

Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning





Commonwealth of Massachusetts

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I. Introduction

Massachusetts coastal communities regularly face impacts associated with storm damage, flooding, and erosion, which affect residential and commercial development, infrastructure and critical facilities, and natural resources and ecosystems. Sea level rise will exacerbate these problems, and as the rate of rise accelerates, not only will the impacts from coastal storm events become more frequent and widespread, but even daily high tides will have adverse effects. Advances in and applications of science, modeling, and other technical approaches can support efforts to begin comprehensive assessment and planning for sea level rise to reduce the risk of current and future coastal flooding. The purpose of this document is to provide background information on local and global sea level rise, summarize the best available sea level rise projections, and provide general guidance in the selection and application of sea level rise scenarios for coastal vulnerability assessments, planning, and decision making for areas that may be at present or future risk from the effects of sea level rise.

II. Background

Sea level rise refers to the increase in mean sea level over time. Sea level has been rising around the globe for thousands of years since the end of the last Ice Age. During the last century, tide gauges and satellites recorded measurements that indicate an acceleration of sea level rise relative to the past rate. Relative sea level rise refers to the combination of *eustatic*, *isostatic*, and other effects at a specific location. Eustatic contributions to sea level rise are global-scale changes and include thermal expansion of seawater as it warms and the addition of water volume from melting land-based glacial ice sheets. Isostatic effects are more localized changes in land surface elevations (e.g., subsidence or sinking).

There is high confidence that the warming atmosphere associated with global climate change is expected to accelerate both the thermal expansion of seawater and the melting of glaciers and ice sheets and will lead to increasing rates of sea level rise (Parris et al., 2012). As relative sea level rises, high water elevations will move landward, areas of coastal shorelines will retreat, and low-lying areas will be increasingly exposed to erosion, tidal inundation, and coastal storm flooding. Developed parts of the coast are especially vulnerable because of the presence of infrastructure, homes, and businesses that can be damaged or destroyed by coastal storms. In addition, development often impedes the ability of natural coastal systems to buffer inland areas from storm damage, further exacerbating the problem (Burkett and Davidson, 2012). Many coastal habitats are also vulnerable to rising sea levels, including salt marshes, beaches and dune systems, and floodplains, because they are generally at or within a few feet of existing sea elevations. These areas provide significant environmental benefits, including

habitat value, filtering of pollutants for improved water quality, protection of inland areas from flooding and storm surge, and extensive recreational opportunities.

Tide gauge stations measure the height of water referenced to a horizontal control point, or benchmark, and gauges are used to track and predict tide levels and longer term sea level. Long-term data sets from tide stations have been used to understand local and global sea level trends. The National Oceanic and Atmospheric Administration’s (NOAA) Center for Operational Oceanographic Products and Services maintains several tide gauge stations at in across coastal Massachusetts, including long-term stations at Boston, Woods Hole, and Nantucket. Mean sea level trends from these long-term stations are listed in Table 1 below. Trends from the Boston tide gauge station are shown in Figure 1 and Figure 2, and the trends from Nantucket and Woods Hole stations are in Appendix A.

Table 1: Mean sea level trends for NOAA’s Massachusetts tide gauge stations.

| Station | Mean sea level trend and 95% confidence interval | | Period | Century rate (feet/100 years) |
|----------------|--|--------------|-----------|-------------------------------|
| | (millimeter/year) | (inch/year) | | |
| Boston, MA | 2.79 ± 0.17 | 0.11 ± 0.007 | 1921-2012 | 0.92 |
| Woods Hole, MA | 2.81 ± 0.19 | 0.11 ± 0.007 | 1932-2012 | 0.92 |
| Nantucket, MA | 3.52 ± 0.42 | 0.14 ± 0.017 | 1965-2012 | 1.15 |

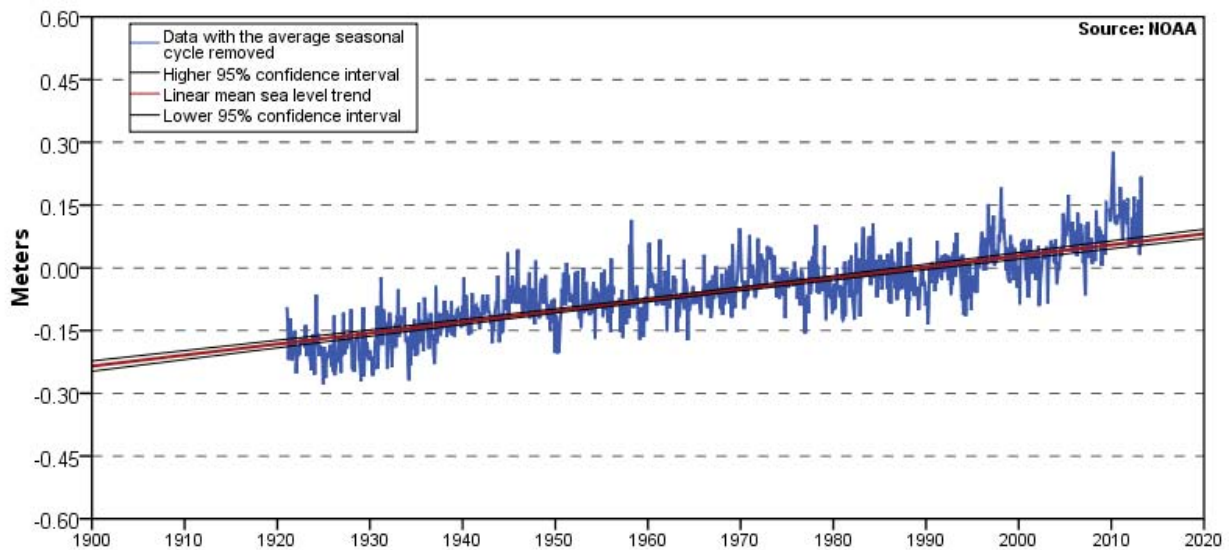


Figure 1. Long-term mean sea level data for NOAA Boston tide gauge station with linear trend and confidence interval.



Figure 2. Mean sea level rates (blue diamonds) and 95% confidence intervals (in millimeters per year) calculated from 1921 to recent years (2006-2012) at the NOAA Boston tide gauge station. Values are the trend of the entire data period up to that year.

The sea level data recorded by NOAA and other tide gauges produce trends in relation to fixed reference levels on land, and therefore the data from these stations includes variation in local land elevations. The Permanent Service for Mean Sea Level provides sea level data from a global network of tide gauges to support the examination of global sea level rise estimates. Since the late 1800s, global mean sea level rise has been a persistent trend, at a rate of about 1.7 ± 0.2 millimeters per year (mm/yr) as recorded by tide gauges (Church and White, 2011). In addition to networks of local tide gauge stations, direct measurements of global changes in mean sea level are made by highly accurate satellite altimeters. Beginning in 1992, a series of satellite missions has been calculating global mean sea level every 10 days. As shown below in Figure 3, NOAA's National Environmental Satellite, Data, and Information Service indicates that global mean sea level has risen at a rate of approximately 3.0 mm/yr over the last 20 years. However, due to multi-decadal natural variability in sea level, a 30 or 40 year record is necessary to calculate a representative long-term sea level trend.

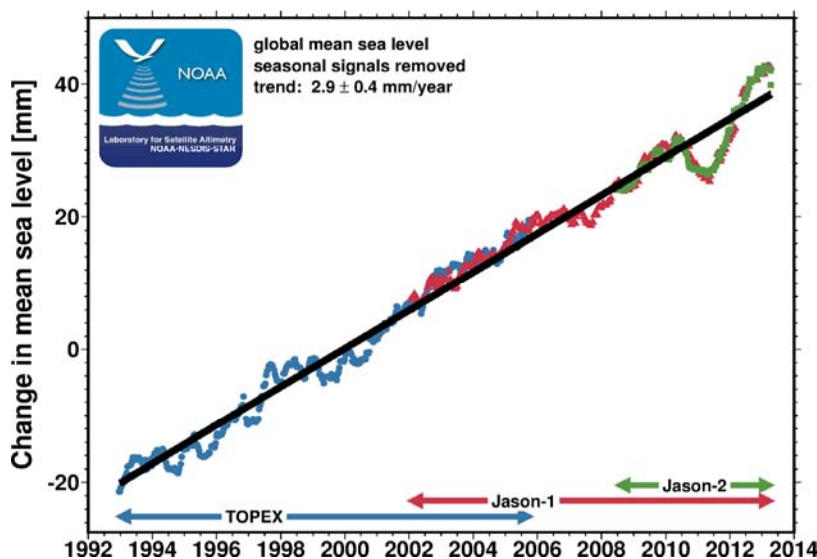


Figure 3. Estimates of global mean sea level trends based on measurements from satellite radar altimeters. Note: TOPEX, Jason-1, and Jason-2 represent satellite missions and observations.

III. Global Sea Level Rise Scenarios

Accelerated rates of global, or eustatic, sea level change are driven principally by increases in the volume of the ocean from two primary factors: thermal expansion and melting ice sheets. Steady increases in global atmospheric temperature serve to expand sea water molecules, which increases ocean volume. Increased global temperatures also result in the melting of glaciers and continental ice masses—such as the Greenland ice sheet that covers terrestrial areas, not ice-covered ocean as in the Arctic—which contribute significant amounts of freshwater input to the Earth's oceans.

There is a wide range of estimates for future sea level rise in peer-reviewed scientific literature. Developed with input from national experts in climate science, physical coastal processes, and coastal management, *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris et al., 2012) represents a coordinated approach to synthesize recent scientific literature and develop a consistent set of future global mean sea level rise scenarios. The four scenarios of future global sea level rise in the report provide the basis for the 2013 Draft National Climate Assessment Report. Because of the range of uncertainty in future global mean sea level rise and the difficulties in generating probabilistic projections of sea level rise, the four estimates provided in the report are intended to represent potential future conditions associated with different scenarios of ocean warming and ice sheet melting, or loss. As stated in the report, there is very high confidence (greater than 90%) that the future rise in sea level will be within the range in the scenarios contained in Table 2 and illustrated in Figure 4 below.

Table 2. Four scenarios with estimates of global mean sea level rise (SLR) by 2100 as contained in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris et al., 2012).

| Scenario | SLR by 2100 (m) | SLR by 2100 (ft) | Summary |
|-------------------|-----------------|------------------|---|
| Highest | 2.0 | 6.6 | Highest scenario derived from ocean warming and maximum ice sheet loss |
| Intermediate-High | 1.2 | 3.9 | Intermediate-High scenario based on limited ice sheet loss plus ocean warming |
| Intermediate-Low | 0.5 | 1.6 | Intermediate-Low scenario based primarily on sea level rise from ocean warming |
| Lowest | 0.2 | 0.7 | Lowest scenario representing linear extrapolation of historical sea level rise rate derived from tide gauge records |

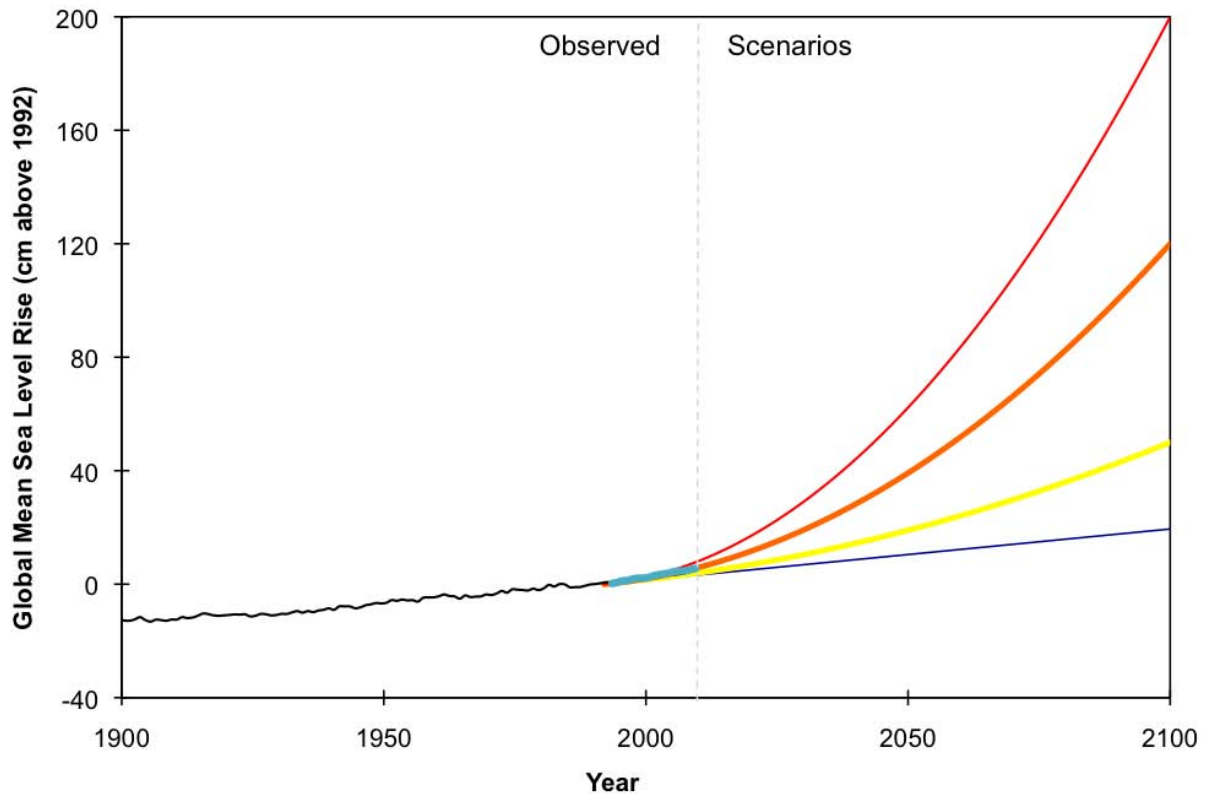


Figure 4. Four global mean sea level rise scenarios for 1992 to 2100 as contained in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris et al., 2012). 1992 was used as the beginning point for the analysis because it is the midpoint of the National Tidal Datum Epoch (NTDE), calculated from 1983 to 2001. To account for variability in sea levels, the 19-year NTDE represents the minimum period for which tide gauge observations can be reduced to obtain mean values.

The four estimates in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris et al., 2012) reflect several possible future states of ocean warming and ice sheet loss, summarized below.

Highest Global Sea Level Rise

This scenario is derived from a combination of estimated ocean warming from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) and a calculation of the maximum possible glacier and ice sheet loss by the end of the century from Pfeffer et al. (2008).

Intermediate-High Global Sea Level Rise

This scenario is based on an average of the high-end, semi-empirical, global sea level rise projections (Grinsted et al., 2009; Horton et al., 2008; Jevrejeva et al., 2010;

Vermeer and Rahmstorf, 2009). These projections use statistical relationships between observed global sea level change, including recent ice sheet loss, and air temperature. The Intermediate-High Scenario provides for risk assessments from sea level rise using only limited ice sheet loss.

Intermediate-Low Global Sea Level Rise

This scenario is based on the upper end of IPCC Fourth Assessment Report global sea level rise projections from the “B1”¹ emissions scenarios. The Intermediate-Low Scenario allows for risk assessment from sea level rise primarily from ocean warming.

Lowest Global Sea Level Rise

This scenario is based on a historical (1900-2009) sea level rise rate (1.7 ± 0.2 mm/yr) derived from tide gauge records around the world (Church and White, 2011). Global sea level increased approximately 0.16 meters (m) or 6.2 inches (in) on average from 1900 to 1992, the starting point for the National Climate Assessment projected curves. Based on a linear extrapolation of the historical rate from 1992, approximately 0.2 m (8 in) is anticipated by 2100 (Figure 4). The rate of global mean sea level rise since 1992 derived from satellite altimetry has been substantially higher (approximately 3 mm/yr), but the period of record is not adequate for projecting century-scale global sea level rise.

IV. Coastal Vulnerability Assessments and Planning

Recognizing the threats posed by rising sea levels, many public and private sector entities are starting to incorporate sea level rise scenarios into their planning and decision making. By engaging in assessment and analysis processes to identify and understand the potential impacts associated with sea level rise, actions to eliminate, reduce, or mitigate those risks can be taken. This type of analysis is generally referred to as a vulnerability assessment and includes steps that define the geographical area of focus and the assessment timeframe, characterize the area under current conditions, identify the future hazard or threat, and assess the potential impacts (including secondary ones). The results of the vulnerability assessment support next steps for planning, including the evaluation of risk and adaptive capacities, communication of results, and identification, examination, and vetting of options to reduce hazards and increase resiliency. In addition to technical issues with sea level rise mapping, other factors that are critical to assessment and planning processes include working with uncertainty, time horizons, and risk and adaptive capacity.

¹ The B1 emissions scenario assumes the world adopts a high level of environmental and social consciousness and chooses a sustainable development path that favors efficiency of resource use.

Coastal Inundation Mapping

Coastal inundation mapping is a key component in assessing vulnerability and planning for sea level rise. Mapping potential future high tide or storm surge requires high-resolution elevation data (e.g., Light Detection and Ranging [LIDAR] data) and a water surface based on a single value or range of model outputs and uncertainties. The capability to map and visualize the potential inland extent and depth of coastal flooding with sea level rise is important for identifying, understanding, and communicating potential impacts and consequences.

There are different methods of modeling and mapping coastal inundation. Still-water (or “bathtub”) models are coarse approaches that use water level and topographical data and apply sea level rise scenarios at constant elevations but do not include other factors such as storm surge, wave dynamics, or landform responses. Maps generated from these models provide the basis for applying the sea level rise scenarios to assess potential extent and severity of flooding. While they have many limitations and should not be used for site-specific analysis, bathtub models are useful for visualizing potential extents of future high water levels to support first-order assessments. Dynamic models (e.g., the Sea, Lake and Overland Surges from Hurricanes model and the Advanced Circulation model) are more complex and include the effects of storm surge—wind generated waves that produce water levels above the highest high tides. While dynamic models are more resource intensive (i.e., greater data input requirements and more expensive to run), the addition of important parameters, such as wind speed and direction, forward speed of the storm, shape of the coastline, and the depth and shape of the seafloor (or bathymetry), greatly improves their predictive capacity for identifying areas that may be impacted by coastal storms.

The quality of both static and dynamic modeling efforts depends on the accuracy of the elevation surfaces used to depict the sea level rise scenarios. It is important to note that these models do not account for coastal landform response, such as erosion, breaching, or migration. Efforts to develop improved decision support models that better consider dynamic landform responses to sea level rise are underway. For any coastal inundation mapping, it is strongly recommended that appropriate technical expertise be sought.

Working with Uncertainty

As with other climate predictions (such as precipitation and storm events), future sea level rise projections are uncertain because they attempt to predict inherently complex

forces and processes, including human response and actions. While certain processes such as thermal expansion are well understood, others such as rapid dynamical changes in ice sheet loss are less so. In the absence of probabilistic projections, descriptions of potential future conditions, or scenarios, provide reasonable ranges that can support many climate change adaptation actions, including assessments of economic and ecological impacts, land use and natural resource management planning, and development of enhanced emergency management plans. The use of multiple scenarios allows for the evaluation and comparison of plausible future conditions given the different factors covered in this guidance. As described below, the time scales for assessments and planning are tightly connected to uncertainty.

Time Horizons

In the process of assessing future risk and planning for rising seas, scenarios must be selected. As detailed above, many scientific papers and assessment reports use a 100-year window, or the generally the year 2100, to set outer bounds of the global sea level rise projections and time points in between. While the century time span provides a convenient long-term view on potential conditions, most applications demand scenarios that consider sea level rise over more near-term periods of time, such as 25 or 50 and in some cases up to 75 years. In the global scenarios described above and shown in Figure 4, the four projection curves are significantly closer in value in the nearer future, and as the time horizon extends out in time, their divergence increases. By the year 2050, the range in sea level rise projections between the lowest and the highest scenarios is about 0.5 m (1.6 ft). By 2100, the range is approximately 1.8 m (5.9 ft). It is very important to emphasize that the curves in these scenarios are best available estimations, and actual rates of sea level change may, in fact, vary. Since climate change and sea level rise will continue for centuries beyond 2100, certain adaptation decisions that will extend into the 22nd century should consider longer-term scenarios.

Resilience, Adaptive Capacity, and Risk

Resilience, adaptive capacity, and risk tolerance should be key factors in the evaluation of different sea level rise scenarios for planning and decision-making. Resilience in this context refers to the ability to endure impacts associated with sea level rise and to respond, recover, and adapt to consequences. An area, site, facility, or project that is highly resilient will be able to accommodate or tolerate more frequent flooding and adverse consequences associated with increasing sea level rise, and one with low resilience and adaptive capacity will be more severely impacted, take longer to recover

(or may not recover at all), and require greater resources for recovery. Risk refers to the potential for, or exposure to, loss or undesirable impacts (or outcomes) and can be characterized as the combination of probability and consequence. In other words, the lower the likelihood and effects, the lower the risk. Some projects or facilities—such as parks, playing fields, or above-ground parking garages—may have greater inherent resilience attributes and may be at lower risk. Conversely, other projects or facilities, including power stations, water and wastewater treatment plants, transportation infrastructure, hospitals, and public safety/emergency service facilities may have relatively lower adaptive capacity and higher risk. Ultimately, the scenario selected for a plan, project site, or design should reflect how much risk can be tolerated and the ability and effort necessary to implement modifications if adverse conditions are encountered in the future.

V. Applying Global Sea Level Rise Scenarios at the Regional and Local Level

As described above, in the development and application of vulnerability assessments for future sea level rise, decision makers should evaluate multiple scenarios within appropriate time horizons. There are many resources available to support analysis and planning for sea level rise that provide detailed information and technical guidance, and a number of these resources are listed and described below in Section VI.

One of the key steps in the assessment and planning process when applying global sea level changes is to account for variability in local land movement and regional ocean circulation patterns to derive relative sea level rise. Other important procedures when applying the global sea level rise scenarios to local geographies are to account for variability of sea level at the local planning area or project site and to adjust the projected values to a geodetic datum. To illustrate this, we provide an example of applying the global scenarios from Parris et al. (2012) for Boston, using guidance, methods, and equations from the U.S. Army Corps of Engineers (2011) and Flick et al. (2012). To account for local subsidence, the estimated vertical land movement values for the NOAA Boston long-term tide gauge station of -0.84 mm/yr (Zervas et al., 2013) were used to adjust the global sea level scenario values. Planners and project proponents are strongly encouraged to determine local conditions for the specific planning area or project site from long-term, continuously operating reference stations or other available data on land subsidence or compaction rates. In this example, to account for inter-annual variability of local sea levels and to provide a more contemporary start time for analysis and planning, a new 19-year tidal epoch was used to calculate mean sea level for the NOAA Boston station for the period 1994-2012. Table 3 shows the values for global sea level rise scenarios

adjusted to reflect relative sea level rise at Boston with 2003—the midpoint of the 1994-2012 tidal epoch—as the beginning year of analysis. As a final step, the mean sea level elevation values collected and reported on a tidal datum were adjusted to a geodetic datum. A geodetic datum is a set of reference points on the Earth's surface used to measure other land elevations and water depths. The North American Vertical Datum 1988 (NAVD88) is the official vertical datum for the conterminous United States and Alaska. Figure 5 shows relative sea level rise estimates in feet NAVD88 for Boston, based on adjustments of the global scenarios from Parris et al. (2012) to account for local vertical land movement (-0.84 mm/yr), with 2003 as the beginning year using methods and equations from Flick et al. (2012) and the U.S. Army Corps of Engineers (2011).

Table 3. Relative sea level rise estimates for Boston, MA. Global scenarios were adjusted to account for local vertical land movement with 2003 as the beginning year of analysis.

| Scenario | 2025 | | 2038 | | 2050 | | 2063 | | 2075 | | 2088 | | 2100 | |
|-------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m | ft | m |
| Highest | 0.49 | 0.15 | 1.08 | 0.33 | 1.81 | 0.55 | 2.80 | 0.85 | 3.92 | 1.19 | 5.33 | 1.63 | 6.83 | 2.08 |
| Intermediate High | 0.36 | 0.11 | 0.73 | 0.22 | 1.19 | 0.36 | 1.80 | 0.55 | 2.47 | 0.75 | 3.32 | 1.01 | 4.20 | 1.28 |
| Intermediate Low | 0.24 | 0.07 | 0.43 | 0.13 | 0.65 | 0.20 | 0.92 | 0.28 | 1.21 | 0.37 | 1.55 | 0.47 | 1.91 | 0.58 |
| Lowest (Historic Trend) | 0.18 | 0.06 | 0.29 | 0.09 | 0.39 | 0.12 | 0.50 | 0.15 | 0.60 | 0.18 | 0.71 | 0.22 | 0.81 | 0.25 |
| Range | 0.31 | 0.09 | 0.79 | 0.24 | 1.42 | 0.43 | 2.30 | 0.70 | 3.32 | 1.01 | 4.62 | 1.41 | 6.02 | 1.83 |

In addition to local vertical land movement, dynamic changes in regional ocean circulation affect local sea level change scenarios. The sea surface is not uniformly flat but has higher and lower surface elevations that result, in part, from the physical forces associated with ocean currents. Recent analysis (Boon, 2012; Sallenger et al., 2012) identified an area of localized accelerated sea level rise in the western Atlantic from Cape Hatteras to above Boston. While information is currently limited, some models forecast the slowing of boundary currents along the U.S. East Coast resulting in a regional rise in sea levels for the northeast (Yin et al. 2009; Yin et al. 2010). The projections shown here do not account for regional increases from ocean circulation patterns which may further add to relative sea level rise trends, with even higher sea levels and potential coastal impacts for the Northeast.

Another important point is that while local elevation conditions and trends (e.g., subsidence and sediment compaction) need to be accounted for in the adjustment of global sea level rise scenarios to derive relative sea level rise, thermal expansion and melting glacial ice sheets are projected to dominate any local changes in land movement by 2025-2050. In consideration of

this, sea level rise scenarios based on historic observations (Lowest - Historical Trend scenario) and ocean warming effects (Intermediate Low scenario) may considerably underestimate actual sea level rise, especially for plans or projects with time horizons beyond 25 years.

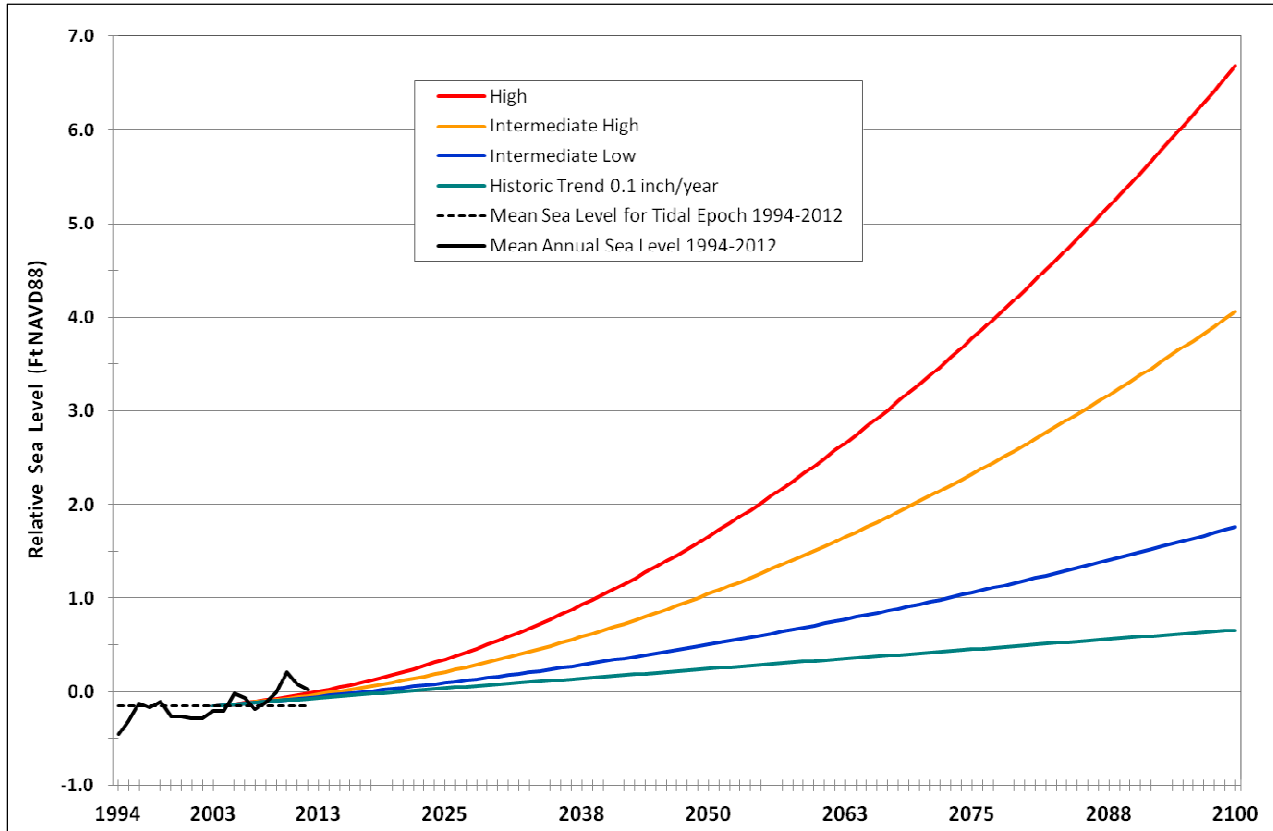


Figure 5. Relative sea level rise scenarios estimates (in feet NAVD88) for Boston, MA. Global scenarios from were adjusted to account for local vertical land movement with 2003 as the beginning year of analysis.

VI. Resources

The following resources provide more detailed information and technical guidance on mapping and planning for sea level rise.

National Climate Assessment and Projections

- *Global Sea Level Rise Scenarios for the United States National Climate Assessment* provides a synthesis of the scientific literature on global sea level rise and presents a set of four scenarios of future global sea level rise.
http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf
- *Coastal Impacts, Adaptation, and Vulnerabilities: A Technical Input to the 2013 National Climate Assessment* examines the known effects and relationships of climate change variables on the coasts of the United States. It describes the impacts on natural and human systems and the progress and challenges to planning and implementing adaptation options.
http://www.cakex.org/sites/default/files/documents/Coastal-NCA-1.13-web.form_0.pdf
- The U.S. Army Corps of Engineers developed a sea level change curve calculator to guide local engineering projects at different time intervals. This calculator was developed with the assistance of coastal scientists from NOAA and the U.S. Geological Survey.
<http://corpsclimate.us/ccaceslcurves.cfm>

Identifying Current Hazards

- The Massachusetts Office of Coastal Zone Management's (CZM) StormSmart Coasts webpage on assessing vulnerability of coastal properties describes how to use, interpret, and recognize the limitations of the Federal Emergency Management Agency Flood Insurance Rate Maps and Flood Insurance Study reports.
<http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/vulnerability/#FloodplainMapsandFloodInsurance>
- The New England District of the U.S. Army Corps of Engineers has created hurricane surge inundation maps for coastal communities in Massachusetts to identify vulnerable areas and guide evacuation planning.
<http://www.mass.gov/eopss/agencies/mema/hurricane-inundation-maps.html>
- The U.S. Geological Survey has launched a National Assessment of Coastal Change Hazards portal that includes shoreline change data, assessments of extreme storms, and sea level vulnerability maps.

<http://marine.usgs.gov/coastalchangehazards>

Sea Level Rise Maps and Visualizations

- *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region* provides background information and guidance on coastal elevations and sea level rise and its effects on the coast.

<http://library.globalchange.gov/products/assessments/2004-2009-synthesis-and-assessment-products/sap-4-1-coastal-sensitivity-to-sea-level-rise-a-focus-on-the-mid-atlantic-region>

- NOAA's *Mapping Coastal Inundation Primer* helps communities understand the process of mapping coastal inundation and some limitations, such as the resolution of elevation data.

http://www.csc.noaa.gov/digitalcoast/_pdf/guidebook.pdf

- NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer provides visualizations of potential sea level rise at 1- to 6-foot intervals for Massachusetts and other coastal states.

<http://www.csc.noaa.gov/digitalcoast/tools/slrviewer>

This sea level rise data can also be accessed on the Massachusetts Ocean Resource Information System (MORIS), which allows users to interactively view the data with other information such as aerial photographs, assessor maps, public facilities and infrastructure locations, and natural resource areas.

<http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/vulnerability/slr.html>

- The Boston Harbor Sea Level Rise Maps produced by The Boston Harbor Association show the impact of 2.5 feet, 5 feet, and 7.5 feet of flooding above mean high tide on the Boston Harbor coastline.

<http://www.tbha.org/boston-harbor-sea-level-rise-maps>

- CZM's StormSmart Coasts pilot project with the town of Hull illustrates how three-dimensional visualizations of flood events and sea level rise can be created. The project technical report provides details on the methodology and includes images of Hull's critical facilities under varying flooding scenarios.

<http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-communities/stormsmart-hull.html>

- CZM and the Buzzards Bay National Estuary Program are evaluating the potential expansion of existing 100-year floodplains using Federal Emergency Management Agency Flood Insurance Rate Map base flood elevations for Buzzards Bay municipalities under three sea

level rise scenarios. Community assets including number of buildings, assessed values, and municipal infrastructure are enumerated.

<http://climate.buzzardsbay.org/flood-zone-expansion.html>

- Scituate, Marshfield, and Duxbury evaluated potential impacts of sea level rise and storm surge scenarios in the three South Shore communities.

<http://necca.stormsmart.org/municipal-grants/scituate-marshfield-and-duxbury-massachusetts>

Sea Level Rise Adaptation Planning Guidance

- *Sea-Level Change Considerations for Civil Works Programs* was developed by the U.S. Army Corps of Engineers in 2011 to guide all phases of Civil Works projects.

<http://planning.usace.army.mil/toolbox/library/ECs/EC11652212Nov2011.pdf>

- The Georgetown Climate Center's 2011 *Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use* describes different land-use tools that can be used to respond to threats posed by sea level rise to both public and private coastal development and infrastructure.

http://www.georgetownclimate.org/sites/default/files/Adaptation_Tool_Kit_SLR.pdf

- *Adapting to Climate Change: A Planning Guide for State Coastal Managers* was developed by NOAA to help state coastal managers develop and implement adaptation plans to reduce the risks associated with climate change on the coast.

<http://coastalmanagement.noaa.gov/climate/adaptation.html>

- *Preparing for the Rising Tide* was released by The Boston Harbor Association and partners in 2013 to provide local case studies of how to assess vulnerability and increase resilience to coastal flooding over time.

<http://www.tbha.org/preparing-rising-tide-report>

VII. References

In addition the references cited below, CZM would like to acknowledge and thank the following experts for their technical review, comments, and assistance in the preparation of this guidance:

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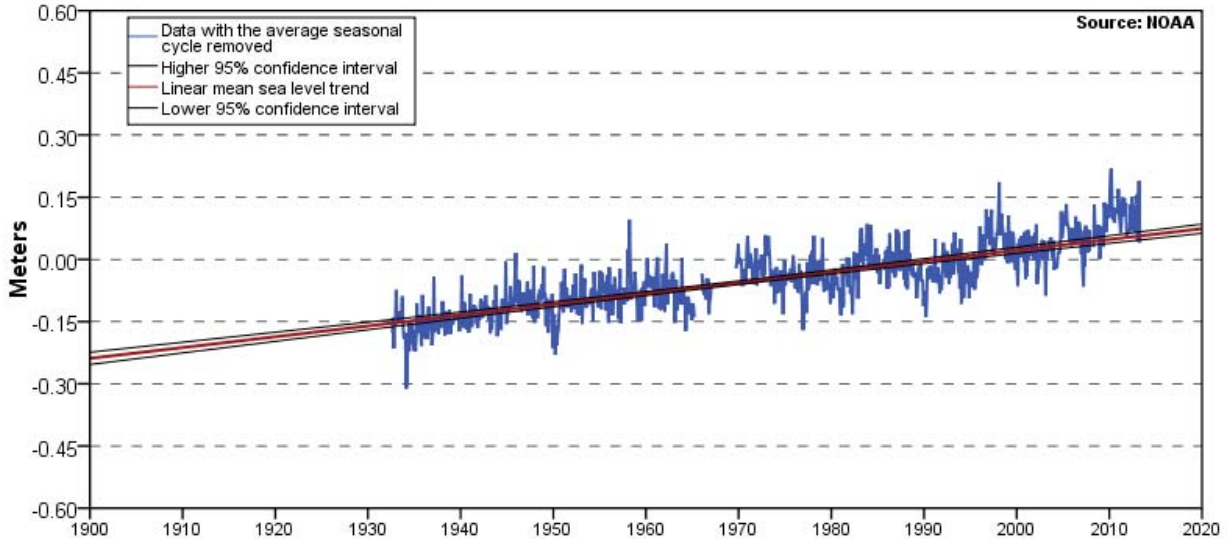
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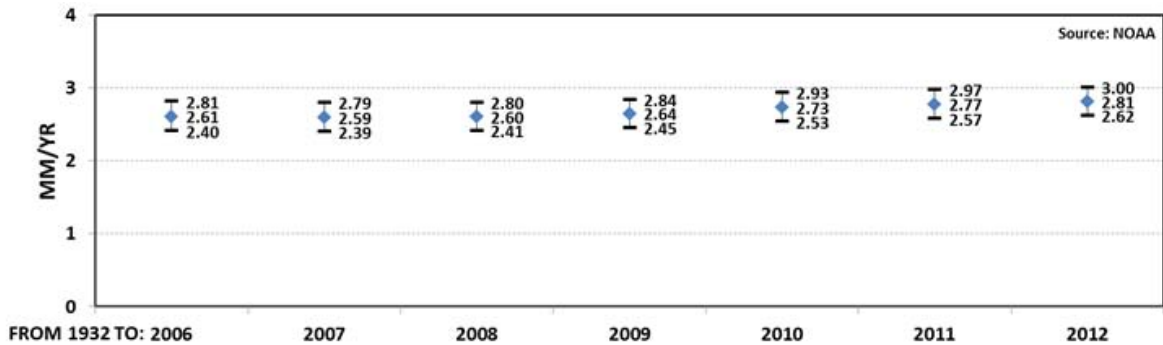
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Appendix A: Mean sea level trends for NOAA long-term tide stations in Woods Hole and Nantucket, Massachusetts

WOODS HOLE

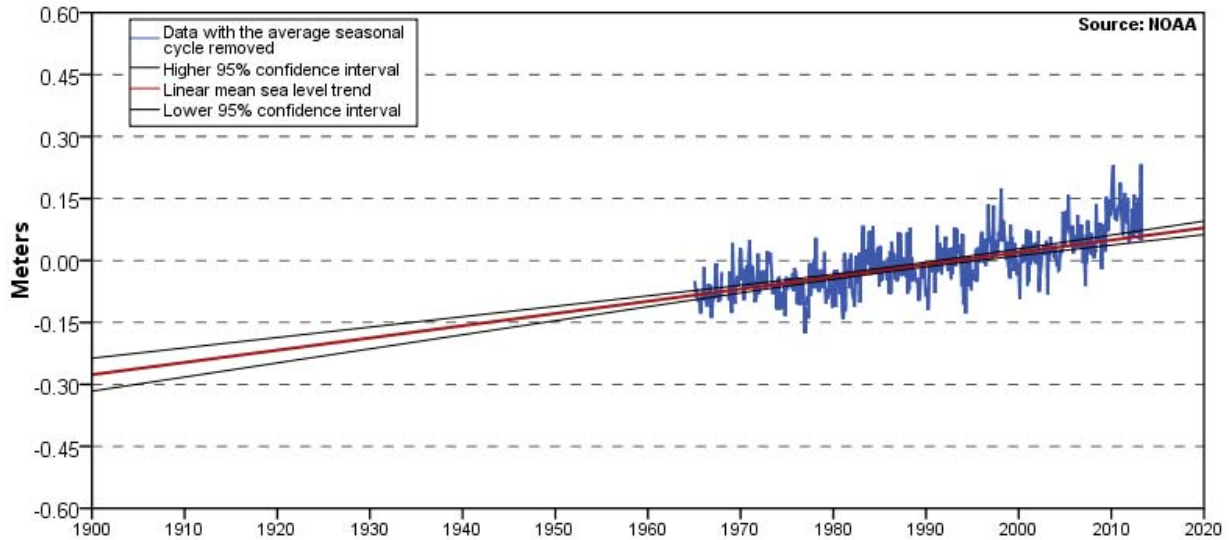


(a) Sea level data for NOAA Woods Hole tide gauge station with linear trend and 95% confidence interval.

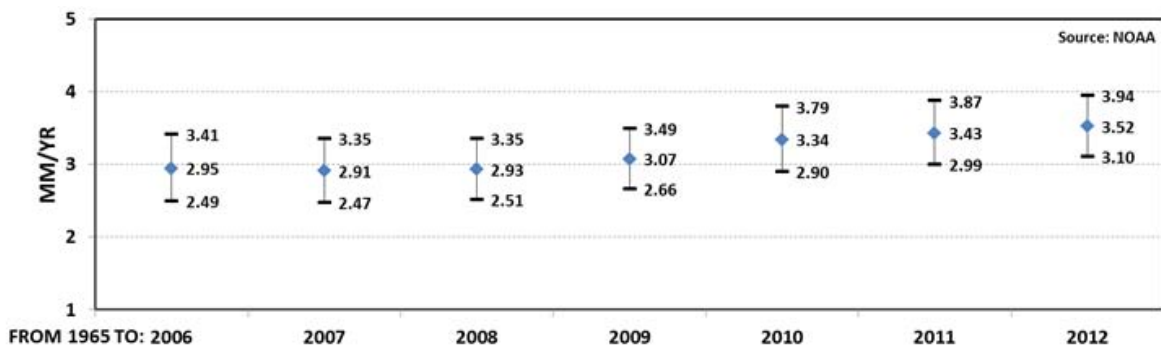


(b) Mean sea level rates (blue diamonds) and 95% confidence intervals (mm/yr) calculated from 1932 to recent years (2006-2012) at the Woods Hole tide gauge station. Values are the trend of the entire data period up to that year.

NANTUCKET



(a) Sea level data for NOAA Nantucket tide gauge station with linear trend and 95% confidence interval.



(b) Mean sea level rates (blue diamonds) and 95% confidence intervals (mm/yr) calculated from 1965 to recent years (2006-2012) at the Nantucket tide gauge station. Values are the trend of the entire data period up to that year.