Section 2: Future Mean Sea Level: Scenarios and Observation-Based Assessments

Since Sweet et al. (2017), the observations and available data records of both sea level change and the associated processes have increased in number and length. In part due to these observations, our understanding of the drivers of sea level change has improved. There have also been significant advances in modeling how these processes will cause sea level to change in the future. This has led to an improved understanding of the possible trajectory of future sea level rise. In this report, these advances are reflected both in an update to the GMSL scenarios and a change in approach from Sweet et al. (2017). The primary change in approach is in separating this section into two different time periods: 1) near term (2020–2050) and 2) long term (2050–2150). There is also a section discussing divergence of the GMSL scenarios and tracking that is particularly relevant during the transition between the near- and long-term time periods. In the remainder of this section, a brief overview of the drivers of global and regional sea level rise is provided. Next, updates to Sweet et al. (2017) are discussed, and the motivation and scientific justification for these changes are given. Finally, the updated information for the two time periods, along with the transition between these periods, is provided.

2.1. Overview of Regional and Global Sea Level Rise

Over long, multidecadal to centennial timescales, the primary drivers of changes in GMSL are thermal expansion due to the heating of the ocean and the addition of water mass associated with ice-mass loss from the ice sheets and glaciers. Other changes in the movement of water between ocean and land, including from groundwater depletion and water impoundment, have a secondary impact on GMSL, although they can increase in importance for certain time periods (see Frederikse et al., 2020). During the 20th century, GMSL estimated from tide-gauge records has been explained by the individual processes contributing to it (see Figure 1.2a; Frederikse et al., 2020). More recently, observed GMSL from satellite altimetry over the past 15 years has been explained using the in situ measurements of the Argo profiling floats and the observations of water-mass change from the GRACE and GRACE-FO satellites (WCRP, 2018). On shorter timescales, considerable interannual and decadal variability in GMSL is linked primarily to variations in terrestrial water storage and driven heavily by the El Niño–Southern Oscillation (ENSO; Boening et al. 2012; Fasullo et al., 2013; Piecuch and Quinn, 2016; Hamlington et al., 2020a, 2020b].

At the regional level, rates of sea level rise can deviate significantly from the globally averaged rate. Sea level rise is not uniform across the globe; rather, it manifests as relative sea level (RSL) rise that also responds to several key factors important at regional and local scales (Kopp et al., 2014; Sweet et al., 2017; Hamlington et al., 2020a; Fox-Kemper et al., 2021). On short timescales and in short records, natural variations on interannual to decadal timescales can impact estimates of rates and accelerations. On long timescales, however, there are three primary causes of regional variations in estimated rates and accelerations: 1) sterodynamic sea level change; 2) gravitational, rotational, and deformational (GRD) changes due to contemporary ice-mass loss and the movement of water between land and ocean; and 3) vertical land movement (VLM; subsidence or uplift) due to glacial isostatic adjustment (GIA), tectonics, sediment compaction, groundwater and fossil fuel withdrawals, and other non-climatic factors. These three causes are discussed briefly below.

Sterodynamic sea level changes are those that arise from changes in the ocean's circulation (currents) and its density (temperature and salinity). Sea level rise associated with sterodynamic sea level change is the combination of global mean thermosteric rise associated with global ocean warming and local deviations from the global mean due to ocean dynamic processes. It is these changes in ocean dynamics that lead to regional differences. Focusing on possible causes of long-term sterodynamic sea level changes for the U.S. coastlines, future changes in the Atlantic meridional overturning circulation (AMOC) are particularly relevant. The IPCC AR6 (IPCC, 2021a) determined that it is *very likely* that the AMOC will decline in the future, although there is still disagreement as to the extent of this decline. A weakening AMOC will lead to an increase in sea level along the coastal Northeast and Southeast regions (Yin et al., 2009; Krasting et al., 2016; see Figure A1.1 for region definitions). For the Northwest and Southwest coastal regions, ENSO plays a substantial role in interannual sea level change, although there is no clear evidence for a sustained shift in ENSO that will result in a long-term increase or decrease in sea level. Some models project future sea level changes associated with ocean dynamics to be large in magnitude in some locations, but these projections remain uncertain (Fox-Kemper et al., 2021).

The ice-mass loss from ice sheets and glaciers to the ocean has a strong influence on regional sea level. Changes in Earth's GRD responses dictate the spatial distribution of water across the global ocean (Farrell and Clark, 1976; Milne and Mitrovica, 1998; Mitrovica et al., 2001). These so-called sea level fingerprints are important to determining regional sea level rise. Mass loss causes a sea level fall in the near-field, a reduced sea level rise at intermediate distances, and a greater-than-global-average sea level rise at larger distances. For U.S. coastlines, particularly in the Northeast, this means that a similar amount of ice-mass loss in Antarctica will have a larger impact than ice-mass loss in Greenland. Similarly, ice-mass loss in Greenland leads to bigger increases in sea level along the Northwest and Southwest coastal regions than along the Northeast coastal region. At any time horizon, the regional sea level rise associated with GRD will be driven both by the amount of ice that is being lost and the source of that ice. These regional fingerprints are tied to projected trajectories of mass loss from the associated source. Changes in terrestrial water storage (groundwater withdrawal and dam building) also have an associated fingerprint, but the regional contribution is generally smaller than that from the ice sheets and glaciers.

Lastly, the VLM considered in this report refers to either subsidence or uplift that occurs in coastal regions and can lead to the change in the height of sea level relative to land. VLM is not a singular phenomenon but instead results from various processes that display different patterns in space and time. These patterns have different impacts from place to place, especially in coastal settings where many of them operate at the same time. For much of the coastal United States, subsidence is driven on local scales by groundwater and fossil fuel withdrawal and on larger scales by GIA. However, in some regions such as southern Alaska, GIA leads to high rates of uplift in coastal regions. GIA is the ongoing response of the solid earth due to ice-mass changes in the past, particularly the deglaciation after the last glacial maximum. GIA induces VLM, in particular subsidence along the U.S. East Coast, as well as changes in the gravity field, which cause local sea level changes. Accurate future projections of VLM require an understanding of the underlying processes and the time and space scales on which they vary. Currently, and in this report, VLM projections are based in part on analysis of past observations. If activities change in a particular location (e.g., reduction in groundwater pumping), an associated change in the rate of VLM will not necessarily be captured. Modeling of future VLM under a range of possible scenarios is not currently available over large scales. (See the vertical land motion use case in Section 4.4 for more information.)

Beyond these processes that impact long-term changes in sea level, there is also considerable natural (or "unforced") climate variability that can lead to significant, albeit temporary, changes to sea level on the order of years or even decades. In many of the available observational records, it can be a challenge to distinguish between these natural signals and those processes discussed above. As an example, in Figure 2.1, the regional rates of sea level rise along U.S. coastlines are shown for the first half (a, 1993–2006), second half (b, 2007–2020), and full (c, 1993–2020) satellite altimeter record (which do not measure VLM effects), along with overlaid tide-gauge rates (which measure VLM effects) measured over the same time period. A significant shift occurs from the first half of the record to the second half, with high sea level rise rates found along all coastlines of CONUS from 2007 to 2020. For the Northwest and Southwest coastal regions, in particular, the rate was near 0 for the first half of the record before shifting to almost 10 mm/year over the second half, driven by decadal variability linked to the Pacific Decadal Oscillation (PDO; e.g., Bromirski et al., 2011; Hamlington et al., 2021). For the full record, there is considerably less spatial variability, with most regions approaching the globally averaged rate of 3.1 mm/year.

In this section of the report, the contribution of natural variability is not assessed directly, but its importance and contribution should be considered when looking at observed rates and assessing possible sea level at a specific time in the future. In other words, there is an "envelope" of naturally occurring sea level variability on top of the sea level rise discussed here that needs to be included to estimate sea level at a particular location at a specific time in the future. A depiction of the relationship between sea level rise and this envelope is provided in Figure 1.3. The median of the distribution increases over time as a result of the rising sea levels, while other sea level variability on a range of timescales contributes to the spread around this central value.

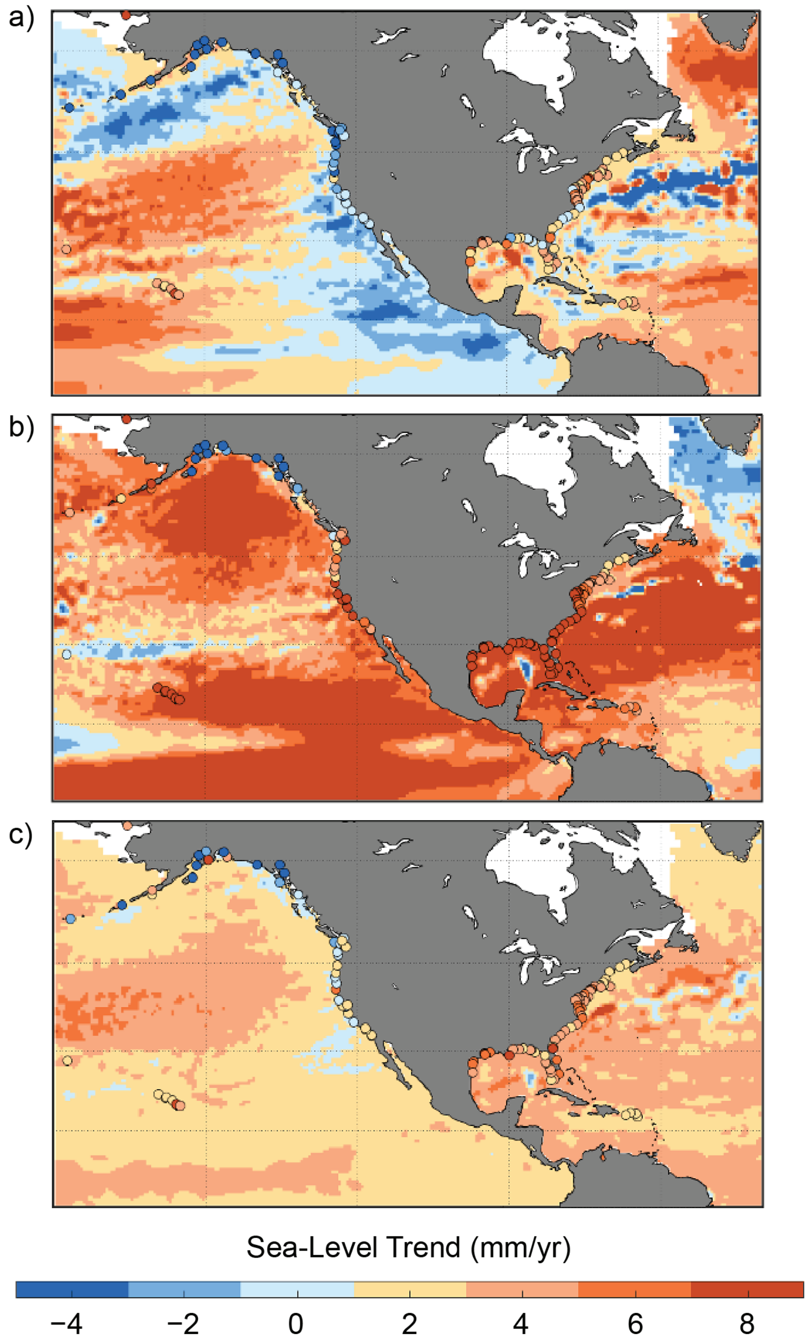

Figure 2.1: Regional sea level linear rates of rise (mm/year) from satellite altimetry over three different time periods: (a) 1993–2006, (b) 2007–2020, and (c) 1993–2020. Linear rates of change of relative sea level (ocean and land height changes) from tide gauges over the same time period are also shown (circles).

2.2. Updates from Sweet et al. (2017)

One of the main structural changes from the Sweet et al. (2017) report to this one is a specific emphasis on the near-term time period, 2020–2050. There is also a detailed discussion of GMSL scenario divergence and tracking that becomes particularly important in the transition from the near term to the long term. The motivation for the focus on these two topics is given below. Following this explanation, the primary advances in the sea level scenarios and assessments of future sea level are discussed in two subsections. The first provides an overview of the science and framework advancements that have led to an update of the scenarios first presented in Sweet et al. (2017). The second covers the inclusion of observation-based assessments of near-term sea level change for the first time.

2.2.1. Inclusion of Near-Term Time Period (2020–2050)

The dedicated focus on the near-term time period represents a new element in this report. Motivation for this change is provided briefly here. With increasing record lengths, the impact of natural sea level variability on estimated rates and accelerations diminishes, revealing more of the underlying climate change signal (see Figure 2.1c, for example). Tide gauges surrounding the U.S. coastlines provide records exceeding 100 years in some locations, and the satellite altimeter record is nearing three decades in length. Recent studies have assessed the degree to which rates and accelerations estimated from these records are reflective of the long-term increase in sea level (via satellite altimetry; e.g., Fasullo and Nerem, 2018; Richter et al., 2020) and RSL (via tide gauges; e.g., Wang et al., 2021). These studies suggest that with appropriate consideration of uncertainty, observation-based extrapolations can be informative in the near term. In this report, an assessment based solely on extrapolation of the observed rates and acceleration out to 2050 is used for trajectory tracking and a comparison to the GMSL and regional scenarios. These trajectories serve as an additional line of evidence for near-term sea level rise and provide a mostly independent (observational VLM information is shared in both) comparison to the model-based scenario. To maintain a distinction between estimates arising from observations and those coming from model-derived GMSL scenarios, the observation-based assessments are referred to in this report as “extrapolations” or “trajectories” and not as “projections.” These terms are also preceded by “observation-based” whenever used.

Beyond this renewed observational focus, the inclusion of this near-term time period is motivated by the fact that for certain decision types, short time horizons and nearer-term assessments are most relevant. For the typical lifetime of buildings and infrastructure in coastal areas, for example, a 30-year planning horizon has particular relevance (e.g., Fu, 2020; Hinkel et al., 2018). Additionally, flexible adaptation pathways and solutions typically require significant lead times on upgrades or replacements of coastal structures that necessitate assessments across a range of timescales. (Haasnoot et al., 2013, 2019; Bloeman et al., 2018; Werners et al., 2021; Hall, Harvey, and Manning, 2019). Knowing whether adaptation actions are required within the next 30 years or afterwards informs decisions about initial designs, the adaptations required, and the metrics that would trigger adaptation.

2.2.2. GMSL Scenario Divergence and Tracking

After 2050, the assessments and comparisons made using the observation-based extrapolations of future sea level rise become less informative and should be made with caution. This is because uncertainty in the current estimates of rates and accelerations leads to large projected ranges and because current estimates may not be reflective of shifts or process changes that may occur in the future with additional emissions and global warming, resulting in increasing divergence between the future GMSL scenarios after 2050. During the transition from near- to long-term assessments, an understanding of when the GMSL scenarios will diverge and what drives this divergence becomes increasingly important. Two types of uncertainty are important to consider in this context: uncertainty in physical processes and uncertainty in future emissions and ensuing warming. Although there are possible alternative definitions and framings, as used in this report, *process uncertainty* (Box 2.1) is associated with how well we currently understand why sea level has changed in the past and how it will change in the future. Stated another way, how well do we understand and model the processes that will combine to impact sea level at a specific time and location in the future? This uncertainty is also reflected in the likely range of future sea level rise for a given GMSL scenario. The spread between the five GMSL rise scenarios is intended to reflect the range of potential future emissions pathways and associated warming levels that depends highly on global socioeconomic factors that have yet to unfold. This unknown future pathway leads to what is referred to here as *emissions uncertainty* (Box 2.1).

At some point in the future, the separation between GMSL rise scenarios will overtake the process uncertainty associated with individual GMSL rise scenarios. In other words, scenario dependence will emerge, and it will be possible to distinguish between the observation-based trajectories associated with two neighboring GMSL rise scenarios. In general, these time periods are important for connecting the near-term similarities between scenarios to the time period where scenarios diverge rapidly. An effort is made here to understand when divergence of the GMSL rise scenarios might occur and to link them to possible future warming and emissions pathways. This analysis then serves as the foundation for process-based monitoring that could be useful in determining the trajectory of ongoing sea level rise and, by extension, the possible future sea level rise out to 2150.

Box 2.1: Uncertainties

When assessing future changes in sea level, this report considers two main sources of uncertainty.

Process Uncertainty

An increase in emissions will cause ice-mass loss, ocean thermal expansion, and local ocean dynamic changes, but the sensitivity of these processes to these forcing changes comes with uncertainty. For example, the sensitivity of the Antarctic ice sheet is not yet fully understood, leading to a substantial uncertainty in how sea level reacts to forcing changes. Additionally, the future contributions from processes, such as changes in ocean circulation and VLM, that impact RSL change more locally have an associated uncertainty. This uncertainty in the contribution of these various processes to future RSL change is referred to in this report as *process uncertainty*.

Emissions Uncertainty

Increasing the amount of greenhouse gases (GHGs) in the atmosphere will trap more heat in the earth system. The amount of GHGs in the atmosphere determines the “forcing” of climate change and its effects, such as changes in temperature and sea level rise. Various forcing scenarios describe possible GHG emissions pathways, which range from quick emissions reduction to unmitigated future emissions. In the IPCC AR6 (IPCC, 2021a), these possible future pathways are referred to as Shared Socioeconomic Pathways (SSPs). The uncertainty in the future pathway is referred to as *emissions uncertainty*.

Uncertainties in this Report

In this report, emissions uncertainty and process uncertainty are combined to generate five sea level scenarios with GMSL target values in 2100: Low (0.3 m), Intermediate-Low (0.5 m), Intermediate (1 m), Intermediate-High (1.5 m), and High (2 m). These sea level scenarios are related to but distinct from the emissions pathway scenarios in the IPCC AR6.

Natural Variability

Next to sea level changes caused by changes in GHG forcing, many physical processes cause natural variations (e.g., ENSO). The scenarios and uncertainty ranges for each scenario and for the observation-based trajectories in this report do *not* include variations due to natural variability (the decadal scenario values are 19-year averages that remove most variability effects). Natural variability is not directly considered a source of uncertainty in the context of this report but does contribute to the uncertainty range in the observation-based extrapolations, as it can influence the estimated rates and accelerations in observational records. Natural, or non-forced, variations can also make significant contributions to sea level on a wide range of timescales. For example, along the U.S. West coast, sea levels are higher during El Niño years. When assessing sea level at a specific location and time in the future, the sea level contribution from natural variability must be combined with the scenarios and trajectories provided here.

2.2.3 Updates to the 2017 Sea Level Scenarios

In order to support decision-making efforts related to future sea level risks, past interagency efforts (Parris et al., 2012; Hall et al., 2016; Sweet et al., 2017) have defined a set of GMSL rise scenarios spanning a range from a Low scenario, consistent with no additional GMSL acceleration, to a worst-case, or high-end, Extreme scenario, judged to be at the physically plausible limits based on the scientific literature. In Sweet et al. (2017), these scenarios were developed to span a range of 21st-century GMSL rise from 0.3 m to 2.5 m. Sweet et al. (2017) built these scenarios upon the probabilistic emissions scenario–driven projections of Kopp et al. (2014). Kopp et al. (2014) combined a variety of different lines of evidence—global climate model (GCM) projections, the IPCC AR5 assessment of ice-sheet changes, and structured expert-judgment ice-sheet projections, among other sources of information—to generate distributions of future global and associated regional sea level changes consistent with low, medium, and high emissions scenarios. Sweet et al. (2017) filtered the ensemble of different future projections generated by Kopp et al. (2014) to identify those subsets consistent with 0.3 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m of 21st-century GMSL rise. These subsets constituted the six Sweet et al. (2017) GMSL scenarios. For most purposes, Sweet et al. (2017) focused on the median of each subset, although 17th and 83rd percentile levels were also reported.

This report retains the Sweet et al. (2017) scenarios (except the Extreme 2.5 m scenario, discussed below), with the principal difference being updated temporal trajectories and exceedance probabilities now based on global warming levels rather than emissions scenarios. Linking to global warming levels provides a straightforward physical link for the GMSL scenarios and establishes a connection to global temperature monitoring efforts. The updates made in this report reflect the underlying ensemble of future projections based on methods used in the IPCC AR6 (Fox-Kemper et al., 2021; Garner et al., 2021) and listed in Table A1.1. As in Sweet et al. (2017), these projections are filtered based on 21st-century GMSL rise. In other words, projected pathways that intersect the GMSL scenario target values in 2100 are retained and then used to generate the GMSL scenarios from Low to High described here.

In addition to being updated based on the latest generation of GCMs and the IPCC AR6, this set of projections incorporates multiple methods of projecting future ice-sheet changes, which are the major sources of future sea level rise and pose the biggest source of uncertainty in projecting the timing and magnitude of future possible rise amounts. For Antarctica, this includes emulators derived from two different ice-sheet model intercomparison exercises (Edwards et al., 2021; Levermann et al., 2020), as well as from a single-model study focused on the potentially high-impact but uncertain-likelihood marine ice cliff instability (MICI) mechanism (DeConto et al. 2021) and a structured expert-judgment study (Bamber et al, 2019). For Greenland, this includes a single intercomparison-derived emulator (Edwards et al., 2021) and a structured expert-judgment study (Bamber et al., 2019). There is now a broader range of both Antarctic and Greenland potential contributions, compared to Sweet et al. (2017). Whereas the high-end scenarios of Sweet et al. (2017) were all dominated by Antarctic contributions, the potential for high Greenland contributions now also adds to these high-end scenarios, and due to its proximity, also drives larger differences along U.S. coastlines.

The use of multiple methods, including methods that consider mechanisms that could substantially increase ice-sheet sensitivity under high emissions scenarios, means that the time path of the higher GMSL scenarios is more realistic than in Sweet et al. (2017), which assumed (based on the underlying Kopp et al. [2014] projections) that ice-sheet loss would accelerate at a constant rate over the remainder of the century. A result is that there is less acceleration in the higher scenarios until about 2050 and greater acceleration toward the end of this century. This has two primary implications. First, despite maintaining the same target values and having the same range between scenarios in 2100, the range covered by the scenarios is smaller in the near term than in Sweet et al. (2017). Second, the likely (17th–83rd percentile) ranges of projections consistent with each scenario before and after the 2100 time point used to define the scenarios tend to be broader than in Sweet et al. (2017).

An important change from the Sweet et al. (2017) report is the exclusion of the Extreme (2.5 m) scenario in this report. Based on the most recent scientific understanding and as discussed in the IPCC AR6, the uncertain physical processes such as ice-sheet loss that could lead to much higher increases in sea level are now viewed as less plausible in the coming decades before potentially becoming a factor toward the end of the 21st century and beyond. A GMSL increase of 2.5 m by 2100 is thus viewed as less plausible, and the associated scenario has been removed from this report. Nevertheless, the increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that potentially reach this threshold in the decades immediately following 2100 (and continue rising).

2.2.4. Observation-Based Extrapolations

As discussed above, the pathways of the updated GMSL scenarios differ from those presented in Sweet et al. (2017), and the range between the scenarios in the near term is now reduced. This report, for the first time, includes observation-based extrapolations to serve as a near-term (2020–2050) comparison for the scenarios. They can also be viewed as "trajectories" of current sea level rise. When interpreting these extrapolations, they should be considered as an additional line of evidence for near-term sea level rise alongside the model-based GMSL scenarios. They are not intended to replace the GMSL scenarios. Additionally, such observation-based extrapolations, or trajectories, can be potentially misleading if not appropriately constrained. This report makes no detailed assessment of whether the long-term rate and acceleration have emerged from the influence of natural variability in the observational record, although recent studies suggest this could be the case in some regions (Lyu et al., 2014; Richter et al., 2020; Fasullo and Nerem, 2018; Wang et al., 2021). Instead, the observation-based extrapolations are presented as computed and without interpretation after several methodological choices were made to generate extrapolations that can be compared to the scenarios and identify those scenarios that "bound" the 2050 extrapolations. These methodological choices are described briefly below.

First, the rates and accelerations are estimated from the tide-gauge records starting in 1970. Recent studies have shown a consistent acceleration in GMSL since 1970 (Dangendorf et al., 2019; Frederikse et al., 2020), and this is a primary motivator for the time period chosen. The impact of varying this start date on the regional scales relied on here was assessed and found to be negligible within a few years of 1970 (more below). This is not true, as a general statement, when using individual tide-gauge records. Second, the observation-based extrapolations are made only to 2050. Beyond that date, it is assumed that processes not fully represented in the observations could become dominant. Third, the uncertainty in the rate and acceleration associated with the influence of natural variability is accounted for as fully as possible and included in the extrapolation. Finally, the extrapolations are made for GMSL, the coastlines of CONUS, and 10 separate coastal regions around the United States and outlying islands (see Figure A1.1 for region definitions). By grouping tide gauges regionally, the influence of localized variability is reduced, and challenges associated with individual tide gauges with incomplete or short records are overcome, thus yielding more useful and narrower extrapolated ranges. These regional comparisons also fulfill the intent of providing an additional line of evidence and comparison point to the GMSL scenarios.

For each individual region, the observation-based extrapolation is performed as follows:

1. The tide gauges in the region are grouped and combined following the virtual station method (see Frederikse et al., 2020) to generate a monthly time series of RSL from 1920 to present.
2. Natural variability is partially removed through regression analysis using climate indices representing the El Niño–Southern Oscillation, Pacific Decadal Oscillation, and North Atlantic Oscillation (see Calafat et al., 2012; Hamlington et al., 2021).
3. The rate and acceleration from 1970 to present is computed, and the uncertainty on each term is assessed, accounting for the influence of remaining natural variability (see Hamlington et al., 2021) and serially correlated variability in the tide-gauge record (Bos et al., 2013, 2014).

4. The rates, accelerations, and uncertainties are used to generate an ensemble of 5,000 extrapolations with a baseline year of 2000 and extending to 2050. Median projections and a likely (17th–83rd) range are computed from this ensemble.

Following this procedure, observation-based extrapolations are obtained for GMSL, CONUS, and 8 coastal regions (Figure A1.1)—the Northeast (Maine to Virginia), the Southeast (North Carolina to the east coast of Florida), the Eastern Gulf (west coast of Florida to Mississippi), the Western Gulf (Louisiana to Texas), the Southwest (California), the Northwest (Oregon to Washington), the Hawaiian Islands, and the Caribbean. Elsewhere in the report, projections are discussed for the Pacific Islands, but due to the availability of tide-gauge data and the geographic range covered by the region, the extrapolations are conducted using only those gauges on the Hawaiian Islands. Observation-based extrapolations are also made for the southern and northern coasts of Alaska and mentioned in the text but not included in the tables below. Differential VLM heavily impacts the tide-gauge records along the southern coastline of Alaska and makes the creation of a regionally representative time series challenging. The observation-based extrapolations for Alaska are thus caveated with increased uncertainty in the underlying regional processes that heavily limit their utility as a comparison to the GMSL scenarios.

2.3. Near-Term Sea Level Change (2020–2050)

In Sweet et al. (2017), the range between the median values of the Low and High GMSL scenarios in 2020, 2030, 2040, and 2050 was 0.05 m, 0.12 m, 0.23 m, and 0.38 m, respectively. As a result of improved science and the updated framework and procedure for generating the GMSL scenarios, the time path of the scenarios—particularly the higher scenarios—is now more realistic and consistent with current process-based understanding. In this report, the range between the Low and High scenarios in 2020, 2030, 2040, and 2050 is now 0.02 m, 0.06 m, 0.15 m, and 0.28 m, respectively (Table 2.1). In other words, there is less divergence between the GMSL scenarios in this near-term time period, which reduces uncertainty in the projected amount of GMSL rise up to the year 2050. The Low scenario remains largely the same between this report and Sweet et al. (2017); this range reduction reflects a downward shift in the higher scenarios in 2050 and times prior, as discussed above. As an example, the projected value in 2050 for the High scenario in this report (~0.4 m) is the same as that for the Intermediate-High projected value in 2050 in Sweet et al. (2017). In short, while the scenarios continue to be defined by projected values of GMSL increase in 2100, it is important to note that the paths to get to these target values have changed in this report compared to the previous one.

Following the procedure outlined in Section 2.2.4, an observation-based extrapolation of GMSL is computed using the global tide-gauge reconstruction from Frederikse et al. (2020; Figure 2.2a; also see top row of Table 2.1). The extrapolated value of GMSL increase in 2050 relative to a baseline of 2000 is 0.24 m, with a likely (17th–83rd percentile) range between 0.19 m and 0.29 m. A similar extrapolation was made using GMSL data measured by satellite altimeters over 1993–2021, resulting in an estimate of 0.23 m of rise from 2000 to 2050 and in agreement with the results of the tide-gauge extrapolation. Based on the updated GMSL scenarios, the median of the 2050 observation-based extrapolation is bounded by (i.e., it falls between) the Intermediate-Low and Intermediate scenarios. The likely ranges for the Low and High scenarios do not overlap with the likely range of observation-based extrapolation in 2050, although the very likely ranges (5th–95th percentiles) do overlap. The likely range of the Intermediate-High scenario does overlap with the likely range of the observation-based extrapolation. A similar observation-based extrapolation is completed using only the tide gauges located around CONUS (Figure 2.2b), resulting in a projected increase of 0.38 m in 2050, with a likely range of 0.32 m to 0.45 m. This range for CONUS is again narrower than in Sweet et al. (2017). Similar to GMSL, this observation-based assessment is bounded by the Intermediate-Low and Intermediate scenarios in 2050.

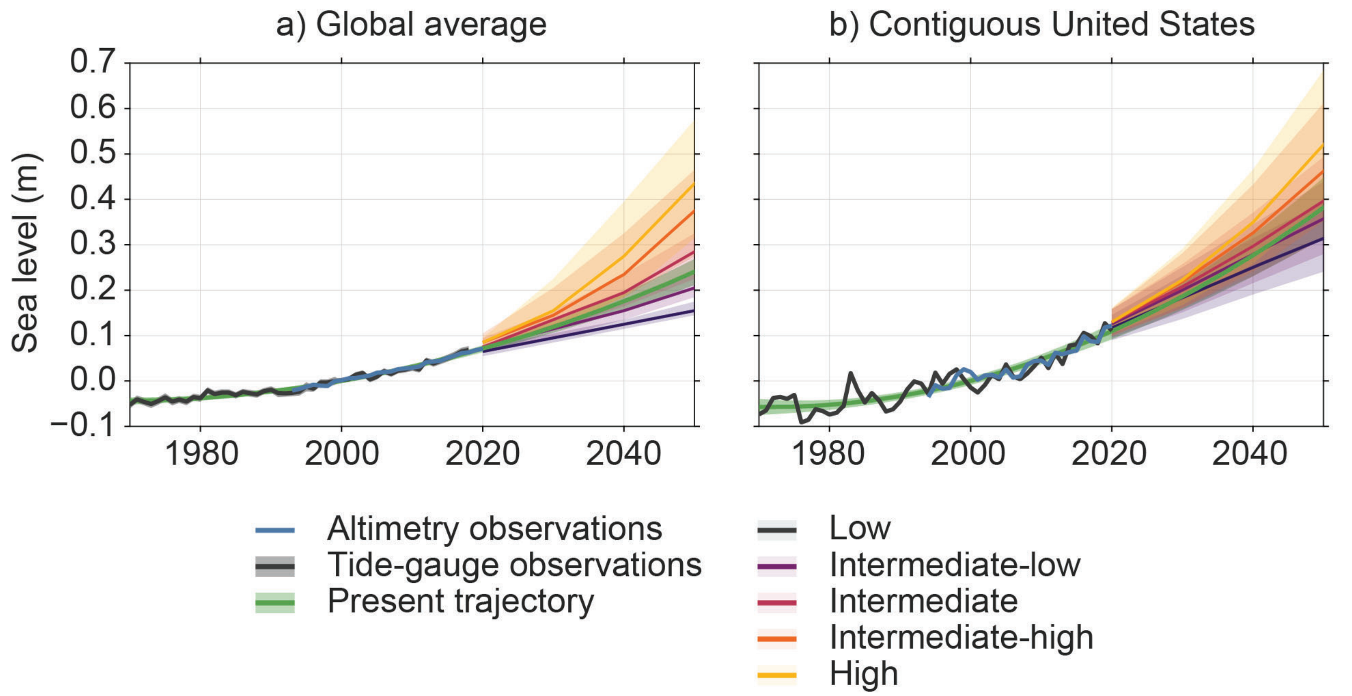

Figure 2.2: Observation-based extrapolations using tide-gauge data and five Scenarios, in meters, for a) global mean sea level and b) relative sea levels for the contiguous United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded regions 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.

As a result of the smaller region used and the increased influence of natural variability and VLM, the likely ranges in 2050 for CONUS in both the scenario projections and observation-based extrapolations are larger than those associated with the GMSL scenarios themselves. The likely range from the observation-based extrapolation does overlap with the likely ranges from both the Low and High scenarios. This is both a reflection of the larger range in the extrapolation for CONUS and the narrower range between the High and Low scenarios in this report. 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). As discussed previously, this is consistent with and a result of the improved process-based understanding and projection approach that has been incorporated in this report.

The observation-based extrapolations are also computed for 10 coastal regions of the United States. Only 8 of these regions are shown in the tables and figures below, with the coastlines of Alaska covered separately in the text. As in the global and national cases, the observation-based extrapolations are extended out to 2050. Following the procedure outlined in section 2.2.4, tide gauges within each of these regions are combined into a single time series prior to extrapolating estimated rates and accelerations. Building on the discussion in section 2.2.4, the motivation for doing these assessments regionally as opposed to at each individual tide gauge location is two-fold. First, the observation-based extrapolations are intended to serve as a comparison to the model-based GMSL scenarios. Outside the possibility of very localized VLM, the processes included in the regionalized GMSL scenarios are generally spatially coherent over the regions considered. Indeed, the selection of specific regions is driven by process-based similarities mostly associated with ocean dynamics and large-scale VLM. Grouping the tide gauges and generating regional comparisons yields a closer analog to the information contained in the scenarios. The regional averages also reduce the influence of local signals—including VLM and other natural ocean variability—that can influence extrapolations and associated ranges. Second, some of the individual tide gauges around the U.S. coastlines have records that either do not span the full time period from 1970 to 2020 or contain data gaps. Generating

Table 2.1: Observation-based extrapolations and five scenarios, in meters, for global mean sea level and relative sea level for the contiguous United States from 2020 to 2050 relative to a baseline of 2000. Median [likely ranges] are shown.

Global Mean Sea Level				
	2020	2030	2040	2050
Obs. Extrapolation	0.07 [0.06, 0.08]	0.12 [0.11, 0.13]	0.18 [0.16, 0.19]	0.24 [0.19, 0.29]
Low	0.06 [0.05, 0.07]	0.09 [0.08, 0.10]	0.12 [0.11, 0.13]	0.15 [0.14, 0.17]
Intermediate-Low	0.07 [0.06, 0.07]	0.11 [0.09, 0.12]	0.15 [0.13, 0.17]	0.20 [0.18, 0.23]
Intermediate	0.07 [0.07, 0.09]	0.13 [0.11, 0.15]	0.19 [0.16, 0.23]	0.28 [0.22, 0.32]
Intermediate-High	0.08 [0.07, 0.10]	0.14 [0.11, 0.20]	0.23 [0.18, 0.32]	0.37 [0.27, 0.46]
High	0.08 [0.07, 0.10]	0.15 [0.11, 0.22]	0.27 [0.18, 0.39]	0.43 [0.31, 0.57]
Contiguous United States				
	2020	2030	2040	2050
Obs. Extrapolation	0.11 [0.09, 0.13]	0.19 [0.16, 0.21]	0.28 [0.23, 0.32]	0.38 [0.32, 0.45]
Low	0.12 [0.09, 0.15]	0.18 [0.14, 0.23]	0.25 [0.19, 0.31]	0.31 [0.24, 0.39]
Intermediate-Low	0.13 [0.10, 0.16]	0.20 [0.15, 0.25]	0.28 [0.22, 0.34]	0.36 [0.28, 0.44]
Intermediate	0.13 [0.10, 0.16]	0.21 [0.16, 0.26]	0.30 [0.23, 0.37]	0.40 [0.31, 0.49]
Intermediate-High	0.13 [0.10, 0.16]	0.22 [0.16, 0.28]	0.33 [0.24, 0.43]	0.46 [0.35, 0.61]
High	0.13 [0.10, 0.16]	0.22 [0.17, 0.29]	0.35 [0.26, 0.47]	0.52 [0.39, 0.68]

regional time series alleviates these challenges and allows us to provide generalized comparisons and assessments about the match between observations and model-based scenarios along the U.S. coastlines. These regional comparisons then provide an additional line of evidence for the possible overall trajectory of sea level in the near term. The result is shown in Figure 2.3, with corresponding values in Table 2.2 for each of the eight regions and compared to the scenarios in each region.

The regional differences in the observation-based extrapolations and scenarios in Figure 2.3 are consistent with the current process-based understanding of sea level rise. Processes such as ocean dynamics, the GRD response to contemporary ice-mass loss (i.e., fingerprints), and coastal VLM lead to differences between the eight regions. Additionally, uncertainty ranges on the extrapolations can be bigger or smaller depending on the number of tide gauges in a particular region and the influence of natural variability on the rate and acceleration estimates. To demonstrate this regionalization, Figure 2.4 shows these regional variations of sea level in 2050 for the Intermediate-Low and Intermediate-High scenarios. In 2050, the regional variation in future sea levels does not change significantly between scenarios. Although the values increase from the Intermediate-Low scenario to the Intermediate-High scenario, the east–west difference in sea level rise is similar. Higher values for both scenarios are found along the entire East and Gulf Coasts. Subsidence leads to the highest rates along the Gulf Coast, driven by regional and local factors, such as river sediment compaction and withdrawal of subsurface fluids (Dokka, 2011; NGS, 2001; Rydlund and Densmore, 2012). Along the East Coast, subsidence is generally associated with the large-scale process of GIA, with fluid extraction being an issue in some areas (Frederikse et al., 2017; Karegar et al., 2016). Beyond VLM, many of the regional differences are driven by differences in the ocean dynamic variability. For example, the sterodynamic contribution from 2000 to 2050 in the Northeast is more than double the sterodynamic contribution in the Southwest. This regional difference is similarly reflected in the observation-based extrapolations in 2050. It should be noted that this difference arises from higher-than-global-average projections for the Northeast as opposed to lower-than-global-average projections for the Southwest, which tracks very closely to the GMSL values shown in Table 2.1.

For the observation-based extrapolations, the largest estimates of sea level rise in 2050 are found along the entire Gulf Coast (Table 2.2). The Western Gulf has the highest extrapolated values in 2050, driven by high rates of coastal subsidence in the region and consistent with the scenarios discussed above. The Northwest and Southwest coastal regions have the lowest observation-based extrapolations to 2050. For the purposes of offering a comparison to the scenarios, the scenarios that either bound or track the median of the observation-based extrapolations are provided (denoted by red text or markers in Table 2.2). Two regions track the Intermediate-Low scenario (Northeast and Hawaiian Islands), and two regions track the Intermediate scenario (Southwest and Caribbean). The Intermediate-Low to Intermediate scenarios bound the Northwest, and the Intermediate to Intermediate-High scenarios bound the Southeast and Western Gulf regions. Finally, the Intermediate-High to High scenarios bound the Eastern Gulf region. With only the exceptions of the low-end scenarios in the Southwest and Eastern Gulf, the likely ranges from the observation-based extrapolations have at least some overlap with the likely ranges of all the scenarios within a given region. This is due to a combination of the larger uncertainty on the observation-based assessments at these regional levels for an individual scenario and the narrower ranges between the median values of each GMSL scenario found in this report compared to Sweet et al. (2017). While not shown in Table 2.2, the observation-based extrapolation for the northern coast of Alaska in 2050 (median value of 0.27 cm) is bracketed by the Intermediate and Intermediate-High scenarios. The extrapolation of the southern coast of Alaska leads to a large RSL decrease in 2050 and is inconsistent with the scenario median values. As mentioned above, this is a result of challenges in generating a representative tide-gauge time series to use in the extrapolation.

As a note on the interpretation of the results provided in this near-term section, the regional comparisons between the observation-based extrapolations and scenarios need to be considered in the context of the global comparison in Figure 2.2. The regional scenarios are intrinsically linked to their associated GMSL target values in 2100. In an ideal framework that perfectly represented the regionalization of these GMSL scenarios and the relevant regional processes, separate comparisons on a regional level would be unnecessary. In other words, all regions and locations would track the same GMSL scenario. Since this is not the case, if a particular region deviates from the others, it would be an indication that either the observation-based extrapolation for that region is biased high or low or that the framework used to generate the regionalization of the GMSL scenarios is not adequately representing the contribution of a regional process. Since the observed GMSL trajectory is near the Intermediate-Low scenario, as shown here, based on the current understanding of the processes driving regional RSL, it is not expected that a particular region would track a much higher scenario. These regional comparisons during the near-term time period then serve two potential purposes: 1) they provide an additional line of evidence along with the GMSL and CONUS comparisons for the near-term trajectory of sea level rise, and 2) they can serve to identify cases when the contributions of regional processes may be tracking differently than represented by the regionalization of the GMSL scenarios.

As a general assessment of these two purposes, the likely ranges of all but one of the regions are either bounded on one side by the Intermediate scenario or tracks a scenario neighboring the Intermediate scenario, showing some level of consistency with the GMSL and CONUS comparisons. This provides additional confidence in the narrower range (when compared to Sweet et al., 2017) of sea level rise at the regional level out to 2050 presented in this report. The Eastern Gulf is the only region bounded by the High scenario. The high observation-based extrapolation for the Eastern Gulf should be interpreted with caution, as it does not necessarily mean a higher scenario is applicable compared to other regions. As a possible explanation, unresolved natural ocean variability in the observational record could lead to an observation-based extrapolation that is biased high. Such variability would need to be low-frequency—or long period—to significantly impact a rate and acceleration estimated in a 50-year record. For all regions considered here, it is likely that natural variability still contributes to the median observation-based extrapolation, and as seen in Figure 2.1, this variability has a substantial impact on the coastlines of the United States. This influence of natural variability on rates and accelerations is captured to the extent possible in the likely ranges of the observation-based extrapolations, and these likely ranges should be considered in tandem with the median values when assessing near-term trajectories. Beyond the possible influence of natural variability, there may also be a mismatch in the process representation between the observations and regionalized, model-based GMSL scenarios that leads to a projection that is too low in the latter. One possibility is non-linear or unresolved VLM in the region. The regionalized GMSL scenarios consider only long-term linear rates of VLM, while the observation-based extrapolations could represent a shift in the rate of VLM in the estimated acceleration.

An explanation of regional differences between observation-based extrapolations and model-based scenarios requires additional investigation, likely on a tide gauge-by-tide gauge basis. As a first step in this direction, the range between Low and High scenarios at each individual tide gauge (considering only the tide gauges with at least 30 years of data—102 of the full set of 121) is provided in Figure A1.2a, and the departure between the observation-based extrapolation and Intermediate scenario at each individual tide gauge is shown in Figure A1.2b. These figures show that the range between Low and High scenarios is generally lower than 20 cm in 2050 at the local level and that most observation-based extrapolations are within 15 cm of the Intermediate scenario in 2050. Of the 102 tide gauges used in this report, 65 have observation-based extrapolations that fall within the narrower Low to High ranges in 2050, and 80 of these 102 are within 15 cm of the Intermediate scenario. The majority of those falling below the Low scenario are found in the Northwest and southern Alaska regions, and the majority of those exceeding the High scenario are found in the two Gulf regions. This supports the regional comparisons shown in Figure 2.3 and Table 2.2 while also conveying that there is general agreement and consistency between the ranges of the observation-based extrapolations and regionalized GMSL scenarios even on a local, tide gauge-by-tide gauge level. A more definitive assessment of why some regions track higher (e.g., Eastern Gulf) or lower relative to others requires further analysis that should be done with consideration of the associated uncertainty and ranges.

As a general concluding statement on this near-term section, the link between the regional and global scenarios needs to be considered when drawing conclusions at the regional level based on the observation-based extrapolations. In practice, regionally identifying the scenario that upper-bounds the observation-based extrapolation at year 2050 (Table 2.2) may help compensate for potential interannual variability when projecting sea level for a particular location. The associated uncertainties in the approaches adopted here do emphasize the importance of ongoing monitoring using the observations and the need to update trajectories. As records continue to lengthen, likely ranges on near-term assessments will narrow. Additionally, satellite altimeter records are reaching sufficient length to be important in such monitoring. As a final note, the same framework used for extrapolating the observations forward can also be used to assess the increases—or offsets—observed over different recent time periods. These offsets are useful for adjusting baselines of the scenarios and are provided for each region in Table A1.2.

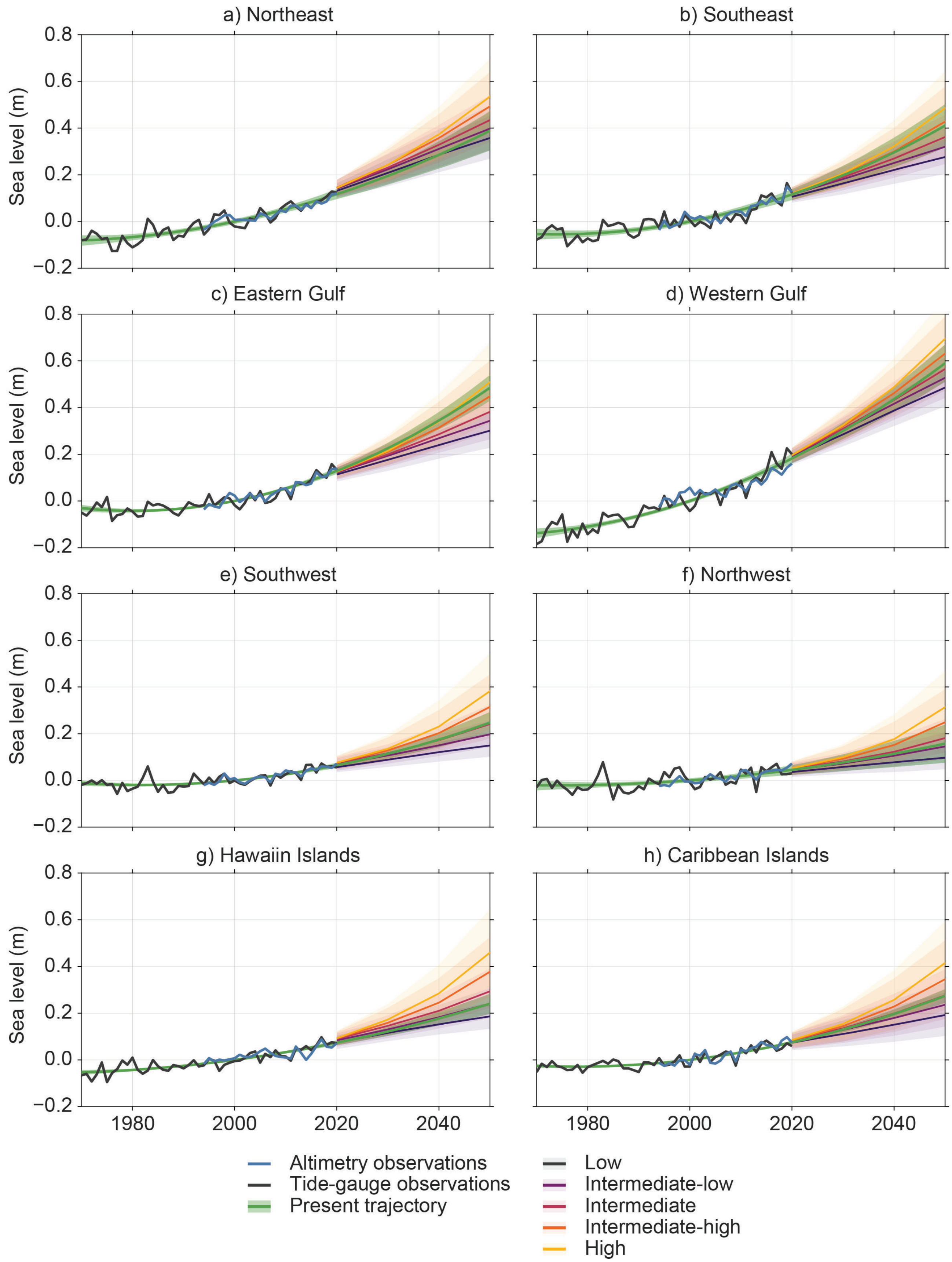

Figure 2.3: Observation-based extrapolations and five regionalized global mean sea level scenario projections, in meters, of relative sea levels for eight coastal regions around the United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded 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.

Table 2.2: Observation-based extrapolation and regionalized global mean sea level scenario–based estimates, in meters, of relative sea level in 2050 relative to a baseline of 2000 for eight coastal regions of the United States. Median [likely ranges] are shown. The two scenarios that bound the median observation-based extrapolation are also provided for each region and indicated by red dividing lines. In regions where the observation-based extrapolation is the same as a particular scenario, the scenario is indicated in red text and the bounding scenarios can be assumed to be the next higher or lower scenario (e.g., the Intermediate bounds the Northeast's observation-based extrapolation).

Observation Extrapolations	Low	Intermediate-Low	Intermediate	Intermediate-High	High	Median Bounding Scenarios
Northeast						
0.40 [0.30, 0.47]	0.36 [0.27, 0.45]	0.40 [0.31, 0.49]	0.43 [0.34, 0.54]	0.49 [0.38, 0.64]	0.54 [0.40, 0.69]	Int-Low
Southeast						
0.41 [0.32, 0.50]	0.28 [0.20, 0.35]	0.32 [0.25, 0.40]	0.36 [0.28, 0.46]	0.43 [0.32, 0.58]	0.49 [0.35, 0.64]	Int–Int-High
Eastern Gulf						
0.48 [0.43, 0.54]	0.30 [0.22, 0.38]	0.34 [0.26, 0.42]	0.38 [0.30, 0.48]	0.45 [0.34, 0.60]	0.51 [0.38, 0.68]	Int-High–High
Western Gulf						
0.59 [0.51,0.67]	0.49 [0.41, 0.57]	0.53 [0.44, 0.62]	0.57 [0.47, 0.67]	0.63 [0.51, 0.79]	0.69 [0.56, 0.87]	Int–Int-High
Southwest						
0.24 [0.20,0.29]	0.15 [0.10, 0.20]	0.20 [0.14, 0.26]	0.24 [0.18, 0.32]	0.31 [0.22, 0.45]	0.38 [0.26, 0.54]	Intermediate
Northwest						
0.16 [0.08, 0.24]	0.10 [0.05, 0.15]	0.15 [0.09, 0.20]	0.18 [0.12, 0.26]	0.25 [0.15, 0.39]	0.31 [0.19, 0.47]	Int-Low–Int
Hawaiian Islands						
0.24 [0.20, 0.28]	0.19 [0.13, 0.24]	0.24 [0.18, 0.31]	0.29 [0.22, 0.39]	0.38 [0.27, 0.53]	0.46 [0.31, 0.64]	Int-Low
Caribbean						
0.28 [0.24, 0.31]	0.19 [0.10, 0.29]	0.24 [0.14, 0.33]	0.28 [0.18, 0.39]	0.35 [0.22, 0.51]	0.42 [0.27, 0.59]	Intermediate

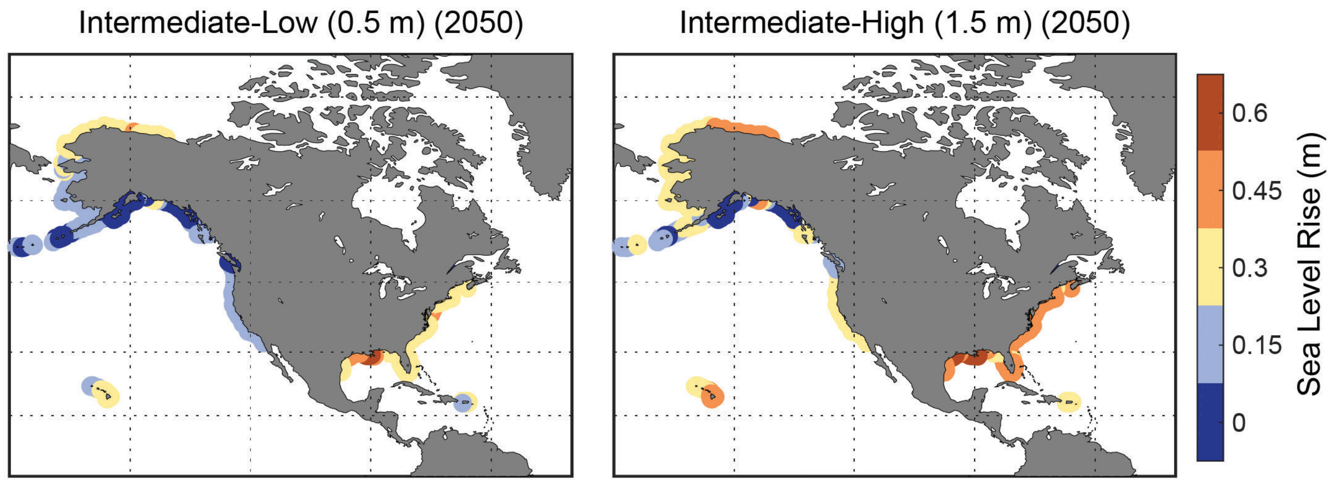

Figure 2.4: Relative sea level rise, in meters, in 2050 for the a) Intermediate-Low and b) Intermediate-High scenarios relative to the year 2000.

2.4. Long-Term Sea Level Change (2050–2150)

The updated GMSL values in 2050, 2100, and 2150 relative to a 2000 baseline are shown for each of the five scenarios in Table 2.3. Note that the current National Tidal Datum Epoch (NTDE) has a baseline of 1992 (midpoint of the 1983–2001 epoch). Comparisons between the projections here and calculations tied to the NTDE will require an adjustment between 1992 and 2000 (see Table A1.2 for offsets). Beyond the middle of this century, the differences between sea level scenarios become increasingly large, and the differences between sea level scenarios become more closely associated with differences in potential future GHG emissions pathways and associated global warming. Although the GMSL scenarios (names and their values) are the same at 2100 for this report and for Sweet et al. (2017), there is a narrowing in the range covered by the scenarios in both 2050 and 2150, driven primarily by a reduction in the values at those two target dates associated with the Intermediate-High and High scenarios in this report. As previously discussed, in 2050, the updated median value for the High scenario is similar to the median value for the Intermediate-High scenario from Sweet et al. (2017). This is not the case in 2150, however, where the separation between the scenarios remains similar to Sweet et al. (2017). Because of this, and because the scenarios are defined by the 2100 values, the same scenario naming is used in this report as in Sweet et al. (2017), with the notable exception of the omission of the Extreme (2.5 m) scenario.

In the very long term (over millennia), the magnitude of global mean sea level rise closely relates to the magnitude of global warming; however, over the timescales of decades and centuries, the magnitude of global warming more closely relates to the *rate* of GMSL rise. It is thus not possible to tie specific levels of warming in general to amounts of sea level rise, but it is possible to relate specific levels of warming *at specific points in time* (e.g., at the end of the century) to different levels of sea level rise. Thus, based on the IPCC AR6 (§9.6.3.4 in Fox-Kemper et al., 2021), it is possible to connect the GMSL rise scenarios to different levels

Table 2.3: Global mean sea level and contiguous United States scenarios, in meters, relative to a 2000 baseline.

Global Mean Sea Level				Contiguous United States			
	2050	2100	2150		2050	2100	2150
Low	0.15	0.3	0.4	Low	0.31	0.6	0.8
Intermediate-Low	0.20	0.5	0.8	Intermediate-Low	0.36	0.7	1.2
Intermediate	0.28	1.0	1.9	Intermediate	0.40	1.2	2.2
Intermediate-High	0.37	1.5	2.7	Intermediate-High	0.46	1.7	2.8
High	0.43	2.0	3.7	High	0.52	2.2	3.9

of future global mean surface air temperature occurring at the end of the century. The median GMSL projection for 2100 for a world with global mean surface air temperature in 2081–2100 averaging 2.0°C above 1850–1900 levels is about 0.5 m (*likely* range of 0.4–0.7 m; Table 2.4), consistent with the Intermediate-Low scenario. The median GMSL projection for a world with global mean surface air temperature in 2081–2100 averaging 4.0°C higher is about 0.7 m (*likely* range of 0.6–0.9 m), between the Intermediate-Low and Intermediate scenarios, with the upper end of the *likely* range approaching the Intermediate scenario. These two scenarios are also consistent with the current observed acceleration, which, if extrapolated, would yield about 0.24 m of GMSL rise by 2050 and 0.69 m by 2100.

However, these projections include only physical processes in which there is at least *medium confidence* in the current scientific understanding. As described in the IPCC AR6 (Box 9.4 in Fox-Kemper et al., 2021), the largest potential contributions to long-term GMSL rise come from ice-sheet processes in which there is currently *low confidence*. Projections that include the magnitudes, rates, and thresholds associated with these ice-sheet processes, particularly under higher emissions futures, could give rise to GMSL rise values well above the *likely* range. Pathways to such unknown-likelihood, high-impact outcomes—“potential surprises” in the words of NCA4 (Kopp et al., 2017)—include

- earlier-than-projected ice-shelf disintegration in Antarctica,
- abrupt, widespread onset of marine ice-sheet instability and/or marine ice-cliff instability in Antarctica, and
- faster-than-projected changes in surface-mass balance on Greenland, potentially associated with changes in atmospheric circulation, cloud processes, or albedo changes.

These outcomes are represented in the IPCC projections (§9.6.3 in Fox-Kemper et al., 2021) through the inclusion of an illustrative very high emissions (SSP5-8.5), *low-confidence* projection range, the 83rd percentile of which for 2100 extends to 1.6 m (modestly above the Intermediate-High scenario) and the 95th percentile of which extends to 2.3 m (above the High scenario). In 2150, the 83rd and 95th percentiles of this *low-confidence* scenario are 4.8 and 5.4 m, respectively. Because these outcomes are based on processes poorly represented in climate and ice-sheet models, the IPCC assessment of these processes incorporates information from a structured expert-judgement study (Bamber et al., 2019) and a single Antarctic ice-sheet modeling study that explicitly incorporates ice-shelf hydrofracturing and ice-cliff collapse mechanisms (DeConto et al., 2021). (See §9.6.3.2, §9.6.3.3, and Box 9.4 of Fox-Kemper et al., 2021, for further discussion.)

To connect this to the scenarios provided here, the Intermediate-High and High scenarios represent potential futures in which these deeply uncertain ice-sheet processes play important roles in the late 21st century and beyond. After 2100, these processes may also play important roles in the Intermediate scenario. These trajectories are highly emissions-dependent. For example, in an illustrative low emissions (SSP1-2.6) future, in which the world achieves net-zero carbon dioxide emissions by the 2070s and net-negative emissions thereafter, the corresponding AR6 l*ow-confidence* ranges in 2100 extend to 0.8 m at the 83rd percentile (between the Intermediate-Low and Intermediate scenarios) and 1.1 m at the 95th percentile (modestly above the Intermediate scenario), reaching 1.3 m (between the Intermediate-Low and Intermediate scenarios) and 1.9 m (consistent with the Intermediate scenario), respectively, in 2150. Thus, in a low emissions future, there is little evidence to support the plausibility of GMSL projections substantially higher than the median Intermediate scenario.

These warming levels are further compared to the five scenarios in this report by assessing the probability that the given GMSL value in 2100 will be exceeded for a particular warming level (Table 2.4). At all warming levels, there is at least a 92% chance of *exceeding* the Low scenario in 2100. The probability for exceeding the Intermediate-Low (0.5 m) scenario drops for all warming levels when compared to the probability for exceeding the Low scenario. For the Intermediate, Intermediate-High, and High scenarios, the probability drops off at each warming level. Consistent with the framing of the five scenarios in this report, greater warming and higher emissions are generally needed to arrive at the Intermediate through High scenarios in 2100.

Table 2.4: IPCC warming level–based global mean sea level projections. Global mean surface air temperature anomalies are projected for years 2081–2100 relative to the 1850–1900 climatology. Sea level anomalies are relative to a 2005 baseline (adapted from Fox-Kemper et al., 2021). The probabilities are *imprecise probabilities*, representing a consensus among all projection methods applied. For imprecise probabilities >50%, all methods agree that the probability of the outcome stated is at least that value; for imprecise probabilities <50%, all methods agree that the probability of the outcome stated is *less than or equal to* the value stated.

Global Mean Surface Air Temperature 2081–2100	1.5°C	2.0°C	3.0°C	4.0°C	5.0°C	Unknown Likelihood, High Impact – Low Emissions	Unknown Likelihood, High Impact – Very High Emissions
Closest Emissions Scenario–Based GMSL Projection	Low (SSP1-2.6)	Low (SSP1-2.6) to Intermediate (SSP2-4.5)	Intermediate (SSP2-4.5) to High (SSP3-7.0)	High (SSP3-7.0)	Very High (SSP5-8.5)	Low (SSP1-2.6), *Low Confidence* processes	Very High (SSP5-8.5), *Low Confidence* processes
Total (2050)	0.18 (0.16–0.24)	0.20 (0.17–0.26)	0.21 (0.18–0.27)	0.22 (0.19–0.28)	0.25 (0.22–0.31)	0.20 (0.16–0.31)	0.24 (0.20–0.40)
Total (2100)	0.44 (0.34–0.59)	0.51 (0.40–0.69)	0.61 (0.50–0.81)	0.70 (0.58–0.92)	0.81 (0.69–1.05)	0.45 (0.32–0.79)	0.88 (0.63–1.60)
Bounding Median Scenarios in 2100	Low to Intermediate-Low	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Low to Intermediate-Low	Intermediate-Low to Intermediate
Probability > Low (0.3 m) in 2100	92%	98%	>99%	>99%	>99%	89%	>99%
Probability > Int.-Low (0.5 m) in 2100	37%	50%	82%	97%	>99%	49%	96%
Probability > Int. (1.0 m) in 2100	<1%	2%	5%	10%	23%	7%	49%
Probability > Int.-High (1.5 m) in 2100	<1%	<1%	<1%	1%	2%	1%	20%
Probability > High (2.0 m) in 2100	<1%	<1%	<1%	<1%	< %	<1%	8%

The median regional scenario values in 2100 and 2150 for the eight coastal regions discussed in Section 2.3 are provided in Table 2.5. The values in 2100 for each region differ from the GMSL value used to define a given scenario due to the combination of regionally relevant factors that are discussed in Section 2.1. Similar to the near term, the highest values across all scenarios are found in the Western Gulf region, followed by the Eastern Gulf. These high values are heavily driven by the high rates of subsidence in the region. For all but two regions (Southwest and Northwest), the projected values exceed the GMSL values associated with a particular scenario. The values for each scenario in the Southwest region correspond closely to the GMSL values, which is consistent with the agreement seen between the observation-based extrapolations in 2050 for the global and regional case discussed in Section 2.3. To further understand the regional variability for a given scenario, Figure 2.5 shows the regional departure from the GMSL value for each scenario in 2100. In other words, the provided maps display the amount that needs to be added to the global value to get the associated regional value for a given scenario. The regional pattern is similar in each case. The Eastern Gulf and Western Gulf regions are consistently much higher than the global value, and the southern coast of Alaska is much lower across all scenarios. In the highest scenarios, the Northeast, Southeast, Northwest, and Southwest regions are near the global values, although there is a larger east–west separation in the lower scenarios. In these lower scenarios, the higher projections for the Northeast, when compared to the Southwest, are a result of both VLM and ocean circulation changes along the U.S. East Coast. In the higher scenarios, the contributions from the ice sheets dominate and lead to less separation between the U.S. East and West Coasts.

Table 2.5: Scenarios of relative sea level, in meters, for eight coastal regions of the United States in 2100 and 2150 relative to a baseline of 2000. Median values are shown.

Region	Low	Intermediate-Low	Intermediate	Intermediate-High	High
Northeast					
2100	0.6	0.8	1.3	1.6	2.1
2150	0.9	1.3	2.3	2.7	3.7
Southeast					
2100	0.5	0.7	1.1	1.6	2.1
2150	0.7	1.1	2.1	2.7	3.7
Eastern Gulf					
2100	0.6	0.8	1.2	1.7	2.2
2150	0.8	1.2	2.2	2.8	3.9
Western Gulf					
2100	0.9	1.1	1.6	2.1	2.6
2150	1.3	1.7	2.8	3.4	4.5
Southwest					
2100	0.3	0.5	1.0	1.5	2.0
2150	0.4	0.8	1.9	2.6	3.7
Northwest					
2100	0.2	0.4	0.8	1.3	1.8
2150	0.3	0.7	1.6	2.3	3.3
Pacific Islands					
2100	0.4	0.6	1.1	1.7	2.3
2150	0.6	1.0	2.2	2.9	4.2
Caribbean					
2100	0.4	0.6	1.0	1.5	2.1
2150	0.5	0.9	2.0	2.6	3.7

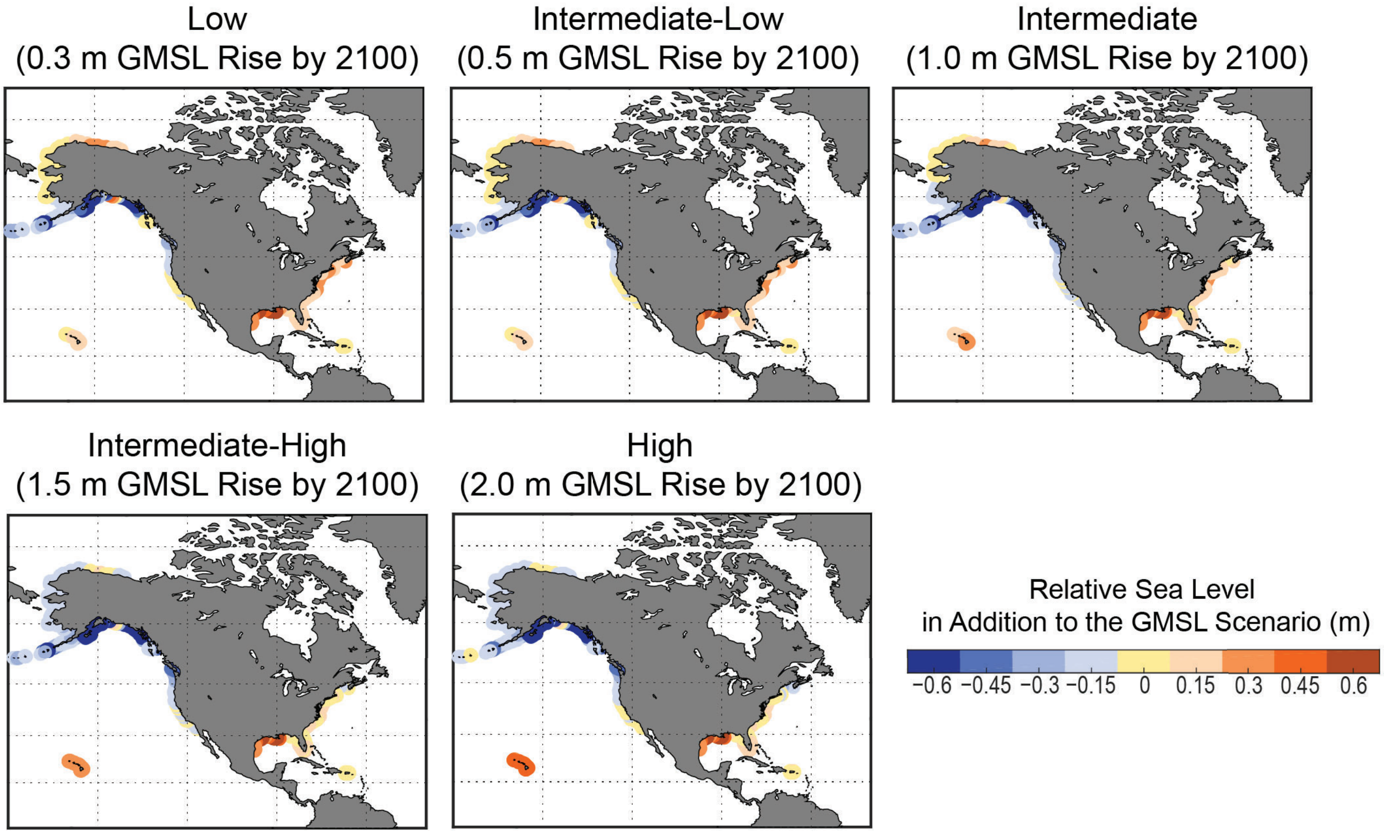

Figure 2.5: Regional deviations of relative sea level from the global mean sea level (GMSL; in meters) value for each scenario in 2100. To obtain the regional projection in 2100 for each scenario, the mapped values must be added to the GMSL value for the associated scenario.

2.5. Scenario Divergence and Tracking

In this report, for the first time, a specific focus is given to the near-term time period (2020–2050). During this window, observations can provide useful information on the trajectory of sea level rise on global and regional scales and serve as a comparison to the model-based GMSL scenarios. Prior to 2050, there is relatively small process uncertainty and little sensitivity to different emissions trajectories, and there is reduced spread between the scenarios in this report compared to Sweet et al. (2017). Connected to this reduced spread, the likely ranges of the revised GMSL scenarios presented here remain overlapping after 2050, whereas the Sweet et al. (2017) scenarios do not overlap after about 2040. In other words, in this report, the process uncertainty continues to exceed the GMSL scenario divergence past the near-term time period. Until the divergence exceeds the range for a given scenario, it will not be possible to determine when higher-end GMSL scenarios will unambiguously emerge from the potential range of the lower-end GMSL scenarios for decades to come. In this report, the time periods (or "gates") when the scenarios become separable are estimated. Different considerations for determining these gates must be made before and after the near-term time period, when the observations are most useful. It should be noted that the gates presented here are based solely on the GMSL differences between scenarios. Regionally, the timing of these gates may be different due to uncertainty in the contributing regional processes. Additionally, other lines of evidence including monitoring of individual processes or emissions trajectories could allow for distinguishing between the scenarios earlier than the gates provided here.

In Figure 2.6, the time pathways of the five GMSL scenarios from 2020 to 2100 are shown, and the gates at which the likely ranges diverge from a particular trajectory or scenario are determined. In Figure 2.6a, the divergence relative to the observation-based GMSL extrapolation is assessed. Note: the GMSL observation-based extrapolation is extended only to 2100 here for the purposes of this divergence assessment. For the Low and High scenarios, the likely ranges separate prior to 2060, with the Intermediate-High scenario separating after 2060. On the other hand, the Intermediate-Low and Intermediate scenarios do not diverge from the extrapolated observation-based trajectory until after 2080. Consistent with the discussion in Section 2.3, if the processes driving sea level rise are assumed to remain similar for the next three decades, the Intermediate-Low and Intermediate scenarios provide useful bounds on GMSL rise for the near-term time period.

In the decades beyond 2050, however, the more uncertain processes described in Section 2.4 could become a factor and the observation-based trajectory becomes less informative. Instead of assessing the divergence relative to this trajectory, the separation gates relative to the Intermediate scenario are shown in Figure 2.6b. In this case, the Intermediate-High and High scenarios will not diverge from the Intermediate scenario until after 2070 and 2060, respectively. Only the Low scenario diverges from the Intermediate scenario prior to 2050. Although not depicted in Figure 2.6, the higher scenarios also start to overlap again after 2100; for example, GMSL rise consistent with the Intermediate scenario in 2100 (1.0 m) does not rule out GMSL rise consistent with the Intermediate-High scenario by 2150. In tying the two different gate assessments together, even though the Intermediate scenario tracks near the current observation-based trajectory, it will not be possible to statistically distinguish between the Intermediate scenario and the two higher scenarios for decades to come. This also provides important context and caution if attempting to use the observations directly to infer future sea level rise beyond the near-term time period.

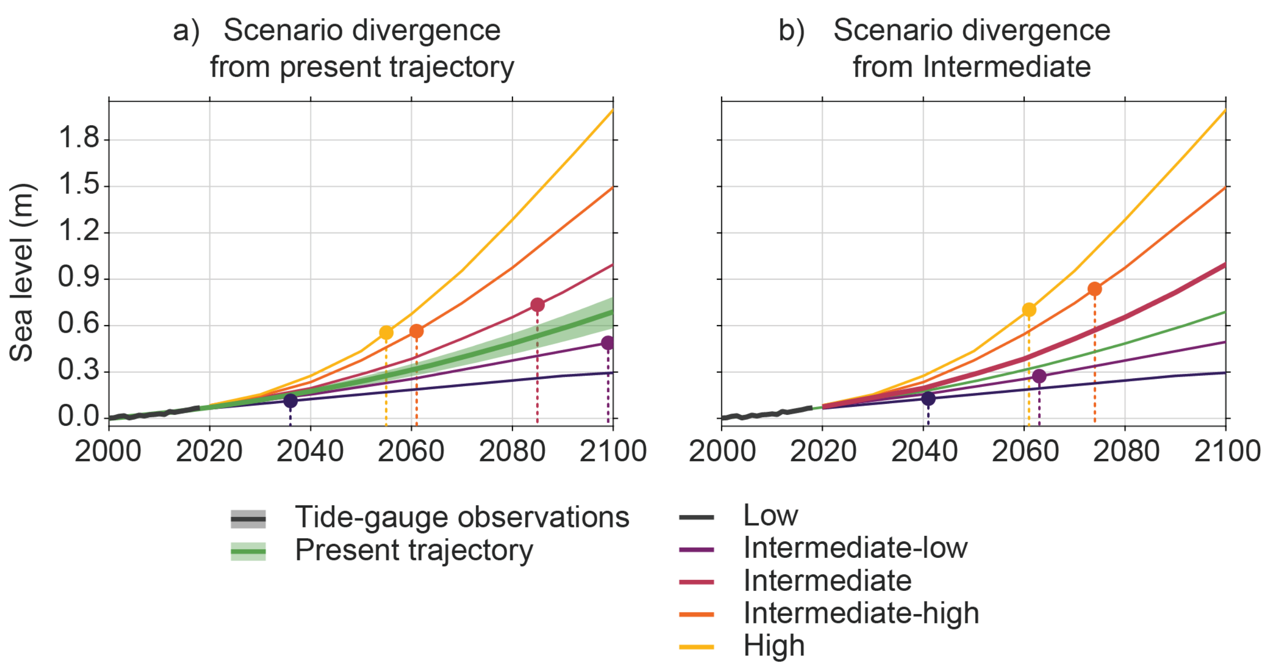

Figure 2.6: Divergence of global mean sea level (GMSL) trajectory and scenarios. The time series shows the observation-based GMSL trajectory and the five GMSL scenarios from 2000 to 2100. The dots denote where each scenario significantly (2 sigma) deviates from the a) observation-based trajectory and from the b) Intermediate scenario.

To explore this further, the proportions of the IPCC AR6 sea level projections contributing to each GMSL rise scenario are shown in Figure 2.7, with contributing emissions pathways specified. As an example interpretation of this figure, the Low scenario generally requires a low emissions pathway, while the Intermediate-Low scenario arises from low, intermediate, and high emissions pathways. Pathways consistent with the Intermediate scenario include low emissions trajectories but are mostly related to high emissions scenarios. In fact, the Intermediate, Intermediate-High, and High scenarios are all heavily driven by high emissions scenarios, and differences between these scenarios are associated predominantly with the possible role and contributions of the low-confidence ice-sheet processes described in section 2.4. The other processes that cause future sea level change have similar contributions across these scenarios. In other words, sterodynamic sea level change is similar for the Intermediate, Intermediate-High, and High scenarios.

These estimates provide a link between the emissions trajectories in the near term and the possible scenario for GMSL rise in the long term. When coupled with the gating assessment in Figure 2.6, these estimates hold particular relevance for assessing the pathway of sea level rise and determining which long-term scenarios are then possible or even likely. As a way of connecting the elements of the report, the time period where the GMSL scenarios begin to diverge can be put in the context of the analysis done in both the near-term and long-term sections. The likely ranges of the Low and Intermediate-Low versus Intermediate scenarios separate at about 2040 and 2065, respectively. The observation-based extrapolations of global GMSL rise have a relatively narrow range out to this time horizon and can therefore play a role in determining whether a particular low-end trajectory or scenario is more or less likely to be exceeded in the coming decades. As shown in Figure 2.7, the Low scenario depends very heavily on a low emissions pathway on any time horizon. Monitoring using observations of both sea level and emissions can be useful for evaluating the likelihood of the Low scenario, both in the near term and long term.

On the other hand, the separations of the likely ranges for the Intermediate to Intermediate-High and Intermediate to High scenarios do not occur until after 2060 and 2070, respectively. The values at the end of the 21st century and beyond for these scenarios can arise under a variety of different emissions pathways, although higher scenarios are predominantly linked to higher emissions, as expected. To state it another way, the near-term trajectories discussed in Section 2.3 do not currently inform the likelihood of a given scenario occurring in 2100 or 2150. However, the observations can provide useful monitoring as the windows of separation (gates) for a different scenario approach in the future. On these global scales, process-based monitoring of the ice sheets, for example, can play an important role, as the higher scenarios (Intermediate to High) are closely linked to the potential for ice-sheet changes. Additionally, a link between the scenarios in 2100–2150, emissions pathways, and warming levels has been established here. Ongoing and continuous monitoring of both global temperatures[9] and emissions[10] will aid in determining the possible trajectory of future GMSL rise. It should be noted that while the windows provided in Figure 2.6 would be different on the national or regional level, the scenarios for a given location are still closely linked to emissions and warming, and the monitoring discussion above is still relevant.

Finally, regardless of future emissions pathways, GMSL rise will continue past 2150. The amount of “committed” rise can be assessed based on historical comparisons, modeling, and the current process-based understanding of GMSL rise. This committed rise is the amount of total sea level rise that will likely occur for a given warming level. For higher warming levels, the ranges of committed sea level are wide, but the possible values are large in magnitude. Even for a relatively low warming level of 1.5°C, the committed sea level over the next 2000 years still ranges between about 2 m and 3 m. For 2°C, the upper range increases to 6 m (IPCC, 2021a). Although the focus of this report is on the time period between 2020 and 2150, it does reinforce the “when, not if” framing provided in Section 1.

[9] https://climate.nasa.gov/vital-signs/global-temperature/

[10] https://gml.noaa.gov/ccgg/trends/

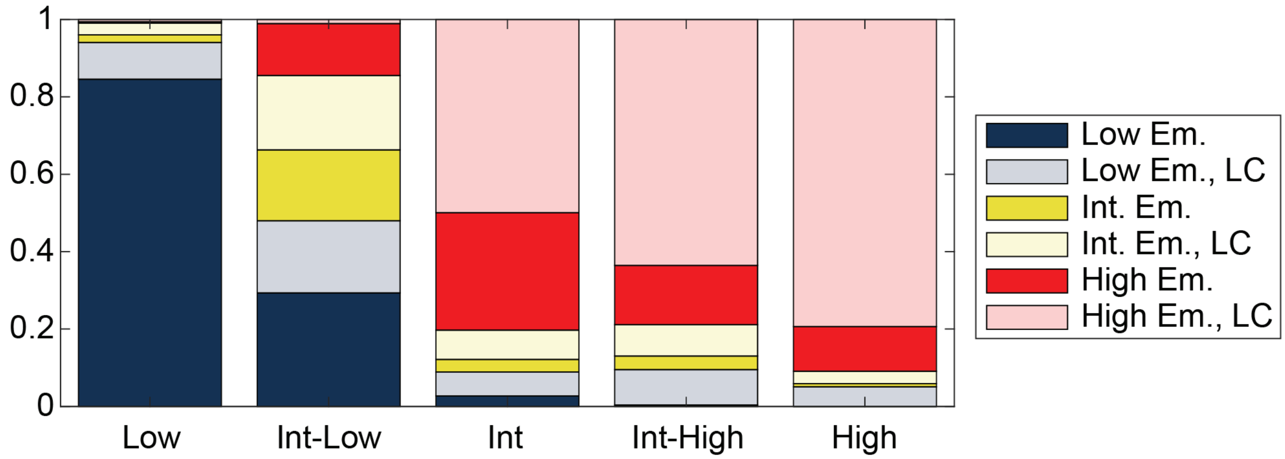

Figure 2.7: Proportions of the contributions from different IPCC AR6 sea level trajectories to each of the five global mean sea level (GMSL) rise scenarios used in this report: Low, Intermediate-Low, Intermediate, Intermediate-High, and High. The IPCC AR6 trajectories are Low Emissions; Low Emissions, 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.