Communicating projection uncertainty and ambiguity in sea-level assessment

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Abstract

Projections of future sea-level change are characterized by both quantifiable uncertainty and by ambiguity. Both types of uncertainty are relevant to users of sea-level projections, particularly those making long-term investment and planning decisions with multigenerational consequences. Communicating information about both types is thus a central challenge faced by scientists who generate sea-level projections to support decision-making. Diverse approaches to communicating uncertainty in future sea-level projections have been taken over the last several decades, but the literature evaluating these approaches is limited and not systematic. Here, we review how the Intergovernmental Panel on Climate Change (IPCC) has approached uncertainty in sealevel projections in past assessment cycles and how this information has been interpreted by national and subnational assessments, as well as alternative approaches used by recent US subnational assessments. The evidence reviewed here generally supports the explicit approach to communicating both types of uncertainty adopted by the IPCC Sixth Assessment Report (AR6).

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Projections of future sea-level change are characterized by both quantifiable uncertainty and by ambiguity. Both types of uncertainty are relevant to users of sea-level projections, particularly those making long-term investment and planning decisions with multigenerational consequences. Communicating information about both types is thus a central challenge faced by scientists who generate sea-level projections to support decision-making. Diverse approaches to communicating uncertainty in future sea-level projections have been taken over the last several decades, but the literature evaluating these approaches is limited and not systematic. Here, we review how the Intergovernmental Panel on Climate Change (IPCC) has approached uncertainty in sea-level projections in past assessment cycles and how this information has been interpreted by national and subnational assessments, as well as alternative approaches used by recent US subnational assessments. The evidence reviewed here generally supports the explicit approach to communicating both types of uncertainty adopted by the IPCC Sixth Assessment Report (AR6).

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Projections of future sea-level change are characterized by two qualitatively different types of uncertainty: quantifiable uncertainty, which can be represented by single, well-defined probability distributions, and ambiguity, which cannot be. Ambiguity is associated with disagreement in probability distributions estimated using alternative approaches and arises in situations in which reasonable analysts can interpret a common set of facts in highly divergent ways. For example, in figures 1a and 1b, quantifiable uncertainty is reflected in individual probability distributions of projected 21st century sea level change, while ambiguity is reflected in the divergence among the several alternative distributions shown. Ambiguity is lower in sea-level projections extexnding only a few decades into the future and under lower emissions scenarios, and higher in the longer term and under higher emissions scenarios [1,2]. The sources of ambiguity in sea-level projections include process-level structural uncertainty, cascades of connected consequences, and other difficult to quantify aspects, particularly involving ice sheets and their interactions with other components of the climate system. Ambiguity poses a challenge for decision frameworks, such as benefit-cost analysis, that presume the existence of well-defined distributions. For risk and ambiguity averse decision makers with substantial value at stake, ambiguity may require the application of robust decision making approaches, such as the development of "adaptation pathways" that begin with low-regret options and identify contingencies to be followed adaptively as various socioenvironmental thresholds are neared [3–5].

Scientific assessment reports are important documents linking climate science researchers and policymakers [6]. Different ways of communicating quantifiable uncertainty and ambiguity in such reports can lead to different interpretations by policymakers and thus, potentially, to different policy outcomes. For example, over-emphasis on quantifiable uncertainty might lead to neglect of ambiguous, but potentially high impact, outcomes associated with significant value at risk, while over-emphasis on ambiguous high-end outcomes might lead to costly and complex decision frameworks and adaptation measures in situations where they are not necessary. Characterizing different ways of communicating uncertainty and ambiguity, as well as their implications for policy end-users, is thus an important area of study.

This paper examines the history of communication of uncertainty and ambiguity in sea-level projections, with a primary focus on scientific assessment reports, and places the approach adopted by the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6) in the context of this history. Specifically, we examine assessment report figures and tables that communicate sea-level rise projections. As architectural elements, figures and tables stand out from report text and receive more attention during drafting, review, approval, and post-publication presentation. Such graphical representations of climate knowledge – as well as anticipated and scrutinized sea-level rise projections themselves – serve as "anchoring devices" that focus epistemic attention and criticism [7,8].

Closely related to the concept of anchoring devices is the concept of "boundary objects": knowledge products that help translate between scales of governance, serve as adaptable items between different audiences, and articulate and maintain boundaries between epistemic domains and types of expertise [9,10]. Here, we consider sea-level rise figures and tables as boundary objects between international researchers and national/subnational decision makers. While IPCC reports are immediately relevant for global climate policy like the Paris Agreement, they often need to be re-packaged for other scales of policy relevance.

For national and subnational decision makers, for example, global findings need to be downscaled. In addition, cultural perceptions, expectations, and styles of communicating risk, uncertainty, and ambiguity may encourage local users to reframe sea-level rise knowledge to make it easier to understand, and therefore, use, in non-global contexts. As boundary objects, key figures and tables in IPCC reports play a central role in the reframing process.

By tracking the history of sea-level projection boundary objects in assessment reports, and in particular the way these boundary objects balance the communication of quantifiable uncertainty and ambiguity, we place the AR6 approach in historical context. We hypothesize that the AR6 approach, which explicitly communicates both types of uncertainty in key boundary objects, will more readily facilitate informed adaptation policy making that appropriately balances the two types based on risk context, and we argue that this hypothesis should be a topic of empirical investigation.

1. Uncertainty and ambiguity

The distinction between quantifiable uncertainty and ambiguity has a long history in risk analysis. Frank Knight [11] distinguished between "measurable uncertainty," which he also dubbed "Risk," and "unmeasurable uncertainty," for which he reserved the term "Uncertainty" and which is sometimes referred to in subsequent literature as "Knightian uncertainty." Knightian risks are characterized by quantifiable probability distributions, and therefore can be the subject of confident investments by risk-taking businesses; Knightian uncertainties cannot be.

Daniel Ellsberg [12] introduced the term 'ambiguity' as a metric of Knightian uncertainty. Ambiguity, in Ellsberg's conception, is an inverse measure of "the amount, type, reliability, and unanimity of information." Higher ambiguity is associated with lower confidence in an assessment of probabilities, and vice versa. In situations of ambiguity, people may exhibit preferences among different possible actions that are not consistent with describing states of nature by a single, self-consistent probability distribution. Ambiguity arises when multiple reasonable probability distributions over states of nature exist and an analyst is not confident assigning weights to them.

The concept of ambiguity is closely related to the concept of 'deep uncertainty', defined by Lempert et al. [13] as referring to states when analysts cannot agree upon "(1) the appropriate models to describe the interactions among a system's variables, (2) the probability distributions to represent uncertainty about key variables and parameters in the models, and/or (3) how to value the desirability of alternative outcomes." The first two elements of the definition of deep uncertainty are associated with high ambiguity, low confidence, and the absence of unanimity, though the 'deep uncertainty' framing suggests a more dichotomous criterion than that of ambiguity.

Though the Intergovernmental Panel on Climate Change (IPCC) did not use the term 'ambiguity' or acknowledge its Ellsbergian heritage, the IPCC has since the Fifth Assessment Report formally distinguished between two axes of uncertainty: likelihood and confidence [14,15].[18] Likelihood corresponds

[18] Throughout this article, we follow IPCC convention an italicize likelihood and confidence language when it was intended by its authors to have a specific, formal definition. We do not italicize these terms when used by authors other than the IPCC.

to quantifiable uncertainty, although in IPCC usage the probabilities reflected with likelihood terms are always imprecise probability terms (e.g., *likely* means '66-100% probability'). Confidence is a measure of the "type, amount, quantity and consistency of evidence" and the "degree of agreement," – with increasing confidence closely parallelling decreases in the Ellsbergian metric of ambiguity. Building off the IPCC typology, Hinkel et al. [16] suggested presenting sea-level projection uncertainty using tiered imprecise probability distributions of different levels of confidence, a concept developed contemporaneously by the AR6 author team and closely related to Ellsberg's original conception of the relationship between ambiguity and probability distributions.

Probability boxes, or p-boxes, provide a convenient way to visualize the distinction between quantifiable uncertainty and ambiguity (Figure 1c-f) [17,18]. Where multiple probability distributions can describe a quantity, the p-box delimits the probability bounds that contain all their cumulative distribution functions. For example, the 83rd percentile of the p-box spans from the lowest 83rd percentile to the highest 83rd percentile of all distributions considered. All probability distributions will agree that there is at least a 66% likelihood (i.e., in IPCC terminology, that it is *likely*) that the true value of a quantity lies between the lower 17th percentile and upper 83rd percentile of the p-box. The width of the p-box is a metric of ambiguity: where there is a high degree of unanimity in the estimate of a given percentile, the p-box will be narrow, while where there is a high degree of ambiguity, the p-box will be wide.

The presence of ambiguity in sea-level and climate projections has implications for decision-making paradigms [2–5]. Benefit-cost analysis (BCA), for example, derives from a subjective expected utility maximization approach, which requires both well-defined probability distributions and preferences that are reducible to a unidimensional utility function [3]. Ambiguous inputs to a decision analysis violate the first requirement, and are also often associated with more complex preference structures. Thus, problems in which decisions are sensitive to ambiguous inputs pose fundamental challenges to BCA, and are often best addressed with alternative, multi-objective robust decision making approaches [4]. Where it is present, clearly communicating ambiguity thus can be of crucial importance for decision making.

2. Communicating uncertainty and ambiguity in the first five IPCC assessment cycles

Since sea-level rise projections first appeared in the modern scientific literature in the 1970s, they have exhibited ambiguity related to ice sheet processes, particularly the behavior of the West Antarctic Ice Sheet (WAIS). WAIS' physical characteristics – with the bulk of the ice sheet grounded below sea level – give rise to dynamics that are a notable challenge to understand, model, and project. As John Mercer [19] noted, "the marine ice sheet in West Antarctica can exist only so long as its grounded portion is buttressed by fringing ice shelves, …. [which] are vulnerable to both oceanic and atmospheric warming." Drawing on geological precedents, Mercer warned of a "threat of disaster" from the WAIS and highlighted the ambiguity of the hazard (emphasis added):

> Present models of the climatic effects of [carbon dioxide] doubling compute a rise in temperature that could cause rapid deglaciation of West Antarctica, leading to a 5 m rise in sea level. Although the models are known to be crude and over-simplified, so that the climatic changes that will actually occur will no doubt differ considerably from their estimates, *there is, at present, no way of knowing whether the models err on the optimistic or pessimistic side.*

Vivien Gornitz and colleagues [20] focused on quantifiable uncertainties, using a statistical model to estimate an 18-year lagged sea-level response to warming of about 16 cm/K, while also noting

> It is not inconceivable that the situation is near a point at which continued warming and rise of sea level could cause rapid, highly nonlinear disintegration of the ice sheet. We should emphasize that we have no evidence for such a process. Indeed the sea level change we have deduced appears to be linear with temperature, and largely a result of the thermal expansion of seawater. Nevertheless, since sea level is at a high point and rising, the West Antarctic ice sheet warrants close attention.

Despite these cautionary notes in the early literature, the first three IPCC assessment reports left rapid ice sheet dynamics out of sea-level rise projection tables. The reports viewed such dynamics as low probability rather than ambiguous; they considered a large contribution to sea-level rise from Antarctic mass loss on a century scale to be "unlikely" [21], "low" likelihood [22], or "*very unlikely*" [23] (Table ED1).

However, the presumed stability of WAIS, and the stability of its representation in climate assessments, changed in the IPCC Fourth Assessment Report (AR4)[7]. A slew of surprising observations had appeared in the literature [24], for which existing ice sheet models could not account [25], and new methods of sea-level projection were emerging that contrasted with the consensus storyline (e.g., ref. 26). There also was increasingly intense public scrutiny over the work of the IPCC itself, along a continuum of interests from climate contrarians to climate activists, as well as a growing number of institutions trying to incorporate climate projections into their planning (e.g., ref. 27).

AR4 cautiously concluded that the likelihood of future changes in ice-sheet discharge – whether steady, reduced, or accelerated – could not be assessed, and therefore assessed neither a best estimate nor a *likely* range of future sea-level change [28] (Table ED1, Figure S1). Instead, 5th-95th percentile ranges were calculated with no interpretation of the ranges in terms of likelihood. Within the AR4 projections chapter, the summary table (ref. 28, table 10.7) and figure (ref. 28, figure 10.33) include estimated ranges of potential contributions from "scaled-up ice sheet discharge" (up to 0.17 m between 1980-1999 and 2080-2099 under the highest emissions scenario) but did not add these estimates into total sea-level rise projections. The figure caption reiterated the caution that "we cannot assess the likelihood of any of [current, reduced, or scaled-up ice sheet discharge], which are presented as illustrative" (ref. 28, figure 10.33). The Summary for Policymakers (SPM) table (ref. 29, table SPM.3) reduces this caution to a column header noting that it is presenting a "model-based range excluding future rapid dynamical changes in ice flows", but also includes in the associated text a caution that "larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or upper bound for sea-level rise" [29].

To this day, the question of whether representing uncertainty, and particularly the ambiguous situation with respect to ice dynamical changes, in this way was a wise choice by AR4 authors remains contested. On the one hand, an opportunity was missed to highlight the state of ambiguity in projections by presenting in figures and tables diverse estimates based on sensitivity tests or other approximation methods and, as a result, IPCC may have caused stakeholders to plan and implement policies based on the partial information captured by quantifiable uncertainty [6]. On the other hand, had diverse estimates of the effects of these dynamical processes been included in tables and figures, that might just as easily have led stakeholders to plan based on excessively high projections [6,7].

Some sophisticated national/subnational assessments did build off of AR4's flag of the potential contribution of accelerated ice sheet discharge, taking AR4 projections plus scaled-up discharge estimates as a point of comparison for independently developed high-end projections [30,31]. Ref. 31 explained the value of such high-end scenarios, noting that a high-end scenario "provides users with estimates of SLR and surge increase beyond the likely range but within physical plausibility. It is useful for contingency planning when a higher level of protection might be needed [and] might also be used to justify a monitoring strategy."

In contrast to AR4, the IPCC Fifth Assessment Report (AR5) did assess *likely* ranges of future sea-level change [32] (Figure S2, S3). The AR5 sea-level projections were generated through a probabilistic approach that involved sampling uncertainties, with the results presented as median and *likely* ranges and the shape of the distribution left unstated. While *'likely'* in the IPCC's post-TAR formal terminology refers to a probability of between 66 and 100%, the authors of the AR5 sea level chapter used a slightly different interpretation. As they clarified in a short letter to *Science* [33], they interpreted that there was "roughly a one-third probability that sea-level rise by 2100 may lie outside the *likely* range" – i.e., the *likely* range as meaning 'about 66%' (roughly a 1-in-3 chance of a value outside the range) rather than 'at least 66%.' (no more than a 1-in-3 chance of a value outside the range).

Notably, the reported *likely* ranges included an adjustment for structural uncertainty based upon the report authors' informal expert judgment. Because the 5th-95th percentile range of transient climate response (TCR) in the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble aligned with the AR5 assessed TCR *likely* range, the *likely* ranges of all long-term projections derived from the CMIP5 ensemble – including the AR5 sea-level projections – were taken from the 5th-95th percentile of the ensemble range [34]. In the context of sea-level projections, this fact, highlighted in a footnote on the SPM table (ref. 35, table SPM.2), appears to have led to considerable confusion, discussed by ref. 36. (The practice is still used in the AR6 for some climate indicators, though not global mean surface air temperature change or sea level change [37].)

AR5 also included a semi-quantitative discussion of ambiguity in global mean sea level (GMSL) projections, in the form of a caveat repeated in the text, the chapter table (ref. 32, table 13.5), and the SPM table: "Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea-level rise during the 21st century" [32,35].

Multiple examples from national and subnational assessments that built upon AR5 indicate that both of these nuances – the interpretation of the likely range derived from the 5th-95th percentile range of model output as "roughly a one-third probability" and the potential for several tenths of a meter additional sea-level rise from marine-based sectors, were not effectively communicated. Of five national or subnational assessments relying quantitatively on the AR5 projections and not including an IPCC lead author as a co-author, four interpreted the *likely* range as having a 90% probability; only one interpreted the *likely* range consistent with the canonical IPCC interpretation (66-100%) and none with the interpretation intended by the authors (about 66%) (see overview in Table ED2). Of these five, four made some attempts to consider the contribution of marine-based Antarctic ice sheet sectors to sea level rise above the IPCC *likely* range, but only one of these four motivated this attempt by reference to the IPCC caveat. Our interpretation is that most experts working on the post-AR5 assessments recognized the importance of considering ambiguity in high-end sea-level rise, but often not because of AR5's cautionary statement.

3. Alternate boundary objects in US subnational assessments

In the period between the AR5 and AR6 assessments, US subnational assessments experimented with a variety of ways of communicating sea level uncertainty and ambiguity. (See ref. 38 for an overview of subnational US assessments.) In general, the quantitative bases of these assessments rested upon probabilistic relative sea-level projections, mostly those produced by Kopp et al. [39,40], rather than the AR5 projections, though the communication challenges posed were similar.

Some subnational assessments communicated uncertainty through presenting a broader set of quantiles than the AR5 likely ranges, and communicated ambiguity through the inclusion of a non-probabilistic, high-end sea-level rise scenario. The 2017 California assessment [41], for example, presented median and likely ranges (in a break from AR5, defined precisely as 17th-83rd percentile), as well as 95th and 99.5th percentiles, and a high-end scenario (Figure S4). The New York City Panel on Climate Change [42] took a similar approach, showing four quantiles of projections (10th, 17th, 83rd, and 90th) and a high-end scenario (Figure S6). In both cases, the high-end scenarios (labeled H++ (high-plus-plus) following [31] in the California assessment and "Antarctic Rapid Ice Melt" in the New York City assessment) were derived from Kopp et al. [39] projections by Sweet et al. [43], based upon an estimate of maximum plausible GMSL rise of 2.5 m by 2100.

Other subnational assessments presented multiple alternative probability distributions with different levels of confidence. The State of Maryland [44] emphasized the relatively conservative probabilistic projections of Kopp et al. (2014) in their primary table, though highlighted the higher end of the projections by including 95th and 99th percentile projections along with 17th, 50th, and 83rd percentiles (Figure S7). In addition, the central table appears immediately above text that presents the 17th-83rd percentile range of higher projections that incorporate an ice sheet model capable of representing Marine Ice Cliff Instability. The decision to emphasize the higher confidence processes in the table while consigning lower confidence processes to text was a deliberate choice; in an early draft, both results were presented in tables, leading to concerns that the difference in confidence would not be accurately conveyed.

A third approach was adopted by the New Jersey Science and Technical Advisory Panel [45] (Figure S8). Rather than presenting probability distributions, the New Jersey assessment utilized (but did not illustrate) p-boxes summarizing across multiple alternative probability distributions. The New Jersey report included in the p-boxes they generated both projections relatively consistent with AR5 [39,46] and projections based on structured expert judgment (SEJ) that incorporate a broader set of processes into the PDF [47]. The central table conveys the idea of a p-box by quoting imprecise probabilities; the likely range, for example, is bounded at the low end by numbers that have “>83% chance” of exceedance and at the high end by numbers that have “<17% chance” of exceedance. In practice, this means that the lower end of the reported values are defined by the more conservative, AR5-aligned projections, and the higher end is defined by the SEJ.

The preceding examples focus on subnational assessment reports in the United States because they demonstrate a variety of alternative forms of uncertainty and ambiguity communication in boundary objects. It is important to bear in mind that many countries lack the capacity or resources to develop tailored sea level assessments. In these cases, the boundary objects within the IPCC reports may serve as a primary resource for decision makers.

4. Reduction of scientific assessments of sea level to scenarios for use

While the examples above are focused on conveyed distributions of future sea-level rise under different emissions scenarios at different points in time, for many end-users this information is too rich. Prior to the SROCC, IPCC provided no guidance on what features of projection uncertainty are important for end users to consider. In practice, such projections are often reduced to a small number of scenarios, either explicitly (as in the case of the US government’s sea level scenarios; ref. 43,48) or implicitly, by focusing on a small number of quantiles, years, and emissions scenarios.

The explicit approach adopted by Sweet et al. [43,48] uses a variety of lines of evidence to demarcate a range of potential levels of 21st century GMSL rise, spanning from a linear continuation of the late 20th century trend at the low end to a high-end scenario requiring strong warming and rapid ice-sheet loss (Figure S9). In ref. 43, the range of scenarios spanned from 0.3 to 2.5 m of GMSL rise over the 21st century, which, based upon the AR6 assessment, was reduced to 0.3 to 2.0 m in ref. 48. These end-of-century GMSL targets were turned into time-varying scenarios of GMSL and local relative sea level (RSL) change by filtering suites of probabilistic projections for samples consistent with the targets. Probabilities are associated with the different sea-level scenarios only contextually. The broad range of the sea-level scenarios is intended to support their use in adaptive decision making.

The implicit reduction approach is exhibited most clearly by the State of California’s Sea Level Guidance [49], which took the projections of the 2017 California sea level assessment and simply drew boxes around particular columns (Figure S5). For decision problems with low risk aversion, for example, the guidance recommended using the 83rd percentile projections; for decision problems with extremely high risk aversion, it recommended using the H++ scenario. Comparison of the presentation of the projections in the California assessment (Figure S4) and guidance (Figure S5) highlights the role of key tables as boundary objects — in this case, at the boundary of the subnational assessment panel and the regulatory body.

5. Communicating sea level uncertainty and ambiguity in the IPCC sixth assessment cycle

The IPCC Special Report on Oceans and Cryosphere in a Changing Climate (SROCC) represented an intermediary step between the AR5 and AR6, and it also served to integrate across IPCC Working Groups 1 (physical science) and 2 (impacts, adaptation, and vulnerability). As such, SROCC updated the AR5 projections to address some of the advances in the literature since AR5, without tackling the development of a completely new set of integrated sea-level projections, a task awaiting completion of the Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate model simulations [50]. In particular, SROCC updated the Antarctic contribution to projected sea-level change while leaving other terms unchanged [51]. Importantly, the report also made an adjustment to the use of *likely* which had previously caused confusion when applied to a range: SROCC used the terms '*likely* range' or '*very likely* range' to indicate that the assessed likelihood of an outcome lies specifically within the 17–83% or 5–95% probability range [52].

The representation of projection data in boundary objects in SROCC was more limited than in AR5 or AR6. SROCC did not have a table capable of serving as a boundary object; the only table with sea-level rise projections focused on the details of removing and replacing the AR5 Antarctic projections in the AR5 GMSL projections (ref. 51, table 4.4). Key figures in SROCC did include elements that drew greater attention to ambiguity and multi-century change than the corresponding figures in AR5. In particular, the SPM figure illustrating GMSL time series (ref. 52, figure SPM.1) extended to 2300, using fainter shading to indicate lower confidence after 2100, and also included bars showing the year 2300 results of one SEJ study [47]; while, like AR5, the figure showed only *likely* ranges, the long timescale emphasized the potential for substantially larger sea-level change past 2100 (Figure S10). The chapter figure with sea-level projections (ref. 51, Fig 4.2) likewise extended to 2300 (Figure S11). It also incorporated bars indicating alternative probability distributions for 2100 and 2300, derived from an Antarctic ice sheet sensitivity study and from the SEJ study.

Notably, leveraging SROCC's status as a cross-working group product, SROCC for the first time provided advice on how to utilize the diversity of projections available [52]:

> The sea level rise range that needs to be considered for planning and implementing coastal responses depends on the risk tolerance of stakeholders. Stakeholders with higher risk tolerance (e.g., those planning for investments that can be very easily adapted to unforeseen conditions) often prefer to use the *likely* range of projections, while stakeholders with a lower risk tolerance (e.g., those deciding on critical infrastructure) also consider global and local mean sea level above the upper end of the *likely* range (globally 1.1 m under RCP8.5 by 2100) and from methods characterized by lower confidence such as from expert elicitation.

AR6 [1] developed a fully new set of integrated sea-level projections and built upon AR5's and SROCC's approaches in several ways. Rather than producing a single set of probability distributions, it produced multiple distributions of GMSL, using different ways of modeling Antarctic and Greenland ice sheet behavior (Figure 1a-d). It then combined these distributions in p-boxes to produce the reported projections (Figure 1e-f). Its *likely* range projections included emulated results from the Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) [53–55] and the Linear Antarctic Response Model Intercomparison Project (LARMIP) [56]; because both of these projects integrated results from suites of ice sheet models, their results were judged to have a *medium level of agreement* and thus *medium confidence.*

The sea level chapter was cautious in its presentation of these *medium confidence* results, noting that they "[consider] only processes for which projections can be made with at least *medium confidence*" [1]. The *likely* range projections, for example, do not include more ambiguous processes unrepresented in ISMIP6-class ice sheet models. (See also ref. 57, which highlights a low bias in ISMIP6 projections of historical Greenland ice sheet changes and the lack of model consensus regarding the sign of historical Antarctic changes.) To address this limitation, AR6 also generated probability distributions that incorporated a broader set of processes. One of these distributions utilized a single Antarctic ice-sheet model that represents Marine Ice Cliff Instability [58]; another relied upon a SEJ study of both Antarctic and Greenland contributions [47]. Because the authors assessed that there was *limited evidence* regarding and *low agreement* on Marine Ice Cliff Instability (MICI), as well as potentially on other processes considered by the experts participating in the SEJ studies, the broader p-boxes including these studies were judged to have *low confidence*. Due to limitations in the underlying literature, *low confidence* projections were produced only for the low emissions SSP1-2.6 and very high emissions SSP5-8.5 scenarios.

Beyond 2150, AR6 considered all ice sheet projections to be *low confidence* and so did not present time series from 2150 to 2300; instead, it reports indicative projections for two emissions scenarios (SSP1-2.6 and SSP5-8.5) at the single time point of 2300. These projections were based on a combination of projections that included (1) no-acceleration extrapolation of ice sheet changes after 2100, (2) literature-based assessment of ice-sheet changes in 2300, (3) SEJ projections, and (4) the single Antarctic model that represents MICI. For SSP5-8.5, the MICI-permitting projections yield ranges that do not overlap with the other methods (9.5-16.2 m vs. 1.7-6.3 m), and so are reported separately.

On still longer timescales, these projections were complemented by assessments, based on model and paleo data, of committed sea-level rise associated with different levels of peak global warming over timescales of 2,000 and 10,000 years. While AR5 [32] had also discussed millennial-scale sea level change, AR6 drew a more direct connection between century- and millennial-scale changes [1]. The AR5 SPM presents paleo sea level, century-scale sea level change, and millennial-scale ice sheet contributions to sea level in separate sections [35]; by contrast, the AR6 SPM, discusses paleo and millennial-scale change as a function of peak global warming in a paragraph that follows immediately after the paragraph presenting century-scale changes [59]. A Technical Summary figure synthesizes sea level change on different timescales as a function of peak global warming level (ref. 60, Box TS.4, Figure 1) (Figure 2b). This figure combines *medium* and *low confidence* model-based century-scale projections and *low confidence* millennial scale model-based projections with *medium confidence* paleo sea level and temperature assessments. It is the first such figure in an IPCC report sufficiently streamlined so as to provide a possible boundary object to facilitate discussions of these relationships.

The AR6 Working Group 1 report reiterated SROCC's guidance about the utility of high end projections, while pointing to the limitations of likelihood assessments given projection ambiguity [1]:

> As noted by SROCC, stakeholders with a low risk tolerance (e.g., those planning for coastal safety in cities and long-term investment in critical infrastructure) may wish to consider global-mean sea level rise above the assessed *likely* range by the year 2100, because '*likely*' implies an assessed likelihood of up to 16% that sea level rise by 2100 will be higher (see also Siegert et al., 2020). Because of our limited understanding of the rate at which some of the governing processes

> contribute to long-term sea level rise, we cannot currently robustly quantify the likelihood with which they can cause higher sea level rise before 2100.

To help ensure that these *low confidence* – but potentially decision-relevant projections – were not lost to practitioners as the AR5 caveat seemingly often was, the *low confidence* projections for a very high-emissions scenario (SSP5-8.5) were presented in core figures and tables alongside the *medium confidence* projections for the suite of SSP scenarios (Figure 2; Figure S12). The AR6 approach represents convergent evolution with the recommendations of ref. 16 that sea-level projections be communicated at different levels of confidence. It also draws inspiration from the California (2017)/New York City (2018) approach of presenting a high-end (*low confidence*) scenario alongside probabilistic projections, and the New Jersey (2019) approach of summarizing multiple probabilistic projections with p-boxes.

The AR6 SPM illustrates the 21st century *low confidence* projections with a curve representing a "*low likelihood*, *high-impact* storyline including ice-sheet instability processes" (Figure 2d). The curve is taken from the upper 83rd percentile of the *low confidence* p-box for SSP5-8.5 and is dashed to indicate the lower degree of confidence. The description draws upon two new frames introduced in AR6. "*Low-likelihood, high-impact* (LLHI) outcomes" are defined as outcomes "whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high" [14]. In the context of an ambiguous projection, as here, the "not well known" probability part of the definition is key – perhaps a bit confusingly, since it is not represented in the name of the concept. Physical climate storylines [61] are, essentially, scenarios of physical changes that provide narrative detail used to contextualize projections and allow quantitative uncertainties to be assessed, conditional upon assumptions regarding more ambiguous narrative elements. Consistent with AR6 practice, Stammer et al. [62] recommend accompanying probabilistic projections with high-end storylines tied to specific physical processes. For the *low confidence* sea-level projections, AR6 presents a storyline in Box 9.4, which highlights elements including strong warming, "faster-than-projected disintegration of marine ice shelves and the abrupt, widespread onset of marine ice cliff instability (MICI) and marine ice sheet instability (MISI) in Antarctica (Section 9.4.2.4), and faster-than-projected changes in both the surface mass balance and dynamical ice loss in Greenland" (Fox-Kemper et al., 2021). Though these details are not presented in any boundary object, the use of the storyline label serves as a pointer to this description.

AR6 also introduced an alternative projection framing, based on evidence that for some end-users, uncertainty in timing of reaching different sea-level rise "milestones" (e.g., 'when' a particular elevation associated with an 'adaptation tipping point' is reached rather than 'if' it will be reached; see also ref. 63) is as useful as uncertainty in level at particular points in time (Figure 2c). Thus AR6 introduced figures showing when, under different emissions scenarios, milestones ranging from 0.5 m to 2.0 m GMSL rise would be exceeded. This visualization also incorporated both the *medium confidence* projections for all SSPs and the *low confidence* projections for SSP1-2.6 and SSP5-8.5.

Recognizing that most end-user decisions are sensitive to local, relative sea-level change rather than GMSL change, the AR6 authors also invested in efforts to make relative sea-level projections more readily available. The AR5 RSL projections were produced and archived by the Integrated Climate Data Center (https://www.cen.uni-hamburg.de/en/icdc/data/ocean/ar5-slr.html) but not communicated more actively. AR6 projections, by contrast, are communicated both through the IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch) and the more targeted NASA/IPCC Sea Level Projection Tool (https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). The NASA/IPCC Sea Level Projection Tool focuses on preserving key design elements of the AR6 boundary objects when presenting regional sea level projections. It allows versions of the core figures and tables presented in the report for GMSL to be produced for RSL projections both at tide gauges and on a global grid. Like the boundary objects in the report, it strives to convey both uncertainty and ambiguity by including *low confidence* projections alongside the *medium confidence, likely* ranges. In addition to these tools, the comprehensive global and regional projections, along with the open-source system used to generate them, were archived following open science principles [64].

6. Conclusions

The presence and magnitude of ambiguity in sea-level projections affects the appropriate use of decision frameworks, and thus is important to communicate this clearly and efficiently. Overall, the AR6 approach attempts to communicate the ambiguity of sea-level projections (and emphasize the non-comprehensive nature of the *likely* range) without overwhelming the projections of those processes on which there is a reasonable degree of agreement. Both SROCC and AR6 also include some guidance related to how users with different risk tolerances might wish to use the projections. The intent of this approach is to inform a wide variety of decision-making paradigms, including both risk-neutral approaches that focus on likely outcomes and more risk-averse approaches that rely upon characterization of high-end outcomes.

The efficacy of the AR6 approach, and of the alternative approaches discussed above, as a tool for communicating to practitioners is an important empirical subject of study. Key questions include: how are IPCC projections, perhaps mediated by national/subnational assessments, simplified for or translated into policy guidance? Does how projections are communicated bear any relationship with acceptance, implementation, and efficacy of adaptation measures? The growing focus of climate and sea level science on usability calls for a deliberate focus on such questions, which require close collaborations between research climate scientists and the social scientists who study them.

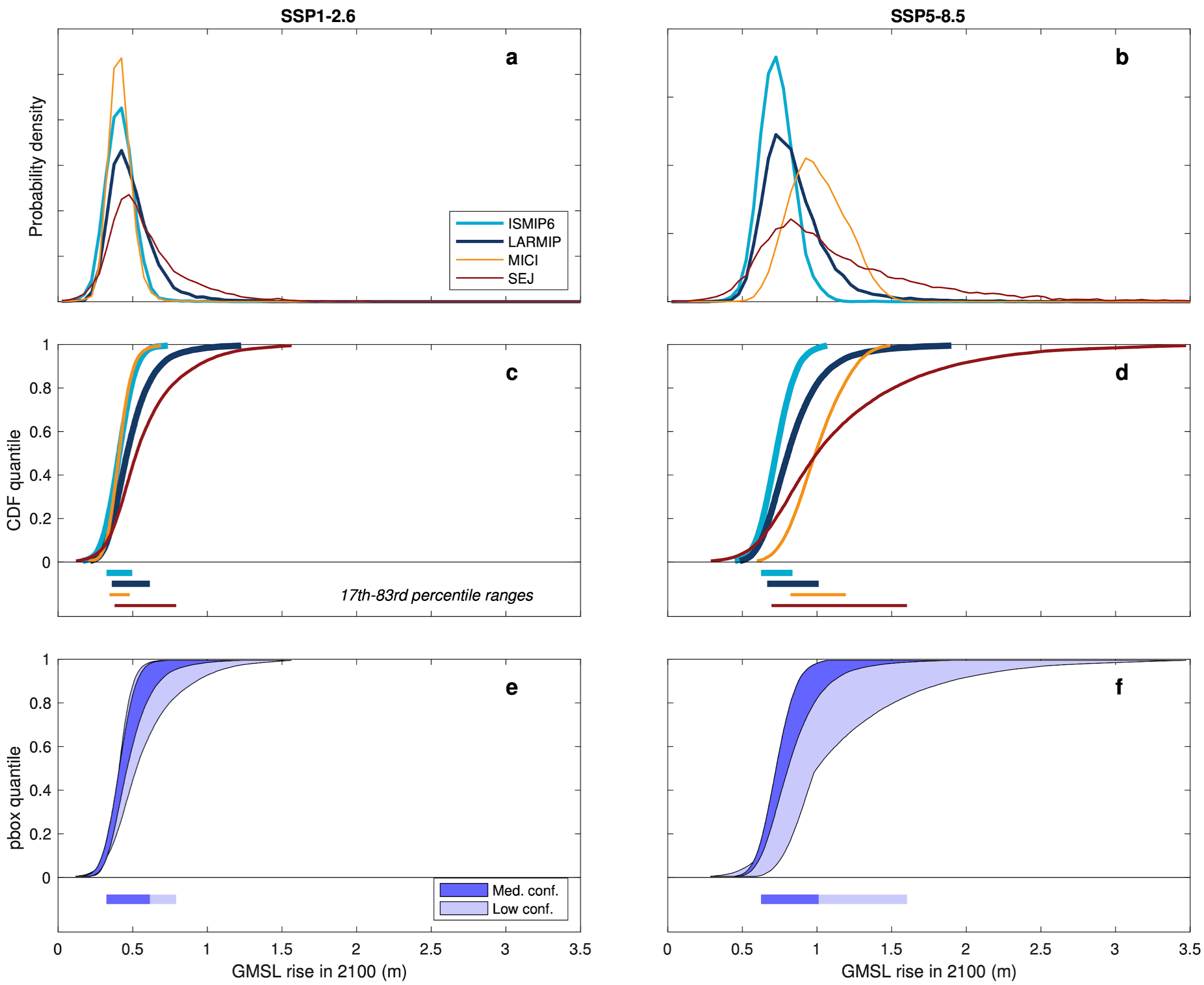
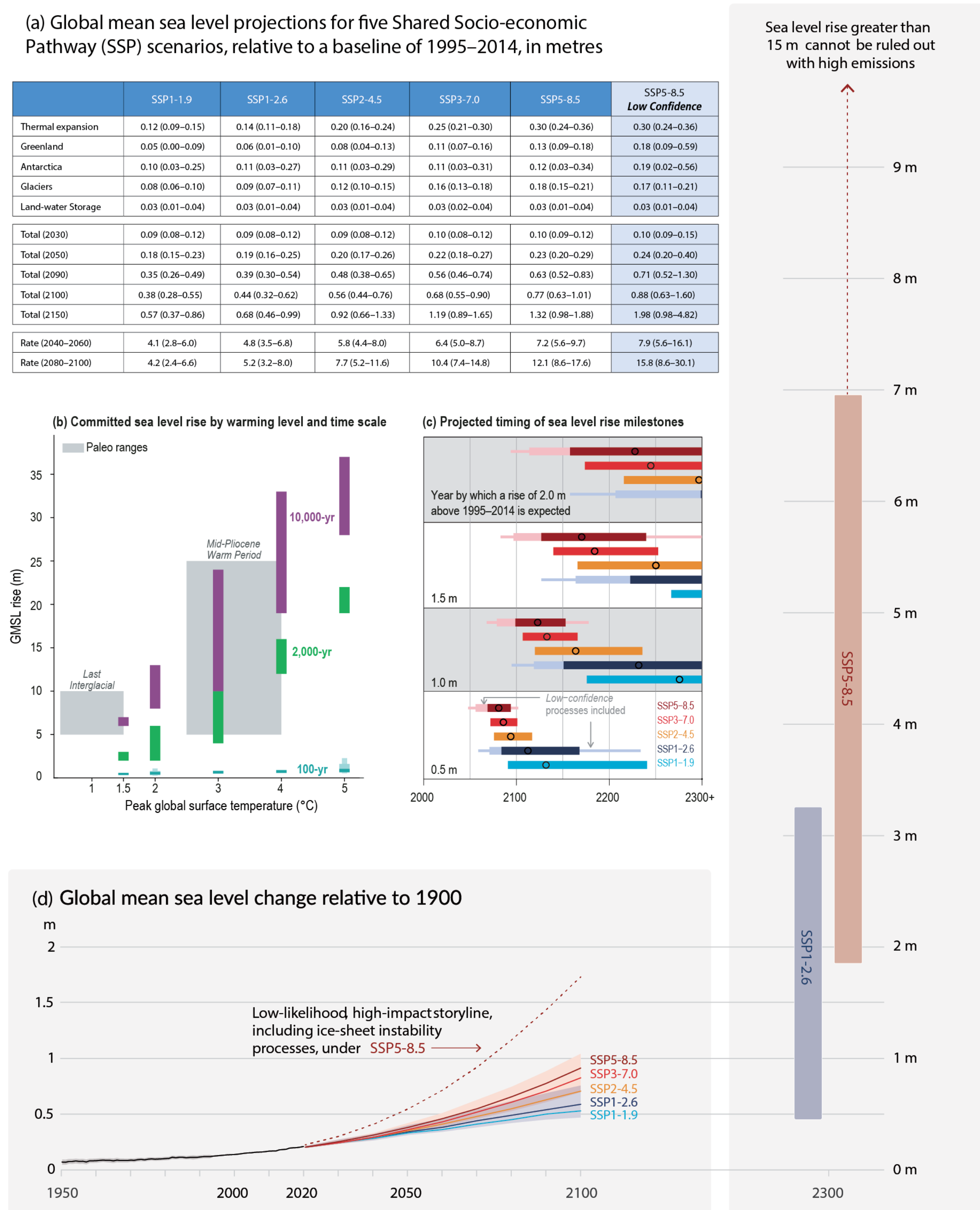


Figure 1. Generation of global mean sea level (GMSL) projection p-boxes in AR6 for SSP1-2.6 (a, c, e) and SSP5-8.5 (b, d, f) in 2100. (a-b) Four alternative probability distributions, incorporating Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6, light blue), Linear Antarctic Response Model Intercomparison Project (LARMIP, dark blue), Antarctic Marine Ice Cliff Instability-permitting (MICI, orange), and ice-sheet structured expert judgment-based (SEJ, red) projections. (c-d) Cumulative distribution functions corresponding to the probability distributions in a-b. (e-f) *Medium confidence* (dark blue) and *low confidence* (light blue) p-boxes. The width of the p-box provides a metric of ambiguity. Bars at bottom of panels c-f show the lower 17th-upper 83rd percentile range for each distribution/p-box. AR6 interpreted the lower 17th-upper 83rd percentile range of the *medium confidence* p-box as representing the *likely* contribution of included processes to GMSL rise. Likelihood labels were not ascribed to other ranges.



(a) Global mean sea level projections for five Shared Socio-economic Pathway (SSP) scenarios, relative to a baseline of 1995–2014, in metres

	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 ***Low Confidence***
Thermal expansion	0.12 (0.09–0.15)	0.14 (0.11–0.18)	0.20 (0.16–0.24)	0.25 (0.21–0.30)	0.30 (0.24–0.36)	0.30 (0.24–0.36)
Greenland	0.05 (0.00–0.09)	0.06 (0.01–0.10)	0.08 (0.04–0.13)	0.11 (0.07–0.16)	0.13 (0.09–0.18)	0.18 (0.09–0.59)
Antarctica	0.10 (0.03–0.25)	0.11 (0.03–0.27)	0.11 (0.03–0.29)	0.11 (0.03–0.31)	0.12 (0.03–0.34)	0.19 (0.02–0.56)
Glaciers	0.08 (0.06–0.10)	0.09 (0.07–0.11)	0.12 (0.10–0.15)	0.16 (0.13–0.18)	0.18 (0.15–0.21)	0.17 (0.11–0.21)
Land-water Storage	0.03 (0.01–0.04)	0.03 (0.01–0.04)	0.03 (0.01–0.04)	0.03 (0.02–0.04)	0.03 (0.01–0.04)	0.03 (0.01–0.04)
Total (2030)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.10 (0.08–0.12)	0.10 (0.09–0.12)	0.10 (0.09–0.15)
Total (2050)	0.18 (0.15–0.23)	0.19 (0.16–0.25)	0.20 (0.17–0.26)	0.22 (0.18–0.27)	0.23 (0.20–0.29)	0.24 (0.20–0.40)
Total (2090)	0.35 (0.26–0.49)	0.39 (0.30–0.54)	0.48 (0.38–0.65)	0.56 (0.46–0.74)	0.63 (0.52–0.83)	0.71 (0.52–1.30)
Total (2100)	0.38 (0.28–0.55)	0.44 (0.32–0.62)	0.56 (0.44–0.76)	0.68 (0.55–0.90)	0.77 (0.63–1.01)	0.88 (0.63–1.60)
Total (2150)	0.57 (0.37–0.86)	0.68 (0.46–0.99)	0.92 (0.66–1.33)	1.19 (0.89–1.65)	1.32 (0.98–1.88)	1.98 (0.98–4.82)
Rate (2040–2060)	4.1 (2.8–6.0)	4.8 (3.5–6.8)	5.8 (4.4–8.0)	6.4 (5.0–8.7)	7.2 (5.6–9.7)	7.9 (5.6–16.1)
Rate (2080–2100)	4.2 (2.4–6.6)	5.2 (3.2–8.0)	7.7 (5.2–11.6)	10.4 (7.4–14.8)	12.1 (8.6–17.6)	15.8 (8.6–30.1)

Figure 2. Different visualizations of global mean sea level (GMSL) projection uncertainty and ambiguity in the IPCC AR6 Working Group 1 report. (a) Tabular presentation of *medium confidence* projections for five

SSP scenarios and *low confidence* projections for SSP5-8.5, presented as Table 9.9 [1]. Projections for individual components (first five rows) are for 2100. Values shown are median and *likely* ranges, except for the *low confidence* projections, where presented ranges are 17th-83rd percentile with no formal likelihood assessed. (b) Projected GMSL change on 100- (blue), 2,000- (green), and 10,000 (magneta) time scales as a function of global surface temperature, relative to 1850-1900, extracted from Box TS.4, Figure 1b [60]. Dark blue projections are *medium confidence*; others are *low confidence*. Shaded regions show the *medium confidence* assessments of temperature and sea level during the Last Interglacial and Mid-Pliocene Warm Period. (c) Uncertainty in the timing of different GMSL milestones, extracted from Box TS.4, Figure 1c [60]. *Low confidence* projections are indicated by light shading on the SSP1-2.6 and SSP5-8.5 bars, showing both 17-83rd percentile (thicker line) and 5th-95th percentile (thin line) projections. (d) GMSL as a function of time, extracted from Figure SPM.8d/e [59]. Ambiguity is represented through the inclusion of a curve representing a "*low-likelihood, high-impact*" storyline. Other projections through 2100 are *medium confidence, likely* ranges. Projections for 2300 are *low confidence* 17th-83rd percentile ranges.

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Table ED1. Text describing ambiguity of ice sheet contributions to sea level in the IPCC report chapters and Summaries for Policy Makers (SPMs).

First Assessment Report (1990)	Chapter [21]	"A rapid disintegration of the West Antarctic Ice Sheet due to global warming is unlikely within the next century."
	SPM [65]	"Within the next century it is not likely that there will be a major outflow of ice from West Antarctica due directly to global warming."
Second Assessment Report (1996)	Chapter [22]	"Concern has been expressed that the West Antarctic Ice Sheet might "surge", causing a rapid rise in sea level. The current lack of knowledge regarding the specific circumstances under which this might occur, either in total or in part, limits the ability to quantify the risk. Nonetheless, the likelihood of a major sea level rise by the year 2100 due to the collapse of the West Antarctic Ice Sheet is considered low."
	SPM [66]	"In these projections, the combined contributions of the Greenland and Antarctic ice sheets are projected to be relatively minor over the next century. However, the possibility of large changes in the volumes of these ice sheets (and, consequently, in sea level) cannot be ruled out, although the likelihood is considered to be low."
Third Assessment Report (2001)	Chapter [23]	"The range of projections given above makes no allowance for ice-dynamic instability of the WAIS. It is now widely agreed that major loss of grounded ice and accelerated sea level rise are very unlikely during the 21st century."
	SPM [67]	"Concerns have been expressed about the stability of the West Antarctic ice sheet because it is grounded below sea level. However, loss of grounded ice leading to substantial sea level rise from this source is now widely agreed to be very unlikely during the 21st century, although its dynamics are still inadequately understood, especially for projections on longer time-scales."
Fourth Assessment Report (2007)	Chapter [28]	"It must be emphasized that we cannot assess the likelihood of any of these three alternatives [(steady, reduced, or scale up ice discharge)], which are presented as illustrative. The state of understanding prevents a best estimate from being made."
	SPM [29]	"For example, if [the ice flow] contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table SPM.3 would increase by 0.1 to 0.2 m. Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."
Fifth Assessment Report (2013)	Chapter [32]	"Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. This potential additional contribution cannot be precisely quantified but there is *medium confidence* that it would not exceed several tenths of a meter of sea level rise during the 21st century."
	SPM [35]	"Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century."
Special Report on the Ocean and	Chapter [51]	"Estimates of sea level rise higher than the *likely* range are also provided here for decision makers with low risk tolerance…. Processes controlling the timing of future ice-shelf loss and the extent of ice sheet instabilities could increase

Cryosphere in a Changing Climate (2019)		Antarctica's contribution to sea level rise to values higher than the *likely* range on century and longer time-scales (*low confidence*). Evolution of the Antarctic Ice Sheet beyond the end of the 21st century is characterized by deep uncertainty, as ice sheet models lack realistic representations of some of the underlying physical processes... There is *low confidence* in threshold temperatures for ice sheet instabilities and the rates of GMSL rise they can produce."
	SPM [52]	"Processes controlling the timing of future ice-shelf loss and the extent of ice sheet instabilities could increase Antarctica's contribution to sea level rise to values substantially higher than the *likely* range on century and longer time-scales (*low confidence*). Considering the consequences of sea level rise that a collapse of parts of the Antarctic Ice Sheet entails, this high impact risk merits attention."
Sixth Assessment Report (2021)	Chapter [1]	"Higher amounts of GMSL rise before 2100 could be caused by earlier-than-projected disintegration of marine ice shelves, the abrupt, widespread onset of marine ice sheet instability and marine ice cliff instability around Antarctica, and faster-than-projected changes in the surface mass balance and discharge from Greenland. These processes are characterized by deep uncertainty arising from limited process understanding, limited availability of evaluation data, uncertainties in their external forcing and high sensitivity to uncertain boundary conditions and parameters. In a low-likelihood, high-impact storyline, under high emissions such processes could in combination contribute more than one additional metre of sea level rise by 2100."
	SPM [59]	"Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice-sheet processes."

Table ED2. National and subnational assessments building upon AR5 sea level projections.

Assessment	**Includes an AR4 or AR5 author as co-author**	**Interpretation of AR5 *likely* range**	**Consideration of marine-based sector collapse?**
Canada 2014 [68]	No	90%	Yes, acknowledges AR5 caveat and includes high-end scenario to represent
Connecticut 2019 [69]	No	90%	Yes, using sources other than AR5 [70,71]
Louisiana 2017 [72]	No	66-100%	Yes, using sources other than AR5 [73,74]
Netherlands 2014 [75]	Yes (AR5 Contributing Author)	90%	Yes, using sources other than AR5 [30]
North Carolina 2015 [76]	No	90%	No
Norway [77]	Yes (AR5 Contributing Author)	66-100%	Yes, acknowledges AR5 caveat and uses probabilistic approach to assess high-end outcomes
Singapore [78,79]	Yes (AR4 Lead Author)	66-100%	Yes, acknowledges AR5 caveat and includes high-end scenario
United Kingdom 2018 [80]	Yes (AR4 Lead Author)	<= 90%	Yes, acknowledges AR5 caveat and uses post-AR5 literature [81,82] to illustrate in appendix

Supplementary Information

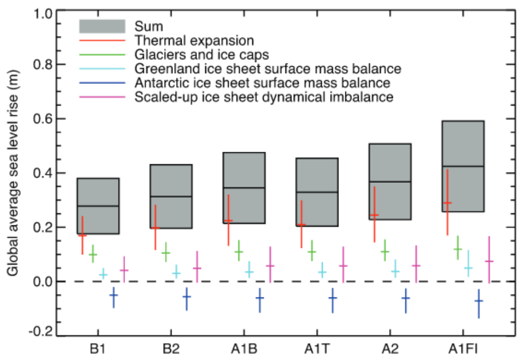

Figure 10.33. *Projections and uncertainties (5 to 95% ranges) of global average sea level rise and its components in 2090 to 2099 (relative to 1980 to 1999) for the six SRES marker scenarios. The projected sea level rise assumes that the part of the present-day ice sheet mass imbalance that is due to recent ice flow acceleration will persist unchanged. It does not include the contribution shown from scaled-up ice sheet discharge, which is an alternative possibility. It is also possible that the present imbalance might be transient, in which case the projected sea level rise is reduced by 0.02 m. It must be emphasized that we cannot assess the likelihood of any of these three alternatives, which are presented as illustrative. The state of understanding prevents a best estimate from being made.*

Table 10.7. *Projected global average sea level rise during the 21st century and its components under SRES marker scenarios. The upper row in each pair gives the 5 to 95% range (m) of the rise in sea level between 1980 to 1999 and 2090 to 2099. The lower row in each pair gives the range of the rate of sea level rise (mm yr^{-1}) during 2090 to 2099. The land ice sum comprises G&IC and ice sheets, including dynamics, but excludes the scaled-up ice sheet discharge (see text). The sea level rise comprises thermal expansion and the land ice sum. Note that for each scenario the lower/upper bound for sea level rise is larger/smaller than the total of the lower/upper bounds of the contributions, since the uncertainties of the contributions are largely independent. See Appendix 10.A for methods.*

		B1		B2		A1B		A1T		A2		A1FI	
Thermal expansion	m	0.10	0.24	0.12	0.28	0.13	0.32	0.12	0.30	0.14	0.35	0.17	0.41
	mm yr^{-1}	1.1	2.6	1.6	4.0	1.7	4.2	1.3	3.2	2.6	6.3	2.8	6.8
G&IC	m	0.07	0.14	0.07	0.15	0.08	0.15	0.08	0.15	0.08	0.16	0.08	0.17
	mm yr^{-1}	0.5	1.3	0.5	1.5	0.6	1.6	0.5	1.4	0.6	1.9	0.7	2.0
Greenland Ice Sheet SMB	m	0.01	0.05	0.01	0.06	0.01	0.08	0.01	0.07	0.01	0.08	0.02	0.12
	mm yr^{-1}	0.2	1.0	0.2	1.5	0.3	1.9	0.2	1.5	0.3	2.8	0.4	3.9
Antarctic Ice Sheet SMB	m	-0.10	-0.02	-0.11	-0.02	-0.12	-0.02	-0.12	-0.02	-0.12	-0.03	-0.14	-0.03
	mm yr^{-1}	-1.4	-0.3	-1.7	-0.3	-1.9	-0.4	-1.7	-0.3	-2.3	-0.4	-2.7	-0.5
Land ice sum	m	0.04	0.18	0.04	0.19	0.04	0.20	0.04	0.20	0.04	0.20	0.04	0.23
	mm yr^{-1}	0.0	1.8	-0.1	2.2	-0.2	2.5	-0.1	2.1	-0.4	3.2	-0.8	4.0
Sea level rise	m	0.18	0.38	0.20	0.43	0.21	0.48	0.20	0.45	0.23	0.51	0.26	0.59
	mm yr^{-1}	1.5	3.9	2.1	5.6	2.1	6.0	1.7	4.7	3.0	8.5	3.0	9.7
Scaled-up ice sheet discharge	m	0.00	0.09	0.00	0.11	-0.01	0.13	-0.01	0.13	-0.01	0.13	-0.01	0.17
	mm yr^{-1}	0.0	1.7	0.0	2.3	0.0	2.6	0.0	2.3	-0.1	3.2	-0.1	3.9

Table SPM.3. *Projected global average surface warming and sea level rise at the end of the 21st century. {10.5, 10.6, Table 10.7}*

	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:
[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs).
[b] Year 2000 constant composition is derived from AOGCMs only.

Figure S1. Tables and figures summarizing GMSL projections from the IPCC Fourth Assessment Report [28,29].

Table 13.5 | Median values and *likely* ranges for projections of global mean sea level (GMSL) rise and its contributions in metres in 2081–2100 relative to 1986–2005 for the four RCP scenarios and SRES A1B, GMSL rise in 2046–2065 and 2100, and rates of GMSL rise in mm yr^{-1} in 2081–2100. See Section 13.5.1 concerning how the *likely* range is defined. Because some of the uncertainties in modelling the contributions are treated as uncorrelated, the sum of the lower bound of contributions does not equal the lower bound of the sum, and similarly for the upper bound (see Supplementary Material). Because of imprecision from rounding, the sum of the medians of contributions may not exactly equal the median of the sum. The net contribution (surface mass balance (SMB) + dynamics) for each ice sheet, and the contribution from rapid dynamical change in both ice sheets together, are shown as additional lines below the sum; they are not contributions in addition to those given above the sum. The contributions from ice-sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, uncorrelated with the magnitude of global climate change (except for the interaction between Antarctic ice sheet SMB and outflow), and as independent of scenario (except that a higher rate of change is used for Greenland ice sheet outflow under RCP8.5). This treatment does not imply that the contributions concerned will not depend on the scenario followed, only that the current state of knowledge does not permit a quantitative assessment of the dependence. Regional sea level change is expected in general to differ from the global mean (see Section 13.6).

	SRES A1B	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Thermal expansion	0.21 [0.16 to 0.26]	0.14 [0.10 to 0.18]	0.19 [0.14 to 0.23]	0.19 [0.15 to 0.24]	0.27 [0.21 to 0.33]
Glaciers[a]	0.14 [0.08 to 0.21]	0.10 [0.04 to 0.16]	0.12 [0.06 to 0.19]	0.12 [0.06 to 0.19]	0.16 [0.09 to 0.23]
Greenland ice-sheet SMB[b]	0.05 [0.02 to 0.12]	0.03 [0.01 to 0.07]	0.04 [0.01 to 0.09]	0.04 [0.01 to 0.09]	0.07 [0.03 to 0.16]
Antarctic ice-sheet SMB[c]	–0.03 [–0.06 to –0.01]	–0.02 [–0.04 to –0.00]	–0.02 [–0.05 to –0.01]	–0.02 [–0.05 to –0.01]	–0.04 [–0.07 to –0.01]
Greenland ice-sheet rapid dynamics	0.04 [0.01 to 0.06]	0.04 [0.01 to 0.06]	0.04 [0.01 to 0.06]	0.04 [0.01 to 0.06]	0.05 [0.02 to 0.07]
Antarctic ice-sheet rapid dynamics	0.07 [–0.01 to 0.16]	0.07 [–0.01 to 0.16]	0.07 [–0.01 to 0.16]	0.07 [–0.01 to 0.16]	0.07 [–0.01 to 0.16]
Land water storage	0.04 [–0.01 to 0.09]	0.04 [–0.01 to 0.09]	0.04 [–0.01 to 0.09]	0.04 [–0.01 to 0.09]	0.04 [–0.01 to 0.09]
Global mean sea level rise in 2081–2100	0.52 [0.37 to 0.69]	0.40 [0.26 to 0.55]	0.47 [0.32 to 0.63]	0.48 [0.33 to 0.63]	0.63 [0.45 to 0.82]
Greenland ice sheet	0.09 [0.05 to 0.15]	0.06 [0.04 to 0.10]	0.08 [0.04 to 0.13]	0.08 [0.04 to 0.13]	0.12 [0.07 to 0.21]
Antarctic ice sheet	0.04 [–0.05 to 0.13]	0.05 [–0.03 to 0.14]	0.05 [–0.04 to 0.13]	0.05 [–0.04 to 0.13]	0.04 [–0.06 to 0.12]
Ice-sheet rapid dynamics	0.10 [0.03 to 0.19]	0.10 [0.03 to 0.19]	0.10 [0.03 to 0.19]	0.10 [0.03 to 0.19]	0.12 [0.03 to 0.20]
Rate of global mean sea level rise	8.1 [5.1 to 11.4]	4.4 [2.0 to 6.8]	6.1 [3.5 to 8.8]	7.4 [4.7 to 10.3]	11.2 [7.5 to 15.7]
Global mean sea level rise in 2046–2065	0.27 [0.19 to 0.34]	0.24 [0.17 to 0.32]	0.26 [0.19 to 0.33]	0.25 [0.18 to 0.32]	0.30 [0.22 to 0.38]
Global mean sea level rise in 2100	0.60 [0.42 to 0.80]	0.44 [0.28 to 0.61]	0.53 [0.36 to 0.71]	0.55 [0.38 to 0.73]	0.74 [0.52 to 0.98]
Only the collapse of the marine-based sectors of the Antarctic ice sheet, if initiated, could cause GMSL to rise substantially above the *likely* range during the 21st century. This potential additional contribution cannot be precisely quantified but there is *medium confidence* that it would not exceed several tenths of a meter of sea level rise.					

Notes:

[a] Excluding glaciers on Antarctica but including glaciers peripheral to the Greenland ice sheet.

[b] Including the height–SMB feedback.

[c] Including the interaction between SMB change and outflow.

Figure S2. Chapter table summarizing GMSL projections from the IPCC Fifth Assessment Report [32]

Table SPM.2 | Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005. {12.4; Table 12.2, Table 13.5}

		2046–2065		2081–2100	
	Scenario	**Mean**	***Likely* range**[c]	**Mean**	***Likely* range**[c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range**[d]	**Mean**	***Likely* range**[d]
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes:

[a] Based on the CMIP5 ensemble; anomalies calculated with respect to 1986–2005. Using HadCRUT4 and its uncertainty estimate (5–95% confidence interval), the observed warming to the reference period 1986–2005 is 0.61 [0.55 to 0.67] °C from 1850–1900, and 0.11 [0.09 to 0.13] °C from 1980–1999, the reference period for projections used in AR4. *Likely* ranges have not been assessed here with respect to earlier reference periods because methods are not generally available in the literature for combining the uncertainties in models and observations. Adding projected and observed changes does not account for potential effects of model biases compared to observations, and for natural internal variability during the observational reference period {2.4; 11.2; Tables 12.2 and 12.3}

[b] Based on 21 CMIP5 models; anomalies calculated with respect to 1986–2005. Where CMIP5 results were not available for a particular AOGCM and scenario, they were estimated as explained in Chapter 13, Table 13.5. The contributions from ice sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as largely independent of scenario. This treatment does not imply that the contributions concerned will not depend on the scenario followed, only that the current state of knowledge does not permit a quantitative assessment of the dependence. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

[c] Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean surface temperature change in 2046–2065 *confidence* is *medium*, because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for 2081–2100. The *likely* ranges for 2046–2065 do not take into account the possible influence of factors that lead to the assessed range for near-term (2016–2035) global mean surface temperature change that is lower than the 5–95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding. {11.3}

[d] Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean sea level rise *confidence* is *medium* for both time horizons.

Figure S3. SPM table summarizing GMSL projections from the IPCC Fifth Assessment Report [35].

Feet above 1991-2009 mean	MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE
Year / Percentile	*50% probability SLR meets or exceeds...*	*67% probability SLR is between...*	*5% probability SLR meets or exceeds...*	*0.5% probability SLR meets or exceeds...*
2030	0.4	0.3 — 0.5	0.6	0.8
2050	0.9	0.6 — 1.1	1.4	1.9
2100 (RCP 2.6)	1.6	1.0 — 2.4	3.2	5.7
2100 (RCP 4.5)	1.9	1.2 — 2.7	3.5	5.9
2100 (RCP 8.5)	2.5	1.6 — 3.4	4.4	6.9
2100 (H++)	10			
2150 (RCP 2.6)	2.4	1.3 — 3.8	5.5	11.0
2150 (RCP 4.5)	3.0	1.7 — 4.6	6.4	11.7
2150 (RCP 8.5)	4.1	2.8 — 5.8	7.7	13.0
2150 (H++)	22			

Figure S4. Table summarizing RSL projections for San Francisco, CA, from the 2017 California sea level assessment [41].

TABLE 1: Projected Sea-Level Rise (in feet) for San Francisco

Probabilistic projections for the height of sea-level rise shown below, along with the H++ scenario (depicted in blue in the far right column), as seen in the Rising Seas Report. The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009. High emissions represents RCP 8.5; low emissions represents RCP 2.6. ***Recommended projections for use in low, medium-high and extreme risk aversion decisions are outlined in blue boxes below.***

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)					*H++ scenario (Sweet et al. 2017) *Single scenario*
		MEDIAN	**LIKELY RANGE**		**1-IN-20 CHANCE**	**1-IN-200 CHANCE**	
		50% probability sea-level rise meets or exceeds…	*66% probability sea-level rise is between…*		*5% probability sea-level rise meets or exceeds…*	*0.5% probability sea-level rise meets or exceeds…*	
				Low Risk Aversion		**Medium - High Risk Aversion**	**Extreme Risk Aversion**
High emissions	2030	0.4	0.3 -	0.5	0.6	0.8	1.0
	2040	0.6	0.5 -	0.8	1.0	1.3	1.8
	2050	0.9	0.6 -	1.1	1.4	1.9	2.7
Low emissions	2060	1.0	0.6 -	1.3	1.6	2.4	
High emissions	2060	1.1	0.8 -	1.5	1.8	2.6	3.9
Low emissions	2070	1.1	0.8 -	1.5	1.9	3.1	
High emissions	2070	1.4	1.0 -	1.9	2.4	3.5	5.2
Low emissions	2080	1.3	0.9 -	1.8	2.3	3.9	
High emissions	2080	1.7	1.2 -	2.4	3.0	4.5	6.6
Low emissions	2090	1.4	1.0 -	2.1	2.8	4.7	
High emissions	2090	2.1	1.4 -	2.9	3.6	5.6	8.3
Low emissions	2100	1.6	1.0 -	2.4	3.2	5.7	
High emissions	2100	2.5	1.6 -	3.4	4.4	6.9	10.2
Low emissions	2110*	1.7	1.2 -	2.5	3.4	6.3	
High emissions	2110*	2.6	1.9 -	3.5	4.5	7.3	11.9
Low emissions	2120	1.9	1.2 -	2.8	3.9	7.4	
High emissions	2120	3	2.2 -	4.1	5.2	8.6	14.2
Low emissions	2130	2.1	1.3 -	3.1	4.4	8.5	
High emissions	2130	3.3	2.4 -	4.6	6.0	10.0	16.6
Low emissions	2140	2.2	1.3 -	3.4	4.9	9.7	
High emissions	2140	3.7	2.6 -	5.2	6.8	11.4	19.1
Low emissions	2150	2.4	1.3 -	3.8	5.5	11.0	
High emissions	2150	4.1	2.8 -	5.8	5.7	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

Figure S5. Table summarizing RSL projections for San Francisco, CA, from the 2018 California sea level rise guidance, highlighting the selection of specific trajectories for different levels of risk aversion [49].

Table 3.2. **New York City sea level rise projections, including the new Antarctic Rapid Ice Melt (ARIM) scenario, relative to 2000–2004 (in feet)**

	NPCC2 2015 sea level rise projections[a] Projections of record for planning			NPCC3 ARIM scenario[b] Growing awareness of long-term risk
Baseline (2000–2004) 0"	Low estimate (10th percentile)	Middle range (25–75th percentile)	High estimate (90th percentile)	ARIM scenario[a]
2020s	0.17 ft	0.33–0.67 ft	0.83 ft	–
2050s	0.67 ft	0.92–1.75 ft	2.5 ft	–
2080s	1.08 ft	1.50–3.25 ft	4.83 ft	6.75 ft
2100	1.25 ft	1.83–4.17 ft	6.25 ft	9.5 ft

[a]The 10th, 25th–75th, and 90th percentile projections are taken from NPCC2 (2015); the six sea level rise components upon which they are based include global and local factors (see Section 3.4.2 and NPCC (2015)). Use of NPCC2 sea level rise projections is confirmed for decision making at this time. The ARIM scenario is based on DeConto and Pollard (2016), Kopp *et al.* (2014; 2017) and informed expert judgments with regard to maximum plausible ice loss rates from Antarctica (see above and Sweet *et al.*, 2017). See this section and Appendix 3.B for full ARIM scenario and explanation.

[b]ARIM represents a new, physically plausible upper-end, low probability (significantly less than 10% likelihood of occurring) scenario for the late 21st century, derived from recent modeling of ice sheet–ocean behavior to supplement the current (NPCC, 2015) sea level rise projections. In the 2020s and 2050s, the ARIM scenario does not lie outside the pre-existing NPCC 2015 range and therefore NPCC 2015 results apply to these two earlier time slices. The ARIM scenario contains uncertainties stemming from incomplete knowledge of ice-sheet processes and atmosphere, ocean, and ice–sheet interactions.

Figure S6. Table summarizing RSL projections for New York, NY, from the 2019 New York City Panel on Climate Change report [42].

Table 2. Projected sea-level rise estimates above 2000 levels for Maryland based on the Baltimore tide-gauge station. Columns correspond to different projection probabilities and rows represent to time horizons and emissions pathways. See caveat in the text concerning potentially greater sea-level rise late this century under higher emissions pathways.

Year	Emissions Pathway	Central Estimate 50% probability SLR meets or exceeds:	Likely Range 67% probability SLR is between:	1 in 20 Chance 5% probability SLR meets or exceeds:	1 in 100 Chance 1% probability SLR meets or exceeds:
2030		0.6 ft	0.4 – 0.9 ft	1.1 ft	1.3 ft
2050		1.2 ft	0.8 – 1.6 ft	2.0 ft	2.3 ft
2080	Growing	**2.3 ft**	1.6 – 3.1 ft	3.7 ft	4.7 ft
	Stabilized	1.9 ft	1.3 – 2.6 ft	3.2 ft	4.1 ft
	Paris Agreement	1.7 ft	1.1 – 2.4 ft	3.0 ft	3.2 ft
2100	Growing	3.0 ft	2.0 – 4.2 ft	5.2 ft	6.9 ft
	Stabilized	2.4 ft	1.6 – 3.4 ft	4.2 ft	5.6 ft
	Paris Agreement	2.0 ft	1.2 – 3.0 ft	3.7 ft	5.4 ft
2150	Growing	4.8 ft	3.4 – 6.6 ft	8.5 ft	12.4 ft
	Stabilized	3.5 ft	2.1 – 5.3 ft	7.1 ft	10.6 ft
	Paris Agreement	2.9 ft	1.8 – 4.2 ft	5.9 ft	9.4 ft

An important caveat using these projections: In not accounting for the prospect of greater polar ice sheet loss, the K14 projections probably underestimate sea-level rise beyond 2050 under higher emissions pathways. While the DP16 projections might be over-estimates, they can serve to inform decisions for which risk aversion is relatively high. Under the Growing Emissions pathway the median (and Likely) sea-level rise projections are 3.6 feet (2.7-4.9 feet) for 2080 and 5.7 feet (4.2-7.9 feet) by 2100. Under the Stabilized Emissions pathway, DP16 projections begin to significantly diverge from K14 after 2080, with median (and Likely) sea-level rise of 3.7 feet (2.6-5.0 feet) for 2100.

Figure S7. Table and text summarizing RSL projections for Baltimore, MD, from the 2018 Maryland sea level rise assessment [44].

Table ES-1: New Jersey Sea-Level Rise above the year 2000 (1991-2009 average) baseline (ft)*

		2030	2050	2070			2100			2150		
				Emissions								
	Chance SLR Exceeds			Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

**2010 (2001-2019 average) Observed = 0.2 ft*

Notes: All values are 19-year means of sea-level measured with respect to a 1991-2009 baseline centered on the year indicated in the top row of the table. Projections are based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Near-term projections (through 2050) exhibit only minor sensitivity to different emissions scenarios (<0.1 feet). Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global-mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low-emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLR exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLR will fall within the values in the 'Likely Range'. Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes.

Figure S8. Table summarizing RSL projections for New Jersey from the 2019 New Jersey Science and Technical Advisory Panel Report [45].

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

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%

Figure S9. Tables summarizing GMSL and contiguous US-average RSL scenarios from the 2022 US Interagency Sea Level Scenarios report (Table 2.3) and linking the 2022 US Interagency Sea Level Scenarios to the IPCC Sixth Assessment Report projections (Table 2.4) [48].

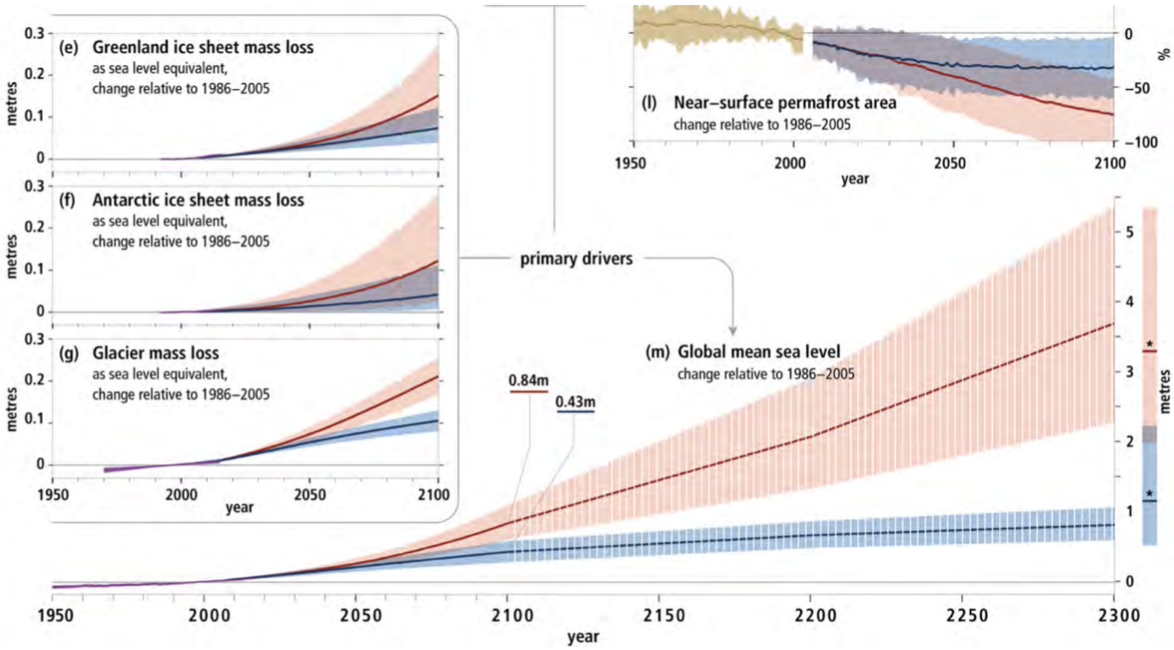

Figure S10. SPM figure from the IPCC SROCC, Figure SPM.1 [52].

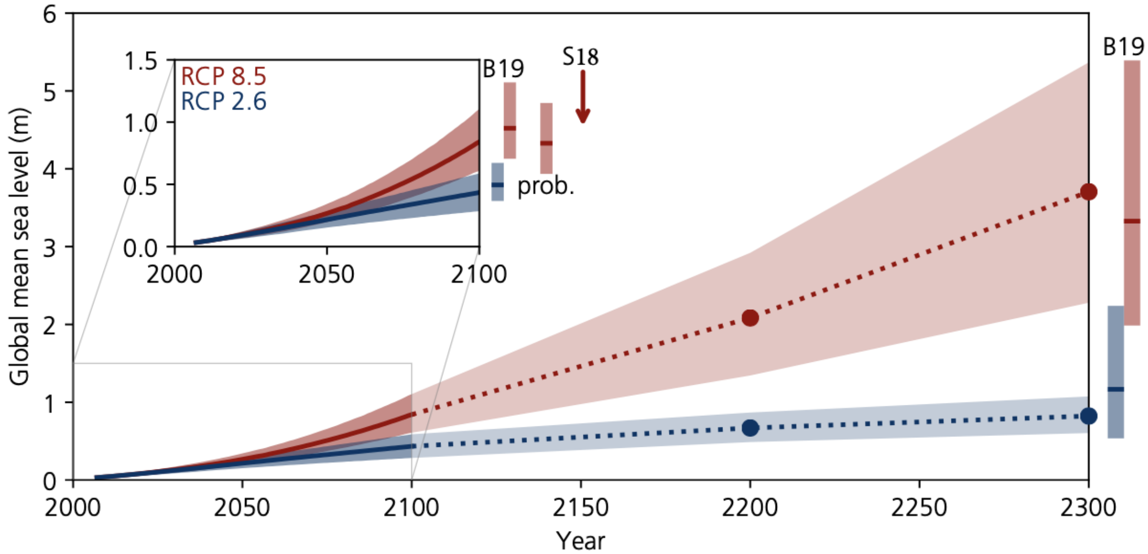

Figure 4.2: Projected sea-level rise until 2300. The inset shows an assessment of the *likely* range of the projections for RCP2.6 and RCP8.5 up to 2100 (*medium confidence*). Projections for longer time scales are highly uncertain but a range is provided (4.2.3.6). For context, results are shown from other estimation approaches in 2100. The two sets of two bars labelled B19 are from an expert elicitation for the Antarctic component (Bamber et al., 2019), and reflect the *likely* range for a 2 and 5°C temperature warming (*low confidence*; details section 4.2.3.3.1). The bar labelled "prob". indicates the *likely* range of a set of probabilistic projections (4.2.3.2). The arrow indicated by S19 shows the result of an extensive sensitivity experiment with a numerical model for the Antarctic ice sheet combined, like the results from B19 and "prob.", with results from Church et al. (2013) for the other components of sea level rise. S19 bars also show the *likely* range.

Figure S11. Chapter figure from the IPCC SROCC [51].

Table 9.9 | Global mean sea level projections for five Shared Socio-economic Pathway (SSP) scenarios, relative to a baseline of 1995–2014, in metres. Individual contributions are shown for the year 2100. Median values (*likely* ranges) are shown. Average rates for total sea level change are shown in mm yr^{-1}. Unshaded cells represent processes in whose projections there is *medium confidence*. Shaded cells incorporate a representation of processes in which there is *low confidence*; in particular, the SSP5-8.5 *low confidence* column shows the 17th–83rd percentile range from a p-box including SEJ- and MICI-based projections rather than an assessed *likely* range. Methods are described in 9.6.3.2.

	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP5-8.5 *Low Confidence*
Thermal expansion	0.12 (0.09–0.15)	0.14 (0.11–0.18)	0.20 (0.16–0.24)	0.25 (0.21–0.30)	0.30 (0.24–0.36)	0.30 (0.24–0.36)
Greenland	0.05 (0.00–0.09)	0.06 (0.01–0.10)	0.08 (0.04–0.13)	0.11 (0.07–0.16)	0.13 (0.09–0.18)	0.18 (0.09–0.59)
Antarctica	0.10 (0.03–0.25)	0.11 (0.03–0.27)	0.11 (0.03–0.29)	0.11 (0.03–0.31)	0.12 (0.03–0.34)	0.19 (0.02–0.56)
Glaciers	0.08 (0.06–0.10)	0.09 (0.07–0.11)	0.12 (0.10–0.15)	0.16 (0.13–0.18)	0.18 (0.15–0.21)	0.17 (0.11–0.21)
Land-water Storage	0.03 (0.01–0.04)	0.03 (0.01–0.04)	0.03 (0.01–0.04)	0.03 (0.02–0.04)	0.03 (0.01–0.04)	0.03 (0.01–0.04)
Total (2030)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.10 (0.08–0.12)	0.10 (0.09–0.12)	0.10 (0.09–0.15)
Total (2050)	0.18 (0.15–0.23)	0.19 (0.16–0.25)	0.20 (0.17–0.26)	0.22 (0.18–0.27)	0.23 (0.20–0.29)	0.24 (0.20–0.40)
Total (2090)	0.35 (0.26–0.49)	0.39 (0.30–0.54)	0.48 (0.38–0.65)	0.56 (0.46–0.74)	0.63 (0.52–0.83)	0.71 (0.52–1.30)
Total (2100)	**0.38 (0.28–0.55)**	**0.44 (0.32–0.62)**	**0.56 (0.44–0.76)**	**0.68 (0.55–0.90)**	**0.77 (0.63–1.01)**	**0.88 (0.63–1.60)**
Total (2150)	0.57 (0.37–0.86)	0.68 (0.46–0.99)	0.92 (0.66–1.33)	1.19 (0.89–1.65)	1.32 (0.98–1.88)	1.98 (0.98–4.82)
Rate (2040–2060)	4.1 (2.8–6.0)	4.8 (3.5–6.8)	5.8 (4.4–8.0)	6.4 (5.0–8.7)	7.2 (5.6–9.7)	7.9 (5.6–16.1)
Rate (2080–2100)	4.2 (2.4–6.6)	5.2 (3.2–8.0)	7.7 (5.2–11.6)	10.4 (7.4–14.8)	12.1 (8.6–17.6)	15.8 (8.6–30.1)

Table 9.10 | Global mean sea level (GMSL) projections and commitments for exceedance of five global warming levels, defined by sorting GSAT change in 2081–2100 with respect to 1850–1900. Median values and (*likely*) ranges are in metres relative to a 1995–2014 baseline. Rates are in mm yr^{-1}. Unshaded cells represent processes in whose projections there is *medium confidence*. Shaded cells incorporate a representation of processes in which there is *low confidence*; in particular, the SSP5-8.5 *low confidence* column shows the 17th–83rd percentile range from a p-box, including projections based on structured expert judgement (SEJ) and marine ice cliff instability (MICI) rather than an assessed *likely* range. Methods are described in 9.6.3.2.

	1.5°C	2.0°C	3.0°C	4.0°C	5.0°C	SSP5-8.5 *Low Confidence*
Closest SSPs	SSP1-2.6	SSP1-2.6/SSP2-4.5	SSP2-4.5/SSP3-7.0	SSP3-7.0	SSP5-8.5	
Total (2050)	0.18 (0.16–0.24) m	0.20 (0.17–0.26) m	0.21 (0.18–0.27) m	0.22 (0.19–0.28) m	0.25 (0.22–0.31) m	0.24 (0.20–0.40) m
Total (2100)	**0.44 (0.34–0.59) m**	**0.51 (0.40–0.69) m**	**0.61 (0.50–0.81) m**	**0.70 (0.58–0.92) m**	**0.81 (0.69–1.05) m**	**0.88 (0.63–1.60) m**
Rate (2040–2060)	4.1 (2.9–5.7) mm yr^{-1}	5.0 (3.7–7.0) mm yr^{-1}	6.0 (4.6–8.1) mm yr^{-1}	6.4 (5.0–8.6) mm yr^{-1}	7.2 (5.7–9.8) mm yr^{-1}	7.9 (5.6–16.1) mm yr^{-1}
Rate (2080–2100)	4.3 (2.6–6.4) mm yr^{-1}	5.5 (3.4–8.4) mm yr^{-1}	7.8 (5.3—11.6) mm yr^{-1}	9.9 (7.1–14.3) mm yr^{-1}	11.7 (8.5–17.0) mm yr^{-1}	15.8 (8.6–30.1) mm yr^{-1}
2000-yr commitment	2 to 3 m	2 to 6 m	4 to 10 m	12 to 16 m	19 to 22 m	
10,000-yr commitment	6 to 7 m	8 to 13 m	10 to 24 m	19 to 33 m	28 to 37 m	

Figure S12. Chapter tables from the IPCC AR6 [1].