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Ice mass loss: Antarctic ice sheets and shelves respond to climate change



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Antarctic ice melt is a significant aspect of climate change that contributes to sea level rise and impacts regional and global climate patterns. The Antarctic Ice Sheet and ice shelves (floating on the ocean) are losing mass through a combination of ocean and atmospheric warming. When relatively warm ocean currents move under ice shelves, the ice melts from below. At the same time, warming air temperatures can increase surface melt, which can cause cracks to form and accelerate collapse. Simulation of past, present, and future change strengthens scientific understanding and improves predictions of ice sheet and climate behaviour.

About this document

This summary aims to inform policy makers and scientific peers about the research into ice mass loss conducted in the Ross Sea region by New Zealand's Antarctic Science Platform (ASP). This research synthesis:

- shares fundamental information about ice sheets and shelves in Antarctica
- highlights climate-related risks to ice environments in the Ross Sea region
- provides insights into the processes that influence ice mass loss and raise global sea level
- provides examples of how the ASP contributes to international science and modelling to understand past, present, and future change in Antarctica and the Southern Ocean.

Key points

- The Antarctic Ice Sheet is a large, continuous mass of ice that covers 98% of the Antarctic continent. It is losing on average 150 gigatonnes of ice annually to the surrounding ocean, contributing to global sea level rise.
- A range of Antarctic Ice Sheet model experiments produce similar meltwater contributions to sea level in the near-term (decades), while long-term outcomes (centuries) diverge significantly. The upper (still plausible) range of these projections highlights the importance of limiting warming now to reduce future sea level rise.
- Antarctic ice shelves, such as the Ross Ice Shelf, are floating extensions of the Antarctic Ice Sheet and play an important role in buttressing flow — preventing the ice on land from flowing more rapidly into the ocean. Monitoring and modelling of basal melt, calving and discharge are essential for understanding ice shelf dynamics and their impact on the stability of the grounded marine ice sheet.
- Crevasses play an important role in circulating seawater beneath the Ross Ice Shelf, potentially influencing their stability.
- Seasonal basal melt influences ice flow variability in some, but not all, Ross Ice Shelf regions. Sensitivity maps produced through ASP research offer important guidance on critical vulnerabilities and for future fieldwork and modelling.

Melting Antarctic ice contributes to sea level rise

Ice mass loss in Antarctica refers to the net decrease in ice on the continent, including melting glaciers and ice sheets on land, as well as the thinning and disintegration of floating ice shelves. The Antarctic Ice Sheet is the largest component (by volume) of the Earth's cryosphere (ice environment), and how it responds to climate change is of global concern. At present, the Antarctic Ice Sheet is losing on average 150 gigatonnes of ice annually to the surrounding ocean, contributing to global sea level rise.

Sea level rise is already impacting coastal communities here in New Zealand, the Pacific Islands, and low-lying coastal areas around the world. By 2050, it is estimated that 800 million people will be affected by coastal flooding through rising sea levels and increased storms. Climate change has caused global sea level to rise by 20cm on average over the past 100 years. Even with a low emission future, 50cm of sea level rise by 2100 is already locked in. In a high emission future, well over 1m of global sea level rise is possible by 2100.

Over 90% of the extra heat retained by Earth due to elevated greenhouse gas concentrations has been absorbed by our oceans. As the Southern Ocean warms, the Antarctic Ice Sheet will continue to contract, causing significant sea level rise. But exactly when and how quickly this process happens depends on factors that are still uncertain.

The West Antarctic Ice Sheet is vulnerable to collapse

Because it mostly rests on land below sea level, the West Antarctic Ice Sheet is highly vulnerable to irreversible collapse, potentially within the 1.5°C to 2°C warming range set by the Paris Agreement. At present, dynamic ice sheet models simulate a wide range of possible outcomes for different emissions scenarios.

Much of the West Antarctic Ice Sheet drains through two regions – the Amundsen and Ross Sea sectors. While extreme melting in the Amundsen Sea region has led to staggering ice mass loss there, quantifying the mass of ice lost to the Ross Sea is more complex.

ASP research explores ice sheet dynamics, particularly the critical interaction between the Antarctic Ice Sheet and the Ross Ice Shelf. To do this, researchers use geological and geophysical techniques in combination with advanced computer modelling to better understand and simulate past, present, and future change. This integrated approach strengthens scientific understanding and improves predictions of ice sheet and climate behaviour.



SWAIS2C research team expands geological records

The ASP is a key partner in the international SWAIS2C project (Sensitivity of the West Antarctic Ice Sheet to 2 degrees Celsius of warming). The focus of this research project is the vulnerability of the ice from West Antarctica that drains through the Ross Ice Shelf. In a world first, the SWAIS2C team developed a lightweight drilling system capable of drilling through up to 1,000m of ice shelf and ocean water column. This system was built to look beneath the Ross Ice Shelf, deploy instruments, and recover ~200m of sediment core from the seafloor that was deposited during past warm periods.

The first two field seasons of the SWAIS2C programme recovered 1– 2 metre long marine sediment cores and collected measurements from the ocean cavity below the ice. These rare samples have revealed microscopic life forms that can survive in the deep, dark, and very cold environment beneath the ocean floor. However, longer sediment records that will help to reconstruct past changes in the West Antarctic Ice Sheet remain elusive. These reconstructions would help us better understand how historic conditions drove ice sheet stability.

Our engineers have learned from field experiences and taken big steps towards future drilling success using groundbreaking technology. The geophysics team has completed mapping of the shape of the seafloor beneath the Ross Ice Shelf at Discovery Deep, and the geochronology team collected rock samples from the Transantarctic Mountains to better understand past ice sheet thinning rates.

Research outputs provide crucial context for current and future Antarctic ice sheet behaviour in a warming world and inform effective adaptation to the unavoidable impacts of sea level rise.

New reconstructions of past ice sheet dynamics

Our palaeoenvironment researchers published two major reconstructions of past Antarctic ice sheet behaviour to improve future projections under climate change.

- Reconstructed sea surface temperatures from sediment cores from the Ross Sea and offshore Adélie Land revealed a strong link between atmospheric CO₂ and Antarctic ice sheet volume over the past 50 million years. Models indicate a threshold near 400 ppm CO₂, above which ocean warming drove rapid ice sheet retreat and significant sea level rise.
- A 6.2 metre marine sediment core collected from the Ross Sea provided information about the past 1.1 million years. Data indicated that the West Antarctic Ice Sheet's cycles of growth and retreat aligned with 41,000-year orbital cycles of the Earth, which affect the amount and distribution of solar radiation. This timing aligned past Antarctic glaciations (when Antarctica became covered in ice) with broader seasonal variations and long-term climate patterns.

Ice flow acceleration through lubrication and ice dynamics

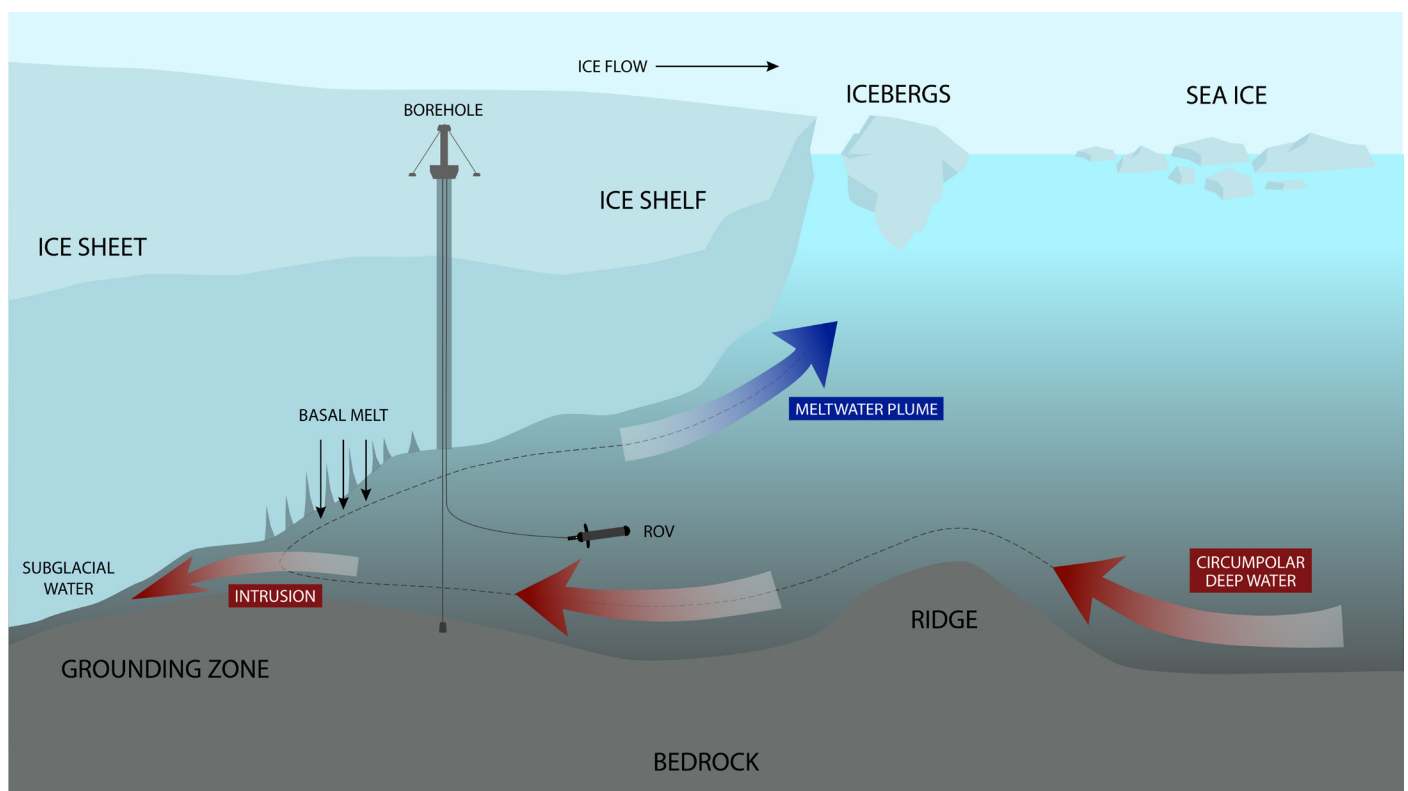
ASP researchers have directly observed *ice pumping* within a crevasse. This process is a cycle of melting, upwelling, and refreezing influenced by underwater ice topography, and has not been seen previously in such environments. This observation was made possible using an 'Icefin'—a long, narrow robot equipped with oceanographic sensors and deployed through a borehole drilled with hot water close to the grounding zone. The Icefin's observations were important as they showed that water has the potential to lubricate ice flow, which can accelerate Antarctic ice mass loss and sea level rise.

In addition, ASP researchers combined over-snow radar surveys and satellite remote sensing to understand how ice flows from the Antarctic continent into the ocean, improving our understanding of ice sheet dynamics at this critical transition zone.

Crevasses influence ice shelf stability

Crevasses play an important role in circulating seawater beneath Antarctic ice shelves, and can potentially influence ice shelf stability. This is one of the key findings of a new study based on a first-of-its-kind exploration by an underwater robot (Icefin). This research presented a high-resolution ocean survey where the grounded ice sheet reaches the ocean and starts to float to form the Ross Ice Shelf. This is known as the grounding zone. The study revealed that crevasses in the underbelly of the ice shelf significantly influence local ocean circulation and mixing. This provided new insights into the potential impact of crevasses on ice shelf stability and Antarctic ice sheet dynamics.

Figure 1: Relatively warm (but still cold $<4^{\circ}\text{C}$) Circumpolar Deep Water forms at intermediate depths and can flow up and across the continental shelf, leading to intrusion and basal melt.



Dating the pace of glacial retreat

The Byrd Glacier Basin, the largest outlet glacier of the Transantarctic Mountains, contributes ~18% of the total ice flow to the Ross Ice Shelf. By dating when rocks at nunataks (rocky mountain peaks poking out of the ice) were last uncovered by thinning ice, ASP research drew the following conclusions.

- The first thinning (i.e. retreat) of the East Antarctic ice draining through Byrd Glacier occurred around 15,000 years ago, with a rapid thinning event around 8,000 years ago.
- Models that best match ice thickness assume high lubrication at the bed (base) of the ice. However, models that best match the timing and rate of thinning assume higher friction. This indicates a shift in the sliding regime during deglaciation.

These findings offer important context for understanding the current and future stability of Byrd Glacier and help improve ice sheet models and hence projections of Antarctic sea level rise contributions.

Past ice sheet dynamics derived from octopus DNA

To help resolve uncertainty about the West Antarctic Ice Sheet's tipping point for irreversible collapse, ASP researchers have studied past warm periods, such as the Last Interglacial period ~125,000 years ago. During this period, global sea levels were 5–10 metres higher than today, while temperatures were only $1\text{--}2^{\circ}\text{C}$ above pre-industrial levels. Genetic data from a circum-Antarctic octopus (i.e. found around the entire continent of Antarctica) suggested connectivity between the Weddell and Ross Seas at that time, consistent with the West Antarctic Ice Sheet having completely collapsed during the Last Interglacial. This provides the first empirical evidence that such a collapse may have already happened in the past under warming, and highlights a collapse could occur again, even with strong climate mitigation efforts.

Our research is an important part of global understanding and call for action

Projecting the Antarctic Ice Sheet's future under different emissions pathways

ASP researchers held leading roles for the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, in particular the Chapters on Ocean, Cryosphere and Sea Level Change, and Water Cycle Changes. IPCC coordinating/lead authors are responsible for evaluating scientific literature and producing comprehensive reports on climate change, its impacts, and potential mitigation and adaptation strategies. This provides good visibility to the ASP team on future policy and research priorities, and how to help address them. It also provides useful connectivity of ASP research to help inform IPCC considerations.

ASP researchers have also contributed to the Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6). The project is a global effort to project how Greenland and Antarctic ice sheets will affect sea level rise under different emissions scenarios, informing the IPCC's Sixth Assessment Report. In updated simulations, the ISMIP6-Antarctica team identified that East Antarctica's Totten and Moscow University glaciers are as vulnerable to ice loss as West Antarctica's Thwaites and Pine Island glaciers. ASP researchers are also a part of the ISMIP6-2300 project, which models Antarctic ice sheet behaviour and sea level rise through to the year 2300, linked to different emissions scenarios and modelling uncertainties.

Collaborating with Our Changing Coast

The SWAIS2C team has strong connections with 'New Zealand Sea Rise' and 'Our Changing Coast' research programmes. This allows for the improved and evolving contributions from Antarctic ice sheets to help inform sea level rise impacts in New Zealand. This partnership directly connects ASP research to national coastal hazard guidance and coastal planning in communities across Aotearoa.

Definitions

Ice sheet: All ice that rests on bedrock, regardless of whether the bedrock is above or below sea level.

Ice shelf: Floating glacial ice that is an extension of the grounded ice sheet (ice is lighter than water so it floats in the ocean).

Marine ice sheet instability: A marine ice sheet is an ice sheet whose base is grounded on rock below sea level. This means the ice is particularly sensitive to retreat through ocean warming, unlike ice sheets that rest on land above sea level. A key feature of marine ice sheets is their grounding line, the boundary where the ice transitions from being grounded on land to floating as an ice shelf. The stability of a marine ice sheet is heavily influenced by the location and movement of this grounding line.

Basal melting: Warm, deep ocean currents flow beneath the floating ice shelves surrounding Antarctica. These currents melt the ice from below, a process called basal melting.

Grounding zone: The grounding zone in Antarctica refers to the area where the grounded ice sheet transitions to a floating ice shelf, typically over a few kilometres. This transition zone is crucial for understanding ice sheet stability, mass balance, and future projections of ice sheet behaviour.

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Selected references

Baldacchino et al. (2023). Modelling GNSS-observed seasonal velocity changes of the Ross Ice Shelf, Antarctica, using the Ice sheet and Sea level System Model (ISSM). EGU sphere. <https://doi.org/10.5194/egusphere-2023-2793>

Davison et al. (2023). Annual mass budget of Antarctic ice shelves from 1997 to 2021. *Science Advances* 9(43). <https://doi.org/10.1126/sciadv.adi0186>

Duncan et al. (2022). Climatic and tectonic drivers of late Oligocene Antarctic ice volume. *Nature Geoscience* 15(10). <https://doi.org/10.1038/s41561-022-01025-x>

Lawrence et al. (2023). Crevasse refreezing and signatures of retreat observed at Kamb Ice Stream grounding zone. *Nature Geoscience* 16(3). <https://doi.org/10.1038/s41561-023-01129-y>

Lau et al. (2023). Genomic evidence for West Antarctic Ice Sheet collapse during the Last Interglacial. *Science* 382(6677). <https://doi.org/10.1126/science.ade0664>

Levy et al. (2024). Melting ice and rising seas – connecting projected change in Antarctica's ice sheets to communities in Aotearoa New Zealand. *Journal of the Royal Society of New Zealand* 54(4). <https://doi.org/10.1080/03036758.2023.2232743>

Marschalek et al. (2021). A large West Antarctic Ice Sheet explains early

Neogene sea level amplitude. *Nature* 600. <https://doi.org/10.1038/s41586-021-04148-0>

Naish et al. (2024). The significance of interseismic vertical land movement at active tectonic margins for sea level rise projections. *Earth's Future* 11(6). <https://doi.org/10.1029/2023EF004165>

Seroussi et al. (2023). Insights into the vulnerability of Antarctic glaciers from the ISMIP6 ice sheet model ensemble and associated uncertainty. *The Cryosphere* 17. <https://doi.org/10.5194/tc-17-5197-2023>

Stutz (2023). Inland thinning of Byrd Glacier, Antarctica, during Ross Ice Sheet retreat. *Earth Surface Processes and Landforms*. <https://doi.org/10.1002/esp.5701>

Venturelli et al. (2020). Mid-Holocene grounding line retreat and readvance at Whillans Ice Stream, West Antarctica. *Geophysical Research Letters* 47(24). <https://doi.org/10.1029/2020GL088476>

Washam et al. (2023). Direct observations of melting, freezing, and ocean circulation in an ice shelf basal crevasse. *Science Advances* 9(43). <https://doi.org/10.1126/sciadv.adi7638>

Whiteford et al. (2022). Melting and refreezing in an ice shelf basal channel at the grounding line of the Kamb Ice Stream, West Antarctica. *Journal of Geophysical Research: Earth Surface* 127. <https://doi.org/10.1029/2021JF006532>

