Factsheet

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Climate Systems

National Environmental Science Program

Oceans and Coasts

Sea level is not actually level so how do we estimate sea-level rise?

Global mean sea level has risen by over 22 cm since 1900, with half of this increase occurring since 1970. In the Australian region, the rate of sea-level rise varies, with the largest increases observed in the north and southeast of the continent.

Global sea levels will continue to rise for decades, even with reduced emissions. While cutting emissions may help to slow the rate of sea-level rise, it cannot reverse the rising trend. Rising sea levels are a major adaptation challenge for Australia as most of our population lives in towns and cities within 50 km of the coast. Although we know sea levels will be higher in the future, the rise is not uniform and varies across regions, adding complexity for planners and decision makers.

READ: Explaining sea level rise to learn more about what contributes to sea-level rise.

Climate models can help explain what to expect

One of the most pressing questions is how much—and how quickly—sea levels will rise. While there is no straightforward answer, we have well-researched tools, such as climate models, that help us explore potential future scenarios.

Sea level projections provide essential information for future planning and adaptation in the coastal zone.
They equip coastal practitioners with the information to identify coastal infrastructure that will be vulnerable in the future and guide land-use planning and adaptive strategies.

Climate models are used to provide these projections.

While most decision-makers focus on how best to apply these projections, some seek to understand the science behind their development and the methodologies employed by researchers.

Understanding what underpins climate modelling

Climate models cannot fully capture all the factors that drive sea-level rise. Developing accurate projections of future sea-level rise requires integration of various types of models to account for the different contributing processes. Additionally, a comprehensive method is needed to combine these components into a cohesive projection.

Using climate models to predict future sea level

Climate models are essential tools for representing dynamic sea-level changes. They simulate thermal expansion, which occurs as ocean water warms, which raise sea levels. This thermal expansion is not uniform across the globe; regional variations arise due to differences in ocean density and circulation patterns closely tied to ocean dynamics.

In addition to thermal expansion, climate models represent precipitation (rain and snow) and temperature changes, which directly impact the gain and loss of ice over ice sheets and glaciers. This process is known as Surface Mass Balance. However, the low spatial resolution of the climate models means that estimates of Surface Mass Balance are not considered sufficiently precise for use in sea-level projections.

Instead, separate glacier and ice sheet models are used to estimate their contributions to sea-level rise. These specialised models focus on processes such as ice flow, melting, and accumulation to produce more accurate predictions. Similarly, changes in land water storage are derived from models for population change and groundwater depletion.

Another critical aspect is the redistribution of mass and the gravitational pull of ice sheets. Redistribution of mass—the movement of mass from glaciers, ice sheets and other land water storages, such as dams and underground aquifers — leads to changes to Earth's gravity, rotation as well as deformation of the Earth's crust (Figure 1). This spatial pattern of change is determined using the so-called sea-level equation. The resulting distribution patterns, known as sea-level fingerprints, are used to adjust the spatial pattern of sea-level rise at different locations across the ocean: sea levels fall near the sources of ice melt, and rise—slightly above the global average—far away from those sources.

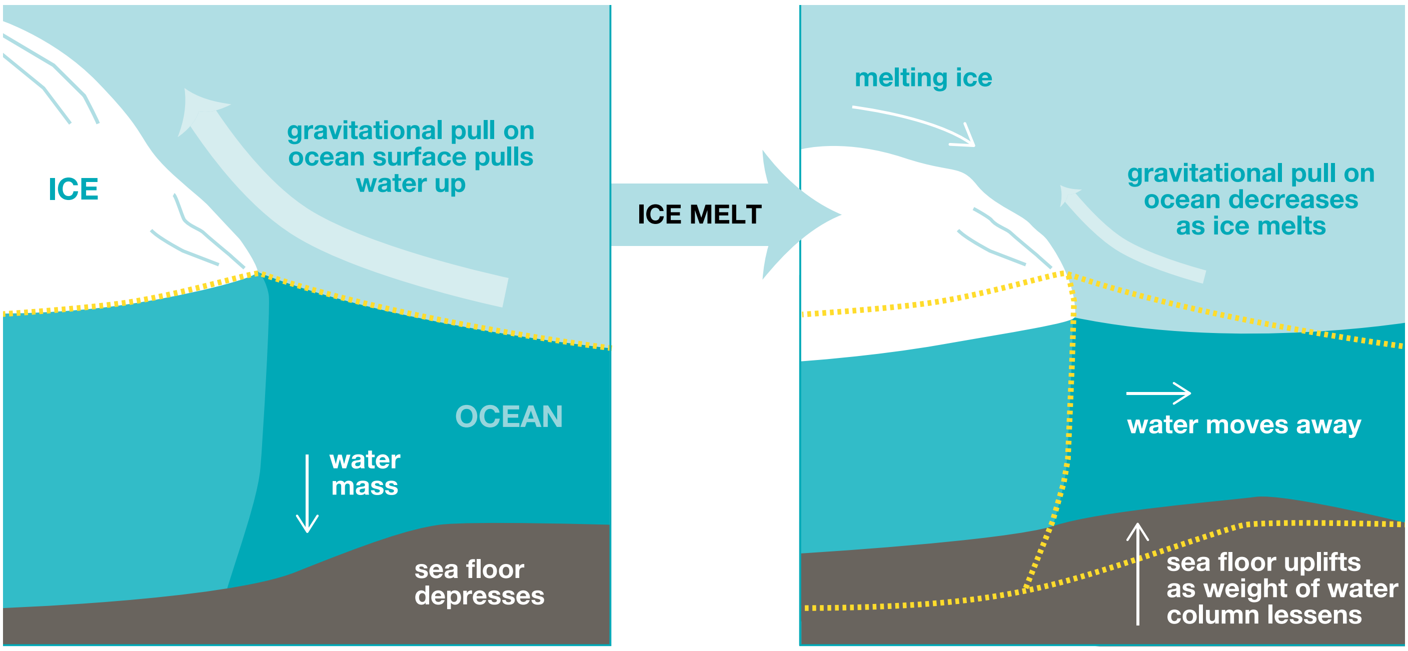

Figure 1: Ice sheets exert a gravitational pull on the ocean surface causing locally higher sea levels and lower sea floor (left). As the ice sheets melt, the gravitational pull on the ocean declines and the water moves away sea floor rebounds, which work together to lead to local sea level fall, but an increase in sea levels in the far fields. Diagram adapted from https://www.antarcticglaciers.org/glaciers-and-climate/sea-level-rise-2/recovering-from-an-ice-age/ and Tamisiea et al., (2003).

Vertical land movement can affect local relative sea-level rise from a few different sources that operate over different time scales.

- An ancient source, known as Glacial Isostatic Adjustment is a slow movement of the Earth's crust in response to melting of large ice sheets after the last ice age, which can cause the land to rise or fall.
- Contemporary land ice mass changes can also induce vertical land movement globally as illustrated in Figure 1.
- On shorter time scales, various processes – such as urban development, sediment compaction, the removal of groundwater, or oil and gas extraction – can lead to land subsidence (sinking of the ground) and an increase in relative sea-level rise.
- Tectonic activity, such as earthquakes and volcanoes, can also lead to ongoing land movement changes or abrupt changes in land level.

Developing IPCC sea-level projections

When projecting future climates using climate models, the starting point is a set of assumptions, or scenarios, about future anthropogenic greenhouse gas and aerosol emissions. These are linked to socio-economic pathways – known as shared socioeconomic pathways (SSPs) – because factors such as population growth, future energy generation and globalisation ultimately determine the amount of greenhouse gases and aerosols that will be emitted.

The International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) uses simplified models or 'emulators' (designed to replicate the outcomes of more complex climate models) to integrate multiple sources of evidence and so provide a more refined estimate of climate warming and narrow the uncertainty range. To improve the accuracy of these emulators, several key factors are incorporated. These include recent historical climate observations, older records from palaeoclimate data, outputs from climate models, energy balance constraints, and feedback mechanisms such as those involving water vapour and clouds.

The estimated warming range for a doubling of carbon dioxide (CO_2) in the AR6 was 2.5°C to 4°C, which is narrower than that from the Fifth Assessment Report (AR5) of 1.5°C to 4.5°C. This reflects improved understanding of climate processes and data from both models and paleoclimate evidence.

The use of emulators has additional benefits. They simplify the process and reduce the computational cost to thoroughly assess model uncertainties. This enables sea-level projections to extend further into the future than most climate model simulations.

Moreover, emulators ensure consistency in representing contributions from ice sheets and glaciers. Many earlier models were developed using different scenarios, but emulators help standardise these contributions across models and scenarios, enhancing the reliability of projections.

Sea-level projections for Australia

The IPCC Sixth Assessment global sea-level projections enhanced our understanding of how sea-level rise may play out globally. However, further analysis was needed to refine these projections and improve the fit for Australia. The AR6 projections included Vertical Land Movement from Glacial Isostatic Adjustment and an estimate of Vertical Land Movement from an analysis of tide-gauge data. However, for some regions in Australia, these estimates of vertical land movement did not align with local observations.

To address this discrepancy, CSIRO developed projections for Australia. These included the Glacial Isostatic Adjustment but excluded Vertical Land Movement that the IPCC evaluated based on tide-gauge and GPS data. This approach is consistent with the IPCC Fifth Assessment Report. Much of the Australian coastline only experiences minimal vertical land motion so mostly, it is sufficient to only consider Glacial Isostatic Adjustment.

Projections for sea-level rise specific to Australia highlight that regional differences are influenced by various factors. For instance, the dynamical (thermal expansion) component of the sea-level pattern projection for 2080–2100 relative to 1995–2014 under a very high emissions scenario (SSP5-8.5) is shown in Figure 2a. It indicates that sea-level rise is projected to be larger along the eastern coastline (around 33–34cm) compared to the southern and western coastline (22–26cm). This difference is related to poleward shifting and strengthening of the East Australian Current.

The projected contribution from melting ice sheets and glaciers will affect Australia's coastline relatively uniformly (Figure 2b).

For example, along the southern Tasmanian coast, this contribution is slightly lower at 48cm, whereas the Torres Strait region is projected to experience a slightly higher contribution of around 51cm. Vertical land movement due to glacial isostatic adjustment is shown in Figure 2c and depicts a small reduction in sea level of around 3–4cm along the entire coastline.

The sum of these components provides the median sea-level rise for the Australian region in 2080–2100 relative to 1995–2014 under a very high emissions scenario (SSP5-8.5), and this is shown in Figure 2d.

These refined projections help provide a more accurate assessment of regional impacts and inform adaptation strategies for Australia's coastal areas.

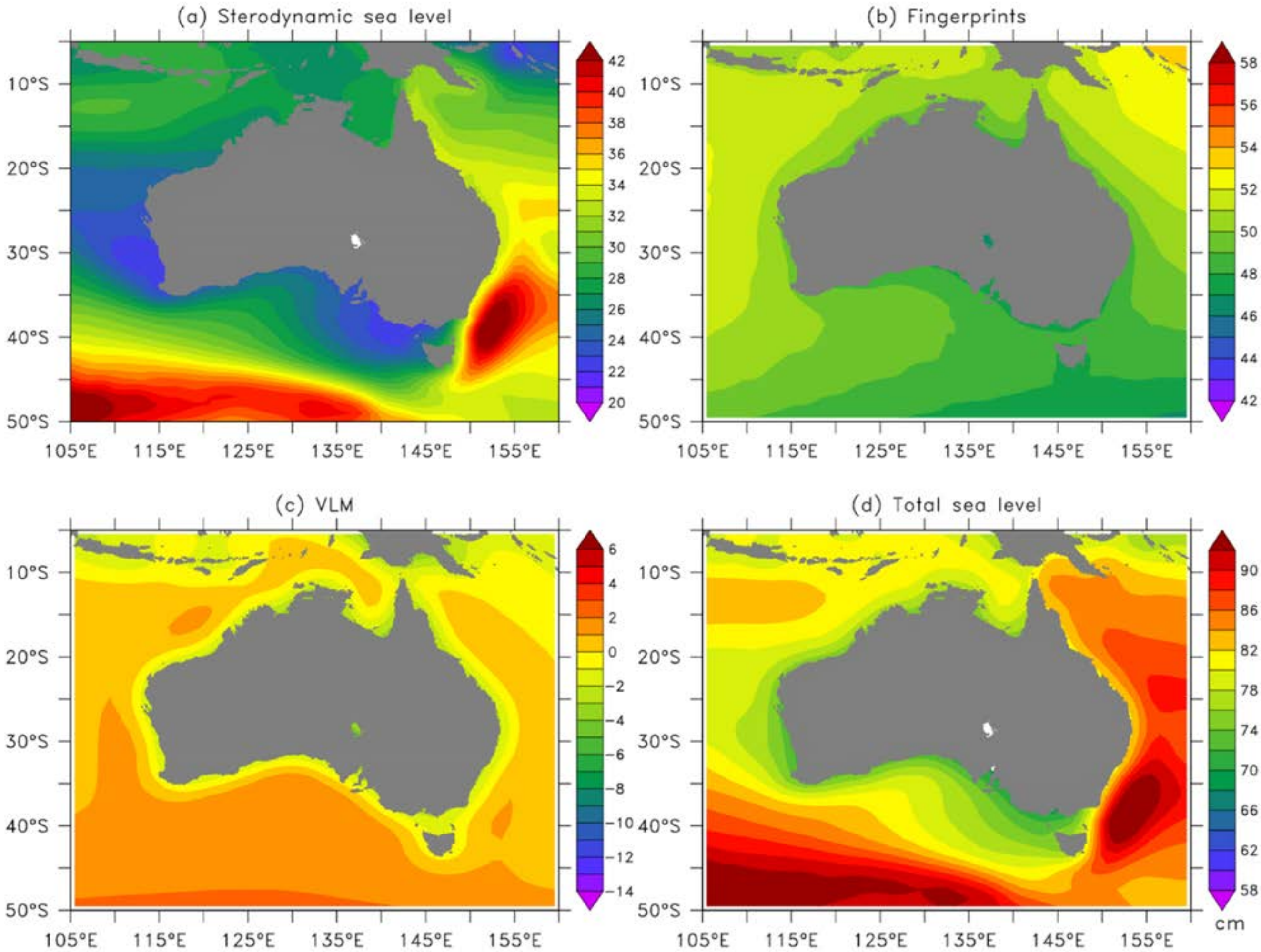

Figure 2: CSIRO projected median regional sea-level change (unit: cm) for the Australian region for the years 2080–2100 relative to 1995–2014 under SSP5-8.5 for (a) sterodynamic sea level (including global mean thermal expansion and regional deviations referred to as dynamic sea level), (b) fingerprints; the sum of various regional sea-level contributions due to changes of land ice mass and groundwater (i.e., sea-level fingerprints including their global means), (c) VLM comprising regional sea level due to glacial isostatic adjustment only.

Total sea-level projections to 2150 are shown for four locations around the Australian coast in Figure 3, under five different emissions scenarios. These reveal that sea-level projections for Sydney and Torres Strait are higher than those for Fremantle and Melbourne. For example, under a very high emissions scenario (SSP5–8.5), the multi-model mean projected sea-level rise for Melbourne in 2100 is 0.69m while for Sydney it is 0.82m, 13cm higher. By 2150, Melbourne's mean projected sea-level rise reaches 1.21m whereas for Sydney it is 1.41m, 20cm higher.

For lower emissions scenarios, the projected sea-level rise and regional differences are lower.

For example, for a very low emissions scenario (SSP1–1.9), the mean sea-level rise projected for 2150 in Melbourne is 0.50m, and for Sydney it is 0.55m. The confidence range for the SSP5–8.5 and SSP1–1.9 scenarios are shown in pale red and blue shading respectively. These indicate that there are more unknowns further into the future, particularly for the upper range of SSP5–8.5 due to the complexities and unknowns around the future behaviour of the Greenland and Antarctic ice sheets under high levels of global warming.

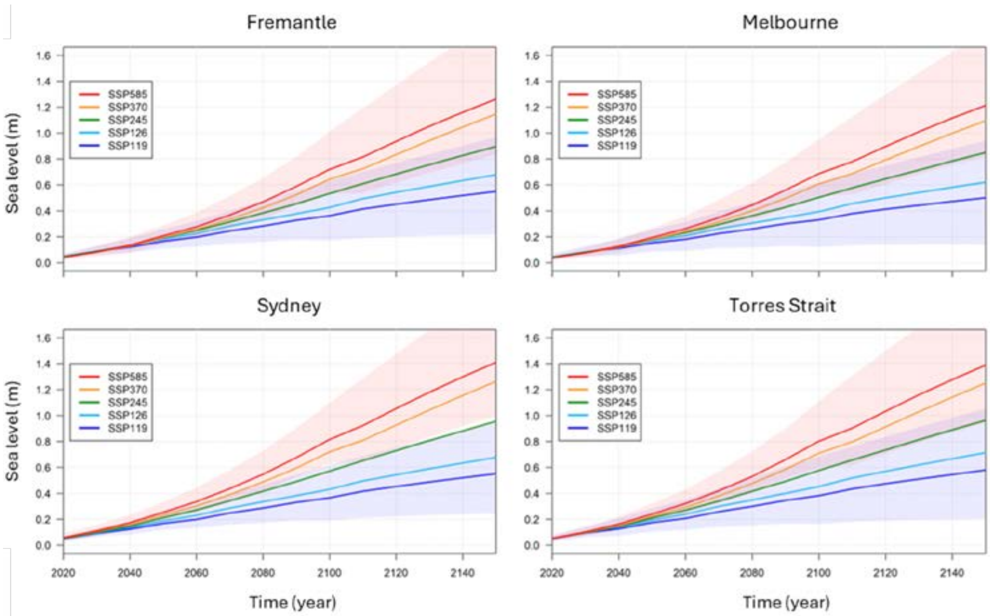

Figure 3: Multi-model mean sea-level projections to 2150 in metres (thick coloured lines) for a range of shared socioeconomic pathways (SSPs). These range from the highest greenhouse gas emissions scenario of SSP5–8.5, through SSP3–7.0, SSP2–4.5, SSP1–2.6 to the lowest scenario of SSP1–1.9 relative to 1995–2014 with likely model ranges for SSP5–8.5 and SSP1–1.9 shown in red and blue shading respectively.

Ongoing research

Ongoing sea-level research is essential to further enhance our understanding, refine projections and improve estimates of the different components of sea-level rise. A key focus is improving estimates of the contributions from ice sheets, which remain a significant source of uncertainty in future predictions. Developing Australian mapping of vertical land movement from satellite data is another transformative avenue of research that will help refine local sea-level projections, particularly in some regions that may undergo larger changes in the future due to factors such as subsidence. By tackling these challenges head-on, we can provide the critical insights needed to protect our coastal communities and ecosystems in the face of a changing climate.

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

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