Antarctic sea ice decline has cascading impacts

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Changing Antarctic sea ice has global consequences. Since 2016, Antarctic sea ice has sharply and unexpectedly declined, likely due to combined effects of changes in the ocean, atmosphere, and winds. Understanding and monitoring changes in sea ice is crucial. This knowledge is needed to project future sea-ice behaviour and to understand the complex interactions between the ocean, atmosphere, ice, and ecosystems.

About this document

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

- shares fundamental information about Antarctic sea ice and how it develops
- highlights the effects of a changing global climate on sea ice in the Ross Sea region
- provides critical baselines and new insights to understand how changing sea ice may impact Antarctica's ice sheets, oceans and ecosystems in a warming world
- provides examples of how the research can be applied by domestic and international collaborators to advance science, environmental management and ecosystem resilience

Key points

- Since 2016, Antarctic sea ice has declined unexpectedly and sharply. The first 3 years of loss was equivalent to 30 years of sea-ice loss in the Arctic. This dramatic decline is predominantly driven by changes in the Ross Sea region.
- Most of the sea-ice decline is observed in drift (pack) ice. In McMurdo Sound, no consistent decline has yet been detected in fast ice (ice connected to coastline) – natural seasonal variability still dominates the signal here. But other parts of Antarctica are showing significant fast ice decline.
- Sea ice plays a major role in global climate and ecological systems, but models are currently unable to accurately predict sea-ice dynamics, including the Antarctic sea-ice decline in recent years.
- To understand changes in sea ice over time and to facilitate better modelling, researchers are using new techniques. High-resolution satellite imagery is used to more accurately characterise sea-ice types and floe dynamics and to measure the spatial extent of polynya (sea-ice factories). Snow and sea-ice measurements are becoming more accurate by integrating airborne and ground-based geophysics and radar.
- Climate change will likely reduce coastal polynya activity. These windswept, coastal ocean regions are sea-ice factories that have an important impact on global ocean currents and the transport of heat, salt, carbon, and nutrients.
- Researchers have established links between sea-ice characteristics, microalgae, and overwintering zooplankton. These links will allow connections between sea-ice changes and ocean food webs to be assessed.

About Antarctic sea ice

The growth and decline of Antarctic sea ice is one of the largest seasonal changes on Earth. Sea ice is the layer of frozen seawater covering the ocean surface at both poles. It grows every winter and contracts in summer. In Antarctica, the area covered by sea ice increases by approximately 16 million km^2, essentially doubling the size of the continent in winter.

Sea ice is broadly classified as first-year and multi-year ice, with further distinctions based on age, thickness, and formation. Sea ice can also be classified by its connection to land — fast ice is attached to the coastline, while drift ice moves north with winds and currents. Most Antarctic sea ice is first-year, drift ice.

Polynyas, which are areas of open water surrounded by sea ice, play a crucial role in producing Antarctic sea ice. These sea-ice factories form in regions where the ocean surface is regularly swept clear of sea ice by winds (coastal polynyas) or by ocean currents during winter (thermal polynyas). This clearing allows new ice to form where the ocean surface is then exposed to freezing temperatures.

Less sea ice affects the rate of global warming, ocean currents, and habitats

Snow-covered sea ice reflects up to 80% of incoming solar radiation into space, helping to keep the Earth cool. It also acts as a barrier, reducing the exchange of heat, greenhouse gases, and wind energy between the ocean and the atmosphere.

When sea ice forms, salty water sinks. This sinking contributes to the creation of Antarctic Bottom Water, the coldest, densest water mass that accounts for 30-40% of total ocean volume and drives global ocean circulation.

Sea ice protects ice shelves from wave action. This protection can slow down the rate of ice sheet melting and retreat, which in turn helps to slow down sea level rise.

Sea ice provides crucial habitats and breeding grounds for many marine species, including sea-ice algae, krill, fish, penguins and seals. Sea ice influences the amount and type of biological productivity in the Southern Ocean, which underpins the complex food web that ultimately supports seabirds, seals, and whales. Changes in sea ice will affect the distribution, abundance, and species composition of both pelagic (deep ocean) and benthic (seafloor) marine ecosystems.

Scientists have established fast ice baseline data

Despite rising air temperatures in recent years, Antarctica's McMurdo Sound region has not yet shown a reduction in fast-ice thickness attributable to climate change. Monitoring data, which now covers over two decades, shows substantial year on year variability but no trending decline in fast ice (attached to the coastline). These data offer a valuable baseline to detect future climate-driven changes. Our research highlights the importance of long-term monitoring for distinguishing variance from trend, with measurements set to continue.

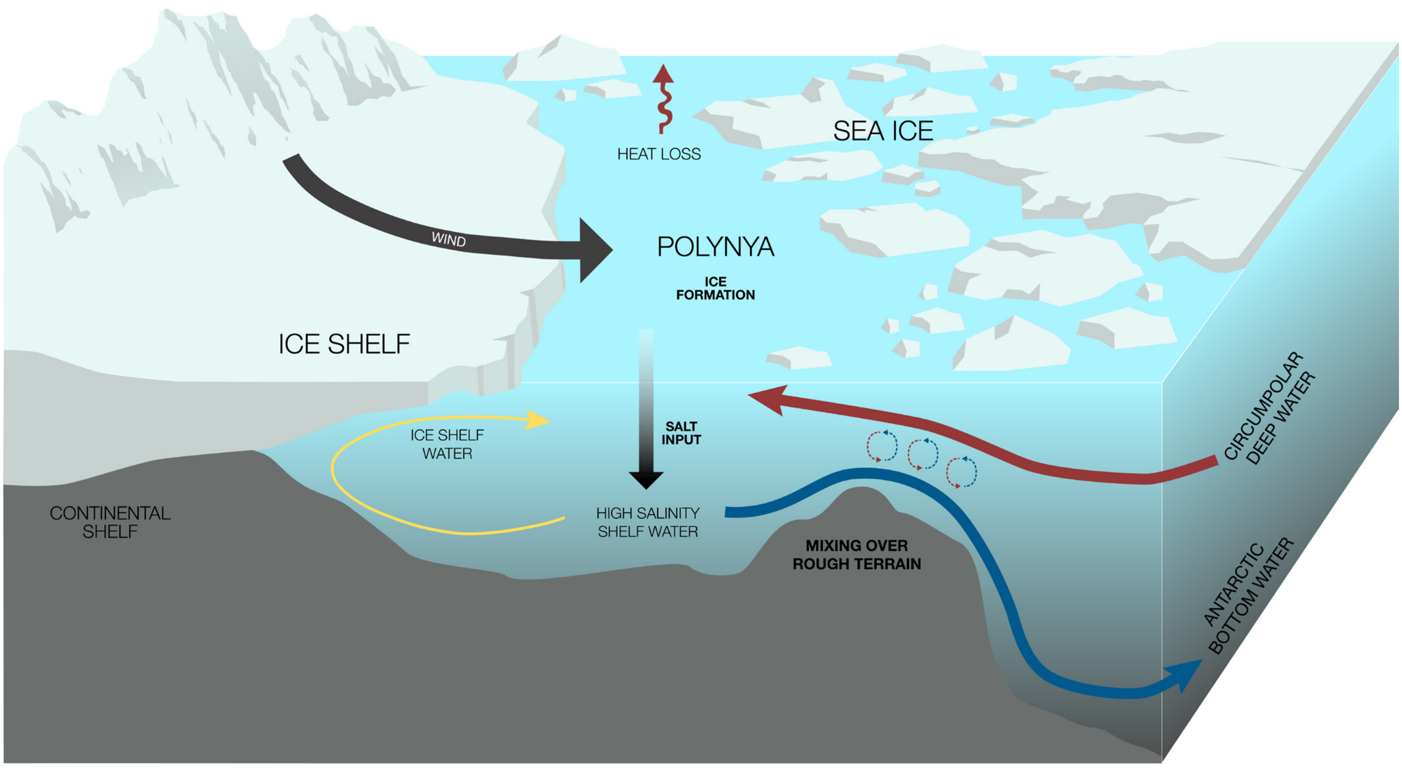

Figure 1: Simplified diagram of the Antarctic ice and ocean environment.

Combined systems can measure sea-ice and snow thickness

Sea-ice thickness is a critical variable that allows people to calculate the total amount of ice formed. But measuring sea-ice thickness is difficult. Satellites provide an accurate 2D picture of sea-ice extent and important insights into the changes in sea-ice area in space and over time. However, satellites have limited ability to reliably measure sea-ice thickness. Salt trapped in the ice is highly reflective to radar, and snow cover needs to be distinguished from sea ice.

Our research developed a new integrated airborne electromagnetic (EM-bird) and snow radar system. This airborne system was deployed beneath helicopters and fixed wing aircraft to survey fast ice-snow thickness in McMurdo Sound. The EM-bird alone, which measures sea-ice thickness, works by detecting the distance between the air-snow and the sea-ice-water interfaces (via changes in electromagnetic induction). However, the EM-bird can't differentiate between the snow and ice layers, leading to an overestimation of sea-ice thickness. The snow radar measures snow depth by recording the time difference between radio pulses scattered at the air–snow and snow–ice interfaces.

The combined system allows for simultaneous, more accurate measurements of sea ice and snow thickness. These measurements improve the assessment of ice conditions and provide better observational data to correct satellite estimates of ice thickness. Comparisons between the airborne measurements and satellite data showed that snow depths reached up to four times the satellite-measured value in some regions – differences that significantly affect estimates of sea-ice thickness.

This EM-bird was also used to detect and determine the thickness of the sub-ice platelet layer in McMurdo Sound.

Sub-ice platelet layers have a role in ecosystem processes

Sub-ice platelet layers (SIPLs) play an understudied role in the rapidly changing ecosystems of Antarctica and the Southern Ocean. These layers form from frazil ice crystals (from supercooled seawater) that rise and accumulate under the sea ice to form a lattice of ice and seawater. SIPLs affect sea-ice growth, ocean-ice interactions, and ecological dynamics.


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Our research introduced a novel SIPL sampler to Antarctic science. This custom-built, ice-coring system was designed to collect platelet ice, interstitial seawater and the incorporated biology from beneath the sea ice in McMurdo Sound. Scientists can analyse quantitative, depth-stratified samples of the entire sea ice-SIPL-water column continuum for microalgae, zooplankton, and nutrient concentrations. Initial results confirm the very high productivity of the SIPL, especially when compared to sea ice with no underlying platelets. DNA analysis of the biological material recovered with the SIPL sampler identified distinct communities associated with a range of environmental conditions.

Long-term trends and cycles are emerging for Antarctic polynyas

Despite their significance, the specific drivers of polynya activity remain poorly understood, and climate models struggle to accurately replicate their behaviour.

Coastal polynyas are primarily driven by strong offshore winds, which open the sea ice and expose and cool the ocean surface, initiating more sea-ice formation. Polynyas play a crucial role in sea-ice production. When sea ice forms salt is excluded into the ocean water and dense 'bottom water' is formed, making polynyas also important for ocean-atmosphere interactions. Due to the absence of light-reflecting ice, polynyas are also points for phytoplankton growth when daylight returns in spring.

Our research used satellite data to determine the spatial extent of polynyas with better accuracy. These data unlock the ability to quantify their role in large-scale processes, such as sea-ice formation, ocean circulation, and their impact on marine ecosystems.

We analysed a 44-year time series of Antarctic sea-ice data and identified long-term trends. A previously unrecognised cyclical pattern of polynya activity in the Ross Sea region was linked to interactions between:

- the Amundsen Sea Low (a permanent a low-pressure area located in the Southern Pacific off West Antarctica)
- the Southern Annular Mode (a ring of climate variability that encircles the South Pole and extends out to the latitudes of New Zealand).

This link suggests that polynyas are strongly connected to atmospheric processes. This knowledge is crucial for more accurately predicting future environmental changes and their potential impacts on Antarctic ecosystems. It is further evidence of the global-scale interactions driving Earth systems.

How Antarctic polynyas will respond to climate change is uncertain

A review by Antarctic Science Platform researchers published in Nature Reviews Earth & Environment examined the significance of Antarctic coastal polynyas in the Earth system, and how they interact with the atmosphere, sea ice, oceans, and biosphere. The location and strength of coastal polynyas varies over time, notably between glacial and interglacial periods, driven by changes in grounded ice sheet extent, atmospheric circulation, and ocean conditions. However, climate change is expected to reduce coastal polynya activity, but the exact impacts remain uncertain. The review calls for improved observational campaigns, including satellite-based measurements with intelligent algorithms. Better observations will improve models and deepen understanding of these important Antarctic features.

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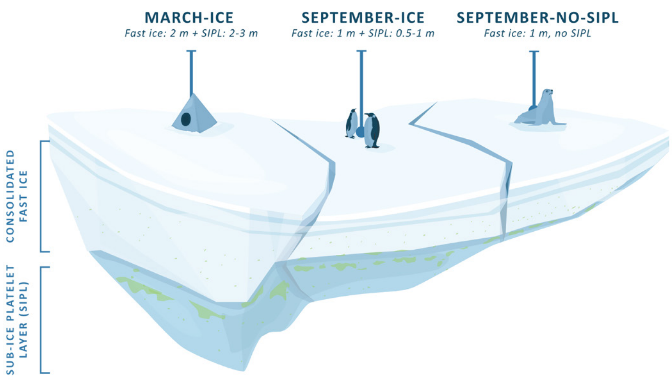

Figure 2: Ice types, formation time and characteristics. Adapted from Stuart et al. 2025

Definitions

Sea ice: Frozen seawater, usually 1-2 meters thick. Antarctic sea ice extends north in the winter and retreats almost to the coastline every summer. Fast ice is attached to the coast and drift ice is not.

Platelet ice: A type of sea ice in Antarctic coastal regions, characterised by thin, disc-shaped ice crystals that can accumulate into sub-ice platelet layers beneath the sea ice or within the sea-ice structure.

Frazil ice: A specific type of ice formation, characterised by tiny, loose, needle-shaped ice crystals that are suspended in turbulent, supercooled water. Frazil ice is a crucial initial stage in the growth of Antarctic sea ice.

Polynya: Sea-ice factories. Naturally occurring open water areas surrounded by sea ice, formed by wind and ocean currents pushing sea ice away from the coast,

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