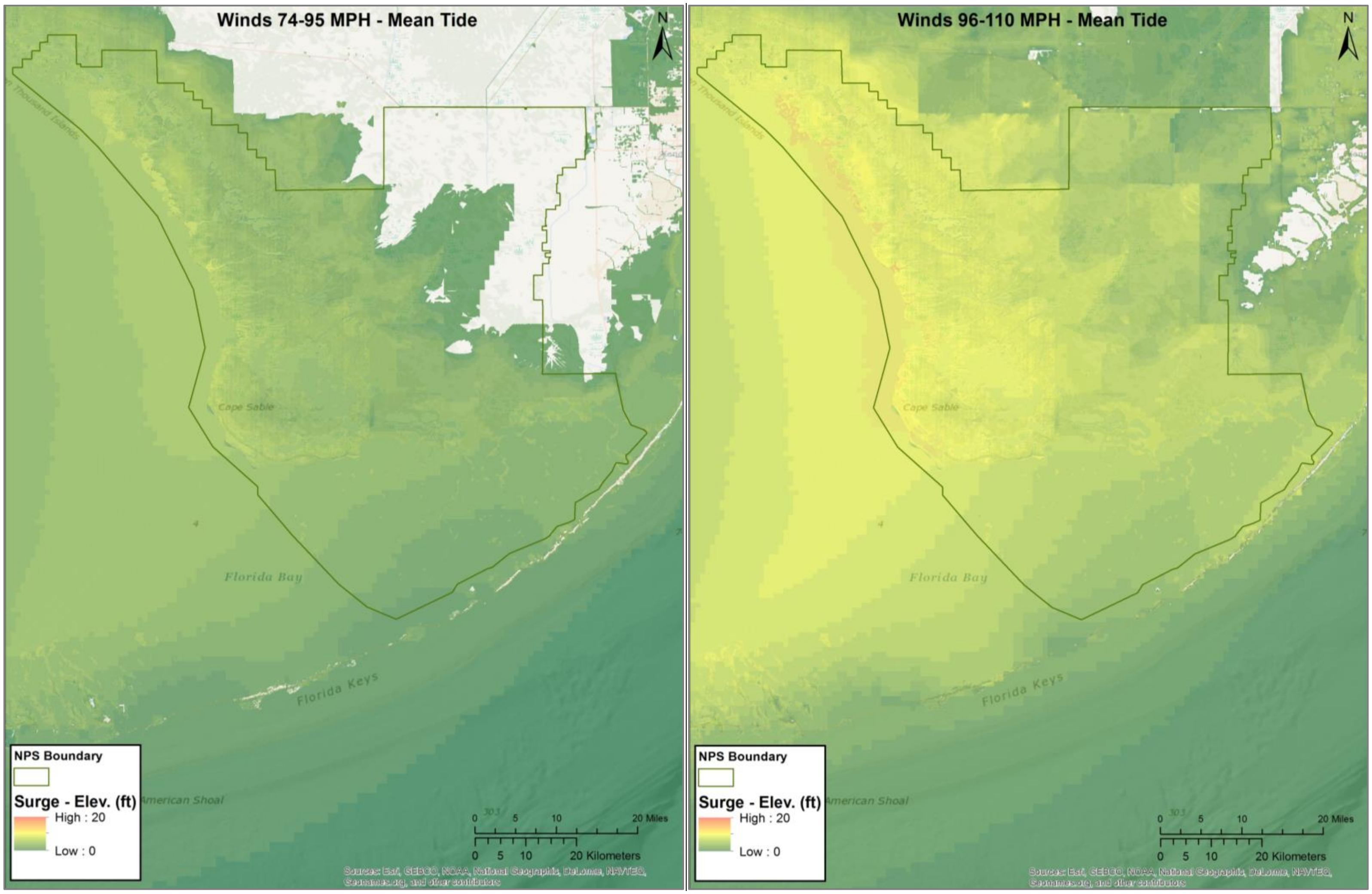

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

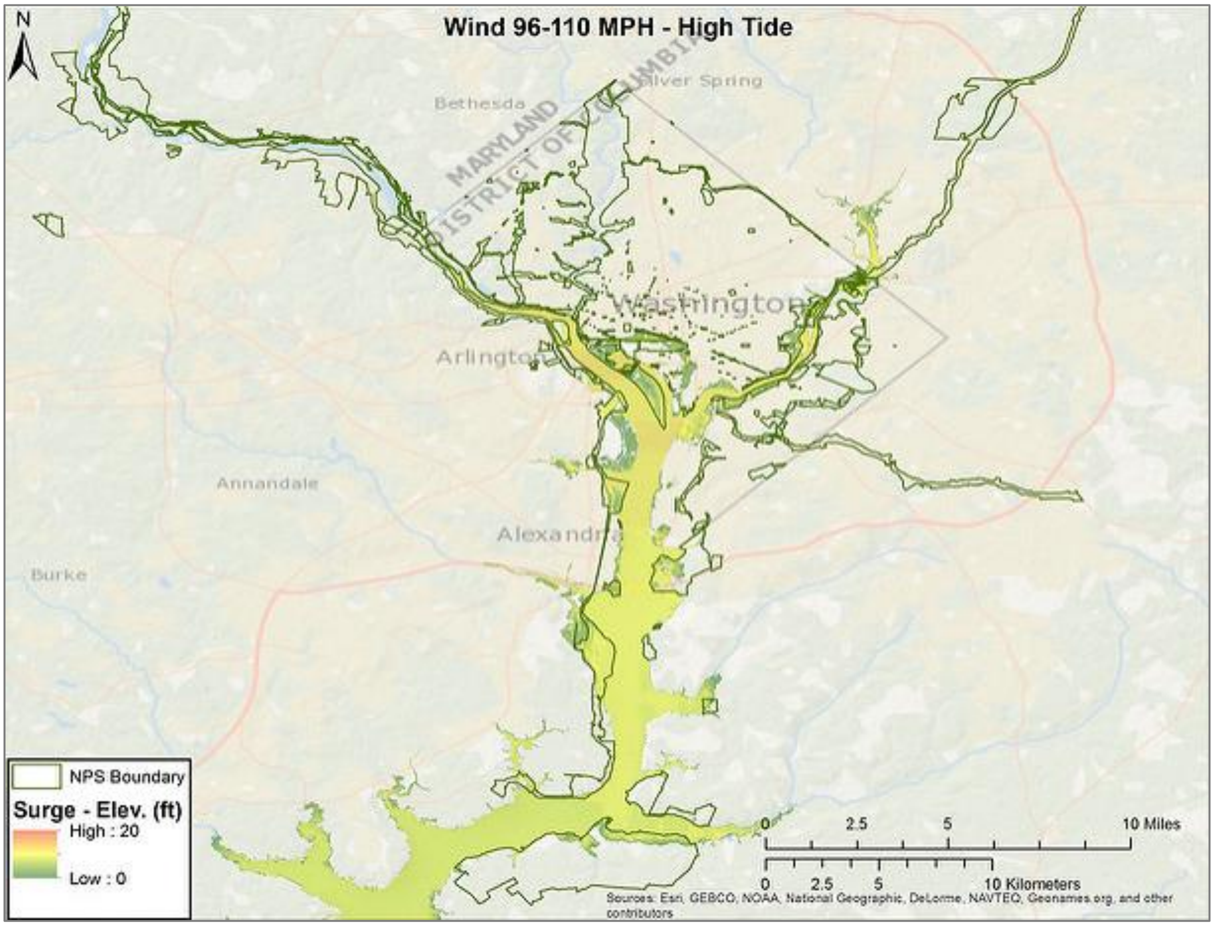

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

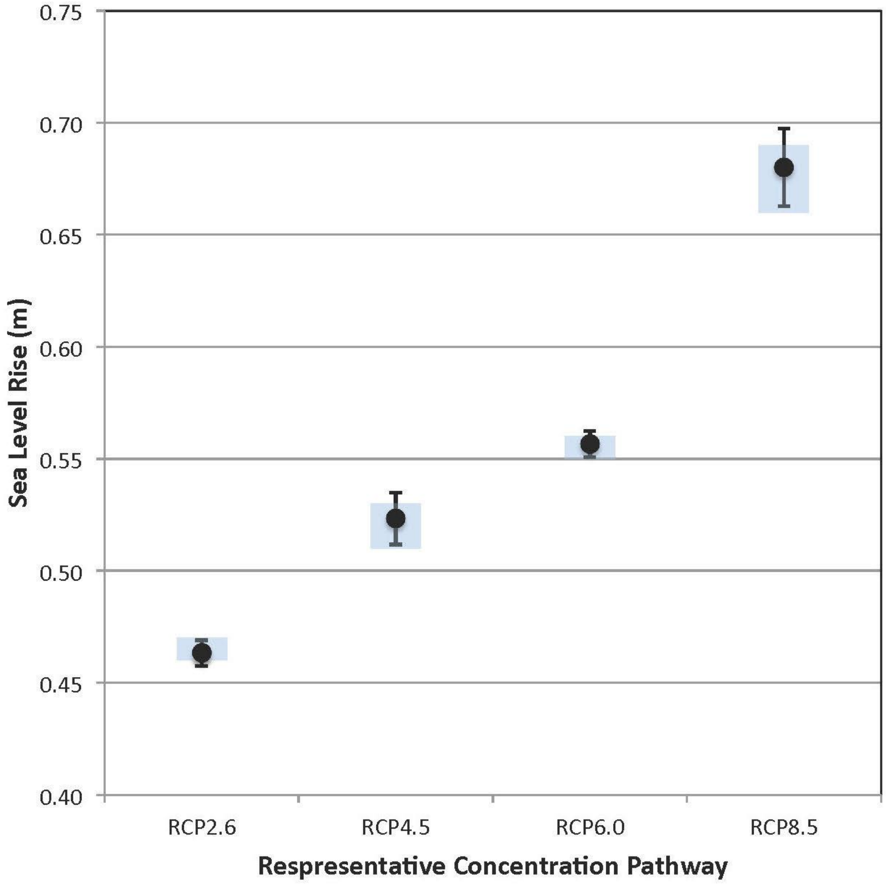

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

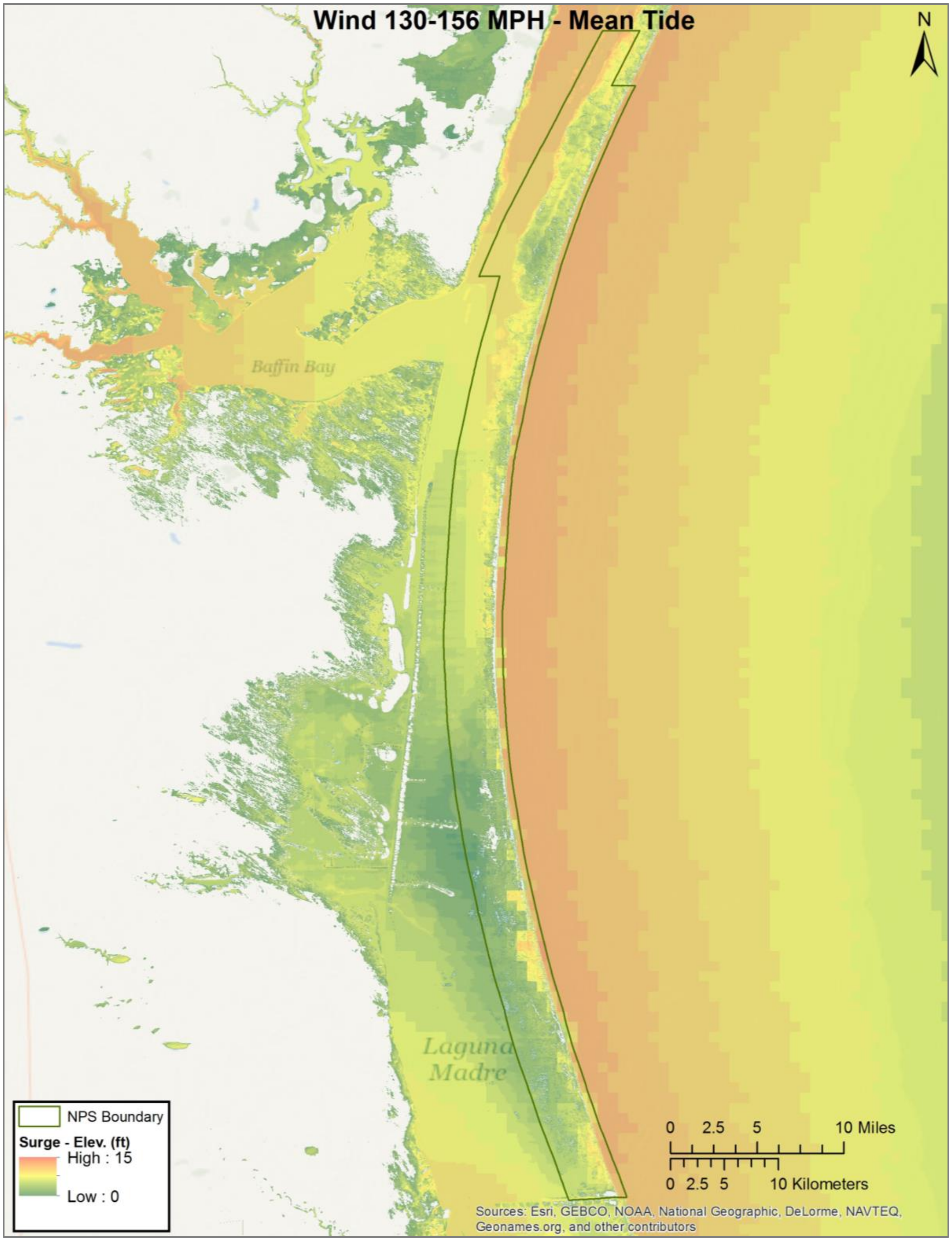

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

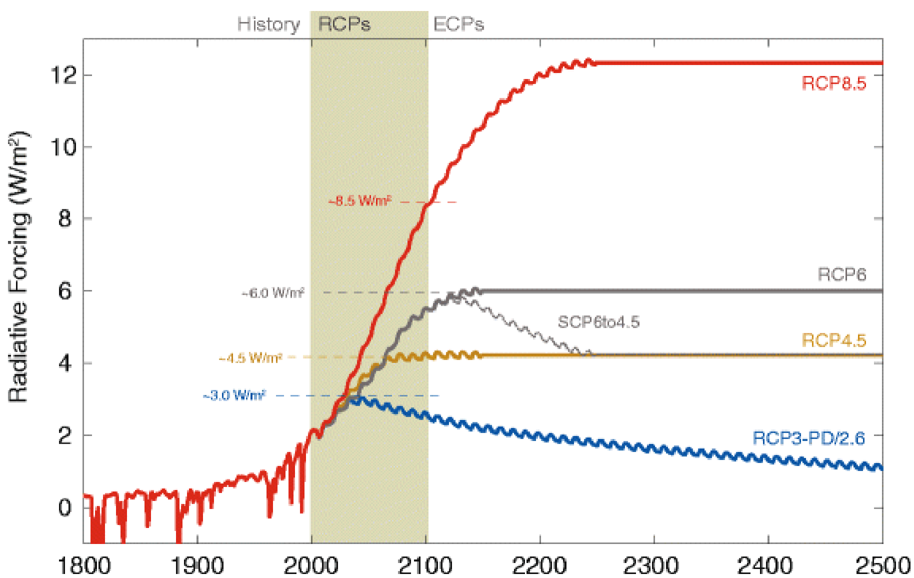

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long

“hotspot” along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region’s parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore[‡]	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site‡	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site‡	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument‡	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*‡	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*‡	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve‡	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield‡	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park‡	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve‡	Fernandina Beach, FL (8720030)	N	110	0.600

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial[‡]	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve‡	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park‡	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park‡	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve‡	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site‡	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*‡	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*‡	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park‡	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*‡	Seattle, WA (9447130)	N	109	0.540

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore‡	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial‡	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*‡	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*‡	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument‡	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*‡	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve‡	No data	No data	No data	No data

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument‡	No data	No data	No data	No data
	Glacier Bay National Park*‡	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*‡	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park‡	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park‡	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park‡	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park‡	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve‡	Cordova, AK (9454050)	N	43	3.450

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Saugus Iron Works National Historic Site	2030	0.11‡	0.11	0.11‡	0.11
		2050	0.19‡	0.2	0.20‡	0.22
		2100	0.37‡	0.45	0.50‡	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve§	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14[‡]	0.13	0.12	0.12
		2050	0.24[‡]	0.23	0.21	0.24
		2100	0.47[‡]	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14[‡]	0.13	0.13[‡]	0.12
		2050	0.25[‡]	0.24	0.24[‡]	0.24
		2100	0.50[‡]	0.54	0.59[‡]	0.68
	Cape Hatteras National Seashore	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.26[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Cape Lookout National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve†§	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway[§]	2030	0.15[‡]	0.15	0.15[‡]	0.14
		2050	0.26[‡]	0.27	0.26[‡]	0.28
		2100	0.53[‡]	0.62	0.66[‡]	0.79
	Harpers Ferry National Historical Park*[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park[§]	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park[§]	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu'uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area[§]	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve[§]	2030	0.09[‡]	0.09	0.09	0.09
		2050	0.15[‡]	0.17	0.16	0.18
		2100	0.31[‡]	0.38	0.4	0.51

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve[§]	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument[§]	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park[†§]	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve[†]	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park[§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve[†§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park[*†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park[*†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve[*§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President's Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, April 2018

National Park Service
U.S. Department of the Interior

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National Park Service
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Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

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April 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Photo 1. Looking towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

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This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Recent analyses reveal that the rate of sea level rise in the last century was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet et al. 2017) Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.

The Importance of Understanding Contemporary Sea Level Change for Parks

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (Photo 3). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges—challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the National Park System. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change exacerbates the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline, and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term “flooding” to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. "Inundation" refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska's crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term "sea level change" as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Photo 3. A National Park Service ranger surveys damage from the aftermath of Hurricane Sandy at Statue of Liberty National Monument, NY. Photo credit: National Park Service.

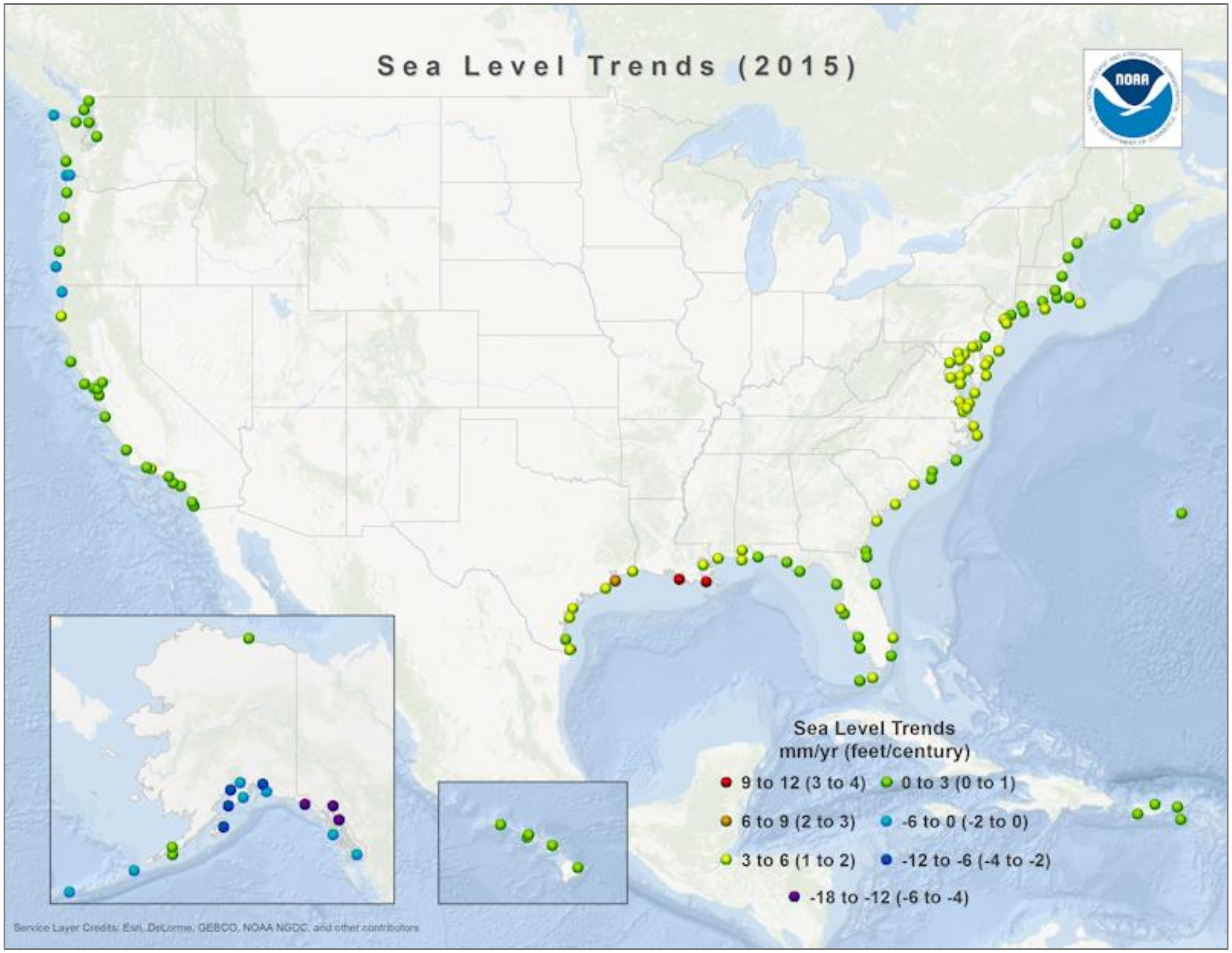

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of

maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

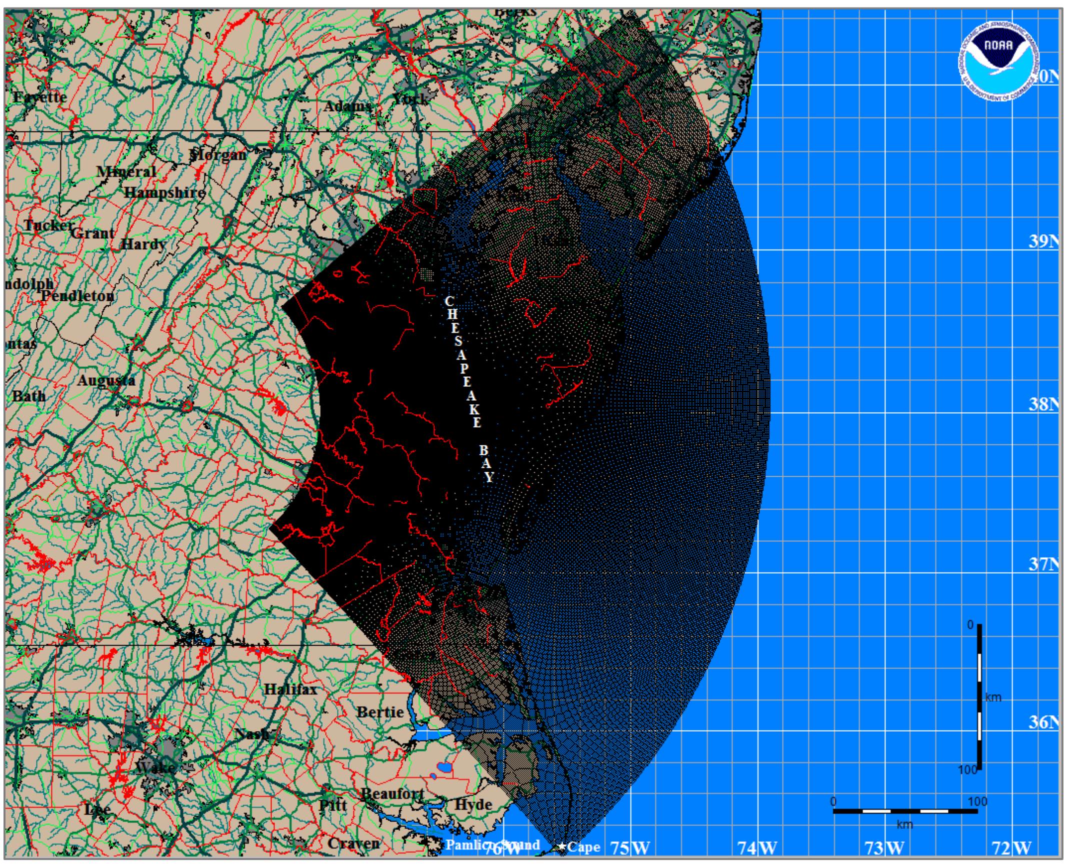

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$a e = E_0 - e_i + R$$

Where; a*e* is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

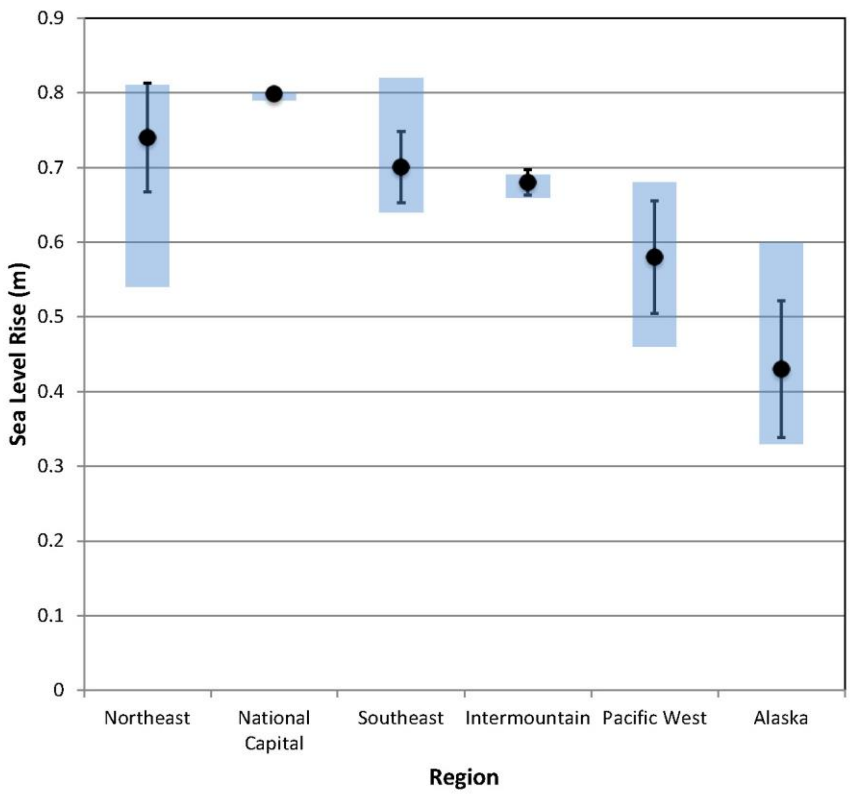

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National

Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

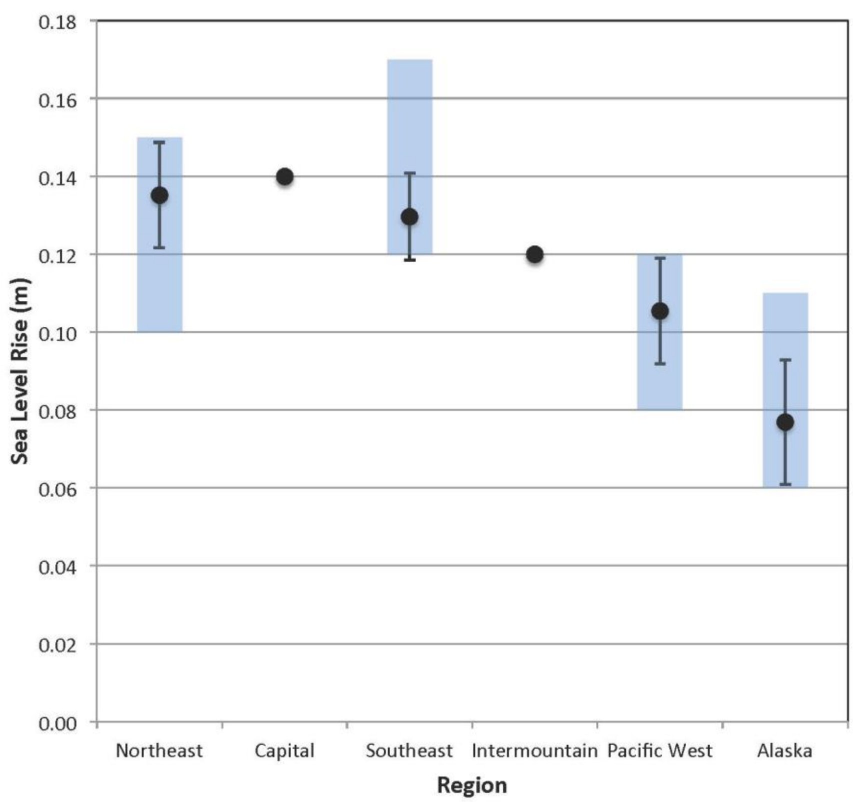

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

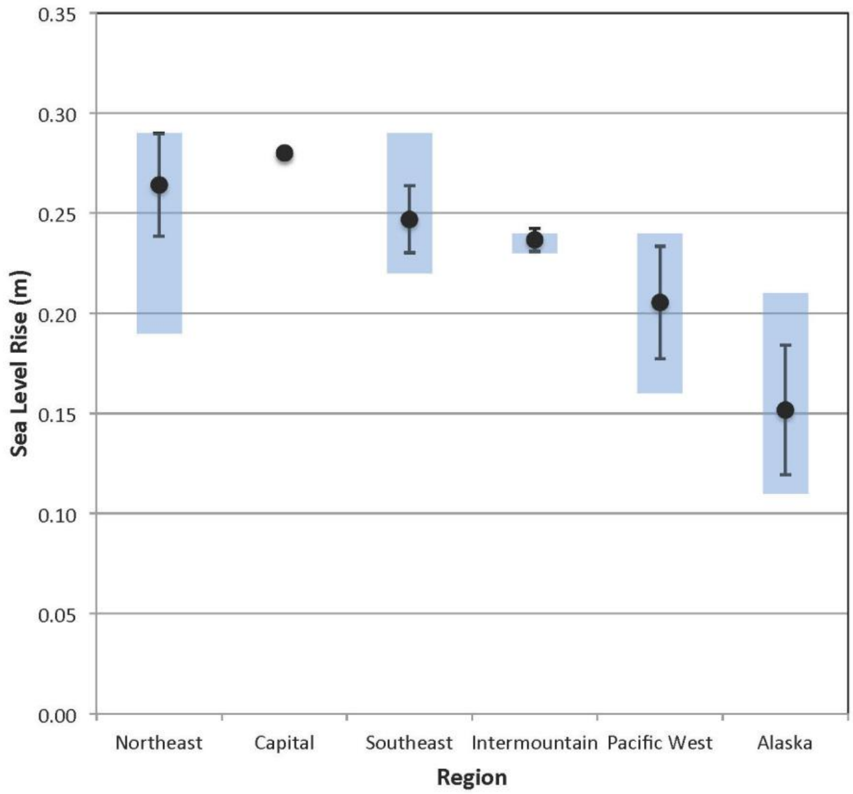

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

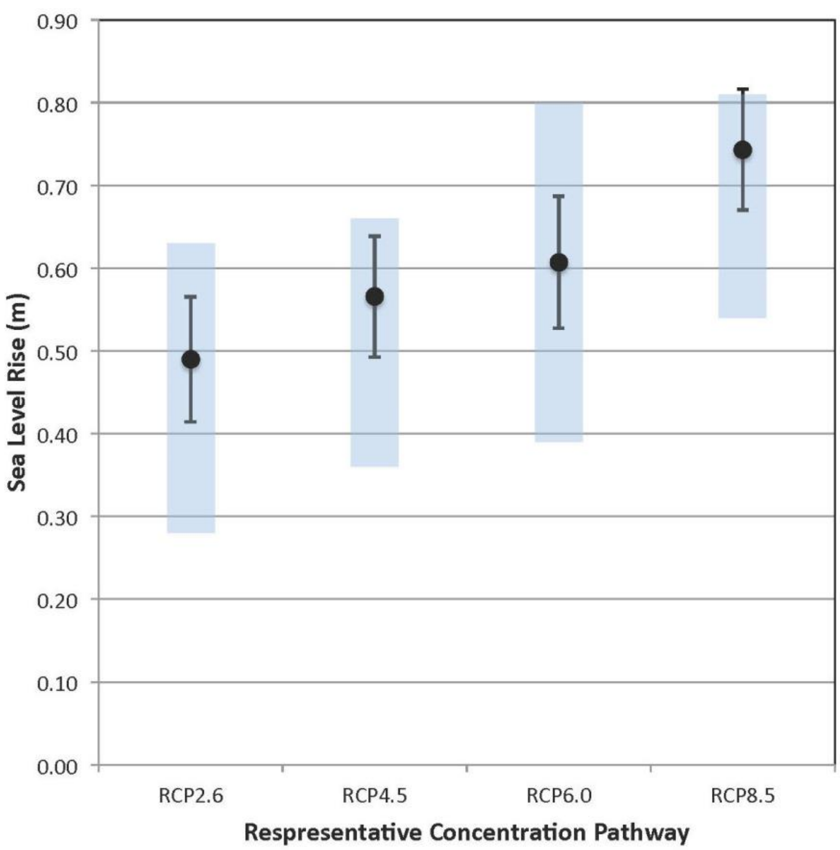

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

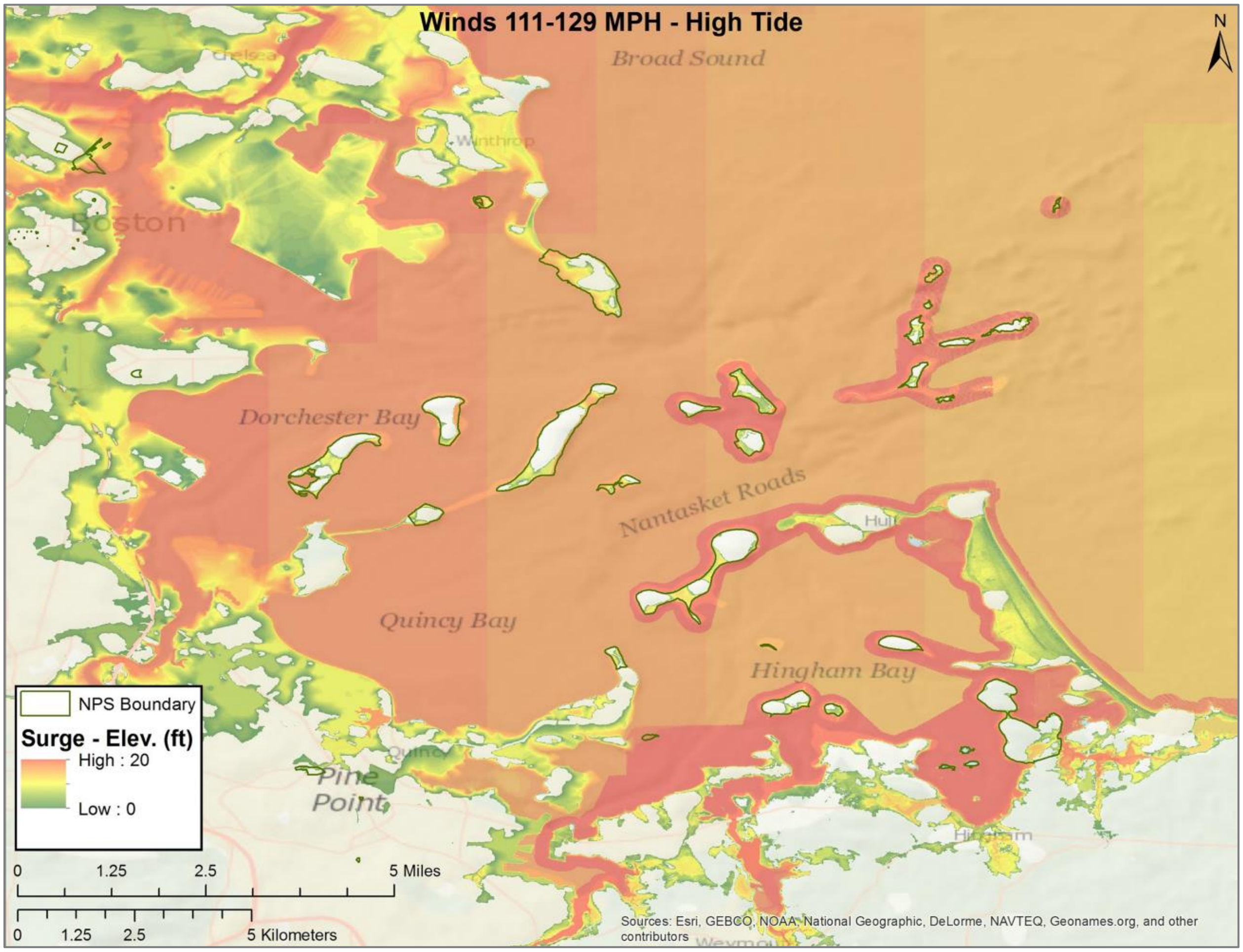

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms.

Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

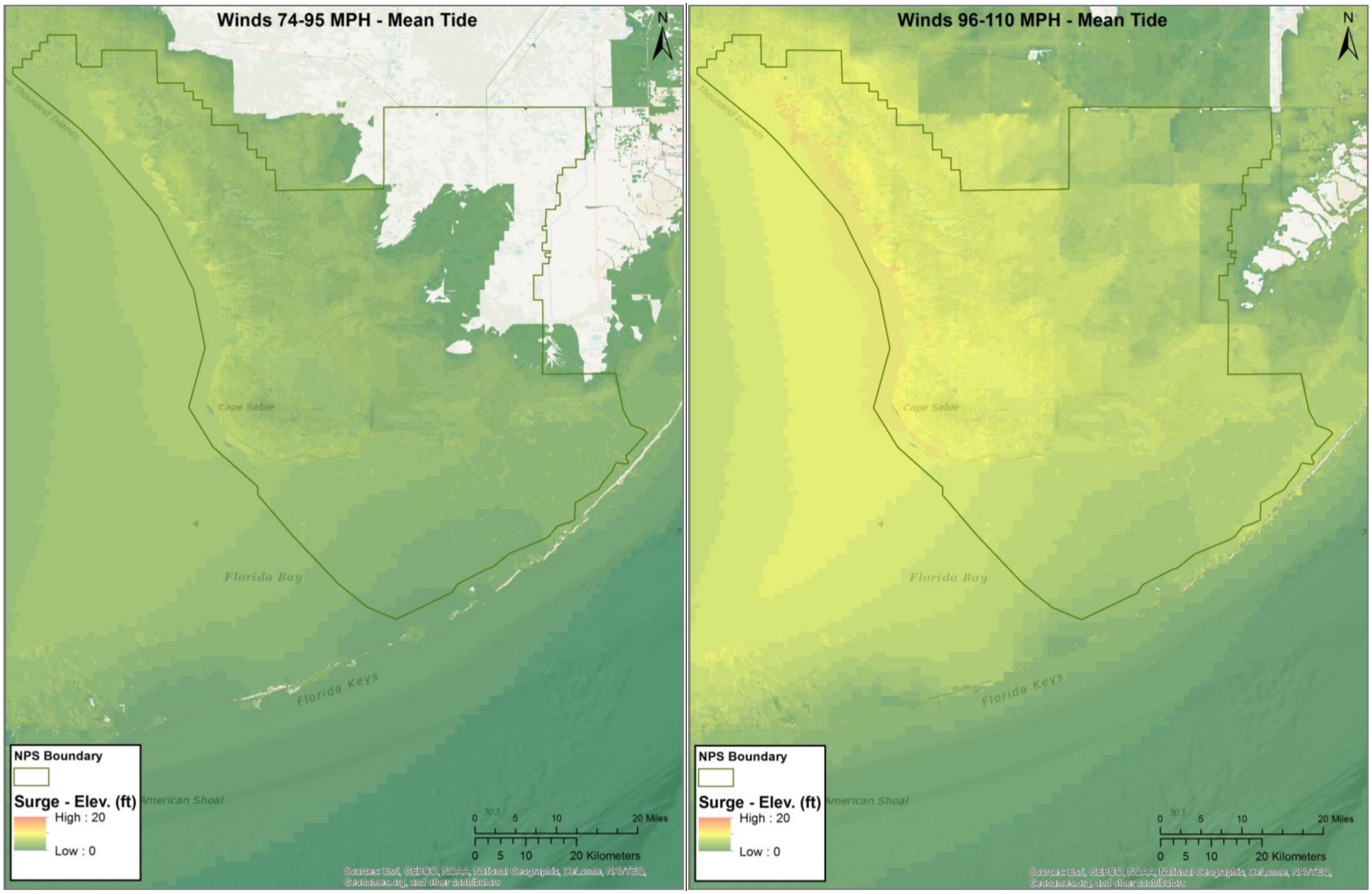

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

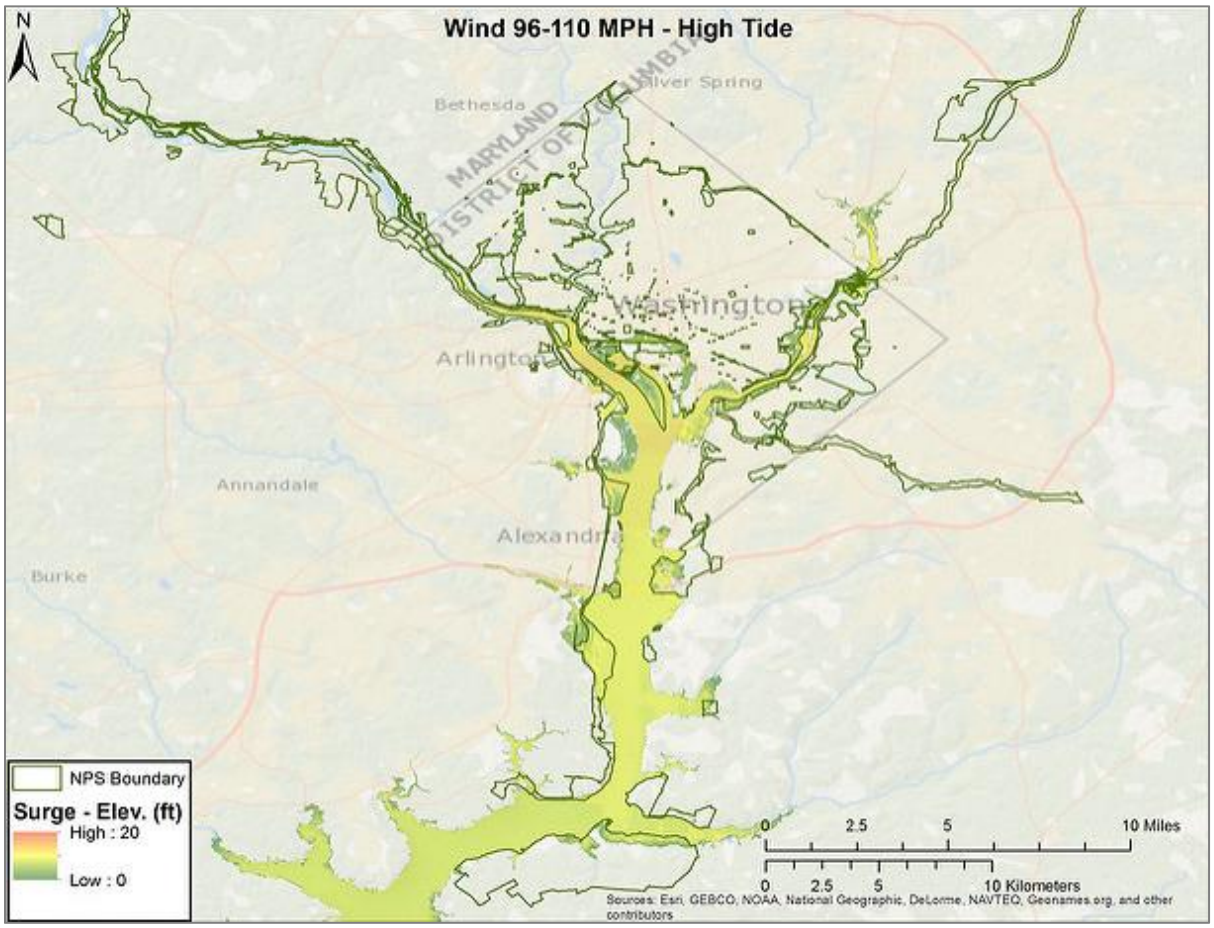

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

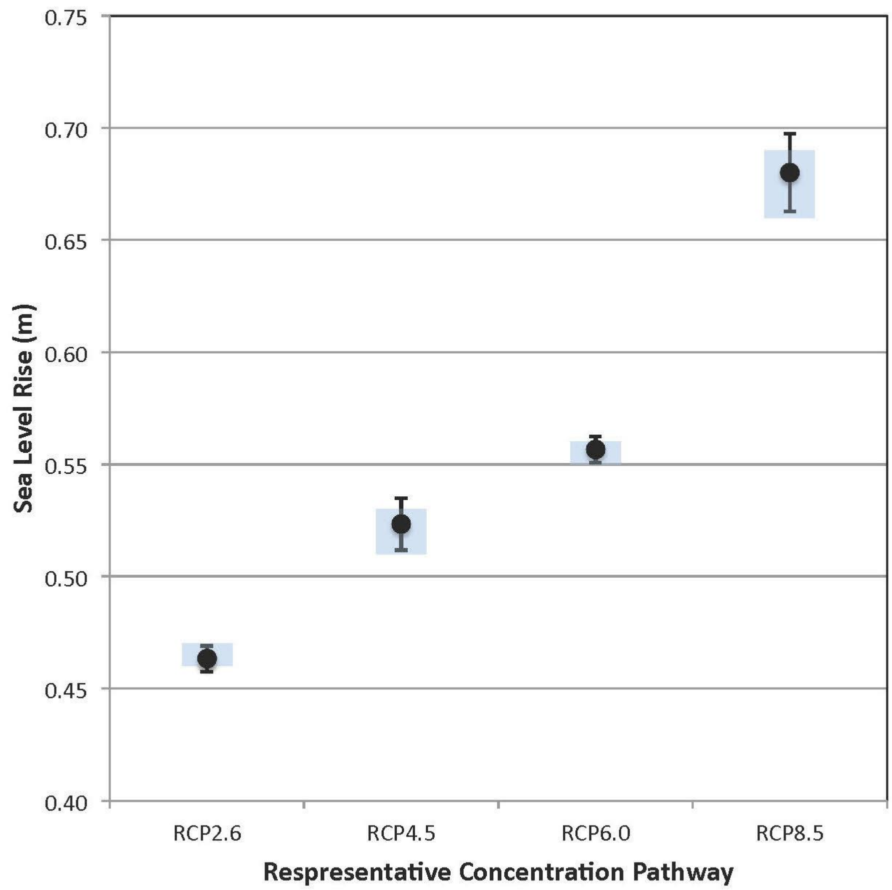

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

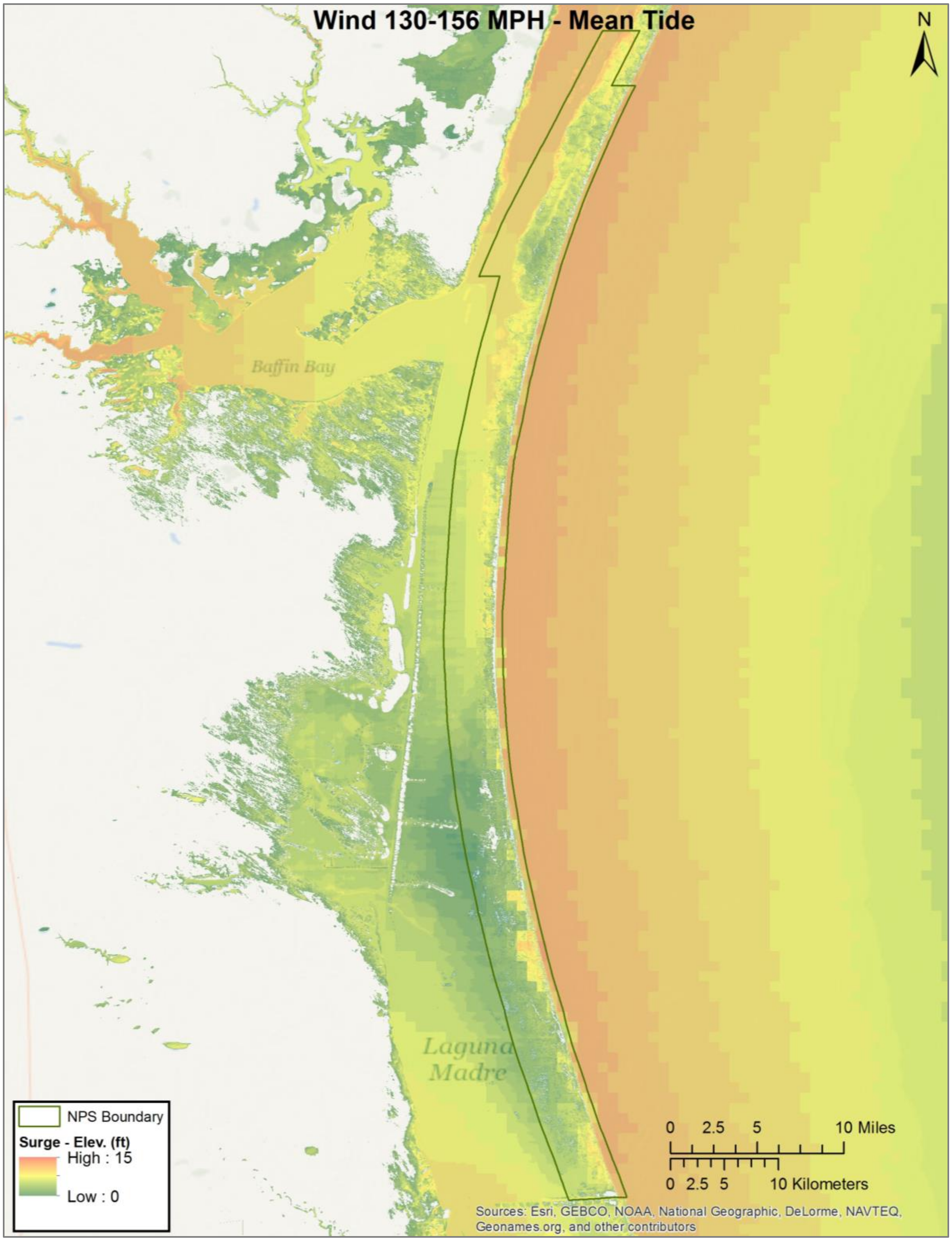

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

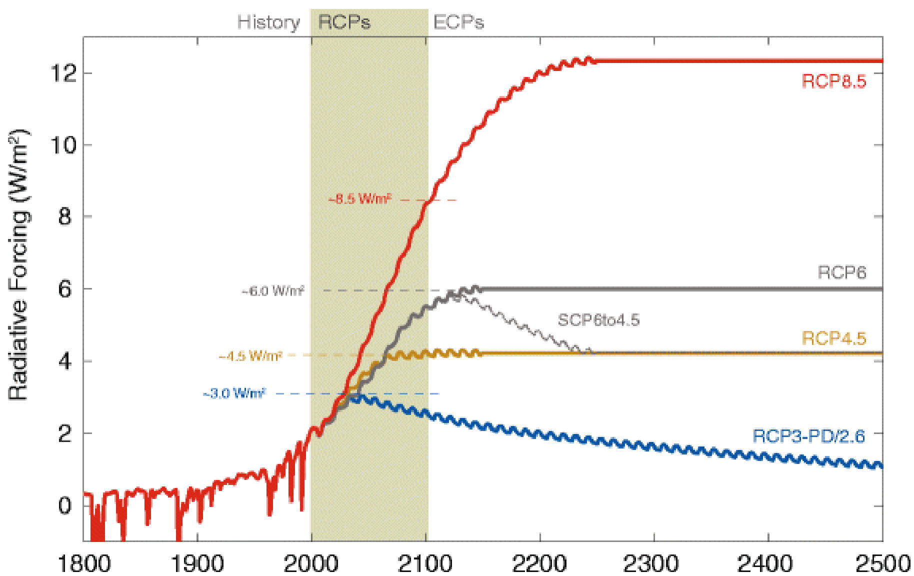

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from “expert elicitations” in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region’s units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long

“hotspot” along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region’s parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore‡	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument‡	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*‡	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument‡	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield‡	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site‡	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site[‡]	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument[‡]	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*[‡]	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*[‡]	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield[‡]	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park[‡]	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve[‡]	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve[‡]	Fernandina Beach, FL (8720030)	N	110	0.600

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial‡	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

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Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve[‡]	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park[‡]	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park[‡]	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park[‡]	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve[‡]	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site[‡]	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park[*‡]	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park[*‡]	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park[‡]	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park[*‡]	Seattle, WA (9447130)	N	109	0.540

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore‡	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial‡	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*‡	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*‡	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument‡	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*‡	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve‡	No data	No data	No data	No data

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument[‡]	No data	No data	No data	No data
	Glacier Bay National Park[*‡]	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve[*‡]	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park[‡]	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park[‡]	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park[‡]	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park[‡]	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park[‡]	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve[‡]	Cordova, AK (9454050)	N	43	3.450

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14‡	0.13	0.12	0.12
		2050	0.24‡	0.23	0.21	0.24
		2100	0.47‡	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14‡	0.13	0.13‡	0.12
		2050	0.25‡	0.24	0.24‡	0.24
		2100	0.50‡	0.54	0.59‡	0.68
	Cape Hatteras National Seashore	2030	0.15‡	0.15	0.15	0.14
		2050	0.26‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Cape Lookout National Seashore§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument[§]	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15[‡]	0.15	0.15	0.14
		2050	0.27[‡]	0.28	0.28	0.28
		2100	0.53[‡]	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve†§	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park§	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15‡	0.16	0.16	0.15
		2050	0.27‡	0.29	0.28	0.29
		2100	0.53‡	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway§	2030	0.15‡	0.15	0.15‡	0.14
		2050	0.26‡	0.27	0.26‡	0.28
		2100	0.53‡	0.62	0.66‡	0.79
	Harpers Ferry National Historical Park*§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

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†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park[§]	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park[§]	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park[§]	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu’uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve[§]	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument[§]	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park[†§]	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve[†]	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park[§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve[†§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

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[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	**Park Unit**	**Highest Recorded Hurricane Within 10 mi (16.1 km)**
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President’s Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

NPS 999/137852, April 2018

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U.S. Department of the Interior

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110 Time to meet today or tomorrow_.pdf

From:	Jennifer Wyse
To:	jeremy_barnum@nps.gov; Olson Jeffrey; april_slayton@nps.gov; Adema Guy; Hoffman Cat
Subject:	Time to meet today or tomorrow?
Date:	Tuesday, April 24, 2018 10:34:38 AM
Attachments:	ATT00001.htm 2018-04-23 Caffrey et al Sea Level Change Report - Agreed Change .pdf

Hi April, Jeremy, and Jeff,

Attached below please find the report. Are you free either today or tomorrow around 230 pm EDT to discuss FAQs and talking points?

Thanks, Jen

Sent from my iPhone

Begin forwarded message:

From: "Hoffman, Cat" <cat_hawkins_hoffman@nps.gov>
To: Jennifer Wyse <jennifer_wyse@nps.gov>
Subject: .pdf attached

Hi Jen -- here is the .pdf of the report.

Content is ready for review. Two things remaining that will be done during final formatting for 508:

- Fagan will assign the NRR series numbers (now shown as XXXX/XXXX)
- Several of the figures shown as left-aligned will be centered on the page.

I am preparing the final administrative review form for Guy to sign.

Cat

--
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Adaptation websites: public, NPS managers
Climate Change Response Resources

110 2 Attachment 2018-04-23 Caffrey et al Sea Level Change Repo_1.pdf

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

ON THIS PAGE
Driftwood washed up on the shoreline of Redwood National Park, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

ON THE COVER
Fort Point National Historic Site and the Golden Gate Bridge, California.
Photograph courtesy of Maria Caffrey, University of Colorado.

Sea Level Rise and Storm Surge Projections for the National Park Service

Natural Resource Report Series NPS/NRSS/NRR—XXXX/XXXX

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April 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the Climate Change Response Program website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov**.**

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Photo 1. Looking towards the Gulf of Mexico from Fort Jefferson, Dry Tortugas National Park. Photo credit: Used with permission from Rachel Sullivan Photography.

Executive Summary

Over one quarter of the units of the National Park System occur along ocean coastlines. Ongoing changes in relative sea levels and the potential for increasing storm surges due to anthropogenic climate change and other factors present challenges to national park managers. This report summarizes work done by the University of Colorado in partnership with the National Park Service (NPS) to provide sea level rise and storm surge projections to coastal area national parks using information from the United Nations Intergovernmental Panel on Climate Change (IPCC) and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models. This research is the first to analyze IPCC and NOAA projections of sea level and storm surge under climate change for U.S. national parks. Results illustrate potential future inundation and storm surge under four greenhouse gas emissions scenarios. In addition to including multiple scenarios, the analysis considers multiple time horizons (2030, 2050 and 2100). This analysis provides sea level rise projections for 118 park units and storm surge projections for 79 of those parks.

Within the National Park Service, the National Capital Region is projected to experience the highest average rate of sea level change by 2100. The coastline adjacent to Wright Brothers National Memorial in the Southeast Region is projected to experience the highest sea level rise by 2100. The Southeast Region is projected to experience the highest storm surges based on historical data and NOAA storm surge models.

These results are intended to inform park planning and adaptation strategies for resources managed by the National Park Service. Sea level change and storm surge pose considerable risks to infrastructure, archeological sites, lighthouses, forts, and other historic structures in coastal units of the national park system. Understanding projections for continued change can better guide protection of such resources for the benefit of long-term visitor enjoyment and safety.

Photo 2. Basement flooding in the visitor center at Rosie the Riveter WWII Home Front National Historical Park. This photograph was taken on December 5, 2012 —12 years after the establishment of the park. Photo credit: Maria Caffrey.

Acknowledgments

This project was awarded funds through the NPS Servicewide Comprehensive Call (FY2013–2015) and augmented by funds from the Natural Resource Stewardship and Science Directorate's Geologic Resources Division and Climate Change Response Program. We would like to thank the members of the communication advisory team (Rebecca Beavers, Lynda Bell, Maria Caffrey, Janet Cakir, Will Elder, Stanton Enomoto, Ann Gallagher, Matt Holly, Shawn Norton, Larry Perez, and Ryan Stubblebine) and science advisory team (Amanda Babson, Rebecca Beavers, Maria Caffrey, Patrick Gonzalez, Steve Nerem, and Rob Thieler) for their time and input into this project.

We would also like to thank Susan Teel and Caroline Rohe at Gulf Islands National Seashore for assistance in designing two wayside exhibits. Likewise, we thank Julie Whitbeck, Aleutia Scott, Kristy Wallisch, and Stacy Meyers for helping design, review, and install a wayside at Jean Lafitte National Historical Park and Preserve. Elizabeth Rogers and Kathy Krause helped design a wayside for Fire Island National Seashore. Doug Wilder, Dorothy Friday, and Neal Jander designed the online map viewer. We would also like to thank Jason Kenworthy, Rebecca Port, Michael Barthelmes, Bob Glahn, Doug Marcy, Chris Zervas, and Claudia Tebaldi for their assistance in editing and reviewing this document. Finally, we thank the National Oceanic and Atmospheric Administration for and the Intergovernmental Panel on Climate Change for providing the respective storm surge and sea level rise data cited throughout this document.

List of Terms

The following list of terms are defined here as they will be used in this report.

Bathtub model: A simplification of the sea as bathtub of water to simulate a change in water level relative to the land. This model does not include other factors such changes in erosion or accretion that change alter the geometry of the coastline.

Flooding: The temporary occurrence of water on the land.

Inundation: The permanent impoundment of water on what had previously been dry land.

Isostatic rebound: A change in land level caused by a change in loadings on the Earth's crust. The most common cause of isostatic rebound is the loading of continental ice during the Last Glacial Maximum in North America. The North American land surface is still returning to equilibrium after the melting of this continental ice in an effort to return to equilibrium with its original pre-loading state.

National Park Service unit: Property owned or managed by the National Park Service.

Radiative Forcing: Is the change in the incoming solar radiation minus the outgoing infrared radiation: the change in heat at the surface of the Earth. Positive radiative forcing means Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy warms the earth, resulting in higher global average temperatures.

Relative sea level: Where the water level can be found compared to some reference point on land. This term is most frequently used in discussion of *changes* in relative sea level. A change in relative sea level could be caused by a change in water volume or a change in land level (or some combination of these two factors).

Sea level: The average level of the seawater surface.

Sea level change: This term is frequently used in reference to *relative* sea level change. This is the product of two main factors, 1) an increase in the volume of ocean water, and 2) a change in land level. These two factors can be broken down further into other drivers that will be discussed in greater detail in other sections. This term is sometimes mistakenly confused with the term *sea level rise*.

Sea level rise: An increase in sea level. This is the result of an increase in ocean water volume caused principally by melting continental ice and thermal expansion. This term is not to be confused with increasing *relative* sea level, which can also be caused by decreasing land levels.

Storm surge: An abnormal rise of water caused by a storm, over and above the predicted astronomical tide.

Introduction

Global sea level is rising. While sea levels have been gradually rising since the last glacial maximum approximately 21,000 years ago (Clark et al. 2009, Lambeck et al. 2014), anthropogenic climate change has significantly increased the rate of global sea level rise (Grinsted et al. 2010, Church and White 2011, Slangen et al. 2016, Fasullo et al. 2016). Recent analyses reveal that the rate of sea level rise in the last century was greater than during any preceding century in at least 2,800 years (Kopp, et al. 2016, Sweet et al. 2017) Human activities continue to release carbon dioxide (CO_2) into the atmosphere, causing the Earth's atmosphere to warm (IPCC 2013, Mearns et al. 2013, Melillo et al. 2014). Further warming of the atmosphere will cause sea levels to continue to rise, which will affect how we protect and manage our national parks. The rate of warming depends on numerous factors considered by the Intergovernmental Panel on Climate Change (IPCC) under four different representative concentration pathways (RCPs; Moss et al. 2010, Meinshausen et al. 2011). Used as the basis for this report, the RCPs are climate change scenarios based on potential greenhouse gas concentration trajectories introduced in the fifth climate change assessment report of the Intergovernmental Panel on Climate Change (IPCC 2013). The IPCC's process-based approach for estimating future sea levels contrasts with other estimates from semi-empirical techniques that commonly generate higher numbers.

This report provides estimates of sea level change due to climate change for 118 National Park Service units and estimates of storm surge for 79 of those units. As temperature increases, sea levels rise due to a number of factors that will be discussed in greater detail.

The Importance of Understanding Contemporary Sea Level Change for Parks

From rocky headlands to gentle beaches, some of the most splendid and beautiful places in the United States are national parks on our ocean shorelines. Over one quarter of all national park units are coastal parks, home to nesting shorebirds and sea turtles, historical forts and lighthouses, and opportunities for recreation and respite. Many are living witness to our national story – true icons of our history (Photo 3). But despite their great diversity, importance, and ability to provide windows to the past, changes in sea level affect them all.

Today's managers of these parks face new challenges—challenges unimagined by builders of the forts and lighthouses within them, challenges unprecedented for the species that inhabit them, and challenges unanticipated by those who secured these places as part of the National Park System. Knowledge of sea level projections must now augment managerial skills in park administration, resource protection and conservation, interpretation, and community and civic engagement. To support managers of coastal park units, this report provides projections for sea level change and storm surge under several scenarios. As a reference for staff, it also summarizes scientific understanding of the basis for these changes, and sources from which scientists develop sea level rise projections.

As sea levels incrementally rise, periods of flooding caused by storms and hurricanes exacerbate the growing problem of coastal inundation (see list of terms). Peek et al. (2015) estimated that the value of infrastructure at risk in 40 National Park Service units could cost billions of dollars if these units were exposed to one-meter of sea level rise.

The passage of Hurricane Sandy in 2012—and more recently Hurricanes Harvey, Irma, and Maria in 2017—caused extensive and costly damage to infrastructure and resources in numerous coastal national park units. While single storms cannot be wholly attributed to anthropogenic climate change, sea level rise associated with climate change exacerbates the effects of associated storm surges, which may be even further amplified during the highest astronomical tides as occurred during Hurricane Sandy (Kemp and Horton 2013). The impacts of extreme storms can bring extreme costs, as tallied through loss of visitor access, impacts to gateway communities and local economies, investments in recovery, and/or the irrevocable loss of unique resources. For example, repair of damage caused in national parks affected by Hurricane Sandy alone exceeded $370M. Under future scenarios of increasing anthropogenic greenhouse gas emissions, models project increasing storm intensities (Mann and Emanuel 2006, Knutson et al. 2010, Lin et al. 2012, Ting et al. 2015). When this change in storm intensity (and therefore, storm surge) is combined with sea level rise, we expect to see increased coastal flooding, the permanent loss of land across much of the United States coastline, and in some locations, a much shorter return interval of flooding. For example, when Hurricane Sandy struck, it was estimated to have a return period between 398 (Lin et al. 2016) and 1570 (Sweet et al. 2013) years. Factoring in future sea level rise to these estimates reduces the potential return interval of a similar storm surge occurring in New York City by 2100 to between 50 years (Sweet et al. 2013) and 90 years (Lin et al. 2016).

The aim of this report is to: 1) quantify projections of sea level rise in coastal National Park Service units over the next century based on the latest IPCC (2013) models, and 2) show how storm surge generated by hurricanes and extratropical storms could also affect these parks.

Format of This Report

This report contains five sections (introduction, methods, results, discussion, and conclusion), and presents results per park alphabetically by region. The 118 park units studied for this project cover six administrative regions: the Northeast, Southeast, National Capital, Intermountain, Pacific West, and Alaska. The scope of this project focuses on sea levels. The scope of this project did not include projected changes in lake levels, although interior waterways and lakes, especially the Great Lakes, are vulnerable to the effects of climate change. Further explanation on how to access the data from this project is available in the methods sections and accompanying appendices.

Frequently Used Terms

Definitions of the most basic terms used in this report occur on page ix. However, some terms require greater explanation for their use. For example, we follow the advice of Flick et al. (2012) in differentiating between the terms *flooding* and *inundation*. While many choose to use these terms interchangeably, we use the term "flooding" to describe the temporary impoundment of water on land. This usually results from storm activity and other short-lived events, such as periodic tidal action, and will therefore be used here in reference to the effects of a storm surge on land. “Inundation” refers to the gradual permanent submergence of land that will occur due to sea level rise.

The terms sea level rise and sea level change are also used differently. Sea level rise refers only to rising water levels resulting from an increase in global ocean volumes. In most parts of the United States this increase in water volume will lead to increasing relative sea levels. However, in some parts of the country relative sea level is *decreasing* due to isostatic rebound. Figure 1 shows current sea level trends based on tide gauge records for United States that span at least 30-years of data.

For example, the Southeast Region of Alaska is experiencing a decrease in relative sea level. Alaska’s crust continues to rebound following the melting of large volumes of ice that occurred for centuries to millennia on land in the form of glaciers and ice fields. Alaska is tectonically complex with extensive faults that contribute to this crustal motion. Although the volume of ocean water in this region is increasing, the rate of sea level rise is less than the rate of isostatic rebound, resulting in a decrease in relative sea level. For this reason, we use the term “sea level change” as it includes regions that will experience a decrease in relative sea level (at least in the early part of this century) as well as those that will see increasing relative sea levels.

Photo 3. A National Park Service ranger surveys damage from the aftermath of Hurricane Sandy at Statue of Liberty National Monument, NY. Photo credit: National Park Service.

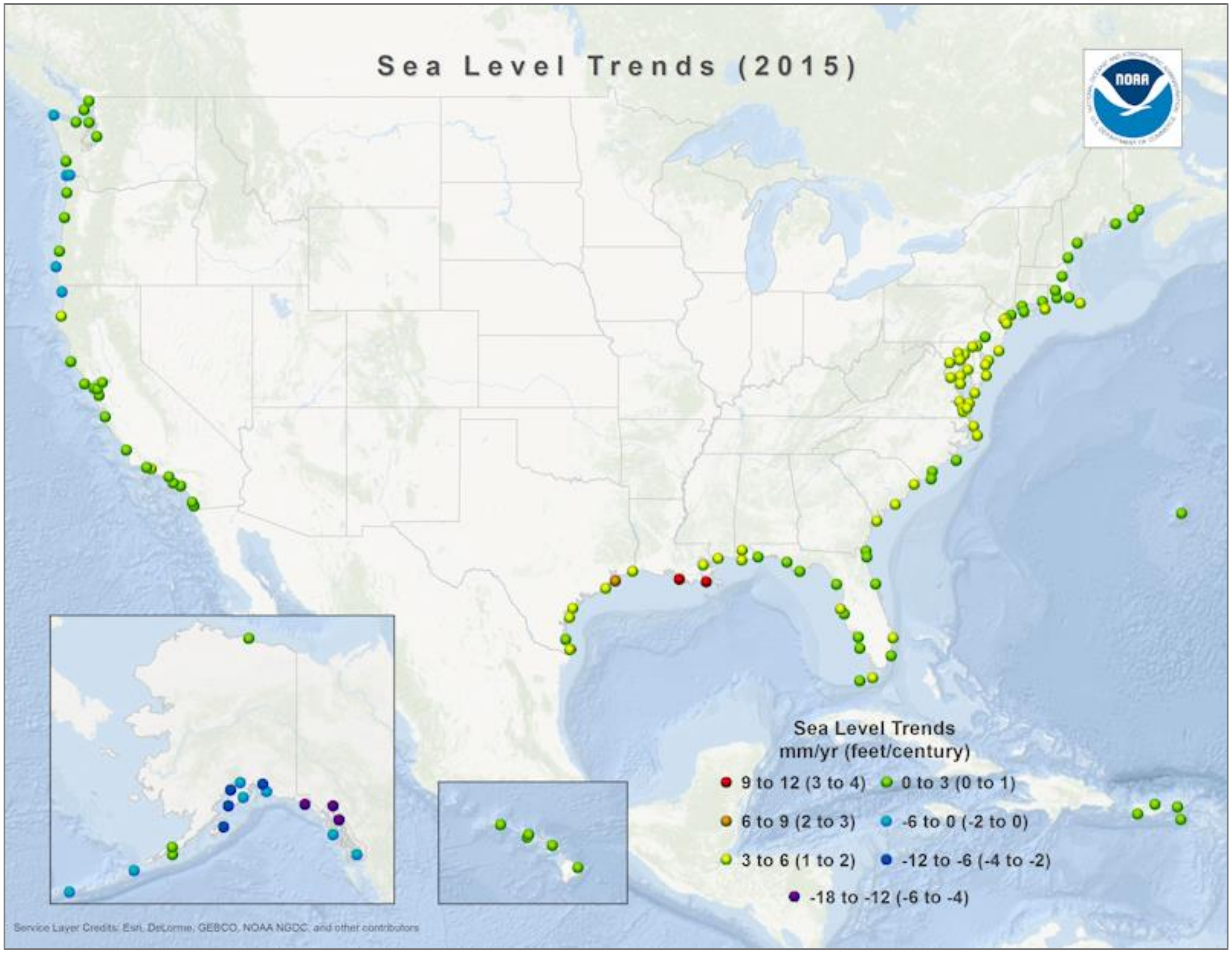

Figure 1. Sea level trends for the United States based on Zervas (2009), for all available data through 2015. Each dot represents the location of a long-term (>30 years) tide gauge station. Green dots represent stations that are experiencing the average global rate of sea level change. Stations depicted by yellow to red dots are experiencing greater than the global average (primarily driven by regional subsidence) and blue to purple dots are stations experiencing less than the global average (due to isostatic rebound or other tectonically-driven factors). Source: https://tidesandcurrents.noaa.gov/sltrends/slrmap.htm

Methods

This report summarizes work of a three-year project initiated in 2013, analyzing sea level change in 118 National Park Service units. Consultation with regional managers regarding units they considered to be potentially vulnerable to sea level change and/or storm surge resulted in selection of these 118 coastal park units (Appendix B). Project activities included the following:

1) Prepare sea level projections over multiple time horizons for each park unit.
2) Estimate potential exposure to storm surge using the National Oceanographic and Atmospheric Administration (NOAA) Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model and Tebaldi et al. (2012).
3) Create wayside exhibits[1] with information about the impacts of climate change in the coastal zone for three National Park Service units.

Based on site recommendations from regional personnel, three National Park Service units now have completed wayside exhibits in place: Gulf Islands National Seashore, Jean Lafitte National Historical Park and Preserve, and Fire Island National Seashore, each with customized designs that reflect the messaging and/or themes of each unit. This report provides results from the first two project activities: sea level rise projections, and potential exposure to storm surge.

Sea Level Rise Data

Sea level rise is caused by numerous factors. As human activities release CO_2 and other greenhouse gases into the atmosphere, mean global temperatures increase (IPCC 2013). Rising global temperatures cause ice located on land and in the sea to melt. The melting of ice found on land, such as Greenland and Antarctica, is a significant driver of sea level rise.

While the melting of sea ice is problematic from an oceanographic and heat budget perspective (primarily because it alters water temperatures and salinity and also because it changes the reflectance of solar energy from the surface), melting sea ice does not cause sea level rise. It is the melting of ice that is currently stored on land that raises global sea levels. Water level does not change when sea ice (ice wholly supported by water) melts. The volume of water in the sea remains the same whether it is frozen or liquid. The phase shift of water from solid to liquid does not displace an additional volume of water.

As ocean waters warm, the density of these waters also changes, causing thermal expansion. Thermal expansion was responsible for two-fifths of sea level rise from 1993 to 2010, while melting ice accounted for half (IPCC 2013). Table 1 lists the contribution to sea level rise from several key sources.

[1] A wayside is an exhibit designed to be installed outside for visitors to learn about a particular subject (https://www nps.gov/hfc/products/waysides/).

Table 1. Observed global mean sea level budget (mm/y) for multiple time periods (IPCC 2013).

Source	1901–1990	1971–2010	1993–2010
Thermal expansion	n/a	0.08	1.1
Glaciers except in Greenland and Antarctica[a]	0.54	0.62	0.76
Glaciers in Greenland	0.15	0.06	0.10[b]
Greenland ice sheet	n/a	n/a	0.33
Antarctic ice sheet	n/a	n/a	0.27
Land water storage	-0.11	0.12	0.38
Total of contributions	**n/a**	**n/a**	**2.80**
Observed	**1.50**	**2.00**	**3.20**
Residual[c]	**0.50**	**0.20**	**0.40**

[a]Data until 2009, not 2010.

[b]This is not included in the total because these numbers have already been included in the Greenland ice sheet.

[c]This is calculated as observed global mean sea level rise – modeled glaciers – observed land water storage. See table 13.1 in IPCC (2013) for more details.

The IPCC sea level rise projections used in this analysis follow a *process-based model* approach, which estimates sea level based on the underlying physical processes. This contrasts with *semi-empirical* models that combine past sea level observations with other variables or theoretical considerations, including, in some cases, expert opinion (surveys or interviews of professionals) (Rahmstorf 2010, Orlic and Pasaric 2013). Often the semi-empirical approach yields higher sea level estimates. IPCC (2013) uses coupled atmosphere-ocean general circulation models (AOGCMs) to simulate the processes of change rather than the statistical inferences of the semi-empirical approach. AOGCMs are considered a process-based technique, although some variables derive from semi-empirical methods (IPCC 2013).

Sea level rise estimates for 2050 and 2100 were taken directly from the IPCC (2013) regional climate models (RCMs) downscaled to a spatial grid resolution of 1˚ x 1˚ from AOGCMs. Because many park units require estimates for shorter time horizons that fit more closely with the expected lifetime of various projects, sea level rise projections for 2030 were calculated using IPCC RCM data for each sea level rise driver shown in Table 2, interpolated to 2030 for each RCP. All projections are reported relative to the period 1986–2005 (see Appendix B for further discussion). All geographic information systems (GIS) maps display the projected sea level on top of mean higher-high water (MHHW) using the most recent tidal datum epoch (1983–2001). MHHW is calculated by averaging the highest daily water level over a 19-year tidal datum epoch.

Table 2. Median values for projections of global mean sea level rise and contributions of individual sources, for 2100, relative to 1986-2005, in meters (IPCC 2013).

Source	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.15	0.20	0.22	0.32
Glaciers	0.11	0.13	0.14	0.18
Greenland ice sheet surface mass balance[a]	0.03	0.05	0.05	0.10
Antarctic ice sheet surface mass balance	-0.02	-0.03	-0.03	-0.05
Greenland ice sheet rapid dynamics	0.04	0.04	0.04	0.05
Antarctic ice sheet rapid dynamics	0.08	0.08	0.08	0.08
Land water storage	0.05	0.05	0.05	0.05
Sea level rise	**0.44**	**0.53**	**0.55**	**0.74**

[a]Changes in ice mass derived through direct observation and satellite data.

The standard error (σ) for each site estimate was not calculated because it was beyond the scope of this project. However, it can be calculated using the following equation and data available from the IPCC (2013, supplementary material):

Eq 1. $$\sigma_{tot}^2 = \left(\sigma_{steric/dyn} + \sigma_{smb\_a} + \sigma_{smb\_g}\right)^2 + \sigma_{glac}^2 + \sigma_{IBE}^2 + \sigma_{GIA}^2 + \sigma_{LW}^2 + \sigma_{dyn\_a}^2 + \sigma_{dyn\_g}^2$$

Where: *steric/dyn* = the global thermal expansion uncertainty plus dynamic sea surface height; *smb_a* = the Antarctic ice sheet surface mass balance uncertainty; *smb_g* = the Greenland ice sheet surface mass balance uncertainty; glac = glacier uncertainty; *IBE* = the inverse barometer effect uncertainty; *GIA* = global isostatic adjustment; *LW* = the land water uncertainty; *dyn_a* = Antarctica ice sheet rapid dynamics uncertainty; and, *dyn_g* = Greenland ice sheet rapid dynamics uncertainty.

Initial data were exported as GeoTIFF files for use in ArcGIS. For parks that crossed more than one pixel, an average sea level rise was calculated by weighting pixel values by the length of park shoreline in each pixel. A standard bathtub model approach was used to identify areas of projected inundation and flooding. In this method, projected sea level under climate change was determined by adding the IPCC RCM value to the current mean higher high water level. The land that would be at or below a projected sea level was then determined by analyzing digital elevation models (DEMs) of land elevation at spatial resolutions of 500 to 7000 m, depending on data availability for the areas of each park. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast). Areas of inundation and flooding are denoted in the maps (Appendix A) in blue. Additional low-lying areas that could be potentially inundated or flooded are shown in green (Figure 2). These low-lying areas do not appear to have any inlet or other pathway for water (based on our elevation datasets), although they should still be considered vulnerable to exposure to either groundwater seepage or potential flooding via breaching. The lack of high-resolution DEMs and time constraints prevented us from attempting a dynamic modeling approach (see limitations below). Maps were created to illustrate inundation for all park units for 2050 and

2100 under RCP4.5 and RCP8.5. These two represent a plausible range of scenarios between significant policy response (RCP4.5) and business as usual (RCP8.5).

Figure 2. An example of how areas of inundation appear in ArcGIS. In this example for the Toms Cove area of Assateague Island National Seashore, areas of inundation (RCP4.5 2050) appear in blue. Green shading indicates other low lying areas that are blocked from inundation by some impediment, but nonetheless could experience flooding should the physical barrier be removed or breached.

Storm Surge Data

NOAA SLOSH data estimate potential storm surge height at current (most recent tidal datum) sea level (NOAA 2016). The NOAA SLOSH model comprises the following three products (P-Surge, MEOW, and MOMs) that utilize three different modeling approaches (probabilistic, deterministic, and composite) to estimate storm surge.

P-Surge (also known as the tropical cyclone storm surge probabilities product) uses a probabilistic approach by examining past events to estimate the storm surge generated by a cyclone that is present and within 72-hours of landfall. It statistically evaluates National Hurricane Center data (calculated in part using a deterministic approach) including the official projected cyclone track and historical forecasting errors. It also incorporates astronomical tide calculations and variations in the radius of

maximum wind into this estimate. These rates of motion variables are then fit to a Cartesian or polar (depending on the location) grid (Jalesnianski et al. 1992).

The Maximum Envelope Of Water (MEOW) calculates flooding using past SLOSH output to create a composite estimate of the potential storm surge generated by a hypothetical storm. This product generates a worst-case scenario based on a hypothetical storm category that includes forward speed, trajectory of the storm when it strikes the coastline, and initial (mean vs. high) tide level that will also incorporate any historical uncertainty from previous landfall forecasts.

The final SLOSH product is the MOM (Maximum of MEOWs) model. MOM is a further composite approach that uses the forward speed, trajectory, and initial tide level data that is also used by MEOW to create a worst-of-the-worst scenario (or "perfect storm"). Storms are simulated for 32 regions (also known as operational basins, Figure 3) defined by NOAA. Data was imported into ArcGIS using the SLOSH display program. Maps were generated showing storm surge for all possible Saffir-Simpson hurricane categories for each site. While most sites had data for Saffir-Simpson hurricane categories 1–5 (Table 3), a few sites, such as Acadia National Park, were missing the highest category. NOAA did not model this scenario because it is considered extremely unlikely at a location that far north in the Atlantic Ocean.

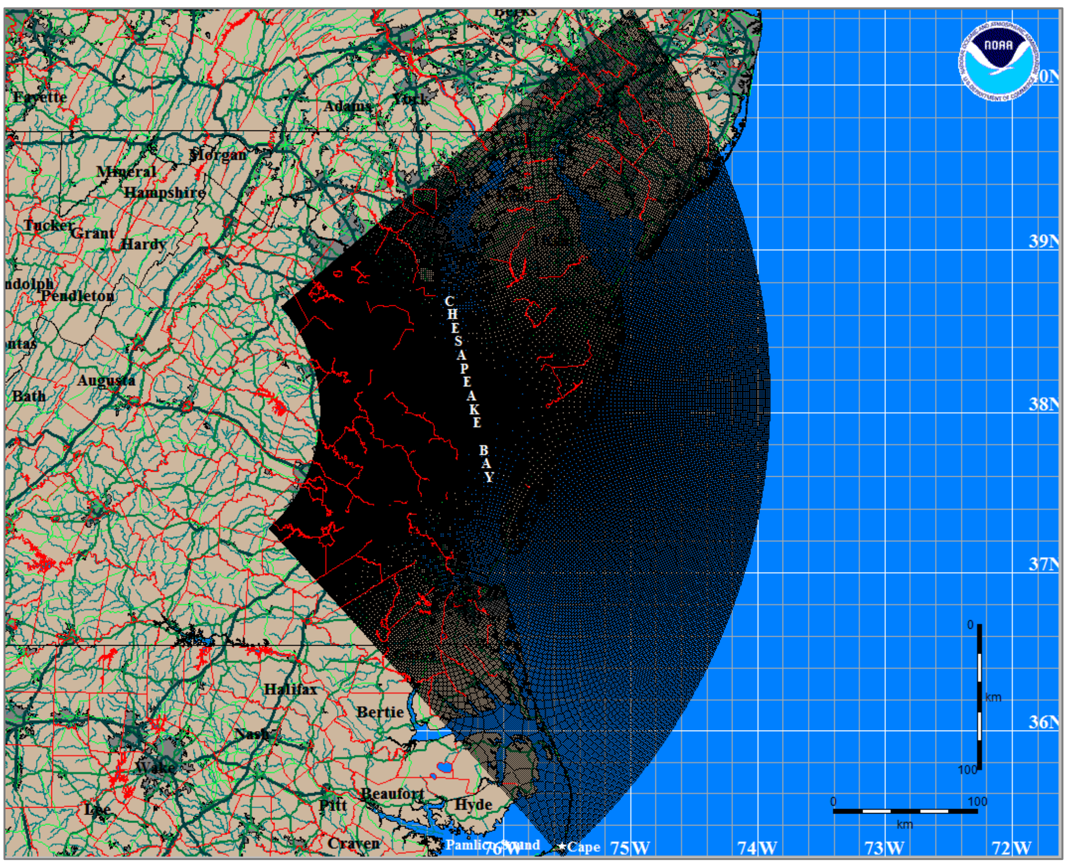

Figure 3. An example of the extent of an operational basin shown in NOAA's SLOSH display program (http://www.nhc.noaa.gov/surge/slosh.php). The black area is the full extent of the operational basin for Chesapeake Bay.

Table 3. Saffir-Simpson hurricane categories.

Saffir-Simpson Hurricane Category	Sustained Wind Speed (miles per hour, mph; knots, kt; kilometers per hour, km/h)
1	74–95 mph; 64–82 kt; 118–153 km/h
2	96–110 mph; 83–95 kt; 154–177 km/h
3	111–129 mph; 96–112 kt; 178–208 km/h
4	130–165 mph; 113–136 kt; 209–251 km/h
5	More than 157 mph; 137 kt; 252 km/h

SLOSH MOM was used to estimate potential storm surge in 79 coastal park units. Unfortunately, MOM data do not exist for the remaining 39 units, so we supplemented this with data from Tebaldi et al. (2012) wherever possible. Tebaldi et al. (2012) used 55 long-term tide gauge records to calculate potential sea level and storm surge estimates above mean high water levels. We used the current 50-year and 100-yr return level data from their paper for any parks near a tide gauge. Unfortunately, due to insufficient coverage by tide gauges in this area, we were unable to use either Tebaldi et al. (2012) or SLOSH MOM data for the Alaska, Guam, and American Samoa park units. It is important to note that the Tebaldi (2012) and SLOSH MOM data differ in their methods of calculation making it inadvisable to compare storm surge values from the Pacific West Region to other regions. However, this method had to be used due to the lack of SLOSH MOM data for the Pacific West Region.

We recommend that parks planning for future hurricanes use information from one hurricane category higher than any previous storm experienced. Historical hurricane data from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al. 2010) is listed in Appendix D (Table D3) to allow staff to determine the highest Saffir-Simpson category hurricane to strike within 10 miles of each park unit. Applying information from one storm category higher than historical data may more closely approximate what could happen in the future, as storms are projected to be more intense under continued climate change (Emanuel 2005, Webster et al. 2005, Mendelsohn et al. 2012). However, we recommend caution in using this approach for any detailed (site-level) planning due to limitations discussed in the following section of this report.

Limitations

All projects of this nature have limitations that should be clearly described to ensure appropriate use and interpretation of these data.

Every effort has been made to incorporate any parks established after this project began (e.g. Harriet Tubman Underground Railroad National Monument); however, some maps might be missing due to lack of available boundary data in new units.

Sea level and storm surge estimates were derived using separate programs from the IPCC and NOAA, respectively. These numbers were then imported into GIS maps using the program ArcGIS. We used a bathtub modeling approach to map the extent of sea level rise and storm surge over every unit. Bathtub modeling simply simulates how high or how far inland water will go under different

climate change scenarios. It does not recognize changes in topography or other environmental or artificial systems that may exist or occur in response to encroaching water. Although the bathtub model is the most widely used technique for modeling inundation, it is also a simplistic approach to simulating how sea level rise will affect a landscape (Storlazzi et al. 2013). Dynamic models could simulate changes in flow around buildings or estimate how topographic features such as dune systems may migrate in response to inundation and flooding, but dynamic models also vary, which can be a severe limitation in trying to standardize data for summary analysis and comparison.

The maps provided through this analysis vary in horizontal and vertical accuracy depending on which digital elevation model (DEM) data were available at the time of mapping. This is discussed in more detail in the metadata that accompany each map. DEM data for most regions were gathered from the NOAA digital coast website (https://coast.noaa.gov/digitalcoast/) which uses source elevation data that either meet or exceed current Federal Emergency Management mapping specifications. These NOAA digital coast data were required to have a minimum root mean square error of 18.5 cm for low lying areas that were then corrected for MHHW using the NOAA VDatum model (Parker et al. 2003). USGS data were used for areas, such as Alaska, where digital coastal data were not available. We recommend referring to Schmid et al. (2014) for further discussion on potential uncertainty of this technique.

Although SLOSH MOM has the widest geographic storm surge coverage of any model in the US, storm surge data were not available for every part of the coastline. Every effort has been made by this project to bridge any gaps where SLOSH MOM does not exist. While the Tebaldi et al. (2012) data cover the California, Oregon, Washington, and southern Alaskan coastlines, they do not cover northern Alaskan, American Samoan, or Guam coastlines. These coastlines are vulnerable to storm surge but we could not find data that satisfied our standards of accuracy sufficiently to be included in our mapping efforts.

Furthermore, storm surge maps are only intended as a rough guide of how flooding caused by storm surge will look today. As more of the coastline becomes inundated we can expect coastal flooding patterns to also change accordingly. The SLOSH model is a multiple scenario approach that uses previous storms to estimate future storm surge. It cannot take into account changes in future basin morphology that could affect the fluid dynamics and propagation of coastal flooding.

SLOSH MOM is modeled using mean sea level (0 m NAVD88) and what NOAA terms “high tide” (which is not tied to the local tidal datum, but is actually a round number based on the modeled average high tide for the region). Jalesnianski et al. (1992) estimate surge estimates to be accurate +/- 20%, although Glahn et al. (2009) discuss how others have found the P-Surge model to be more accurate than originally estimated. Such factors must be kept in mind when using these numbers for mapping.

Land Level Change

It is important to include changes in land level while interpreting changes in sea level. The IPCC (2013) includes a limited amount of data regarding changes in relative sea level in their calculations of sea level change. Our sea level rise results include the IPCC estimates of how changes in land

level will change over time based on estimates of glacial isostatic adjustment. Land level change is an important variable when calculating relative sea level. Land levels have changed over time in response to numerous factors. Changes in various land-based loadings—such as ice sheets during the last glacial maximum—has been a significant cause of land level change in the U.S. Post-glacial isostatic rebound is the result of this pressure being released after the removal of ice sheets on the Earth's crust. Land level can also be altered by other factors such as tectonic shifts, particularly along the Alaska and continental U.S. Pacific coastlines. These drivers can often prompt a relative increase or decrease in land level depending on location. Other factors such as aquifer drawdown and the draining of coastal swamps can create decreases in relative land level.

Quantifying how land levels are changing is difficult given the paucity of data available prior to modern satellite data. An upcoming NASA publication on land-based movement (Nerem pers. comm.) will help to address this data need, providing numbers for land-based movement across the country. Data from the NASA report can then be incorporated with sea level rise numbers from this analysis using the following equation (after Lentz et al. 2016):

Eq. 2 $$ae = E_0 - e_i + R$$

Where; ae is the adjusted elevation, E_0 is the initial land elevation, e_i is the future sea level for either 2030, 2050, or 2100, and R is the current rate of land movement over time due to isostatic adjustments.

In the interim, tide gauges can provide further data regarding changes in land level, but should be used cautiously. We have listed tide gauge data for the rate of change in land level for tide gauges nearest to all units for this study in Appendix D; however, only Fort Pulaski National Monument and Golden Gate National Recreation Area have a long-term tide gauge on site. This lack of nearby long-term data can limit the accuracy of these numbers if they are applied to sea level change projections for almost all other parks units. We indicate in Table D1 which of the nearest tides gauges we do not recommend using to estimate land movement. This is because in many case the boundary of the park unit is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. Land level changes were only reported for long-term tide gauges that had at least thirty years of data in order to ensure a statistically robust dataset. Based on these limited records, we estimate that seven park units are currently experiencing decreasing relative sea levels (Glacier Bay National Park, Glacier Bay Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park), although we cannot be certain of this number given that many of the park units are some distance from a tide gauge. We expect the release of the NASA data (Nerem pers. comm.) to help refine these estimates.

A discussion of the applicability of these land level numbers (with a natural resources manager or similar expert) should accompany use of individual park maps from this analysis to ensure that the nearest tide gauge to any particular project site is appropriate. Current rates of subsidence at these tide gauges range between +7.6 mm/y (Grand Isle, Louisiana) and -19 mm/y (Skagway, Alaska; Table D1). In selecting an appropriate tide gauge to use, variables including oceanographic setting, length of the record, completeness of data, and geography of the coastline must be considered. The

science team for this project decided against setting a threshold for how close a park unit should be to a long-term tide gauge based on considerations discussed above.

Where to Access the Data

All GIS data from this project are available at https://irma.nps.gov/Portal for archiving by park.

A website discussing this project is available at the following address:
https://www.nps.gov/subjects/climatechange/sealevelchange.htm

The raw IPCC (2013) data can be downloaded using the following link:
http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_ch13sm_datafiles.zip

Results

Sea level and storm surge maps are in Appendix A. A full list of the 118 park units and a table listing sea level projections by park are available in Appendix D. Following the methods outlined above, we found that sea level rise projections across the 118 park units average between 0.45 m (RCP2.6) and 0.67 m (RCP8.5) by 2100. However, this number masks how these projections will vary geographically. Figure 4 shows these projections in more detail and provides sea level estimates by region. Error bars in Figure 4 denote the standard deviation for each average per region, further revealing how these numbers can vary. A high standard deviation and range signals that sea level estimates vary between units within regions, whereas a low standard deviation and small range are to be expected in smaller regions where sea level rise estimates do not cover such a large geographic area.

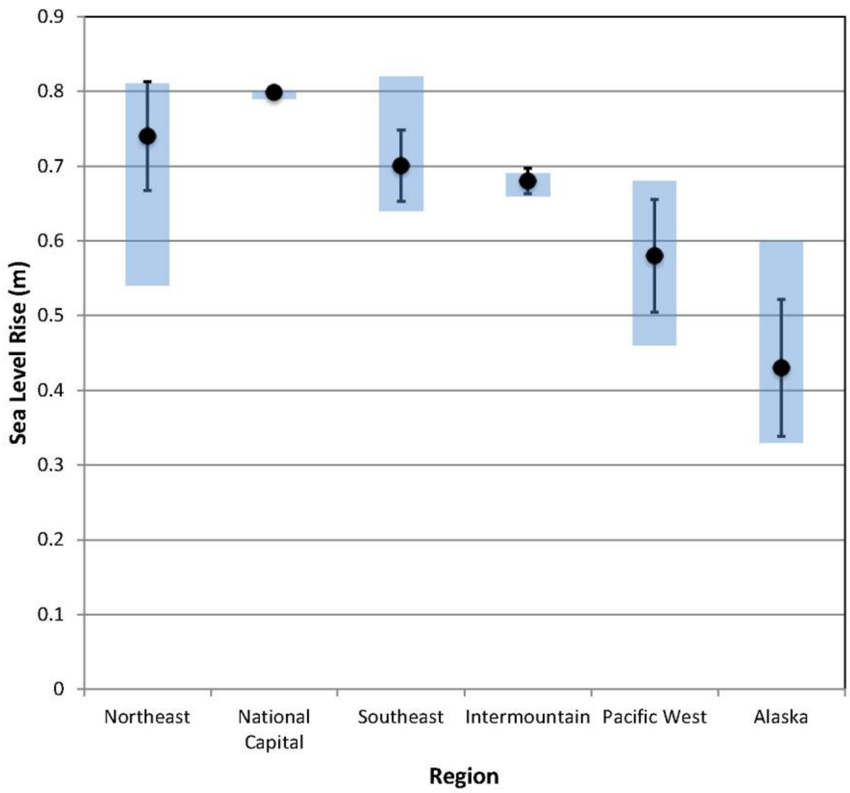

Figure 4. Projected future sea level by NPS region for 2100 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Based on the averages per region, we found that the shoreline within the National Capital Region is projected to experience the highest sea level rise by 2100 (0.80 m RCP8.5), although this number does not include the full extent of changes in land level over the same time interval. The shoreline near Wright Brothers National Memorial in the Southeast Region has the highest overall projected sea level rise (0.82 m, RCP8.5, 2100). Glacier Bay Preserve and Klondike Gold Rush National

Historical Park are tied for lowest projected sea level rise at 0.33 m using RCP8.5 for 2100. The Alaska Region also has the highest standard deviation among park units. The National Capital Region conversely has very little standard deviation due to the compact nature of the region (meaning that all of the parks units fell within the same raster cell). This is not to say that all of the parks will experience exactly the same rate of sea level rise, but that the IPCC model projected that sea levels could rise up to an average 0.80 m (RCP8.5) for that region by 2100. The sea level rise maps (discussed in the National Capital section below) illustrate differences among the National Capital parks in more detail.

Comparing RCP8.5 data for 2030 and 2050 (Figures 5 and 6, respectively) shows the Northeast Region almost tied with the National Capital Region in 2030 based on average projected sea level rise, with the National Capital Region ranked highest. The Alaska Region ranks lowest for all three time intervals followed by the Pacific Northwest region, Intermountain Region, and Southeast Region. The Northeast Region ranks second highest for 2050 and 2100.

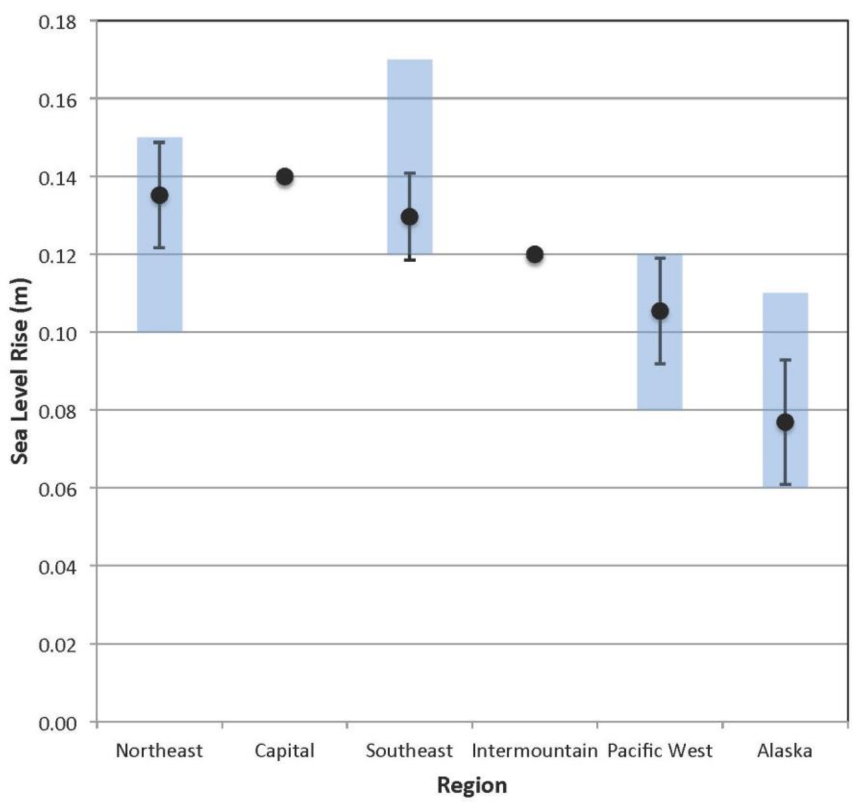

Figure 5. Projected future sea level rise by NPS region for 2030 under RCP8.5 (the “business as usual” climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

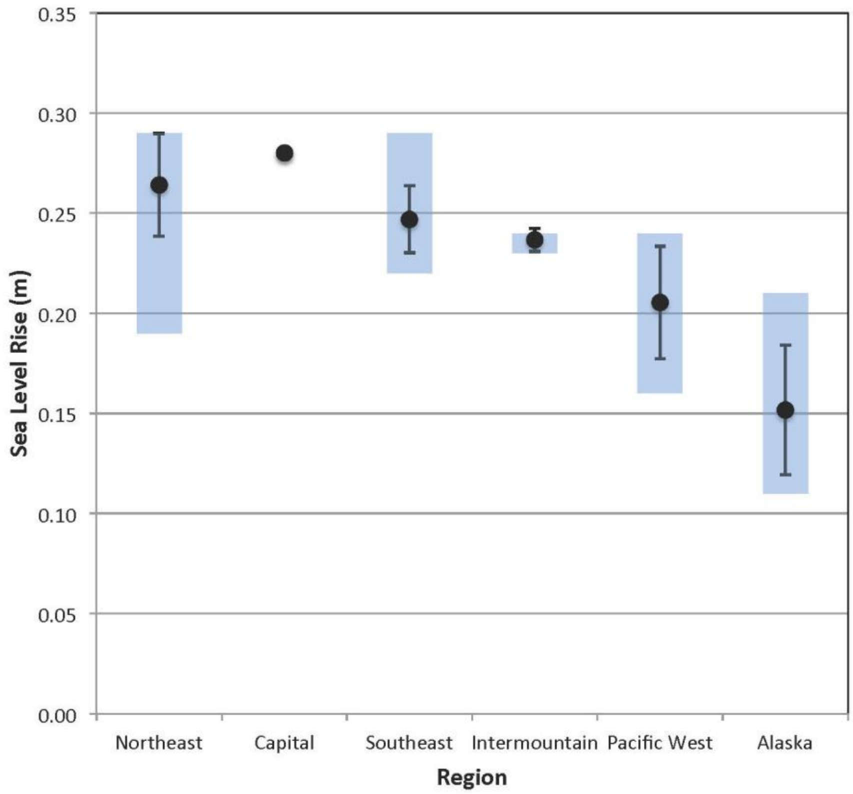

Figure 6. Projected future sea level rise by NPS region for 2050 under RCP8.5 (the "business as usual" climate change scenario). Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each region.

Storm surge was mapped for 79 park units. We list data for one storm category higher than the highest historical storm in Table D3 in Appendix D. Some (31) park units did not have a historical storm path occurrence within 10 miles of their boundaries, so a Saffir-Simpson hurricane 1 was simulated for these locations. The lack of a historical storm does not mean that these parks are not subject to strong storms. It may merely be that these parks are in regions that either do not have extensive historical records or they experience strong storms, such as nor'easters, that behave differently and are not part of the NOAA database.

The Southeast Region has the strongest historical hurricanes (average of highest recorded storm categories = 2.79), followed by the Intermountain Region (average = 2.33), National Capital Region (average = 1.90), and the Northeast (average = 1.03). None of the historical data intersected with the 10-mile (16.1 km) buffers around the Alaska Region parks. The Pacific West Region has experienced some tropical depressions, particularly in Hawaii, but most of their storm surges are driven by other phenomena, such as mid-latitude cyclones or extreme tides (sometimes colloquially referred to as king tides). The strongest (highest winds) and most intense (lowest pressure at landfall) recorded historical storm to have impacted a park unit was the "Labor Day Hurricane" that passed within 10 miles of Everglades National Park in 1935. While this storm may have been the highest intensity storm, it is certainly not the most damaging or costly storm in National Park Service history.

Northeast Region

Colonial National Historical Park, Fort Monroe National Monument, and Petersburg National Battlefield have the highest projected sea level rise in 2050 and 2100, and, together with Edgar Allen Poe National Historic Site, Fort McHenry National Monument and Historic Shrine, Independence National Historical Park, and Thaddeus Kosciusko National Memorial (parks near coastlines) they also have the highest projected sea level rise for 2030. However, while these parks may have ranked highly, caution should be used in applying these results. Many of these parks do not have coastline and so these projections are based on sea level rise for the coastline adjacent to these parks. The maps in Appendix A show how the projected sea level rise may affect each of these parks. Colonial National Historical Park, Fort McHenry, and Fort Monroe National Monument are the only park units of this highest rise grouping that contain coastline with their boundaries.

Figure 7 shows the range of sea level projections for the Northeast Region for 2100, averaging between 0.49 m (RCP2.6) and 0.74 m (RCP8.5) of sea level rise by the end of the century. Acadia National Park had the lowest projected rates of sea level rise for 2030 (0.08–0.10 m), 2050 (0.14–0.19 m), and 2100 (0.28–0.54 m).

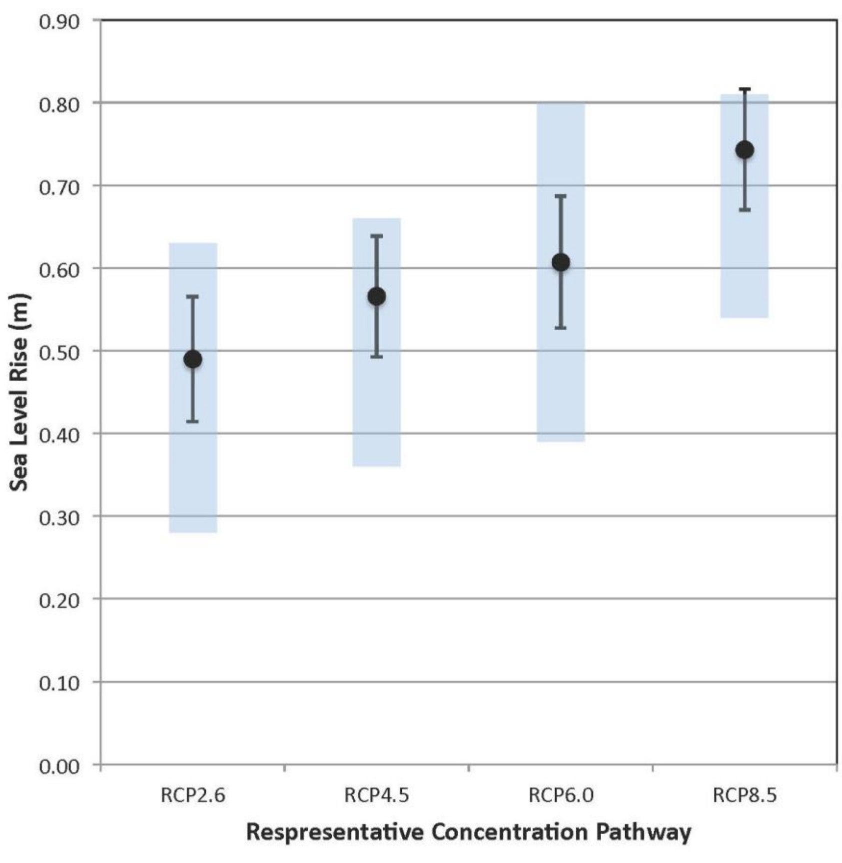

Figure 7. Projected future sea level rise by 2100 for the NPS Northeast Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation of each mean. Blue bars mark the full range of sea level estimates for each category.

Regarding storm surge, the highest recorded storm to have travelled within 10 miles of any of the 29 parks units identified for study was an officially unnamed hurricane in 1869 known colloquially as Saxby's Gale, which was classified as a Saffir-Simpson 3 hurricane. The storm path passed present-day Boston National Historical Park and Roger Williams National Memorial. Figure 8 shows the estimated extent and height of a storm surge from category 3 hurricane striking Boston Harbor Islands National Recreation Area at mean tide.

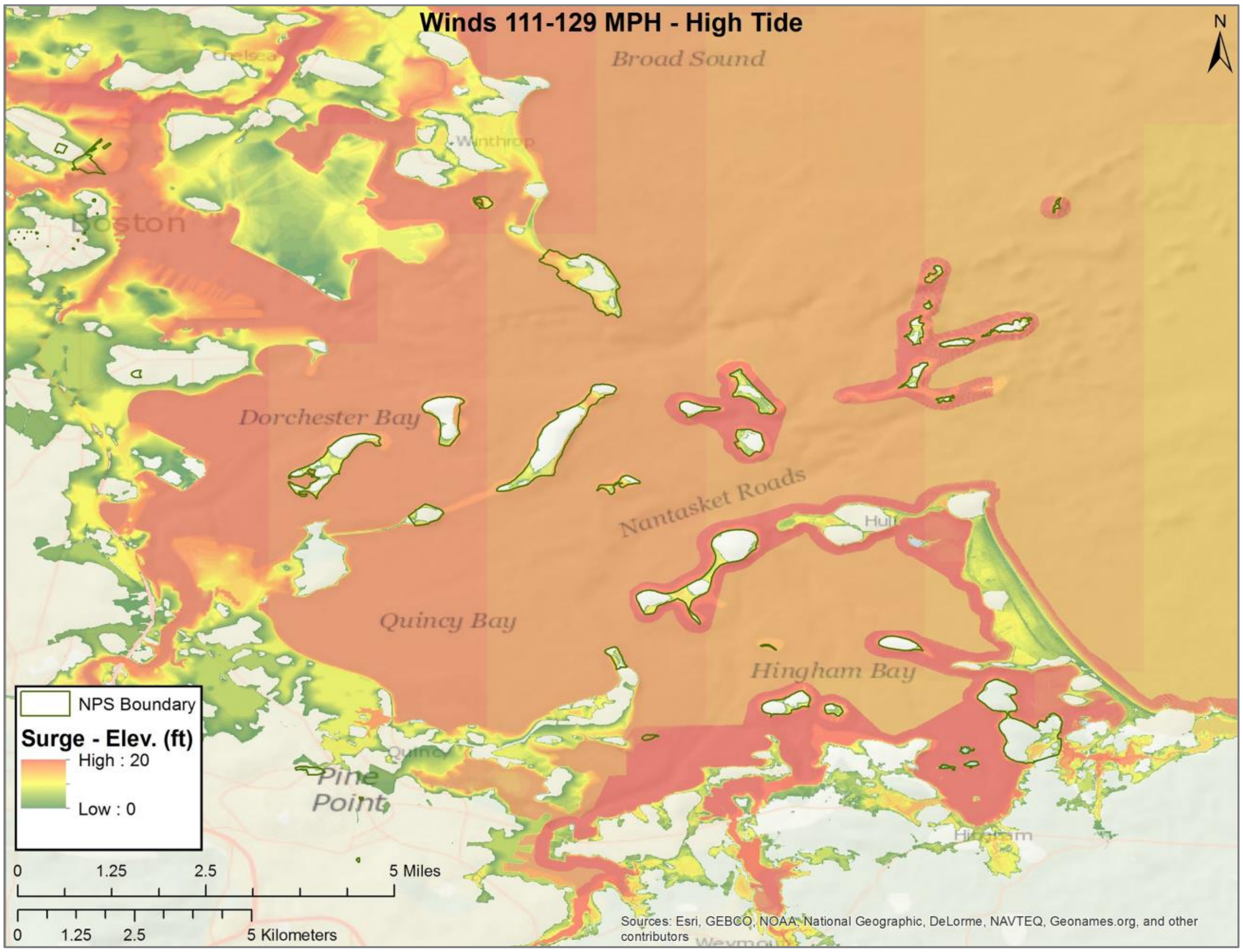

Figure 8. Estimated storm surge created by Saffir-Simpson category 3 hurricane occurring at high tide near Boston Harbor Islands National Recreation Area. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Southeast Region

Historically, the Southeast Region has the highest intensity storms (highest Saffir-Simpson storm category); Everglades National Park has recorded a category 5 hurricane within 10 miles of its boundary, the colored areas in Figure 9 indicate the potential height and extent of a storm generated by two different categories of hurricane. A category 2 hurricane could completely flood the park.

Future storm surges will be exacerbated by future sea level rise nationwide; this could be especially dangerous for the Southeast Region where they already experience hurricane-strength storms.

Moreover, sea level rise projections only include changes in land movement due to glacial isostatic adjustment and do not include the full range of drivers of potential changes in land level. Using Table D1 from Appendix D as a rough guide, changing land level for parks near tide gauges can be evaluated. For example, the Eugene Island, Louisiana tide gauge's current rate of sea level rise is the highest in the country at 9.65 mm/y, owing in part to the large rate of subsidence in the region (Figure 1). Using the nearest tide gauge to Jean Lafitte National Historical Park and Preserve (Grand Isle, Louisiana, gauge 8761724) we can estimate that land will subside by 7.60 mm/y. Applying this estimate of subsidence (using a baseline of 1992) to our RCP8.5 projections, the park could experience approximately 0.41 m of *relative* sea level rise by 2030 followed by 0.69 m by 2050 and 1.50 m by 2100. This is an inexact estimate of the land movement for the park given that Jean Lafitte National Historical Park and Preserve is approximately 60 miles (97 km) from the tide gauge; still, factoring in changes in land level, we can see that relative change in sea level is more than double the projected change in sea level using the IPCC estimates alone.

This analysis projects that, by 2100, the shoreline adjacent to Wright Brothers National Memorial may have the greatest sea level rise among the Southeast Region's parks (0.82 m RCP8.5). Given elevations within the park, this may not inundate a large area of the memorial, unless combined with other factors such as a storm surge. For example, the park may be almost completely flooded if a category 2 or higher hurricane strikes on top of inundation from sea level rise.

Nearby Cape Hatteras and Cape Lookout National Seashores are projected to experience sea level rise of up to 0.79 m and 0.76 m, respectively (RCP8.5) by 2100, resulting in large areas of inundation. While sea level rise around these national seashores may not be as high as what has been projected for Wright Brothers National Memorial, they serve as examples of how caution must be used when using these numbers to assess which park units are most vulnerable to sea level rise. Other factors, such as percent of exposed land, changes in land movement, and adaptive capacity must also be taken into account for vulnerability analyses (Peek et al. 2015).

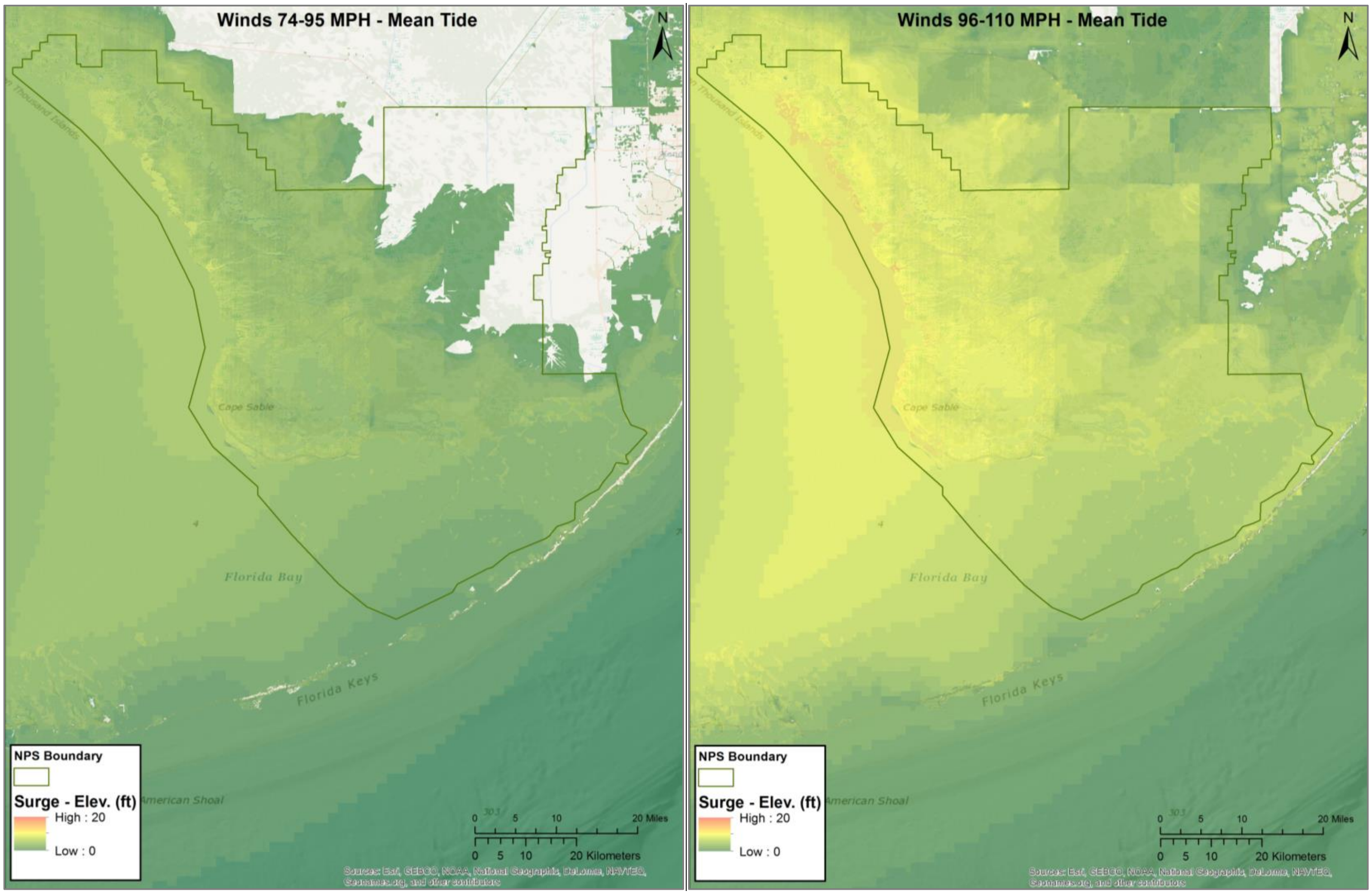

Figure 9. SLOSH MOM storm surge maps for a Saffir-Simpson category 1 (left) versus category 2 hurricane striking Everglades National Park at mean tide (right). Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

National Capital

National Capital Region has minimal variability in projected sea level rise because all park units selected for study are adjacent to the same section of coastline that was modeled. Their proximity also explains why they share the same storm history. Despite these similarities, projected sea level rise may affect each individual park unit differently based on local topography. The strongest storm recorded within 10 miles (16.1 km) of the National Capital Region parks was a Saffir-Simpson category 2 hurricane that struck the city in 1878. While the 1878 storm caused relatively little damage, we can expect a significantly larger amount of damage if a similar storm struck the city again given considerable development now existing in the area. Figure 10 shows the extent of flooding caused by a Saffir-Simpson category 2 hurricane. A storm surge measuring more than 3 m could travel up the Potomac River causing large amounts of flooding. Such a storm surge could be worse by the end of this century given projected sea level rise around the Capital Region of up to 0.8 m.

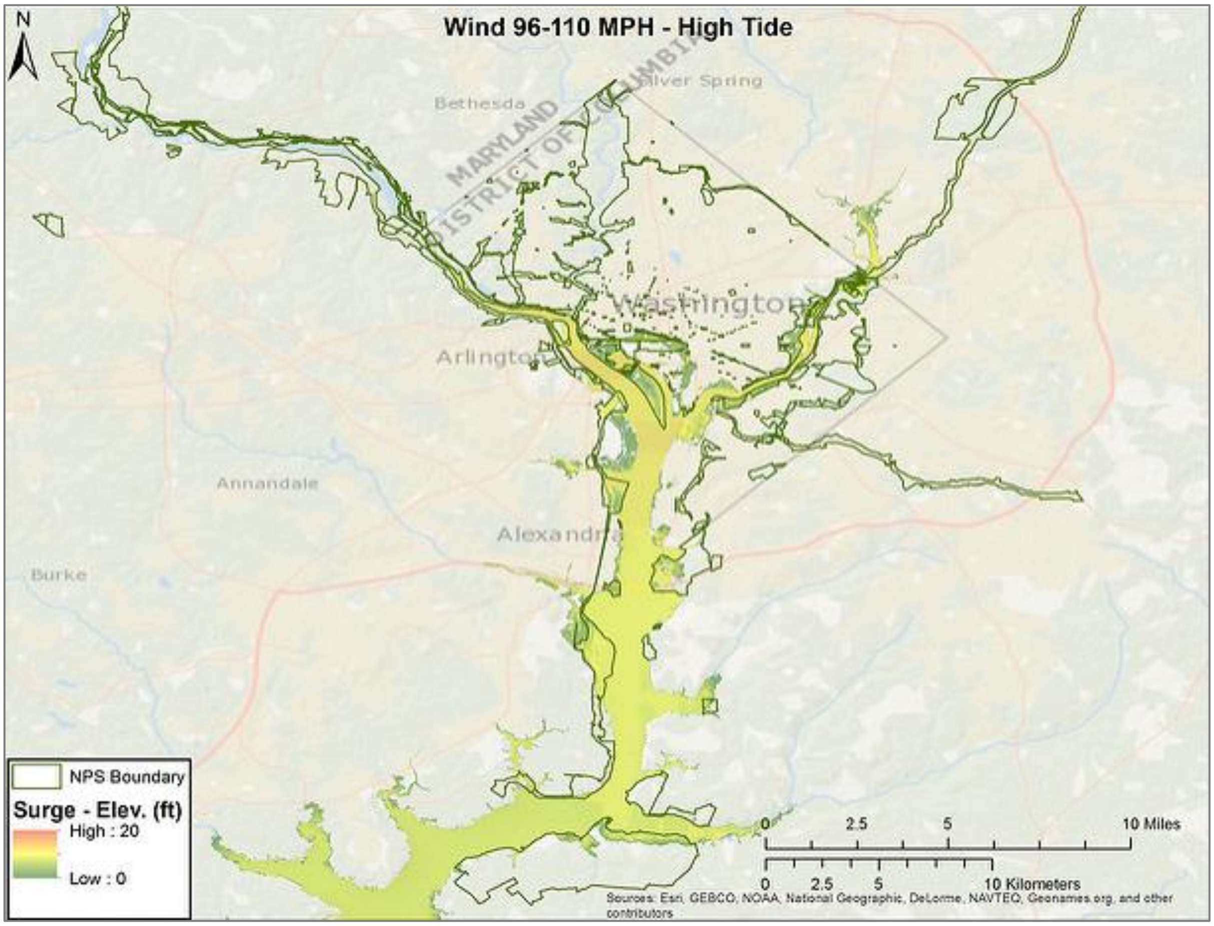

Figure 10. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 2 hurricane striking the Washington D.C. region at high tide. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

IPCC/SLOSH models showed either storm surge or sea level rise (or some combination of the two) affecting every National Capital Region park included in this analysis, with the exception of Harpers Ferry National Historical Park. Our mapping efforts revealed that Harpers Ferry National Historical Park (located approximately 149 m above sea level) is unlikely to experience any impacts of sea level rise due to its elevation and is unlikely to be damaged by storm surge from a hurricane, given its relatively protected location behind several dams along the Potomac and Shenandoah Rivers.

Sea level rise alone is not expected to spread very far into Washington D.C., although a large section on the east side of Theodore Roosevelt Island could be inundated. However, storm surge flooding on top of this sea level rise would have widespread impacts.

Intermountain Region

The Intermountain Region covers mostly inland park units stretching from Texas to Montana. Within the region, only three park units in Texas are subject to sea level change: Big Thicket National Preserve, Palo Alto Battlefield National Historical Park, and Padre Island National Seashore. Of these, Padre Island National Seashore may experience the greatest effects of sea level and storm surge; sea level is projected to rise 0.46–0.69 m (RCP2.6–8.5, Figure 11) by 2100. The same amount of sea level rise is projected for the shoreline near Palo Alto Battlefield National Historical Park, but inundation is not projected to extend far enough to reach the park. Palo Alto Battlefield National Historical Park has no history of being within 10 miles of any hurricane, making the site unlikely to be flooded by storm surge. SLOSH MOM models for the park unit show that that the region would have to have either a Saffir-Simpson category 4 hurricane striking at high tide or a category 5 hurricane striking at any tide in order for the park to experience any storm surge. On the other hand, Figure 12 shows that Padre Island National Seashore, located to the east of Palo Alto Battlefield National Historical Park, historically was within 10 miles of a category 4 hurricane. SLOSH MOM data show that should a category 4 hurricane occur here again, it would likely flood almost the entire island.

Storm surge could potentially travel up the Neches River and flood the southernmost part of Big Thicket National Preserve, although both artificial and natural storm surge defenses in Beaumont, Texas, to the south of the preserve, may buffer it from any surge.

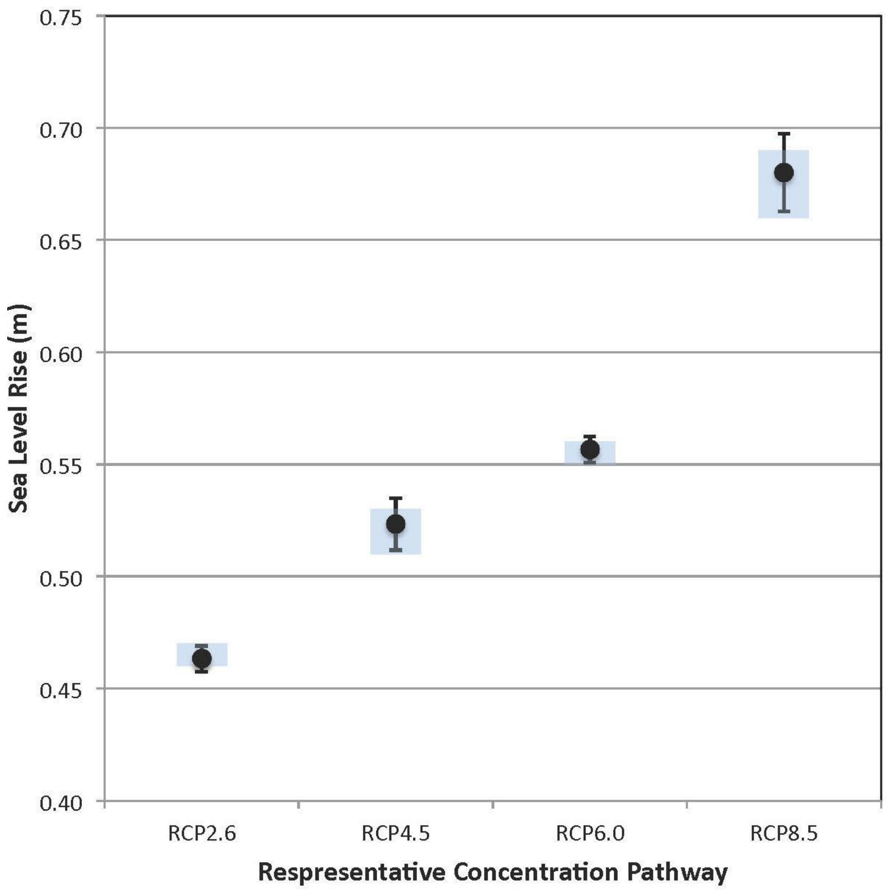

Figure 11. Projected future sea level rise by 2100 for the NPS Intermountain Region under all of the representative concentration pathways. Black dots indicate the average sea level rise (m) for all units within the respective regions. Black bars represent the standard deviation from each mean. Blue bars mark the full range of sea level estimates for each category.

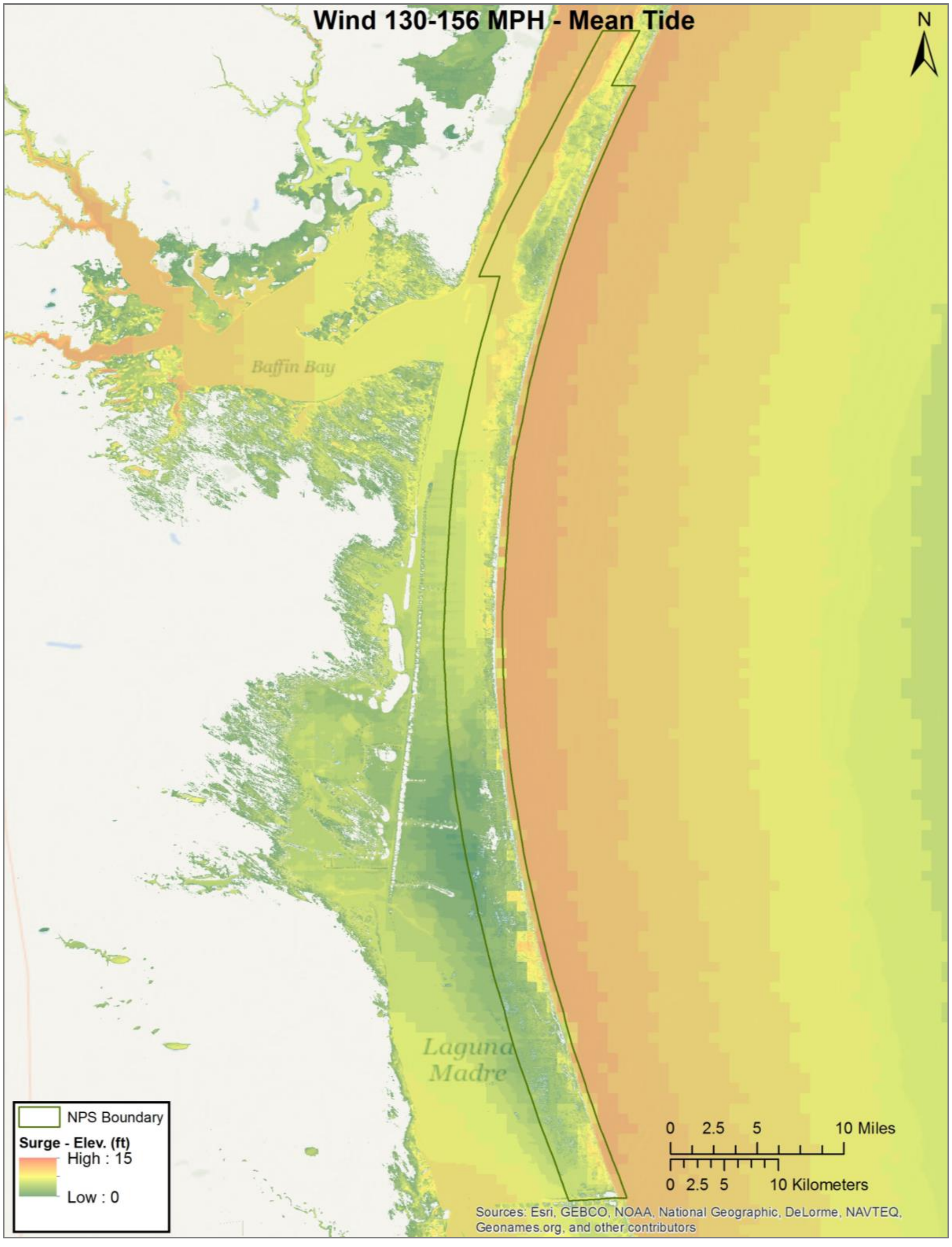

Figure 12. A SLOSH MOM map showing storm surge height and extent created by a Saffir-Simspon category 4 hurricane striking the southwestern Texas region at mean tide. The dark green line around the island represents the boundary of Padre Island National Seashore. Colored areas represent areas of flooding. Colors from green to red show estimated height of a storm surge (see inset legend for estimated range).

Pacific West Region

The Pacific West Region identified 24 park units for analysis in this study that could be vulnerable to sea level rise and/or storm surge. These units occur over a large area that includes California, Oregon, Washington, Hawaii, American Samoa, and Guam. War in the Pacific National Historical Park in Guam has the highest projected sea level rise at 0.68 m (RCP8.5) by 2100, and shares the highest projected sea level rise with almost all of the Hawaiian park units in 2030 and 2050. The average projected sea level rise range is 0.40–0.58 m (RCP2.6–8.5) by 2100 for the whole region; high standard deviations (0.04 m and 0.08 m for RCP2.6 and RCP8.5, respectively) indicate that park-specific projections vary widely across the region.

At the other end of the spectrum, projected sea level rise around Washington's Olympic Peninsula and in the San Juan Islands, affecting Ebey's Landing National Historical Reserve, Olympic National Park, and San Juan Island Historical Park, is expected to occur more slowly, reaching a maximum 0.46 m (RCP8.5) by 2100. This region is subject to tectonic shifts and continuing land movement due to isostatic rebound, further complicating sea level projections. Long-term tide gauge records at Neah Bay, Washington (gauge 9443090), and Tofino, British Columbia, Canada (gauge 822-116), show relative sea levels currently decreasing while tide gauges in Port Angeles, Washington (gauge 9444090), Victoria, Canada (gauge 822-101), and Seattle, Washington (gauge 9447130), show it to be increasing (Zervas 2009). Our projections indicate rising sea level in this region throughout this century, although further investigation of localized changes in land movement could shed more light on this matter.

Park units in the Pacific West Region need to be concerned about potential future storms that could travel along the eastern Pacific Ocean's increasingly warmer waters. Because of the relative lack of hurricanes in this region historically, we used data from Tebaldi et al. (2012), which includes anomalous surges that could be created by storms, and other factors (very high tides sometimes referred to as king tides). Based on the Tebaldi et al. (2012) data, La Jolla, California (gauge 9410230), has the lowest 100-year storm surge (0.95 m) and Toke Point, Washington (gauge 9440910), has the highest 100-year storm surge (1.96 m) in the Pacific West Region. Tebaldi et al. (2012) did not analyze storm data for Hawaii, Guam, or American Samoa, although IBTrACS (Knapp et al. 2010) does have hurricane records for these areas. Only tropical depressions have been recorded within 10 miles of almost all of the Hawaiian park units we analyzed (Haleakala National Park, Hawaii Volcanoes National Park, Kalaupapa National Historical Park, Kaloko-Honokohau National Historical Park, Puukohola Heiau National Historic Site, and World War II Valor in the Pacific National Monument).

Alaska Region

The Alaska Region has the lowest average projected sea level rise (0.28–0.43 m by 2100) compared to the five regions described above. Glacier Bay National Park and Preserve and Klondike Gold Rush National Historical Park in southeastern Alaska share the lowest projected sea level rise (0.33 m, RCP8.5, 2100) while Bering Land Bridge National Preserve on the west coast of the state has the highest projected sea level rise (0.60 m, RCP8.5, 2100).

Figure 1 shows how current relative sea levels vary across the state. Land levels are rapidly rising in the southeast of the region due to isostatic rebound and other tectonic shifts. The net result of these increasing land levels is decreasing relative sea levels for at least the early part of this century. Relative sea level in Skagway, Alaska is decreasing at an average rate of 17.6 mm/y (Zervas 2009). Despite melting ice and other factors outlined in Table 1 that increase ocean water volume, the amount of rising water is insufficient to keep up with land level changes. Seven park units (Glacier Bay National Park, Glacier Bay National Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park) are identified as potentially having decreasing relative sea levels based on the nearest tide gauge data to each of these parks. None of these parks have long-term tide gauges with data spanning at least thirty years. A great strength of using the IPCC (2013) process-based model approach is that, unlike many other semi-empirical models, it does not rely on long-term tide gauge records to statistically project future sea levels. However, sea level projections in this analysis do not include changes in land level. The estimates that we report here represent the expected rise due to water volume expansion alone near to each of these park units. Table D1 shows how land levels are changing at long-term tide gauges across the country. However, given that all of these park units are located far from a tide gauge and that the region is relatively geologically complex, we do not recommend using the land movement numbers from the nearest tide gauge for any of the Alaskan parks.

Storm surge is also very difficult to model for this region. Historically, many of the parks had sea ice along the coastline that helped protect these parks from storm surge. Consequently, NOAA does not have SLOSH MOM models for this region. IBTrACS data (Knapp et al. 2010) show a few storm paths that have moved towards the region, but these types of storms typically do not make landfall once they move over colder waters. Alaska does hold the record for the highest intensity (lowest central pressure) storm (Duff 2015). A downgraded super typhoon, Nuri, struck Adak Island, Alaska, in 2014 with recorded winds gusting up to 122 mph. It is impossible to determine an average or peak historical storm surge without adequate tide gauge data.

Discussion

Global mean sea levels have been rising since the last glacial maximum (Lambeck and Chappell 2001, Clark and Mix 2002, Lambeck et al. 2014). Church and White (2006) estimated that twentieth century global sea levels rose at a rate of approximately 1.7 mm/y, although this rate accelerated over the latter part of the century. Slangen et al. (2016) found that emissions of greenhouse gases from human activities have been the primary driver of global sea level change since 1970 and that the rate of sea level rise has increased over time (Table 1). Satellite altimetry data shows that present-day global relative sea levels are increasing at approximately 3.3 mm/y (Cazenave et al. 2014, Fasullo et al. 2016).

The IPCC (2013) projects that, without greenhouse gas emissions reductions, this rate will increase, and that global average sea levels could rise by 0.40–0.63 m (RCP2.6–8.5) by 2100. We used regional sea level projections from the IPCC (2013) generated for 2050 and 2100 in combination with our interpolated projections for 2030 to estimate the amount of sea level rise 118 coastal national park units could experience in the future. Our projections are based on the new representative concentration pathways (Moss et al. 2010, Figure 13), using a process-based model approach.

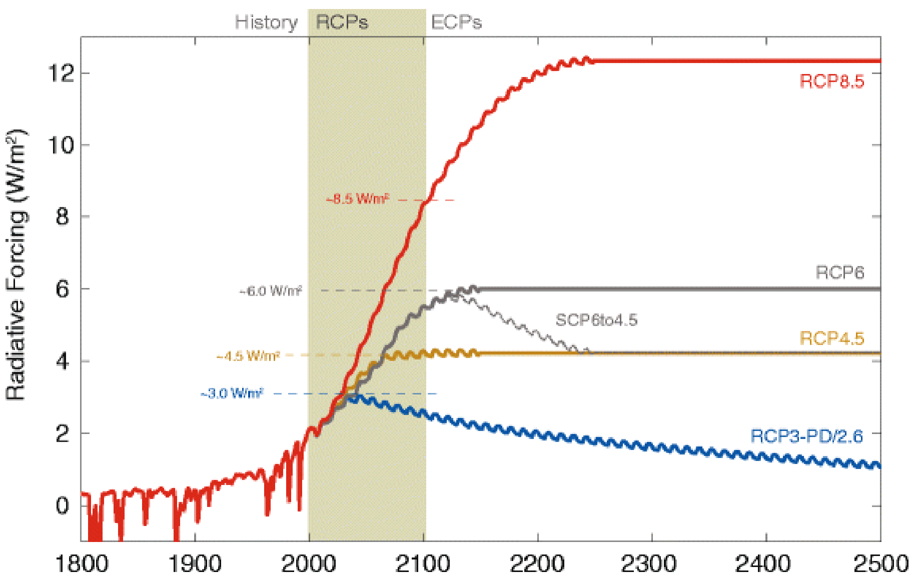

Figure 13. Radiative forcing (see list of terms) for each of the Representative Concentration Pathways (RCPs). An increase in radiative forcing (due to the loading of anthropogenic gases into the atmosphere) will result in higher global average temperatures. RCPs replace the IPCC SRES scenarios. Note how RCP4.5 (yellow line) projections are slightly higher than RCP6.0 (gray line) in the early part of this century. Source: Meinshausen et al. 2011.

Numerous academic articles use mostly semi-empirical models (Rahmstorf 2007) to estimate sea level rise regions across the U.S. The IPCC (2013) lists several semi-empirical sea level rise estimates, all of which result in projections of future sea level that are higher than the IPCC (2013) approach. The differences in these approaches can be attributed to many factors. For example, some of the older papers may have higher sea level estimates because they are based on the older IPCC SRES scenarios (e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2010, Jevrejeva et al. 2010). Other papers may include input from "expert elicitations" in their sea level projections, in which experts provide their opinion on how much sea level (or a related factor) could rise in the future (e.g. Bamber and Aspinall 2013, Jevrejeva et al. 2014, Horton et al. 2014). Some published articles criticize the IPCC sea level estimates as being too conservative or underestimating rates of future sea level change (e.g. Kerr 2013, Horton et al. 2014). Church et al. (2013) addresses these criticisms by explaining how the IPCC define the probability and likelihood of their estimates, and so they are not discussed in detail here. Recent analyses by Clark et al. (2015) further support the findings of the IPCC.

A key strength of the methods used in this analysis lies in providing a unified approach to identify how sea level change may affect all coastal park units across the National Park System, rather than relying on sea level data generated for specific areas. Our analyses revealed that the National Capital Region is projected to experience the greatest increase in sea level (not taking into account changes in land level). This rise will affect each of the region's units in different ways depending on the elevation of the individual unit, but it could be significant if combined with a storm surge from a storm such as the Saffir-Simpson category 2 hurricane in 1878.

At the individual park level, IPCC projections reveal the sea level along the coastline adjacent to Wright Brothers National Memorial could rise up 0.82 m (RCP8.5) by 2100, which could lead to significant flooding if the dynamic landforms are not able to keep pace with such high rates of sea level rise. In addition, storm surge impacts at this higher sea level would be significant. The Southeast Region as a whole is generally susceptible to inundation and flooding due to its low-lying nature in many places, particularly in Cape Hatteras and Cape Lookout National Seashores. Our sea level rise maps (Appendix A) highlight how much all of these park units may be affected.

These estimates do not include the latest data on changing land levels. The IPCC included estimates of global isostatic adjustment (Equation 1) in their predictions, but those do not include changes in land level due to other factors, such as earthquakes and groundwater extraction. We can roughly estimate relative sea level change for a small number of parks based on current rates of subsidence gathered from nearby long-term tide gauge data. We project Jean Lafitte National Historical Park and Preserve to have the greatest relative sea level increase based on the current rate of land movement. Our sea level projections agree with current sea level trends in showing that the southeast Alaska region is experiencing the least amount of sea level rise of anywhere in the National Park System.

Sallenger et al. (2012) discussed how changes in Atlantic Ocean temperatures and salinity (resulting from changes in circulation) could lead to changes in sea level that could create a 1000-km long

“hotspot” along the North Atlantic coast from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. We estimate that almost all of the coastal park units in this area would be flooded under these conditions.

It is unknown exactly to what degree future storm surge will affect the Alaskan park units. Accurate long-term (>30 years) storm surge data do not exist for the Alaska region. Even if such data did exist, it would be not be analogous to future conditions in the region because sea ice that had previously protected the shores for many of the western Alaska park units melts to reveal an easily erodible coastline (Frey et al. 2015). The warming of ocean waters in the Gulf of Alaska and Pacific Ocean could also make it more conducive for more storms like Typhoon Nuri to travel north without losing energy as under historic conditions.

The Pacific West Region shows high variability among parks. War in The Pacific National Historical Park in Guam ranks highest in projected sea level rise among units in the Pacific West Region. The large area of the region partly explains the relatively high standard deviation in results for the region. The tectonically complex setting of many of the region’s parks also complicates future sea level estimates. Changes in land movement are somewhat gradual nationwide in comparison to Alaska and the Pacific West Region, especially where earthquakes can rapidly change the position of the land relative to the sea.

Island park units in general are particularly exposed to the impacts of sea level change and storm surge. Many of the barrier island parks, such as Fire Island National Seashore, Assateague Island National Seashore, Palo Alto Battlefield National Historical Park, Gulf Islands National Seashore, and Cape Hatteras National Seashore, are all projected to experience sea level rise of over 0.69 m by 2100 (RCP8.5). This sea level rise, combined with storm surge, could be especially difficult for isolated island park units, such as the Caribbean park units, the National Park of American Samoa, and War in the Pacific National Historical Park, where access to aid in the event of a natural disaster may not be immediately available.

Conclusions

This report presents projections of sea level change (118 parks) and storm surge (79 parks) in coastal park units administered by the National Park Service. Sea level change and storm surge vary geographically, resulting in locally-specific challenges for adaptation and management. It is important to acknowledge that sea level change will affect some parts of Alaska differently than coastal parks in the rest of the country. Northwest Alaska can expect relative sea levels to increase over time; while in southeast Alaska, relative sea levels may continue to decrease over the first part of this century, followed by an increase in relative sea level towards the end of the century.

This project is an important first step in assessing how changes in sea level and storm surge may affect national park units. Using sea level rise and storm surge information, parks can begin to plan for effects on resources, facilities, access, and other areas of management. While methods used here are not appropriate for combining the separate sea level rise and storm surge results, parks should be aware of the potential for synergistic effects of sea level rise and storm surge causing impacts larger than either may cause individually. It is clear that more research can be done on these complex issues to assess how these changes may affect parks and regions. These data can inform future projects related to both natural and cultural resources as well as the planning and management of infrastructure.

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Appendix A

Links to Data Sources

Maps were created for this project using NOAA DEM data. For further information regarding our methods refer to methods section on page 3.

Digital versions of our sea level rise maps will be available at www.irma.gov

Storm surge maps are also available on www.irma.gov and www.flickr.com/photos/125040673@N03/albums/with/72157645643578558

Appendix B

Frequently Asked Questions

Q. How were the parks in this project selected?

A. Parks were selected after consultation with regional managers. Regional managers were given a list of parks that authors considered to be vulnerable to sea level change and/or storm surge. This list was vetted by regional managers and their staff who added or subtracted park names based on their knowledge of the region.

Q. Who originally identified which park units should be used in this study?

A. The initial list of parks was approved by the following regional managers: Northeast Region, Amanda Babson (signed 11/27/13); Southeast Region, Shawn Benge (signed 11/14/13); National Capital Region, Perry Wheelock (signed 3/17/14); Intermountain Region, Patrick Malone signed on behalf of Tammy Whittington (signed 11/13/13); Pacific West Region, Jay Goldsmith (signed 11/26/13); Alaska Region, Robert Winfree (signed 11/15/13).

Q. What's the timeline of this project?

A. This is the culmination of a three-year project that was proposed in February 2012. Initial Fiscal year of funding was 2013.

Q. In what instance did you use data from Tebaldi et al. (2012)?

A. NOAA's Sea Lake and Overland Surge from Hurricanes (SLOSH) model does not include storm surge predictions for all of the parks used in this study. We used data from Tebaldi et al. (2012) where reasonable to provide data for park units in California, Oregon, Washington, and southern Alaska. The following parks used Tebaldi et al. (2012) data: Cabrillo National Monument, Channel Islands National Park, Ebey's Landing National Historical Reserve, Fort Point National Historic Site, Fort Vancouver National Historic Site, Golden Gate National Recreation Area, Klondike Gold Rush National Historical Park, Lewis and Clark National Historical Park, Olympic National Park, Port Chicago Naval Magazine National Scenic Trail, Point Reyes National Seashore, Redwood National Park, Rosie the Riveter WWII Home Front National Historical Park, San Francisco Maritime National Historical Park, San Juan Island National Historical Park, and Santa Monica Mountains National Recreation Area.

Q. Why don't all of the parks have storm surge maps?

A. Unfortunately some parks do not have enough data to complete a storm surge map. These were parks that were not modeled by NOAA's SLOSH MOM model or near any of the tide gauges used by Tebaldi et al. (2012). These parks are: Aniakchak Preserve, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Glacier Bay National Park and Preserve, Katmai National Park, Kenai Fjords National Park, Lake Clark National Park, Sitka National Historical Park, War in the Pacific National Historical Park, and Wrangell – St. Elias National Park and Preserve.

Q. My park only has storm surge maps covering a few Saffir-Simpson categories. Why is that?

A. Some parks, particularly those in the Northeast Region, were not modeled by NOAA for the full range of Saffir-Simpson storm scenarios. This is because it is considered very unlikely that a Saffir-Simpson category 4 or 5 hurricane would be able to sustain itself into the northern latitudes of that region.

Q. Why are the storm surge maps in NAVD88?

A. That is the default datum for SLOSH data. This was a decision made by NOAA.

Q. What are the effects of NAVD88 on sea level and storm surge projections for some parks?

A. The North American Vertical Datum of 1988 (NAVD88) is a datum that is commonly used in North America to refer to the "elevation" of a location. It uses a fixed value for the height of North America's mean sea level. While this is a popular datum for mapping, it has the limitation that it is based on the observed mean sea level for a single location: Rimouski, Canada. As you move further away from this location you can expect actual sea level to differ from the mean sea level at Rimouski. For locations such as California this can result in a significant difference between observed mean sea level and NAVD88. Your natural resource or GIS specialist will likely have further information about your specific location. Alternatively you can look up the differences in your region by checking the datum information for your nearest tide gauge station: https://tidesandcurrents.noaa.gov/stations.html?type=Datums

Q. Which sea level change or storm surge scenario would you recommend I use?

A. All parks are different, as are all projects. Your choice of scenario may depend on many different factors including risk tolerance and expected time horizon of the project. The NPS has not yet released any guidance on which climate change scenarios to use for planning. We would recommend you contact the appropriate project lead, natural or cultural resource manager, or someone from the Climate Change Response Program for further guidance depending on your situation.

Q. How accurate are these numbers?

A. The accuracy of these data varies depending on the data source. SLOSH data has +/- 20% accuracy, although this is discussed in greater detail by Glahn et al. (2009). Further information about storm surge data generated by Tebaldi et al. can be found in Tebaladi et al. (2012). IPCC global sea level rise projections range between 0.26 m (RCP2.6 minimum likely range) and 0.82 m (RCP8.5 maximum likely range) by 2100. The standard error of the IPCC is explained in greater detail in the Chapter 13 supplementary material in AR5 (IPCC 2013). An explanation on the horizontal and vertical accuracy of the digital elevation models used for mapping can be found in the metadata that accompanies the map data on www.irma.gov. DEM data were required to have a ≤18.5 cm root mean square error vertical accuracy before they were converted to MHHW. An exception to this was in Alaska where these data were not available.

Q. We have had higher/lower storm surge numbers in the past. Why?

A. The numbers given here are meant to represent a maximum based on a typical storm surge category. As described above, there is likely to be some deviation around that number. Certain periods are also likely to result in higher than average storm surges. For example, periodic changes in regional water temperatures (caused by phenomena such as El Niño and La Niña) will impact water levels that will add to any storm surge. Likewise, changes in the North Atlantic Oscillation and Pacific Decadal Oscillation will also affect ocean conditions. This must be taken into account when using these numbers. All of these factors vary temporally and geographically, so contact your natural resource manager if you are unsure how this could impact your particular park unit.

Q. What other factors should I consider when looking at these numbers?

A. These projections do not include the impact of all man-made structures, such as flood barriers, levees, and dams. They also do not take into account how smaller features, such as dune systems or vegetation changes could impact coastal flooding. There are many meso- and micro-scale factors that need to be taken into account such as differences in topography, the presence/absence of any wetlands etc. It should also be expected that as sea levels change, areas of the shoreline will change accordingly, particularly due to erosion and accretion.

Q. Why don't you recommend that I add storm surge numbers on top of the sea level change numbers?

A. Higher sea level and permanent inundation will change the way waves propagate within a basin. Sea level change is expected to have a significant impact on the geomorphology of the coastline. Changing water levels will lead to areas of greater erosion in some areas as well as increasing accretion in other places. As sea level changes, the fluid dynamics of a particular region will also change. For example, tidal distance will change as water levels rise, which will alter the spatial extent of a storm surge as well as potentially impacting wave height. This is not something NOAA takes into account in their SLOSH model.

Q. Where can I get more information about the sea level models used in this study?

A. https://www.ipcc.ch/report/ar5/wg1/

Q. Where can I get more information about the NOAA SLOSH model?

A. http://www.nhc.noaa.gov/surge/slosh.php

Q. So, based on your maps, can I assume that my location will stay dry in the future?

A. No. As explained above, these numbers are accurate within a certain range. Also, these maps are based on "bathtub" models where water is simulated as rising over a static surface. In reality, your coastline will change in response to storms and other coastal dynamics. These numbers are intended for guidance only.

Q. Why do you use the period 1986–2005 as a baseline for your sea level rise projections?

A. We are following the standard approach used by the IPCC, USACE, and much of the academic literature. If you would like your estimate to start from a specific year you can do one of two things: 1) subtract the observed rate of sea level rise since 1992 for your location, or 2) contact park, region, or Climate Change Response Program staff for assistance. It may be possible to interpolate projections further to estimate the amount of rise the models estimate to have taken place between the baseline and whichever year you choose. We must caution that if you follow option 1 you will be introducing some inaccuracy to sea level projections, especially if you use data from a tide gauge that is not close to your location.

Q. The SLOSH/IPCC projections seem lower/higher than X source I've found. Why is that?

A. Projections can vary depending on a number of factors such as choice of model, approach, or the age of the study. We would recommend that you speak to a climate specialist when choosing sources.

Q. What are other impacts from sea level rise that parks should consider?

A. Impacts from sea level rise could include, but are not limited to, increased erosion, damaged cultural resources, damage to above and below ground infrastructure, difficulty accessing inundated infrastructure, increased groundwater intrusion, altered groundwater salinity, diminished space for recreational activities (possibly leading to conflict between different recreational users), and the complete loss or migration of certain coastal ecosystems. For more information on the topic, please see the Coastal Adaptation Strategies Handbook at: http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

Appendix C

Data Tables

Table C1. The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region	Acadia National Park	Bar Harbor, ME (8413320)	N	60	0.750
	Assateague Island National Seashore‡	Lewes, DE (8557380)	N	88	1.660
	Boston Harbor Islands National Recreation Area	Boston, MA (8443970)	N	86	0.840
	Boston National Historical Park	Boston, MA (8443970)	N	86	0.840
	Cape Cod National Seashore	Woods Hole, MA (8447930)	N	75	0.970
	Castle Clinton National Monument	New York, The Battery, NY (8518750)	N	151	1.220
	Colonial National Historical Park	Sewells Point, VA (8638610)	N	80	2.610
	Edgar Allen Poe National Historic Site	Philadelphia, PA (8545240)	N	107	1.060
	Federal Hall National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Fire Island National Seashore	Montauk, NY (8510560)	N	60	1.230
	Fort McHenry National Monument and Historic Shrine	Baltimore, MD (8574680)	N	105	1.330

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)[†]	Rate of Subsidence (mm/y)
Northeast Region (continued)	Fort Monroe National Monument[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Gateway National Recreation Area*[‡]	Sandy Hook, NJ (8531680)	N	75	2.270
	General Grant National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	George Washington Birthplace National Monument[‡]	Solomons Island, MD (8577330)	N	70	1.830
	Governors Island National Monument[‡]	New York, The Battery, NY (8518750)	N	151	1.220
	Hamilton Grange National Memorial	New York, The Battery, NY (8518750)	N	151	1.220
	Harriet Tubman Underground Railroad National Monument	Cambridge, MD (8571892)	N	64	1.900
	Independence National Historical Park	Philadelphia, PA (8545240)	N	107	1.060
	New Bedford Whaling National Historical Park	Woods Hole, MA (8447930)	N	75	0.970
	Petersburg National Battlefield[‡]	Sewells Point, VA (8638610)	N	80	2.610
	Roger Williams National Memorial	Providence, RI (8454000)	N	69	0.300

[†]Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

[‡]It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Northeast Region (continued)	Sagamore Hill National Historic Site	Kings Point, NY (8516945)	N	76	0.670
	Saint Croix Island International Historic Site‡	Eastport, ME (8410140)	N	78	0.350
	Salem Maritime National Historic Site	Boston, MA (8443970)	N	86	0.840
	Saugus Iron Works National Historic Site	Boston, MA (8443970)	N	86	0.840
	Statue of Liberty National Monument‡	New York, The Battery, NY (8518750)	N	151	1.220
	Thaddeus Kosciuszko National Memorial	Philadelphia, PA (8545240)	N	107	1.060
	Theodore Roosevelt Birthplace National Historic Site	New York, The Battery, NY (8518750)	N	151	1.220
Southeast Region	Big Cypress National Preserve	Naples, FL (8725110)	N	42	0.270
	Biscayne National Park‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Buck Island Reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Canaveral National Seashore	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Cape Hatteras National Seashore*‡	Beaufort, NC (8656483)	N	54	0.790
	Cape Lookout National Seashore	Beaufort, NC (8656483)	N	54	0.790
	Castillo De San Marcos National Monument‡	Mayport, FL (8720218)	N	79	0.590
	Charles Pinckney National Historic Site	Charleston, SC (8665530)	N	86	1.240
	Christiansted National Historic Site‡	San Juan, Puerto Rico (9755371)	N	45	-0.202
	Cumberland Island National Seashore‡	Fernandina Beach, FL (8720030)	N	110	0.600
	De Soto National Memorial	St. Petersburg, FL (8726520)	N	60	0.920
	Dry Tortugas National Park‡	Key West, FL (8724580)	N	94	0.500
	Everglades National Park*‡	Miami Beach, FL (Inactive – 8723170)	N	51	0.690
	Fort Caroline National Memorial‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Frederica National Monument‡	Fernandina Beach, FL (8720030)	N	110	0.600
	Fort Matanzas National Monument‡	Daytona Beach Shores, FL (Inactive – 8721120)	N	59	0.620

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Fort Pulaski National Monument	Fort Pulaski, GA (8670870)	Y	72	1.360
	Fort Raleigh National Historic Site‡	Beaufort, NC (8656483)	N	54	0.790
	Fort Sumter National Monument‡	Charleston, SC (8665530)	N	86	1.240
	Gulf Islands National Seashore (Alabama section)*‡	Dauphin Island, AL (8735180)	N	41	1.220
	Gulf Islands National Seashore (Florida section)*‡	Pensacola, FL (8729840)	N	84	0.330
	Jean Lafitte National Historical Park and Preserve‡	Grand Isle, LA (8761724)	N	60	7.600
	Moores Creek National Battlefield‡	Wilmington, NC (8658120)	N	72	0.430
	New Orleans Jazz National Historical Park‡	Grand Isle, LA (8761724)	N	60	7.600
	Salt River Bay National Historical Park and Ecological Preserve‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	San Juan National Historic Site	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Timucuan Ecological and Historic Preserve‡	Fernandina Beach, FL (8720030)	N	110	0.600

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Southeast Region (continued)	Virgin Islands Coral reef National Monument‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Virgin Islands National Park‡	San Juan, Puerto Rico (9755371)	N	45	-0.020
	Wright Brothers National Memorial‡	Sewells Point, VA (8638610)	N	80	2.610
National Capital Region	Anacostia Park	Washington, DC (8594900)	N	83	1.340
	Chesapeake and Ohio Canal National Historical Park	Washington, DC (8594900)	N	83	1.340
	Constitution Gardens	Washington, DC (8594900)	N	83	1.340
	Fort Washington Park	Washington, DC (8594900)	N	83	1.340
	George Washington Memorial Parkway	Washington, DC (8594900)	N	83	1.340
	Harpers Ferry National Historical Park	Washington, DC (8594900)	N	83	1.340
	Korean War Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Lincoln Memorial	Washington, DC (8594900)	N	83	1.340
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Washington, DC (8594900)	N	83	1.340
	Martin Luther King Jr. Memorial	Washington, DC (8594900)	N	83	1.340

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
National Capital Region (continued)	National Mall	Washington, DC (8594900)	N	83	1.340
	National Mall and Memorial Parks	Washington, DC (8594900)	N	83	1.340
	National World War II Memorial	Washington, DC (8594900)	N	83	1.340
	Piscataway Park	Washington, DC (8594900)	N	83	1.340
	Potomac Heritage National Scenic Trail	Washington, DC (8594900)	N	83	1.340
	President's Park (White House)	Washington, DC (8594900)	N	83	1.340
	Rock Creek Park	Washington, DC (8594900)	N	83	1.340
	Theodore Roosevelt Island Park	Washington, DC (8594900)	N	83	1.340
	Thomas Jefferson Memorial	Washington, DC (8594900)	N	83	1.340
	Vietnam Veterans Memorial	Washington, DC (8594900)	N	83	1.340
	Washington Monument	Washington, DC (8594900)	N	83	1.340
Intermountain Region	Big Thicket National Preserve‡	Sabine Pass, TX (8770570)	N	49	3.850
	Palo Alto Battlefield National Historical Park‡	Port Isabel, TX (8779770)	N	63	2.160
	Padre Island National Seashore*	Padre Island, TX (8779750)	N	49	1.780

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region	American Memorial Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	Cabrillo National Monument	San Diego, CA (9410170)	N	101	0.370
	Channel Islands National Park‡	Santa Monica, CA (9410840)	N	74	-0.280
	Ebey's Landing National Historical Reserve‡	Friday Harbor, WA (9449880)	N	73	-0.580
	Fort Point National Historic Site	San Francisco, CA (9414290)	Y	110	0.360
	Fort Vancouver National Historic Site‡	Astoria, OR (9439040)	N	82	-2.100
	Golden Gate National Recreation Area	San Francisco, CA (9414290)	N	110	0.360
	Haleakala National Park*‡	Kahului, HI (1615680)	N	60	0.510
	Hawaii Volcanoes National Park*‡	Hilo, HI (1617760)	N	80	1.470
	Kaloko-Honokohau National Historical Park‡	Hilo, HI (1617760)	N	80	1.470
	Lewis and Clark National Historical Park	Astoria, OR (9439040)	N	82	-2.100
	National Park of American Samoa	Pago Pago, American Samoa (1770000)	N	59	0.370
	Olympic National Park*‡	Seattle, WA (9447130)	N	109	0.540

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

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*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Pacific West Region (continued)	Point Reyes National Seashore‡	San Francisco, CA (9414290)	N	110	0.360
	Port Chicago Naval Magazine National Memorial‡	Alameda, CA (9414750)	N	68	-0.780
	Pu'uhonua O Honaunau National Historical Park*‡	Hilo, HI (1617760)	N	80	1.470
	Puukohola Heiau National Historic Site*‡	Hilo, HI (1617760)	N	80	1.470
	Redwood National and State Parks	Crescent City, CA (9419750)	N	74	-2.380
	Rosie the Riveter WWII Home Front National Historical Park*	Alameda, CA (9414750)	N	68	-0.780
	San Francisco Maritime National Historical Park	San Francisco, CA (9414290)	N	110	0.360
	Santa Monica Mountains National Recreation Area	Santa Monica, CA (9410840)	N	74	-0.280
	War in the Pacific National Historical Park‡	Marianas Islands, Guam (Inactive – 1630000)	N	46	-2.750
	World War II Valor in the Pacific National Monument‡	Honolulu, HI (1612340)	N	102	-0.180
Alaska Region	Aniakchak Preserve*‡	Unalaska, AK (9462620)	N	50	-7.250
	Bering Land Bridge National Preserve‡	No data	No data	No data	No data

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C1 (continued). The nearest long-term tide gauge to each of the 118 national park service units used in this report.

Region	Park Unit	Nearest Tide Gauge	Is Tide Gauge Within The Park Boundary?	Length of Record Used (y)†	Rate of Subsidence (mm/y)
Alaska Region (continued)	Cape Krusenstern National Monument‡	No data	No data	No data	No data
	Glacier Bay National Park*‡	Juneau, AK (9452210)	N	71	-14.620
	Glacier Bay Preserve*‡	Juneau, AK (9452210)	N	71	-14.620
	Katmai National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Kenai Fjords National Park‡	Seward, AK (9455090)	N	43	-3.820
	Klondike Gold Rush National Historical Park‡	Skagway, AK (9452400)	N	63	-18.960
	Lake Clark National Park‡	Seldovia, AK (9455500)	N	43	-11.420
	Sitka National Historical Park‡	Sitka, AK (9451600)	N	83	-3.710
	Wrangell – St. Elias National Park‡	Cordova, AK (9454050)	N	43	3.450
	Wrangell – St. Elias National Preserve‡	Cordova, AK (9454050)	N	43	3.450

†Number of years used by the USACE to calculate sea level change (source: http://www.corpsclimate.us/ccaceslcurves(superseded).cfm)

‡It is not recommended that you use this tide gauge data to determine land level for this park. The boundary is located either too far away or on a different land mass to where the nearest tide gauge is, which increases the inaccuracy of this data. It is strongly recommended that you wait for the forthcoming NASA report on land level (Nerem in prep).

*The park boundary stretches over either large or multiple areas. More than one tide gauge record is appropriate for this park.

Table C2. Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	**Park Unit**	**Year**	**RCP2.6**	**RCP4.5**	**RCP6.0**	**RCP8.5**
Northeast Region	Acadia National Park	2030	0.08	0.09	0.09	0.1
		2050	0.14	0.16	0.16	0.19
		2100	0.28	0.36	0.39	0.54
	Assateague Island National Seashore[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Boston Harbor Islands National Recreation Area	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Boston National Historical Park	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Cape Cod National Seashore[§]	2030	0.13	0.15	0.13	0.15
		2050	0.23	0.27	0.23	0.29
		2100	0.45	0.51	0.57	0.69
	Castle Clinton National Monument*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Colonial National Historical Park	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Edgar Allen Poe National Historic Site*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Federal Hall National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Fire Island National Seashore§	2030	0.14	0.14	0.14	0.14
		2050	0.25	0.26	0.25	0.27
		2100	0.5	0.58	0.62	0.76
	Fort McHenry National Monument and Historic Shrine	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	Fort Monroe National Monument	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Gateway National Recreation Area	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	General Grant National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	George Washington Birthplace National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Governors Island National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Hamilton Grange National Memorial*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Harriet Tubman Underground Railroad National Monument	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Independence National Historical Park*	2030	0.16‡	0.15	0.15‡	0.14
		2050	0.27‡	0.27	0.27‡	0.28
		2100	0.54‡	0.62	0.68‡	0.79
	New Bedford Whaling National Historical Park*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Petersburg National Battlefield*	2030	0.16	0.15	0.15	0.15
		2050	0.27	0.28	0.27	0.29
		2100	0.55	0.64	0.67	0.81
	Roger Williams National Memorial*	2030	0.13	0.13	0.12	0.13
		2050	0.22	0.23	0.22	0.25
		2100	0.45	0.53	0.55	0.7
	Sagamore Hill National Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Saint Croix Island International Historic Site	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.26	0.26	0.27
		2100	0.52	0.59	0.64	0.76

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Northeast Region (continued)	Salem Maritime National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Saugus Iron Works National Historic Site	2030	0.11[‡]	0.11	0.11[‡]	0.11
		2050	0.19[‡]	0.2	0.20[‡]	0.22
		2100	0.37[‡]	0.45	0.50[‡]	0.62
	Statue of Liberty National Monument	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
	Thaddeus Kosciuszko National Memorial*	2030	0.16[‡]	0.15	0.15[‡]	0.14
		2050	0.27[‡]	0.27	0.27[‡]	0.28
		2100	0.54[‡]	0.62	0.68[‡]	0.79
	Theodore Roosevelt Birthplace National Historic Site*	2030	0.15	0.14	0.14	0.14
		2050	0.26	0.25	0.25	0.27
		2100	0.52	0.58	0.62	0.77
Southeast Region	Big Cypress National Preserve[§]	2030	0.13	0.13	0.12	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.46	0.54	0.55	0.69

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Biscayne National Park	2030	0.14‡	0.13	0.12	0.12
		2050	0.24‡	0.23	0.21	0.24
		2100	0.47‡	0.53	0.53	0.68
	Buck Island Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Canaveral National Seashore	2030	0.14‡	0.13	0.13‡	0.12
		2050	0.25‡	0.24	0.24‡	0.24
		2100	0.50‡	0.54	0.59‡	0.68
	Cape Hatteras National Seashore	2030	0.15‡	0.15	0.15	0.14
		2050	0.26‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Cape Lookout National Seashore§	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	Castillo De San Marcos National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Charles Pinckney National Historic Site*	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Christiansted National Historic Site	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	Cumberland Island National Seashore	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	De Soto National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.56	0.57	0.72
	Dry Tortugas National Park§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.24
		2100	0.47	0.54	0.56	0.69
	Everglades National Park§	2030	0.13	0.13	0.12	0.17
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.54	0.68

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Fort Caroline National Memorial	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Frederica National Monument	2030	0.14	0.13	0.12	0.12
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.54	0.54	0.69
	Fort Matanzas National Monument	2030	0.14	0.13	0.13	0.13
		2050	0.23	0.24	0.22	0.24
		2100	0.47	0.56	0.56	0.7
	Fort Pulaski National Monument§	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72
	Fort Raleigh National Historic Site	2030	0.15‡	0.15	0.15	0.14
		2050	0.27‡	0.28	0.28	0.28
		2100	0.53‡	0.63	0.68	0.79
	Fort Sumter National Monument	2030	0.14	0.14	0.13	0.13
		2050	0.25	0.25	0.24	0.25
		2100	0.49	0.57	0.59	0.72

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

‡No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Gulf Islands National Seashore§	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.48	0.55	0.57	0.7
	Jean Lafitte National Historical Park and Preserve†§	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Moores Creek National Battlefield*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.27
		2100	0.53	0.61	0.65	0.76
	New Orleans Jazz National Historical Park*	2030	0.14	0.13	0.13	0.12
		2050	0.24	0.23	0.23	0.24
		2100	0.48	0.54	0.56	0.68
	Salt River Bay National Historic Park and Ecological Preserve	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.23
		2100	0.44	0.5	0.51	0.64
	San Juan National Historic Site	2030	0.12	0.12	0.11	0.12
		2050	0.22	0.22	0.2	0.22
		2100	0.43	0.49	0.5	0.64

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Southeast Region (continued)	Timucuan Ecological and Historic Preserve	2030	0.14	0.13	0.13	0.13
		2050	0.24	0.24	0.23	0.25
		2100	0.47	0.56	0.56	0.7
	Virgin Islands Coral Reef National Monument	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Virgin Islands National Park[§]	2030	0.13	0.12	0.11	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.51	0.64
	Wright Brothers National Memorial*	2030	0.15[‡]	0.16	0.16	0.15
		2050	0.27[‡]	0.29	0.28	0.29
		2100	0.53[‡]	0.65	0.7	0.82
National Capital Region	Anacostia Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Chesapeake & Ohio Canal National Historical Park[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Constitution Gardens*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Fort Washington Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	George Washington Memorial Parkway[§]	2030	0.15[‡]	0.15	0.15[‡]	0.14
		2050	0.26[‡]	0.27	0.26[‡]	0.28
		2100	0.53[‡]	0.62	0.66[‡]	0.79
	Harpers Ferry National Historical Park*[§]	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.62	0.66	0.79
	Korean War Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Lincoln Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

[‡]No data was available for this scenario. Data from an adjacent cell was used in lieu.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Martin Luther King Jr. Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National Mall & Memorial Parks*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	National World War II Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Piscataway Park*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Potomac Heritage National Scenic Trail	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	President's Park (White House)*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Rock Creek Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Theodore Roosevelt Island Park	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Thomas Jefferson Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
	Vietnam Veterans Memorial*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
National Capital Region (continued)	Washington Monument*	2030	0.15	0.15	0.15	0.14
		2050	0.26	0.27	0.26	0.28
		2100	0.53	0.63	0.66	0.8
Intermountain Region	Big Thicket National Preserve*	2030	0.14‡	0.12	0.12‡	0.12
		2050	0.23‡	0.23	0.22‡	0.23
		2100	0.47‡	0.51	0.55‡	0.66
	Palo Alto Battlefield National Historical Park*§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
	Padre Island National Seashore§	2030	0.13	0.13	0.13	0.12
		2050	0.23	0.23	0.22	0.24
		2100	0.46	0.53	0.56	0.69
Pacific West Region	American Memorial Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	Cabrillo National Monument	2030	0.1	0.1	0.09	0.1
		2050	0.17	0.17	0.17	0.19
		2100	0.35	0.4	0.41	0.53

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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§Parks that cover two or more cells. Data were averaged between these parks based on percentage of shoreline in each cell. Adjacent cells were used in cases where boundaries crossed into null data cells.

Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Channel Islands National Park§	2030	0.11	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.39	0.44	0.46	0.57
	Ebey's Landing National Historical Reserve	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Fort Point National Historic Site	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Fort Vancouver National Historic Site*	2030	0.12	0.11	0.11	0.1
		2050	0.21	0.2	0.19	0.19
		2100	0.42	0.45	0.47	0.55
	Golden Gate National Recreation Area§	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.18	0.17	0.19
		2100	0.37	0.42	0.43	0.54
	Haleakala National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Hawaii Volcanoes National Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Kalaupapa National Historical Park§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.66
	Kaloko-Honokohau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Lewis and Clark National Historical Park§	2030	0.12	0.1	0.1	0.1
		2050	0.2	0.19	0.18	0.19
		2100	0.4	0.44	0.46	0.53
	National Park of American Samoa	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.65
	Olympic National Park§	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

†Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	Point Reyes National Seashore[§]	2030	0.11	0.1	0.1	0.1
		2050	0.19	0.19	0.18	0.19
		2100	0.38	0.43	0.45	0.55
	Port Chicago Naval Magazine National Memorial	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	Pu’uhonua O Honaunau National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.5	0.52	0.67
	Puukohola Heiau National Historic Site	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.24
		2100	0.44	0.51	0.52	0.67
	Redwood National and State Parks	2030	0.12	0.11	0.1	0.1
		2050	0.2	0.19	0.18	0.2
		2100	0.4	0.44	0.46	0.56
	Rosie the Riveter WWII Home Front National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Pacific West Region (continued)	San Francisco Maritime National Historical Park	2030	0.11	0.1	0.1	0.1
		2050	0.18	0.18	0.17	0.19
		2100	0.37	0.41	0.43	0.53
	San Juan Island National Historical Park	2030	0.1	0.09	0.09	0.08
		2050	0.17	0.16	0.16	0.16
		2100	0.34	0.37	0.39	0.46
	Santa Monica Mountains National Recreation Area§	2030	0.12	0.11	0.1	0.11
		2050	0.2	0.2	0.19	0.2
		2100	0.4	0.45	0.46	0.58
	War in the Pacific National Historical Park	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.22	0.24
		2100	0.44	0.51	0.54	0.68
	World War II Valor in the Pacific National Monument§	2030	0.13	0.12	0.12	0.12
		2050	0.22	0.22	0.21	0.23
		2100	0.44	0.5	0.52	0.67
Alaska Region	Aniakchak Preserve§	2030	0.09‡	0.09	0.09	0.09
		2050	0.15‡	0.17	0.16	0.18
		2100	0.31‡	0.38	0.4	0.51

*Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Bering Land Bridge National Preserve[§]	2030	0.11	0.11	0.1	0.11
		2050	0.18	0.19	0.18	0.21
		2100	0.37	0.44	0.45	0.6
	Cape Krusenstern National Monument[§]	2030	0.1	0.1	0.1	0.1
		2050	0.17	0.18	0.17	0.2
		2100	0.35	0.42	0.43	0.58
	Glacier Bay National Park[†§]	2030	0.07	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.12
		2100	0.23	0.25	0.28	0.34
	Glacier Bay Preserve[†]	2030	0.06	0.06	0.06	0.06
		2050	0.11	0.11	0.11	0.11
		2100	0.22	0.24	0.27	0.33
	Katmai National Park[§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.15	0.16
		2100	0.31	0.34	0.37	0.47
	Katmai National Preserve[†§]	2030	0.09	0.08	0.08	0.08
		2050	0.15	0.15	0.14	0.16
		2100	0.3	0.33	0.34	0.45

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C2 (continued). Sea level rise numbers by NPS unit. Results are sorted by region. Values are reported in meters. See table footnotes for further details.

Region	Park Unit	Year	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alaska Region (continued)	Kenai Fjords National Park[†§]	2030	0.09[‡]	0.08	0.08[‡]	0.08
		2050	0.15[‡]	0.14	0.14[‡]	0.15
		2100	0.30[‡]	0.33	0.34[‡]	0.44
	Klondike Gold Rush National Historical Park*[†§]	2030	0.06[‡]	0.06	0.06[‡]	0.06
		2050	0.11	0.11	0.11[‡]	0.11
		2100	0.22	0.24	0.27	0.33
	Lake Clark National Park*[†]	2030	0.08	0.08	0.07	0.08
		2050	0.14	0.14	0.13	0.15
		2100	0.29	0.32	0.33	0.43
	Sitka National Historical Park[†]	2030	0.08	0.07	0.07	0.07
		2050	0.14	0.14	0.13	0.14
		2100	0.28	0.31	0.33	0.41
	Wrangell - St. Elias National Park[§]	2030	0.07	0.06	0.06	0.07
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.8	0.35
	Wrangell – St. Elias National Preserve*[§]	2030	0.07	0.06	0.06	0.06
		2050	0.12	0.12	0.11	0.12
		2100	0.23	0.26	0.29	0.35

[*]Parks that do not have shoreline. These numbers are for the nearest shoreline to the park.

[†]Parks that are likely to be significantly impacted by changes in land level that could result *decreasing* relative sea level in the short term followed by *increased* relative sea level by the end of the century. Refer to section methods for more information.

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Table C3. IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region	Acadia National Park	Hurricane, Saffir-Simpson category 1
	Assateague Island National Seashore	Hurricane, Saffir-Simpson category 1
	Boston Harbor Islands National Recreation Area	Hurricane, Saffir-Simpson category 2
	Boston National Historical Park	Hurricane, Saffir-Simpson category 3
	Cape Cod National Seashore	Hurricane, Saffir-Simpson category 2
	Castle Clinton National Monument	Hurricane, Saffir-Simpson category 1
	Colonial National Historical Park	Tropical storm
	Edgar Allen Poe National Historic Site	Extratropical storm
	Federal Hall National Memorial	Hurricane, Saffir-Simpson category 1
	Fire Island National Seashore	Hurricane, Saffir-Simpson category 2
	Fort McHenry National Monument and Historic Shrine	Tropical storm
	Fort Monroe National Monument	Tropical storm
	Gateway National Recreation Area	Hurricane, Saffir-Simpson category 1
	General Grant National Memorial	Hurricane, Saffir-Simpson category 1
	George Washington Birthplace National Monument	Extratropical storm
	Governors Island National Monument	Hurricane, Saffir-Simpson category 1
	Hamilton Grange National Memorial	Hurricane, Saffir-Simpson category 1
	Harriet Tubman Underground Railroad National Monument	Tropical storm
	Independence National Historical Park	Extratropical storm
	New Bedford Whaling National Historical Park	Extratropical storm
	Petersburg National Battlefield	Hurricane, Saffir-Simpson category 2
	Roger Williams National Memorial	Hurricane, Saffir-Simpson category 3
	Sagamore Hill National Historic Site	Hurricane, Saffir-Simpson category 2
	Saint Croix Island International Historic Site	Hurricane, Saffir-Simpson category 2
	Salem Maritime National Historic Site	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Northeast Region (continued)	Saugus Iron Works National Historic Site	Hurricane, Saffir-Simpson category 1
	Statue of Liberty National Monument	Hurricane, Saffir-Simpson category 1
	Thaddeus Kosciuszko National Memorial	Extratropical storm
	Theodore Roosevelt Birthplace National Historic Site	Hurricane, Saffir-Simpson category 1
Southeast Region	Big Cypress National Preserve	Hurricane, Saffir-Simpson category 4
	Biscayne National Park	Hurricane, Saffir-Simpson category 4
	Buck Island Reef National Monument	Hurricane, Saffir-Simpson category 2
	Canaveral National Seashore	Hurricane, Saffir-Simpson category 2
	Cape Hatteras National Seashore	Hurricane, Saffir-Simpson category 3
	Cape Lookout National Seashore	Hurricane, Saffir-Simpson category 3
	Castillo De San Marcos National Monument	Hurricane, Saffir-Simpson category 3
	Charles Pinckney National Historic Site	Hurricane, Saffir-Simpson category 4
	Christiansted National Historic Site	Hurricane, Saffir-Simpson category 4
	Cumberland Island National Seashore	Hurricane, Saffir-Simpson category 4
	De Soto National Memorial	Hurricane, Saffir-Simpson category 1
	Dry Tortugas National Park	Hurricane, Saffir-Simpson category 4
	Everglades National Park	Hurricane, Saffir-Simpson category 5
	Fort Caroline National Memorial	Hurricane, Saffir-Simpson category 2
	Fort Frederica National Monument	Hurricane, Saffir-Simpson category 1
	Fort Matanzas National Monument	Hurricane, Saffir-Simpson category 1
	Fort Pulaski National Monument	Hurricane, Saffir-Simpson category 2
	Fort Raleigh National Historic Site	Hurricane, Saffir-Simpson category 2
	Fort Sumter National Monument	Hurricane, Saffir-Simpson category 4
	Gulf Islands National Seashore	Hurricane, Saffir-Simpson category 4
	Jean Lafitte National Historical Park and Preserve	Hurricane, Saffir-Simpson category 2
	Moores Creek National Battlefield	Hurricane, Saffir-Simpson category 1

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Southeast Region (continued)	New Orleans Jazz National Historical Park	Hurricane, Saffir-Simpson category 2
	Salt River Bay National Historic Park and Ecological Preserve	Hurricane, Saffir-Simpson category 4
	San Juan National Historic Site	Hurricane, Saffir-Simpson category 3
	Timucuan Ecological and Historic Preserve	Hurricane, Saffir-Simpson category 2
	Virgin Islands Coral Reef National Monument	Hurricane, Saffir-Simpson category 3
	Virgin Islands National Park	Hurricane, Saffir-Simpson category 3
	Wright Brothers National Memorial	Hurricane, Saffir-Simpson category 2
National Capital Region	Anacostia Park	Hurricane, Saffir-Simpson category 2
	Chesapeake & Ohio Canal National Historical Park	Hurricane, Saffir-Simpson category 2
	Constitution Gardens	Hurricane, Saffir-Simpson category 2
	Fort Washington Park	Hurricane, Saffir-Simpson category 2
	George Washington Memorial Parkway	Hurricane, Saffir-Simpson category 2
	Harpers Ferry National Historical Park	Extratropical storm
	Korean War Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Lincoln Memorial	Hurricane, Saffir-Simpson category 2
	Lyndon Baines Johnson Memorial Grove on the Potomac National Memorial	Hurricane, Saffir-Simpson category 2
	Martin Luther King Jr. Memorial	Hurricane, Saffir-Simpson category 2
	National Mall	Hurricane, Saffir-Simpson category 2
	National Mall & Memorial Parks	Hurricane, Saffir-Simpson category 2
	National World War II Memorial	Hurricane, Saffir-Simpson category 2
	Piscataway Park	Hurricane, Saffir-Simpson category 2
	Potomac Heritage National Scenic Trail	Hurricane, Saffir-Simpson category 2
	President's Park (White House)	Hurricane, Saffir-Simpson category 2
	Rock Creek Park	Hurricane, Saffir-Simpson category 2
	Theodore Roosevelt Island Park	Hurricane, Saffir-Simpson category 2
	Thomas Jefferson Memorial	Hurricane, Saffir-Simpson category 2

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
National Capital Region (continued)	Vietnam Veterans Memorial	Hurricane, Saffir-Simpson category 2
	Washington Monument	Hurricane, Saffir-Simpson category 2
Intermountain Region	Big Thicket National Preserve	Hurricane, Saffir-Simpson category 3
	Palo Alto Battlefield National Historical Park	No recorded historical storm
	Padre Island National Seashore	Hurricane, Saffir-Simpson category 4
Pacific West Region	American Memorial Park	Tropical storm
	Cabrillo National Monument	Tropical depression
	Channel Islands National Park	No recorded historical storm
	Ebey's Landing National Historical Reserve	No recorded historical storm
	Fort Point National Historic Site	No recorded historical storm
	Fort Vancouver National Historic Site	No recorded historical storm
	Golden Gate National Recreation Area	No recorded historical storm
	Haleakala National Park	Tropical depression
	Hawaii Volcanoes National Park	Tropical depression
	Kalaupapa National Historical Park	Tropical depression
	Kaloko-Honokohau National Historical Park	Tropical depression
	Lewis and Clark National Historical Park	No recorded historical storm
	National Park of American Samoa	No recorded historical storm
	Olympic National Park	No recorded historical storm
	Point Reyes National Seashore	No recorded historical storm
	Port Chicago Naval Magazine National Memorial	No recorded historical storm
	Pu'uhonua O Honaunau National Historical Park	No recorded historical storm
	Puukohola Heiau National Historic Site	Tropical depression
	Redwood National and State Parks	No recorded historical storm

Table C3 (continued). IBTrACS data (Knapp et al. 2010) were used to identify the highest recorded storm track to have passed within 10 miles of each of the park units.

Region	Park Unit	Highest Recorded Hurricane Within 10 mi (16.1 km)
Pacific West Region (continued)	Rosie the Riveter WWII Home Front National Historical Park	No recorded historical storm
	San Francisco Maritime National Historical Park	No recorded historical storm
	San Juan Island National Historical Park	No recorded historical storm
	Santa Monica Mountains National Recreation Area	No recorded historical storm
	War in the Pacific National Historical Park	No recorded historical storm
	World War II Valor in the Pacific National Monument	Tropical depression
Alaska Region	Aniakchak Preserve	No recorded historical storm
	Bering Land Bridge National Preserve	No recorded historical storm
	Cape Krusenstern National Monument	No recorded historical storm
	Glacier Bay National Park	No recorded historical storm
	Glacier Bay Preserve	No recorded historical storm
	Katmai National Park	No recorded historical storm
	Katmai National Preserve	No recorded historical storm
	Kenai Fjords National Park	No recorded historical storm
	Klondike Gold Rush National Historical Park	No recorded historical storm
	Lake Clark National Park	No recorded historical storm
	Sitka National Historical Park	No recorded historical storm
	Wrangell - St. Elias National Park	No recorded historical storm
	Wrangell – St. Elias National Preserve	No recorded historical storm

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