Global and Regional Sea Level Rise Scenarios for the United States

Credit ©Gary-Kohn

NOAA · United States Environmental Protection Agency · NASA · U.S. Department of Defense · University of Hawaii · US Army Corps of Engineers · USGS science for a changing world

RUTGERS UNIVERSITY | NEW BRUNSWICK · U.S. Department of Homeland Security · FEMA · FIU Institute of Environment FLORIDA INTERNATIONAL UNIVERSITY

Cover Image: Flooding from 15-knot northerly winds on Smith Island, Maryland, on November 23, 2015. Credit ©Gary J. Kohn

National Oceanic and Atmospheric Administration
U.S. Department of Commerce
National Ocean Service
Silver Spring, Maryland
February, 2022

Global and Regional Sea Level Rise Scenarios for the United States:
Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines

Authors

William V. Sweet
NOAA National Ocean Service

Benjamin D. Hamlington
NASA Jet Propulsion Laboratory,
California Institute of Technology

Robert E. Kopp
Rutgers University

Christopher P. Weaver
U.S. Environmental Protection Agency

Patrick L. Barnard
U.S. Geological Survey

David Bekaert
NASA Jet Propulsion Laboratory,
California Institute of Technology

William Brooks
NOAA National Ocean Service

Michael Craghan
U.S. Environmental Protection Agency

Gregory Dusek
NOAA National Ocean Service

Thomas Frederikse
NASA Jet Propulsion Laboratory
California Institute of Technology

Gregory Garner
Rutgers University

Ayesha S. Genz
University of Hawai'i at Mānoa, Cooperative
Institute for Marine and Atmospheric Research

John P. Krasting
NOAA Geophysical Fluid Dynamics Laboratory

Eric Larour
NASA Jet Propulsion Laboratory,
California Institute of Technology

Doug Marcy
NOAA National Ocean Service

John J. Marra
NOAA National Centers for Environmental
Information

Jayantha Obeysekera
Florida International University

Mark Osler
NOAA National Ocean Service

Matthew Pendleton
Lynker

Daniel Roman
NOAA National Ocean Service

Lauren Schmied
FEMA Risk Management Directorate

Will Veatch
U.S. Army Corps of Engineers

Kathleen D. White
U.S. Department of Defense

Casey Zuzak
FEMA Risk Management Directorate

Table of Contents

List of Figures

Schematic (not to scale) showing physical factors affecting coastal flood exposure. Due to the clear and strong relative sea level rise signal (i.e., combination of sea level rise and sinking lands), the probability of flooding and impacts are increasing along most U.S. coastlines.

a) Observed annual global mean sea level (GMSL) change from global tide gauges (blue line), along with the sum (orange line) of contributions from thermal expansion (thermosteric) and four distinct water-mass-driven increases in GMSL. b) GMSL change (blue line) as shown in a) with the annual average relative sea level change measured by tide gauges around the contiguous United States (black line; with a linear regression estimate of 28 cm of sea level rise from 1920 to 2020). (Adaptation of Frederikse et al., 2020).

a) Annual probability density and b) annual expected exceedances for daily highest water levels relative to the 1983–2001 mean higher high water (MHHW) tidal datum showing increases in NOAA minor, moderate, and major high tide flooding (HTF) probabilities/frequencies due to relative sea level (RSL) rise at the NOAA tide gauge in Charleston, South Carolina.

Regional sea level linear rates of rise (mm/year) from satellite altimetry over three different time periods: (a) 1993–2006, (b) 2007–2020, and (c) 1993–2020. Linear rates of change of relative sea level (ocean and land height changes) from tide gauges over the same time period are also shown (circles).

Observation-based extrapolations using tide-gauge data and five Scenarios, in meters, for a) global mean sea level and b) relative sea levels for the contiguous United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded regions represent the likely ranges for the observation-based extrapolations and each scenario. Altimetry data (1993–2020) and tide-gauge data (1970–2020) are overlaid for reference.

Observation-based extrapolations and five regionalized global mean sea level scenario projections, in meters, of relative sea levels for eight coastal regions around the United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded regions represent the likely ranges for the observation-based extrapolations and each scenario. Tide-gauge data (1970 to 2020) are overlaid for reference, along with satellite altimetry observations, which do not include contributions from vertical land motion.

Relative sea level rise, in meters, in 2050 for the a) Intermediate-Low and b) Intermediate-High scenarios relative to the year 2000.

Regional deviations of relative sea level from the global mean sea level (GMSL; in meters) value for each scenario in 2100. To obtain the regional projection in 2100 for each scenario, the mapped values must be added to the GMSL value for the associated scenario.

Divergence of global mean sea level (GMSL) trajectory and scenarios. The time series shows the observation-based GMSL trajectory and the five GMSL scenarios from 2000 to 2100. The dots denote where each scenario significantly (2 sigma) deviates from the a) observation-based trajectory and from the b) Intermediate scenario.

Proportions of the contributions from different IPCC AR6 sea level trajectories to each of the five global mean sea level (GMSL) rise scenarios used in this report: Low, Intermediate-Low, Intermediate, Intermediate-High, and High. The IPCC AR6 trajectories are Low Emissions; Low Emissions, LC (where LC indicates inclusion of low-confidence ice-sheet processes); Intermediate Emissions; Intermediate Emissions, LC; High Emissions; and High Emissions LC. The emissions pathways associated with the IPCC AR6 trajectories are as follows: Low Emissions = Shared Socioeconomic Pathway (SSP) 1-1.9 or SSP1-2.6; Intermediate Emissions = SSP 2-4.5; High Emissions = SSP3-7.0 or SSP5-8.5. Shifts between different GMSL rise scenarios approximately reflect the relative odds of being close to a given scenario under different emissions pathways; e.g., the Low scenario is much more plausible under a low emissions pathway, while Intermediate and higher scenarios are much more likely to be associated with high emissions pathways, as well as with low-confidence ice-sheet processes.

National median rate of minor high tide flooding and relative sea level, in meters, from 98 NOAA tide gauges along U.S. coastlines outside of Alaska used to monitor and track flood-frequency changes (from Sweet et al., 2021). Relative sea levels reference the lowest annual (1925) level.

Regional Frequency Analysis 1-degree grids and local index values (u) relative to local mean higher high water tidal datum at the NOAA tide gauges used in this study.

a) Empirical probability densities of hourly water levels and their daily maxima measured by the NOAA tide gauge at The Battery (New York City), as well as the tidal datums of mean lower low water (MLLW), great diurnal tide range (GT), local high tide flood (HTF) heights, and the local index (u) used to localize the RFA-gridded EWL for this location (see Figure A2.2f). All values are referenced to the mean higher high water (MHHW) tidal datum and shown in b) as a return interval curve with the 95% confidence interval (2.5% and 97.5% levels) normalized to year 2020 RSLs.

Current (circa 2020 relative sea levels) EWLlocal that a) occur annually on average and b) have a 0.01-year average event frequency. Note: the scales in the two figures are not the same, and to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

Comparison between (a–c) this study's EWLlocal to those of NOAA (Zervas, 2013) based on a GEV fit of annual highest water levels and to (d–f) the stillwater (storm surge, tides, and wave set-up) components of FEMA used in their Flood Insurance Study at the 0.01-year, 0.1-year, and 0.5-year average event frequency levels.

a) Map showing active NOAA tide gauges indicating Grand Bay, Mississippi, which has about 4–5 years of hourly data, b) tide range to local index (u) regression relative to the 1983–2001 tidal datum epoch with fit equation, goodness of fit (R2), and associated root mean square error (RMSE) for the surrounding region, c) RMSE for estimates of u based on 1–19 years of consecutive data over the 2001–2019 period based on the regional tide gauges for the surrounding region; and d) a 2020 EWLlocal return level curve for Grand Bay using a local index (u) from tide range regression. Note: to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

NOAA minor (red layer: land between mean higher high water [MHHW] and minor high tide flood [HTF] height above MHHW), moderate (orange layer), and major (yellow layer) HTF maps showing a regional layered map with individual layer panes to the right for a) Charleston, South Carolina, and b) West Palm Beach, Florida. MHHW for 1983–2001 is the shoreline edge. Note: to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

List of Tables

The parameters of generalized extreme value computed using the peaks-over-threshold Generalized Pareto Distribution model (Coles 2001).

Results of the risk-based design for all tide gauges shown in Figure 4.2. Average recurrence interval (ARI) is listed and is the reciprocal of average event frequency. Values in the last column have been rounded to the closest 5-year interval. Note: to be useful for decision-making, a conversion of the return level to land-based heights (e.g., geodetic datum such as NAVD88) should be made.

Projections methods employed.

Offsets, in meters, for different time periods and for each region considered in Section 2. These offsets are assessed using the trajectory determined from the available tide-gauge data in each region.

Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.