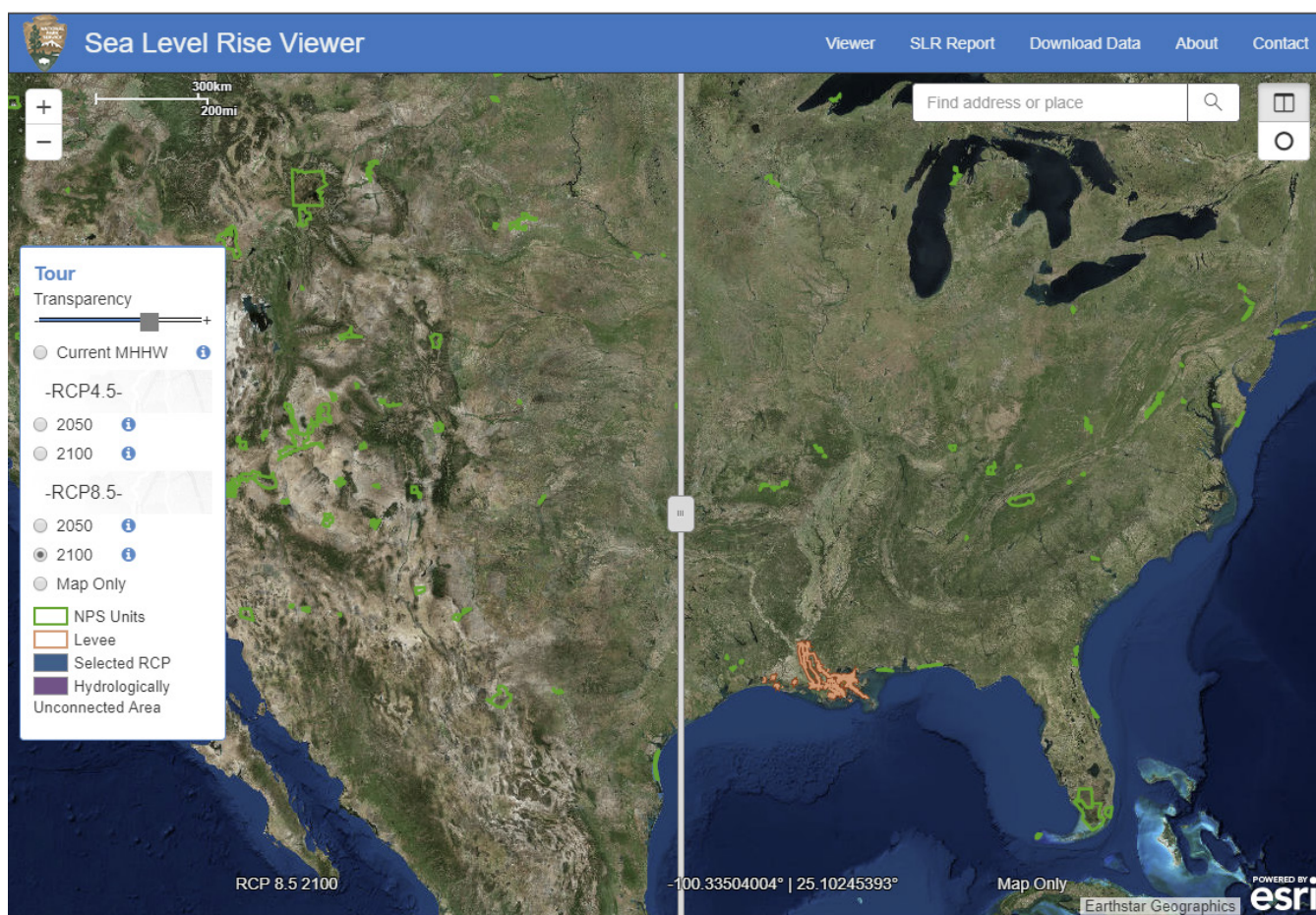




U.S. National Park Service, Sea Level Rise Viewer

Natural Resource Report

Natural Resource Report NPS/NRSS/CCRP/NRR—2019/2027



ON THE COVER

A screenshot of the sea level rise viewer.

U.S. National Park Service, Sea Level Rise Viewer

Natural Resource Report

Natural Resource Report NPS/NRSS/CCRP/NRR—2019/2027

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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 informal peer review by subject matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Executive Summary

Areas of potential future inundation due to sea level rise, as examined in a recent report (Caffrey et al. 2018), are displayed in a new [NPS Sea Level Rise Viewer web mapping application](#) to allow comparison between modeled scenarios and current aerial imagery. Low-lying areas that may flood and National Park unit boundaries are also displayed.

The Sea Level Rise Viewer, utilizing a vector tile service, displays a dataset (Caffrey et al. 2015) generated from geospatial analysis of gridded sea level rise estimates, tidal data, and digital elevation models. In addition to standard web map tools, "swipe" and "spy glass" tools may be used to compare data at different scales. The transparency of modeled data can be adjusted to facilitate data exploration. The interface includes a tour and information buttons to facilitate user orientation.

The NPS units and their surrounding areas were modeled with the best available elevation data for that unit (Caffrey et al. 2015). Model accuracy varies by source elevation model. National Park units in Alaska are not included due to uncertainties associated with lower resolution digital elevation models.

Modeled results do not display beyond 1:500 scale. Model results display over aerial imagery and may appear to cover raised structures. Model result edges retain original raster modeling and appear blocky; no cartographic smoothing is applied.

The mean higher high water used in modeling may not align with shorelines depicted in the aerial imagery due to varying image vintage.

Levee-protected areas around New Orleans are included in the model results, however protected areas are blocked (masked) in the map display.

Model updates or additional data may be added to the web map as they become available to improve presentation of modeled data.

List of Terms

Terms used in this report are provided below.

Flooding—The temporary occurrence of water on the land.

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

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. Relative sea level change is caused by the combined effects of global sea level variations (due to climate change) and local vertical land movement (due to subsidence or isostatic rebound, oceanographic factors, and changes in land-ice mass).

Mean sea level—The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.

Sea level Change—This term is frequently used in reference to *global* and *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 are discussed in Caffrey et al. 2018. 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.

Anthropogenic Climate Forcing—Climate forcing is the difference between the rate of energy received by absorption of solar radiation and the rate of energy emitted by the top of the Earth's atmosphere, expressed in watts per square meter (Charlson et al. 1992). Anthropogenic climate forcing refers to the condition when the rate of energy difference is affected by human activities such as emissions of gases that alter the rate of energy emitted by the top of Earth's atmosphere.

Introduction

This new Sea Level Rise Viewer presents a data release consisting of the estimated extent of inundation due to sea level change for the U.S. national coastal parks of the continental United States, Hawaii, Puerto Rico, U.S. Virgin Islands, American Samoa, and Guam (Caffrey et al. 2015; 2018). The results and viewer allow for examination of potential coastal flooding for modeled park units.

The estimated inundation extent was achieved by utilizing a modified bathtub approach as developed by the Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Coastal Services Center (CSC) (Allen et al. 2010). The NOAA methodology “attempts to account for local and regional tidal variability and hydrological connectivity.” Sea level change polygon extents consist of four model run scenarios using sea level change maps tied to Representative Concentration Pathways (RCPs), which are greenhouse gas concentration trajectories evaluated as part of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC; Church et al. 2013). The analysis by Caffrey et al. (2015) chose two RCPs projected to the years 2050 and 2100.

Other data available in this series include low-lying areas, defined by NOAA as “hydrologically unconnected areas that may flood”; the Digital Elevation Model (DEM) used to model the inundation; and USGS DEMs for selected park units. The estimated extents and DEM are available in ArcGIS geodatabase format via the [NPS Data Store Geospatial Dataset page](#). The USGS DEMs are available in geoTIFF format. The extents and DEM are in a UTM projection using the NAD83 (2011) datum. The USGS DEMs are in a “geographic” projection, NAD83 horizontal datum, and NAVD88 vertical datum unless otherwise noted.

With questions, please contact Dr. Rebecca Beavers, Coastal Geology and Coastal Adaptation to Climate Change Coordinator, National Park Service, rebecca_beavers@nps.gov, 303-987-6945.

Methods

Projecting Sea Level Rise Data

Sea level rise data were obtained from the IPCC data distribution center as part of their fifth assessment report (IPCC 2013). The IPCC data were used in conjunction with land level data to calculate potential areas of inundation (Caffrey et al. 2015). The areas of inundation were calculated using sea level rise scenarios from Church et al. (2013). The sea level scenarios are the result of two different representative concentration pathways of future greenhouse gas emissions. RCP4.5 is based on an average 4.5 W/m^2 of warming by 2100 whereas RCP8.5 is based on 8.5 W/m^2 of warming by 2100. The RCP8.5 is the highest scenario prepared by the Church et al. (2013).

These should be considered conservative estimates of future sea level rise (Garner et al. 2018), whereby RCP8.5 represents a “business-as-usual” scenario and whereas RCP4.5 could only be achieved by reducing current greenhouse gas emissions (Tebaldi and Wehner 2018). Sea level modeling does not account for local subsidence or rebound in land level. Modeling was not performed for the Great Lakes. The methods used to create the models shown in the web viewer are discussed in further detail in Caffrey et al. (2018).

The purpose of these maps is to illustrate the potential impact of climate on national park units. The maps and data are not to be used for property or insurance evaluations. Please refer to the metadata on the [NPS Data Store Geospatial Dataset page](#) for more information regarding the accuracy of each layer. Project data are based on external data sources for which the National Park Service is not responsible. Do not use these maps for navigation.

Web Map Technical Details

The web mapping application was generated using the ArcGIS Application Program Interface (API) for JavaScript version 3.23. The API exists to assist in the integration of mapping products into web interfaces. The sea level rise viewer is modified from a web mapping template created by the Systems Ecology Laboratory at the University of Texas El Paso, managed by Dr. Craig E. Tweedie for their Barrow Area Information Map Server.

The analysis results of the sea level rise scenarios are published as vector tile layers on ArcGIS Online to optimize web map performance. This allows for seamless zooming and panning of the map in complex sea level rise scenarios in places such as the Florida Everglades (Figure 1).

Blue areas represents the extent of the inundation. Purple areas are low-lying areas that could be inundated but that do not presently have a pathway for water to reach them. The hydrologically-unconnected areas depicted in the map are based on digital elevation models from various sources. See Caffrey et al. (2015) for more information about DEMs and methods used to derive the models. The mapping may not accurately capture detailed hydrologic or hydraulic features such as canals, ditches and stormwater infrastructure.

The center divider can be moved to examine different sea level rise scenarios against aerial imagery.

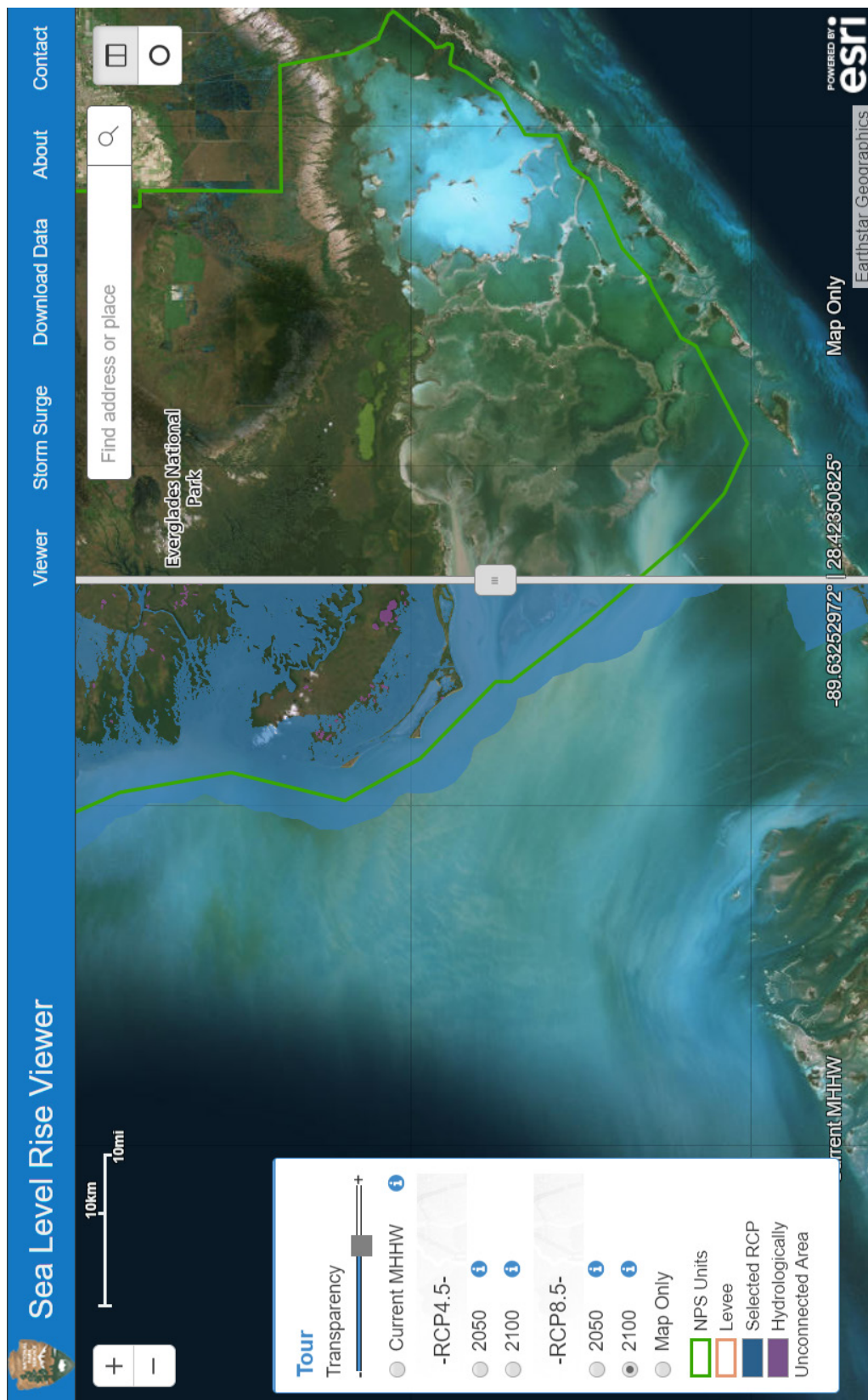


Figure 1. Example use of the viewer -- examining potential inundated area around Everglades National Park

Web Map Interface Instructions

General Use

The web mapping interface is designed to allow comparison of modeled results to mean higher high water (MHHW) and general aerial imagery. Map viewer interface elements and controls are identified in Figure 2. Model results may be viewed by clicking the buttons in the scenario selector next to the modeled years 2050 and 2100 under either the RCP4.5 or RCP8.5 scenario. Results are displayed to the left of the vertical slider located in the middle of the map. The slider may be dragged left and right using the computer mouse to examine locations of modeled inundation. Model results shown in the left pane overlay (are on top of) the aerial imagery. The transparency of data for the left pane may be adjusted to better view the aerial imagery.

Panning

Using the left mouse button, click and drag the map to center into a desired location.

Zooming

Modeled results are best examined by first zooming into an area of interest using the “+” and “-“ buttons on the interface or the computer mouse wheel.

Swipe (Divider) Tool

The swipe tool in the middle of the viewer allows for detailed comparison of modeled results to aerial imagery. Display results in the left pane by clicking the buttons next to the modeled RCP values and year (Figure 2). A transparency slider for the left pane may be used to compare modeled results to aerial imagery. Alternatively, a “spyglass” swipe tool can be enabled via the overlay tool type selector near the upper right of the viewer interface.

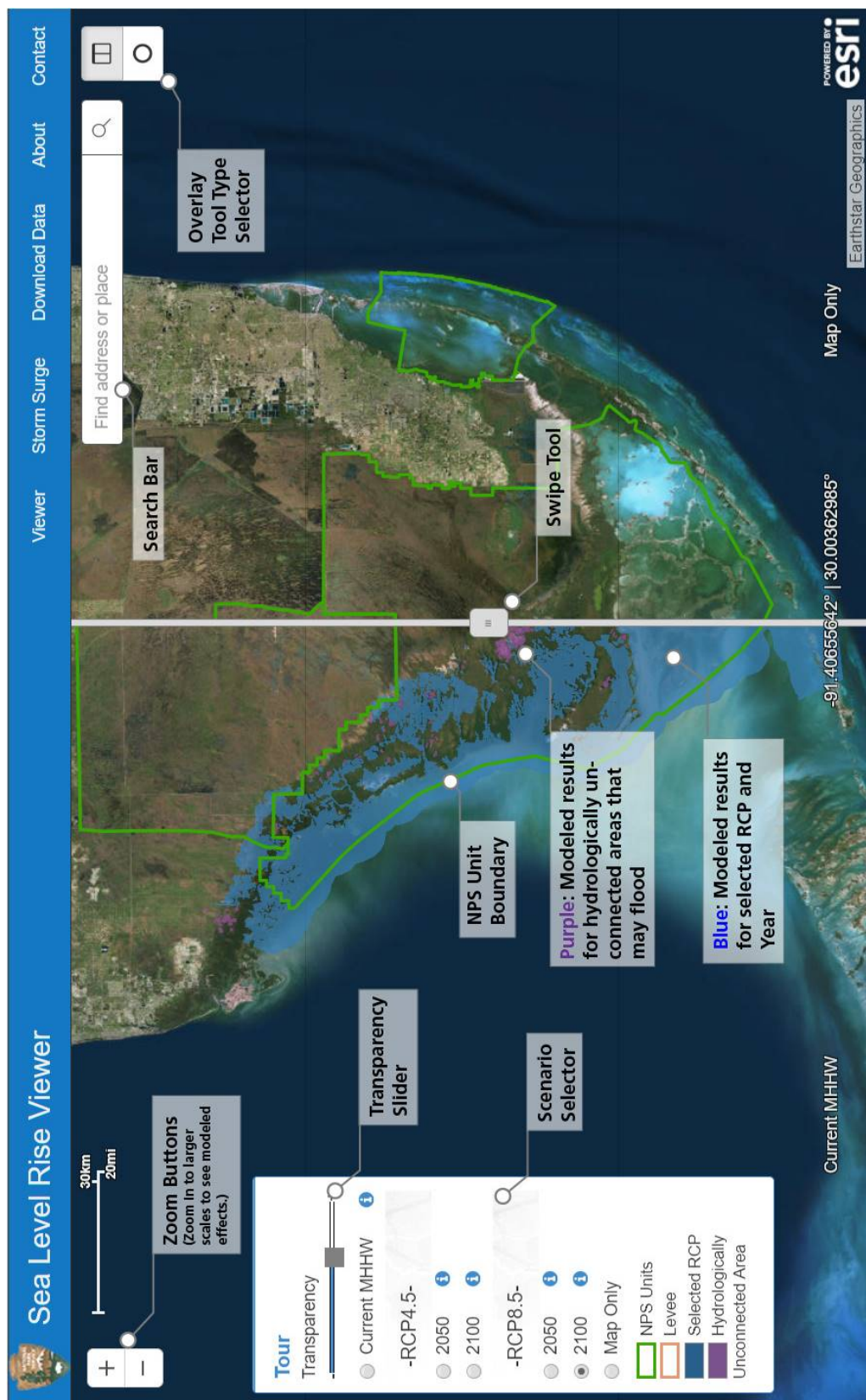


Figure 2. Annotated map viewer layout

Scenario Explanations

Current MHHW

MHHW is an average of the highest tide height calculated using a 19 year period of data collected from tide gauges. Mean higher high water (MHHW) data were obtained from National Oceanic and Atmospheric Administration (NOAA). Consult the metadata for the data release (Caffrey et al. 2015, [NPS Data Store Geospatial Dataset page](#)) as well as an associated report (Caffrey et al. 2018) for further information about the methods used in this project.

RCP4.5 2050

Selecting this button will turn on a blue layer showing projected sea level rise by the year 2050 under RCP4.5. RCPs are the newest iteration of climate change scenarios prepared by the IPCC. The RCP4.5 scenario represents a moderate amount of anthropogenic climate forcing that would raise global temperature anomalies by an average 2.4 °C (4.5 W/m² radiative forcing, 650 ppm CO² equivalent) by 2100 (Moss et al. 2010). The RCP4.5 scenario is very roughly equivalent to the previous IPCC SRES B1 scenario (Rogelj et al. 2012).

RCP4.5 2100

Selecting this button will turn on a blue layer showing projected sea level rise by the year 2100 under RCP4.5. The RCP4.5 scenario represents a moderate amount of anthropogenic climate forcing that would raise global temperature anomalies by an average 2.4° C (4.5 W/m² radiative forcing, 650 ppm CO² equivalent) by 2100 (Moss et al. 2010). The RCP4.5 scenario is very roughly equivalent to the previous IPCC SRES B1 scenario (Rogelj et al. 2012).

RCP8.5 2050

Selecting this button will turn on a blue layer showing projected sea level rise by the year 2050 under RCP8.5. The RCP8.5 scenario represents a moderate amount of anthropogenic climate forcing that would raise global temperature anomalies by an average 4.9° C (8.5 W/m² radiative forcing, 1370 ppm CO² equivalent) by 2100 (Moss et al. 2010). The RCP8.5 scenario is very roughly equivalent to the previous IPCC SRES A1FI scenario (Rogelj et al. 2012).

RCP8.5 2100

Selecting this button will turn on a blue layer showing projected sea level rise by the year 2100 under RCP8.5. The RCP8.5 scenario represents a moderate amount of anthropogenic climate forcing that would raise global temperature anomalies by an average 4.9° C (8.5 W/m² radiative forcing, 1370 ppm CO² equivalent) by 2100 (Moss et al. 2010). The RCP8.5 scenario is very roughly equivalent to the previous IPCC SRES A1FI scenario (Rogelj et al. 2012).

Discussion and Conclusions

This data series report focuses on the web mapping of data created by Caffrey et al. (2015). Each NPS unit and the surrounding area was modeled with the best available elevation data for that unit at the time of initial mapping. Model accuracy varies by source elevation model. National Park units in Alaska are not included due to uncertainties in the modeling, which had to rely on lower resolution Digital Elevation Models (DEM).

The modeled results are best viewed at map scales no greater than 1:500 where features such as roads and parking lots are discernible. Differences in RCP scenario results may be difficult to notice unless zoomed to a scale where the scale bar units appear as meters or feet.

Sea level rise models are based on bare-earth elevations in some NPS units and may not account for structures such as bridges. Sea level rise models overlaying base aerial imagery draped on the elevation model may therefore show bridges or other structures as inundated. Structures built above the elevation model may not therefore be fully inundated as may be suggested by the mapped imagery.

Mapped model edges are not smoothed for cartographic purposes. The underlying aerial imagery was captured in different years and by different instruments depending on location. Due to shoreline dynamics, actual shorelines will vary over time. The modeling process used a shoreline calculated from DEMs provided by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). Horizontal resolution of the DEMs varies between 3 and 10 meters. Because of this and variations in the aerial imagery noted above, the edge of the MHHW may not closely match shorelines depicted in the aerial imagery in places. Detailed metadata for each DEM used in this study may be found at the [NPS Data Store Geospatial Dataset page](#).

Levee-protected areas around New Orleans were provided by NOAA. Sea level rise modeling includes levee-protected areas however, these areas are covered (masked) in the web mapping application since the modeling does not account for effects of levees.

Anticipated Future Viewer Enhancements

The sea level viewer is intended as a first step in communicating the vulnerability of national parks to climate change. Future enhancements could include the following:

- Results from future studies that model sea level rise can be added to the viewer to allow comparison of modeling methods.
- Display the impact of storm surge in addition to rising sea levels.
- Estimates of how adaptation strategies (such as the inclusion of sea walls or levees) could impact the extent of flooding. Viewer could include levees throughout the U.S.
- Selected additional data such as natural and cultural resources and facilities may be added to the viewer to allow for comparison with model results.

- Geospatial analysis of potential future inundation and flooding due to sea level rise could be improved in the future through use of higher resolution DEMs, when available; expanding options for presentation of the data to show depth of flooding; and potential use of 3D models and dynamic hydrographic modeling.
- The viewer may also be improved to include a variety of mapping and data tools to allow further comparison, interaction and summary of modeled results.
- The viewer may be further developed to ensure compliance with section 508 of the Rehabilitation Act.
- Additional place names or an optional basemap may be added to facilitate user orientation and place-finding.

Disclaimer

The purpose of these maps is to illustrate the potential impact of climate on national park units. The maps and data are not to be used for property or insurance evaluations. Please refer to the metadata for the source dataset (Caffrey et al., 2015; [NPS Data Store Geospatial Dataset page](#)) for more information regarding the accuracy of each layer before use in any project. Project data are based on external data sources for which the National Park Service is not responsible. Do not use these maps for navigation.

Acknowledgements

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Copyright

These data have not been evaluated for copyright or other use restrictions. All improvements made to original data are not the responsibility of the National Park Service (NPS) or the Institute of Arctic and Alpine Research (INSTAAR). The user of National Park Service data agrees not to resell or redistribute shared data. Use at your own risk. Users assume responsibility to determine the usability of the dataset, as well as dataset resolution and accuracy, for their purposes. It is not recommended that the data be used at a scale larger than source scale. Any use of this data should be cited as: Caffrey, M., L. Lestak, W. Manley, and A. Forget, 2015, Estimated Extent of Coastal Flooding due to Sea Level Change and Storm Surge for 118 U.S. National Parks: NPS NRSS, University of Colorado at Boulder (<https://www.nps.gov/subjects/climatechange/upload/2018-NPS-Sea-Level-Change-Storm-Surge-Report-508Compliant.pdf>).

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