Factsheet

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Climate Systems

National Environmental Science Program

Oceans and Coasts

Understanding sea-level projections

Projecting future sea-level rise is complex. Future sea-level projections carry an inherent degree of uncertainty, driven by the complex interaction of various factors, which can be broadly grouped into four categories.

Greenhouse gas emissions and policy responses

The uncertainty of the amount of sea-level rise (SLR) we will experience stems from not being able to foresee future choices and actions of governments and citizens.

- The level of future SLR largely depends on the rise or fall of global emissions of greenhouse gases (GHG) in coming decades. This trajectory is governed by socioeconomic factors, advances in technology and responses through international policy and action (or inaction).
- A series of emissions scenarios is outlined by the Intergovernmental Panel on Climate Change (IPCC): Representative Concentration Pathways (RCPs) and more recently, Shared Socioeconomic Pathways (SSPs).
- Modelling these emissions scenarios shows different expected levels of warming and, consequently, projected sea-level rise.

Climate models

Uncertainty arises because of differences between climate models.

- Climate models are crucial tools used for projecting future changes in 'dynamic sea levels.' Dynamic sea level change is a critical factor in regional sea-level projections. It is influenced by ocean dynamics, which include various oceanic and atmospheric processes such as currents and wind.
- Uncertainty in climate models arises due to gaps in knowledge of the Earth's climate system. Different models produce varying results depending on the underlying assumptions, how key processes are simulated or parameterised, and how they simulate interactions between the atmosphere, oceans, and ice sheets.

Ice sheet dynamics

A significant challenge in precisely determining sea-level projections stems from our limited understanding of how ice sheets at both poles will respond to future climate changes.

- Greenland and Antarctica contain significant amounts of frozen water: if all this frozen water melted it would equate to around 7m (from Greenland), and 58 m (from Antarctica), of sea level rise equivalent.
- The dynamics of ice sheet melting are complex and not fully understood (or simulated through models). Significant uncertainty comes from factors such as the instability of ice cliffs, the rate of melting at the base of ice sheets, and the speed that glaciers flow into the ocean. These processes are difficult to model accurately, and small changes in ice sheet behaviour could lead to large variations in sea-level rise.

Regional variability

Sea-level rise is not uniform across the globe and can vary a lot.

Regional variation is caused by:

- ocean currents and atmospheric changes that are simulated directly by climate models
- gravitational-rotational-deformational response to land ice mass changes, known as sea-level fingerprints
- land subsidence (for example, due to groundwater extraction)
- tectonic activity from volcano eruptions.

This adds another layer of complexity in future sea-level projections for specific areas.

Figure 1 illustrates several sources of uncertainty.

- The uncertainty in greenhouse gas emissions is represented by a set of illustrative shared socioeconomic pathway emission scenarios, ranging from one representing very low greenhouse gas emissions (SSP1–1.9) to one representing very high greenhouse gas emissions (SSP5–8.5). The uncertainty here is because we do not understand the societal and political decisions that will influence which SSP we will track.
- There is also uncertainty from factors that contribute to sea-level rise. The mean sea-level projections for each scenario are provided by the solid line while the uncertainty arising from the models' representation of factors such as ocean dynamics and ice sheet dynamics is represented by light shading for the lowest and highest pathways. For example, in 2120 under the SSP1–1.9 scenario sea-level rise is projected to be 0.41 m higher than the 1995 to 2014 baseline but with an uncertainty range of 0.14 to 0.75 m: whereas for SSP5–8.5 it is projected to be 0.90 m with an uncertainty range of 0.61 to 1.30 m.

For the purposes of sea-level projections, the set of projections illustrated in Figure 1 is considered to be of 'medium confidence' because it includes processes for which scientists have medium confidence that they will occur as projected.

Scientists also produce 'low confidence' projections that account for potentially larger contributions to sea-level rise from ice sheet processes, such as ice cliff instability: these are currently poorly understood but are an active area of research.

Such projections are useful for practitioners who are risk averse. That is, they may have low risk tolerance in planning for critical infrastructure such as cities, ports, industries or cultural heritage and may wish to consider a plausible worst-case scenario. These projections are also used for risk screening and stress testing adaptation options.

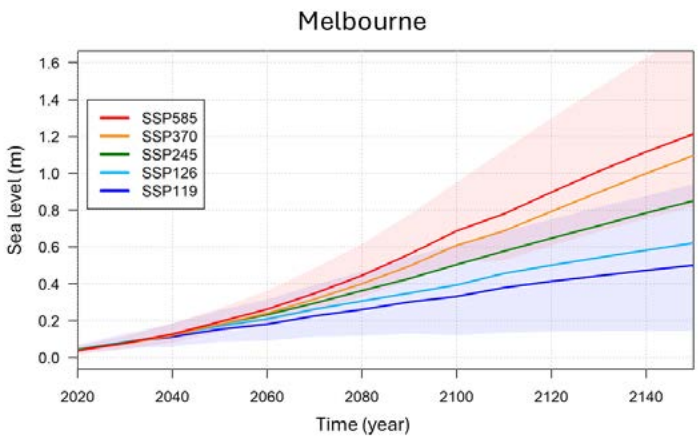

Figure 1: The projected sea level changes to 2150 for five shared socioeconomic pathways (SSPs) for Melbourne relative to the baseline period of 1995–2014. For each pathway, the thickened solid curve indicates the median value and for the lowest (blue line) and highest (red line) pathways, the pale shading indicates the uncertainty.

How to account for sea-level rise uncertainty in adaptation decision-making

Engage with decision makers

Determining expected sea-level rise for a specific location is a complex process. Engaging in a participatory approach that involves local communities, stakeholders, and decision-makers can effectively convey the intricate details underlying the projections.

By including those most directly impacted by sea-level rise, adaptation strategies can be tailored to reflect local needs, values, priorities, and risk tolerance. This collaborative approach also fosters public support for essential adaptive measures, even when these measures could be costly.

Understand the context

Given there is a range of possible outcomes provided by sea-level projections, adaptation strategies must be robust, flexible, and able to accommodate a range of potential futures.

The starting point for adaptation planning involves identifying the decision context.

1. The level of uncertainty that should be considered, or what is the 'uncertainty tolerance'.

   Decision makers may be risk averse and have a low tolerance for uncertainty, where a low uncertainty tolerance equates to preparing for unlikely but extreme outcomes.

   For example, London's Thames Barrier was built to protect London from extreme storm surges and sea-level rise. Designed to handle worst-case scenarios, the barrier has regular upgrades to ensure it can continue protecting against higher-than-expected sea-level rise.

   Decision makers with a higher tolerance for uncertainty may take a more flexible or minimal approach, focusing on the most likely scenarios rather than extreme ones.

   For example, coastal communities could opt for more gradual adaptation options (such as elevating homes, restoring wetlands as buffers, land-use planning to re-zone vulnerable areas) that buy time while encouraging longer term relocation. Such strategies may accept there will be long term change in the future but adopt incremental rather than more radical adaptation.

2. The decision or time horizon for planning, implementation and operation of the adaptation measures.

   These can range from short- to long-term strategies, spanning years to centuries.

   - Short-term: strategies such as beach nourishment, where eroding beaches are replenished with sand on a timescale of years.
   - Medium-term: strategies like building seawalls to protect properties over several decades.
   - Long-term: approaches involving critical infrastructure or land-use that account for changes up to or beyond 2100.

3. The ability to adaptively manage the response, which is most relevant for long-term adaptation, with strategies adjusted over time to respond to new data and changing conditions.

Scenario-based planning

Scenario-based planning, rather than focus on a single sea-level rise pathway, explores several plausible scenarios to develop adaptation strategies that are flexible across a range of possible futures. This approach uses different emissions and sea-level rise scenarios (for example, low, medium, and high) to test how different adaptation measures perform. By considering a spectrum of outcomes, planners can avoid over-reliance on any single projection and better prepare for uncertain futures.

Adaptive decision-making

Adaptive decision-making emphasises flexibility and the need for strategies to be reassessed as more information becomes available. This means developing strategies that can be adjusted over time in response to new scientific findings or as the impacts of sea-level rise become clearer.

For instance, coastal defences might be built with the capacity to be heightened or strengthened as sea levels rise.

Included in adaptive decision-making approaches is real-option analysis or optimal control, which applies financial concepts to adaptation planning, allowing decision-makers to weigh the costs and benefits of acting now versus waiting for more information. This method helps balance the cost of acting too early—such as investing in expensive sea defences before they are needed—against the risks of waiting too long, like being unprepared for faster-than-expected sea-level rise. It supports a phased approach to adaptation where investments are made incrementally, allowing future adjustments based on how sea-level rise evolves.

No-regret and low-regret options

No-regret strategies are those that deliver benefits regardless of the degree of sea-level rise. For example, restoring wetlands provides natural flood protection while also enhancing biodiversity and improving water quality, regardless of how much sea levels rise.

Similarly, elevating or improving infrastructure in flood-prone areas may reduce risks today and in the future. For example, Perth, Western Australia, has invested in better stormwater systems, which not only address potential flooding from sea-level rise but also help manage heavy rainfall events, reduce urban runoff pollution, and improve water quality in rivers and oceans.

Low-regret options, on the other hand, involve actions that have relatively low costs but significant potential benefits if sea levels rise as expected. For example, floodplain planning documents recommend increasing floor heights for new or existing developments to allow for the effects of sea-level rise and establishing local adaptation plans to manage the future risk from flooding and tidal inundation in low-lying suburbs.

Risk assessment and probabilistic approaches

Risk-based approaches incorporate sea-level projections with different probabilities into decision-making, to support policymakers to evaluate the likelihood of different outcomes.

For example, using this information in conjunction with other modelling – such as applications that consider the likely extent of coastal erosion – could provide more comprehensive insights to inform decision-making.

This helps in setting acceptable risk thresholds for various adaptation measures. For instance, critical infrastructure such as power plants or airports may require protection against extreme, high-end projections of sea-level rise, while less critical infrastructure may rely on lower projections of sea-level rise.

Looking ahead

The uncertainty surrounding future sea-level rise presents challenges for adaptation decision-making. By combining flexible, robust, and risk-based strategies, decision-makers can reduce vulnerability to future changes, even in the face of unknown outcomes. Proactive planning, combined with regular reassessment and adaptive management, will be key to effectively managing the risks posed by sea-level rise.

More information

This explainer is delivered in conjunction with the National Environmental Science Program's Climate Systems Hub Oceans and Coasts project.

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To understand more about sea-level rise impacts and response options visit the CoastAdapt website www.coastadapt.com.au

Cite this article as:

McInnes, K., Zhang, X., Bloustein, H., & Dalla Pozza, R. (2025). Explaining sea-level rise. National Environmental Science Program Climate Systems Hub.