DRAFT

Sea-Level Rise Update
Provided to the Coastal Resource Commission by the Science Panel
April 2024

Introduction

Given that sea level rise is of great importance to the State, its policy makers and the citizens of North Carolina, the Coastal Resources Commission (CRC) charged the Science Panel with providing periodic updates to help inform planning and decision making. The charge includes a request for the Science Panel to determine "whether any new scientific literature and/or data have become available that have implications on sea level rise projections, or associated inundation-related hazards at the State, sub-regional, and local scales." The charge also states, "If the Panel feels sufficient new information is available to warrant a report, or new analyses, they will present their findings to the Commission and the public in the form of oral presentations and/or written briefs/fact sheets."

In 2022, the U.S. Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force (which includes representatives from NASA, NOAA, USGS, FEMA, USACE and the DOD), released a report and accompanying datasets, titled "Global and Regional Sea Level Rise Scenarios for the United States" (Sweet et al., 2022). Based on the latest sea level rise science and methodologies, this report provides sea level rise scenarios for the next century and beyond (by decade). As the report states, in recent years, confidence regarding the expected amount of sea level rise by mid-century has increased, based on consistency between extrapolation of tide gauge observations (which now show the anticipated acceleration in sea level rise) and global mean sea level model scenarios. For the Southeast U.S., Sweet et al. (2022) project 1 foot to 1.4 feet of sea level rise by 2050 (with the actual amount depending on future greenhouse gas emissions, and how much ice is lost from the Greenland and Antarctic ice sheets). Sweet et al. (2022) projections for sea level rise beyond 2050 are less certain because they depend more strongly on future greenhouse gas emissions and rate of ice loss from Greenland and Antarctica. However, rates of sea level rise are expected to increase toward the latter half of this century. Sweet et al. (2022) project sea level rise of 2 -7 feet by 2100.

As noted in the report, there are considerable local variations in sea level rise, largely because vertical motion of the land varies from place to place. When considering sea level rise, it is important to distinguish between changes in global mean sea level (GMSL) and relative sea level (RSL). GMSL is controlled by how much ice is stored on land and steric effects, including the temperature and salinity of ocean water, which affect water density and thus volume. RSL is controlled by these factors as well as local variations in water level (e.g., due to dynamic effects of ocean currents) and vertical land motion (which varies along the NC coast and has recently been reported in detail by Barnard et al., [2023]). Additionally, recent work by Dangendorf et al.

(2023), including along the NC coast, highlights the potential for sterodynamic processes (ocean circulation, temperature, salinity) to cause multi-year variability in sea level rise that can either amplify or mask overall trends and acceleration (for example, sea level rise rates have been on the order of 10 mm/yr for the last decade within the vicinity of Cape Hatteras [Dangendorf et al. (2023]. The combination of all these factors has caused relative sea level rise to vary within North Carolina with higher rates of rise in the north relative to the south.

The interagency task force report (Sweet et al., 2022) also provides probabilistic projections of extreme water levels along the U.S. coastline, which indicate substantial increases in the frequency of coastal flooding as sea level rises. The Executive Summary states the purpose of the report as the following: "This report will be a key technical input for the Fifth National Climate Assessment (NCA5). These data and information are being incorporated into current and planned agency tools and services, such as NOAA's Sea Level Rise Viewer and Inundation Dashboard, NASA's Sea Level Change Portal, and others. Although the intent of the 2022 report is not to provide authoritative guidance or design specifications for a specific project, it is intended to help inform Federal agencies, state and local governments, and stakeholders in coastal communities about current and future sea level rise to help contextualize its effects for decision-making purposes" (Sweet et al., 2022, p. xii).

Given that the painstaking work of preparing sea level rise projections based on the latest science has already been carried out by Sweet et al. (2022), the Science Panel's sea level rise update consists of 1) a restatement of the key messages from Sweet et al. (2022); 2) a brief summary of the regional sea level rise projections from Sweet et al. (2022) most relevant to North Carolina, and 3) based on results from Sweet et al. (2022), updated sea level rise projections and assessment of high-tide flooding frequencies for Duck, Beaufort and Wilmington, NC, generously conducted by the lead author of the task force report and NOAA scientist, Dr. William Sweet. We also refer the CRC to the interagency task force report itself, and especially the executive summary, for further detail. Additionally, a 2023 report and a Flood Viewer Tool (Wood et al., 2023) published by the U.S. Geological Survey, which uses the sea level rise projections from Sweet et al. (2022), provides an analysis of storm flooding exposure along the NC coast for 2050 and beyond (Barnard et al., 2023; Jones et al., 2017; Jones et al., 2023).

1) Key Messages from the Executive Summary of Sweet et al., 2022

Below, we provide, for the CRC's reference, text from the Executive Summary of Sweet et al., 2022. We have emphasized, with bold font, a few points highlighting the East Coast region relative to other U.S. coastal regions. Conversions to feet or inches are shown in italicized brackets and have been added by the authors of this sea level rise update. From Sweet et al. (2022) pages xiii - xiv:

"Key Message #1:
Multiple lines of evidence provide increased confidence, regardless of the emissions pathway, in a narrower range of projected global, national, and regional sea level rise at 2050 than previously reported (Sweet et al., 2017).

- Both trajectories assessed by extrapolating rates and accelerations estimated from historical tide gauge observations, and model projections, fall within the same range in all cases, giving higher confidence in these relative sea level (RSL; land and ocean height changes) rise amounts by 2050.
- Relative sea level along the contiguous U.S. (CONUS) coastline is expected to rise on average as much over the next 30 years (0.25–0.30 m *[0.82 - 0.98 ft]* over 2020–2050) as it has over the last 100 years (1920–2020).
- Due to processes driving regional changes in sea level, there are similar regional differences in both the modeled scenarios and observation-based extrapolations, **with higher RSL rise along the East (0–5 cm** *[0 - 1.96 in]* **higher on average than CONUS)** and Gulf Coasts (10–15 cm *[3.94 - 5.91 in]* higher) as compared to the West (10–15 cm lower) and Hawaiian/Caribbean (5–10 cm *[1.96 - 3.94 in]* lower) Coasts.
- The projections do not include natural year-to-year sea level variability that occurs along U.S. coastlines in response to climatic modes such as the El Niño–Southern Oscillation."

"Key Message #2
By 2050, the expected relative sea level (RSL) will cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes, with major and moderate high tide flood events occurring as frequently as moderate and minor high tide flood events occur today. Without additional risk-reduction measures, U.S. coastal infrastructure, communities, and ecosystems will face significant consequences.

- Minor/disruptive high tide flooding (HTF; about 0.55 m *[1.8 ft]* above mean higher high water [MHHW][4]) is projected to increase from a U.S average frequency of about 3 events/year in 2020 to >10 events/year[5] by 2050.
- Moderate/typically damaging HTF (about 0.85 m *[2.8 ft]*above MHHW) is projected to increase from a U.S. average frequency of 0.3 events/year in 2020 to about 4 events/year in 2050.
- Major/often destructive HTF (about 1.20 m *[3.9 ft]*above MHHW) is projected to increase from a U.S. average frequency of 0.04 events/year in 2020 to 0.2 events/year by 2050.
- **Across all severities (minor, moderate, major), HTF along the U.S. East and Gulf Coasts will largely continue to occur at or above the national average frequency."**

"4 Mean higher high water (MHHW) level is estimated over the 1983–2001 tidal epoch period and, in this case, is considered a fixed elevation that does not change with sea level rise.
5 The extreme value statistical methods in this report do not directly resolve frequencies >10 events/year."

“Key Message #3:
Higher global temperatures increase the chances of higher sea level by the end of the century and beyond. The scenario projections of relative sea level along the contiguous U.S. (CONUS) coastline are about 0.6 – 2.2 m *[2.0 - 7.2 ft]* in 2100 and 0.8 – 3.9 m *[2.6 - 12.8 ft]* in 2150 (relative to sea level in 2000); these ranges are driven by uncertainty in future emissions pathways and the response of the underlying physical processes.

- With an increase in average global temperature of 2°C above preindustrial levels, and not considering the potential contributions from ice-sheet processes with limited agreement (low confidence) among modeling approaches, the probability of exceeding 0.5 m rise globally (0.7 m along the CONUS coastline) by 2100 is about 50%. With 3°–5°C of warming under high emissions pathways, this probability rises to >80% to >99%. The probability of exceeding 1 m globally (1.2 m CONUS) by 2100 rises from <5% with 3°C warming to almost 25% with 5°C warming.
- Considering low-confidence ice-sheet processes and high emissions pathways with warming approaching 5°C, probabilities rise to about 50%, 20%, and 10% of exceeding 1.0 m, 1.5 m, or 2.0 m *[3.3, 4.9 or 6.6 ft]* of global rise by 2100, respectively. These processes are unlikely to make significant contributions with 2°C of warming, but how much warming might be required to trigger them is currently unknown.
- As a result of improved understanding of the timing of possible large future contributions from ice-sheet loss, the “Extreme” scenario from the 2017 report (2.5 m *[8.2 ft]* global mean sea level rise by 2100) is now viewed as less plausible and has been removed. Nevertheless, the potential for increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that could reach this threshold in the decades immediately following 2100 (and continue rising).
- Regionally, the projections are near or higher than the global average in 2100 and 2150 for almost all U.S. coastlines due to the effects from vertical land motion (VLM); gravitational, rotational, and deformational effects due to land ice loss; and ocean circulation changes. Largely due to VLM, RSL projections are lower than the global amounts along the southern Alaska coast and are higher along the Eastern and Western Gulf coastlines.”

“Key Message #4
Monitoring the sources of ongoing sea level rise and the processes driving changes in sea level is critical for assessing scenario divergence and tracking the trajectory of observed sea level rise, particularly during the time period when future emissions pathways lead to increased ranges in projected sea level rise.”

- Efforts are under way to narrow the uncertainties in ice-sheet dynamics and future sea level rise amounts in response to increasing greenhouse gas forcing and associated global warming.

- Early indicators of changes in sea level rise trajectories can serve to trigger adaptive management plans and are identified through continuous monitoring and assessment of changes in sea level (on global and local scales) and of the key drivers of sea level change that most affect U.S. coastlines, such as ocean heat content, ice-mass loss from Greenland and Antarctica, vertical land motion, and Gulf Stream system changes."

2) Sweet et al. (2022) Sea Level Rise Projections Most Relevant to NC

Chapter two of Sweet et al. (2022) presents sea level rise projections for eight regions of the U.S. Below, in Figure 1 of this update, we show panels a and b of Figure 2.3 from the report, which includes a sea level rise projection for the Southeast U.S. relative to the year 2000, under five different scenarios: low, intermediate-low, intermediate, intermediate high and high.

It is important to note that these projections are based on an extrapolation of observations and on modeled global mean sea level scenarios, and that out to 2050, both lines of evidence agree, lending greater confidence in the projection of 1 foot to 1.4 feet of sea level rise for the U.S. Southeast coast by 2050. In the words of Sweet et al. (2022, p. 14): "A key takeaway from this assessment is that on global and national scales, two lines of evidence (observations and GMSL scenarios) are consistent out to 2050 and support a narrower range in possible near-term sea level change than provided in Sweet et al. (2017)."

From Sweet et al. (2022) (Figure 2.3, p. 18; We show two regions out of eight):

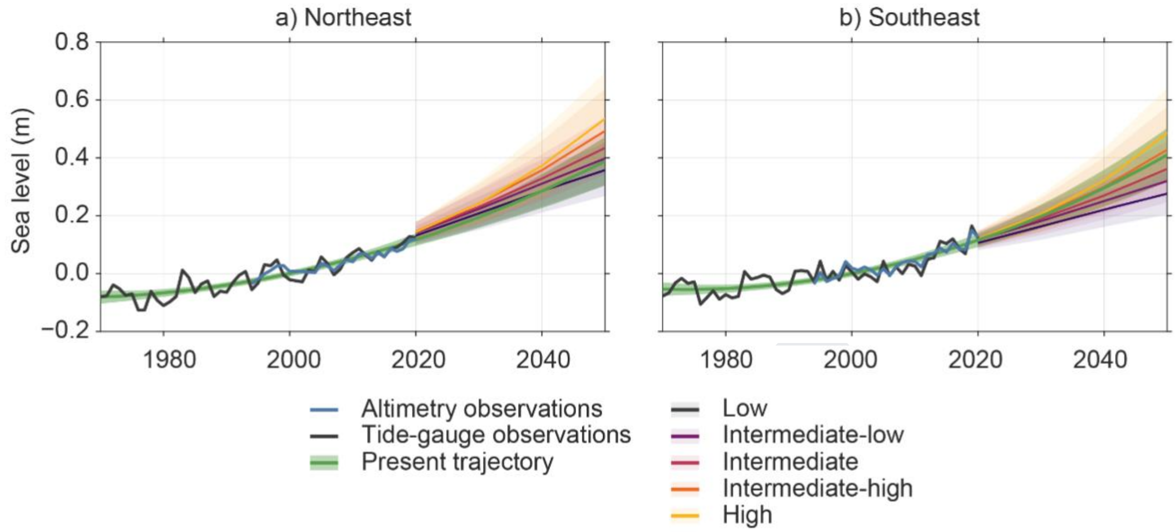

Figure 1. Caption from Sweet et al. (2022): "Observation-based extrapolations and five regionalized global mean sea level scenario projections, in meters, of relative sea levels for [two] coastal regions around the United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown 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."

As shown in Figure 2 of this report (Figure 2.4 from Sweet et al. 2022) for the intermediate-low and intermediate-high scenarios, regional relative sea level rise projections for 2050 vary considerably around the U.S. Relative sea level rise projections vary mostly because vertical land motion is different in different places.

From Sweet et al. (2022) (Figure 2.4, p. 20):

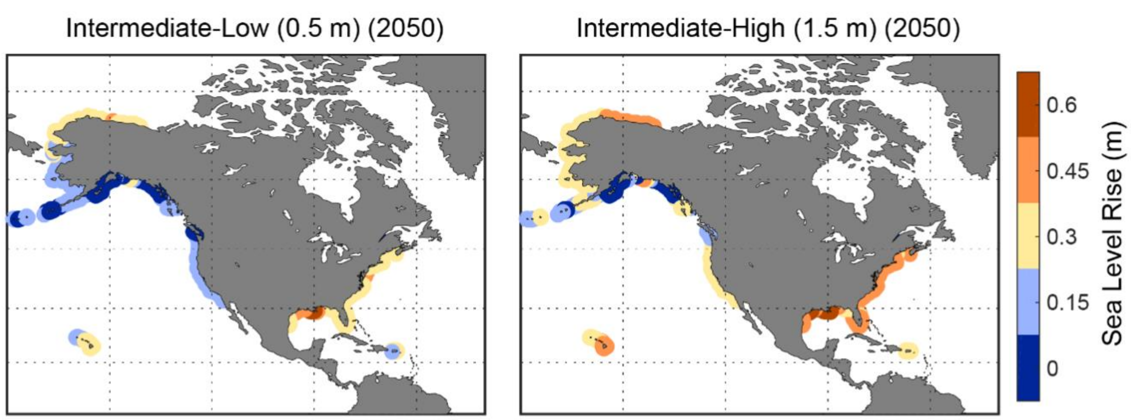

Figure 2. Caption from Sweet et al. (2022): "Relative sea level rise, in meters, in 2050 for the a) Intermediate-Low and b) Intermediate-High scenarios relative to the year 2000."

3) Updated Sea Level Rise Projections and High-tide Flood Frequency Analyses for NC

The sea level rise projections and high-tide flood analyses for Duck, Beaufort and Wilmington, NC shown below were developed by Dr. William Sweet for the purposes of this update, using the same methods as those used in Sweet et al. (2022) and Sweet et al. (2018). These projections are based on 'medium confidence' scenarios meaning that actual sea level rise may be higher but is not likely to be lower. High-tide flooding is calculated as the number of days per year that flooding is projected to occur at an elevation of 1.75 feet above MHHW (mean higher high water).

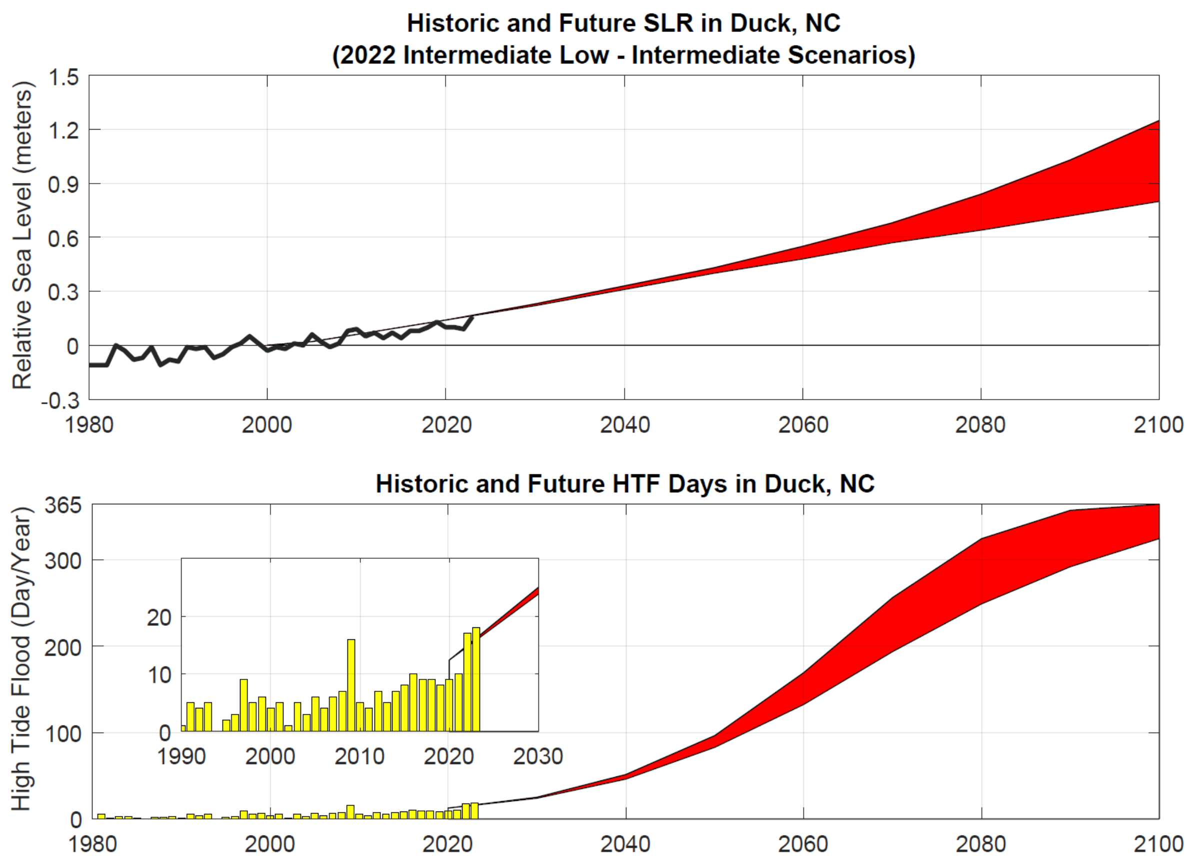

Figure 3. Top: Historic and projected future SLR in Duck, NC for the Intermediate-Low to Intermediate Scenarios from Sweet et al. (2022). Bottom: Historic and projected future high-tide flooding (HTF) days in Duck, NC for an elevation of 1.75 feet above MHHW (mean higher high water). In both panels, the historic values are annual whereas the future projections are decadal averages, e.g., 2040 is shown as the 2031-2040 average.

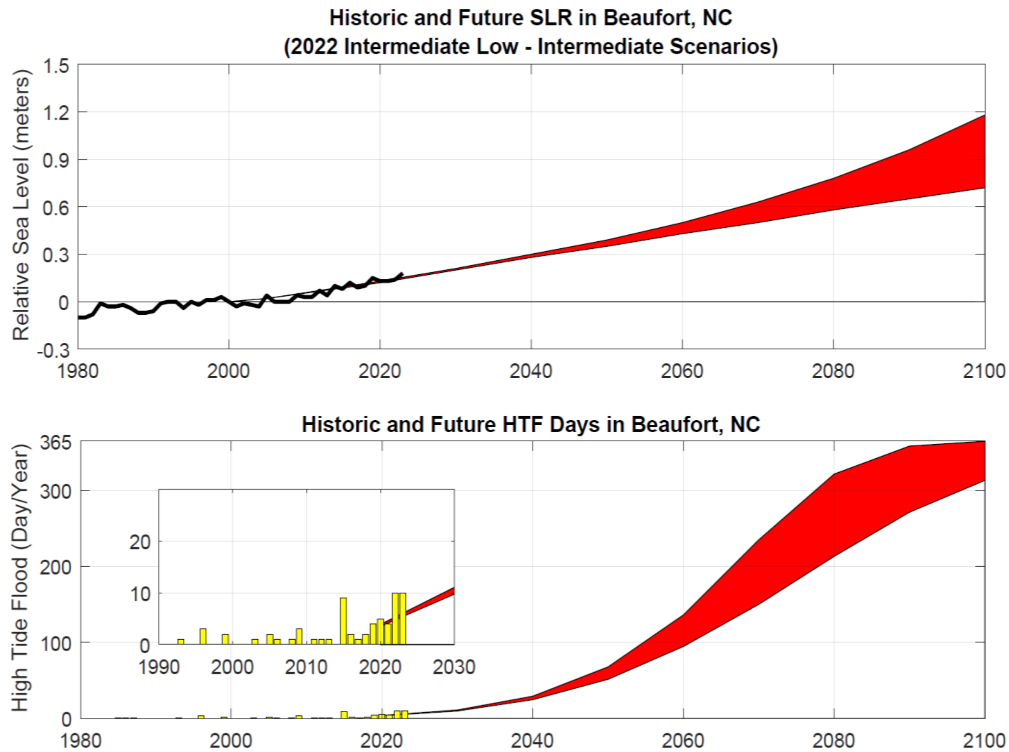

Figure 4. Top: Historic and projected future SLR in Beaufort, NC for the Intermediate-Low to Intermediate Scenarios from Sweet et al. (2022). Bottom: Historic and projected future high-tide flooding (HTF) days in Beaufort, NC for an elevation of 1.75 feet above MHHW (mean higher high water). In both panels, the historic values are annual whereas the future projections are decadal averages, e.g., 2040 is shown as the 2031-2040 average.

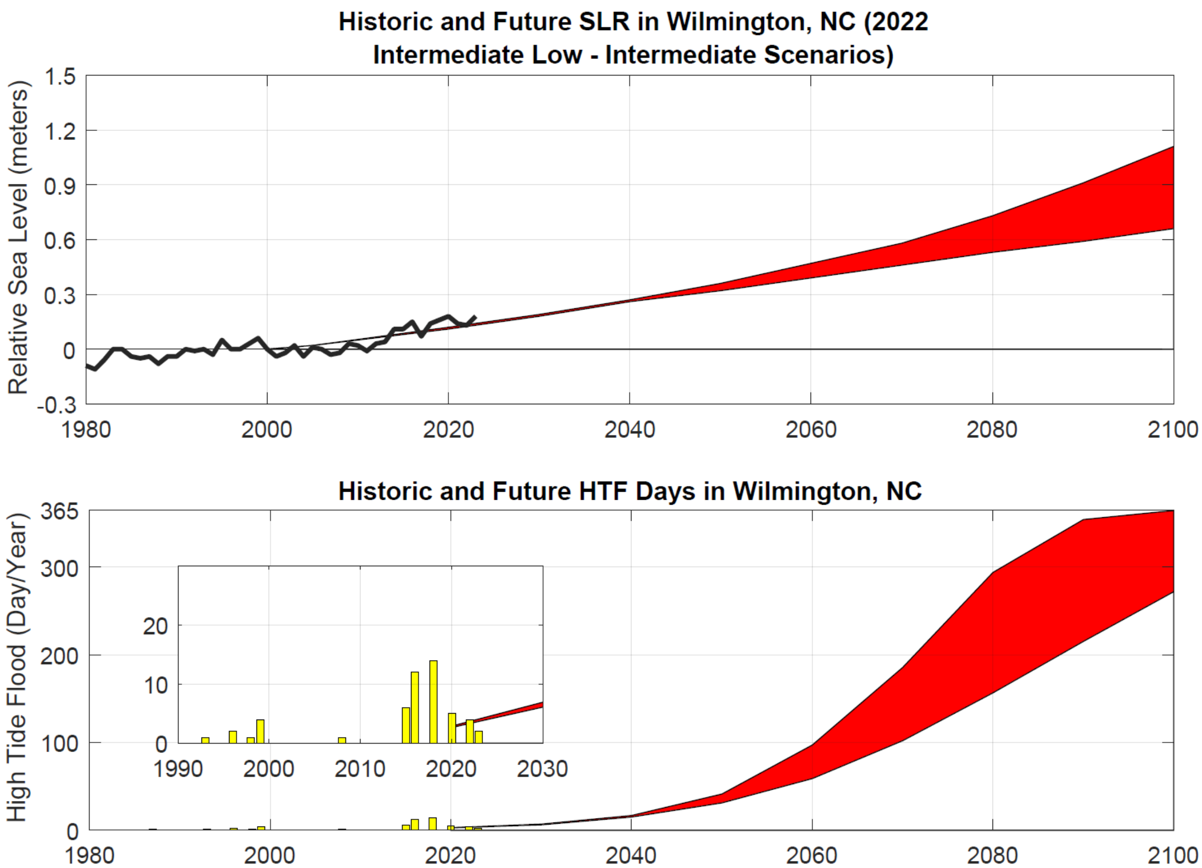

Figure 5. Top: Historic and projected future SLR in Wilmington, NC for the Intermediate-Low to Intermediate Scenarios from Sweet et al. (2022). Bottom: Historic and projected future high-tide flooding (HTF) days in Wilmington, NC for an elevation of 1.75 feet above MHHW (mean higher high water). In both panels, the historic values are annual whereas the future projections are decadal averages, e.g., 2040 is shown as the 2031-2040 average.

Acknowledgements
The Science Panel thanks Dr. William Sweet of NOAA for providing an updated analysis of historic and future sea level rise and historic and future high-tide flooding days in Duck, Beaufort and Wilmington, NC, conducted for the purposes of this update.

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