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Australian Centre for Excellence in Antarctic Science

How does the melting of Antarctica affect the Australian climate?

The accelerated melting of the Antarctic Ice Sheet is adding freshwater to the Southern Ocean, altering ocean circulation and climate patterns globally, including in Australia.

Most current climate models do not account for the impacts of Antarctic meltwater, resulting in projections missing important climate change impacts.

New climate model experiments that incorporate meltwater effects show that Antarctic meltwater may partially reduce projected climate change warming, while rainfall responses remain unclear.

Improving the representation of Antarctic meltwater and rainfall in Australian climate models is crucial for better preparing for the future.

Introduction

The Antarctic Ice Sheet is the largest mass of land ice on Earth, covering almost the entire continent of Antarctica and holding about 60% of the planet's freshwater in the form of ice[1].

The ice sheet has been melting faster in recent decades, releasing large amounts of meltwater into the Southern Ocean[2]. This input of freshwater contributes to rising global sea levels and alters ocean circulation and sea ice formation[3]. These ocean and sea ice changes may, in turn, influence rainfall and temperature patterns over land, including in Australia.

However, these effects are not well studied because most current climate models do not fully account for the impact of Antarctic meltwater. As a result, climate projections may overlook important climate change impacts.

To address this gap, scientists worldwide, including those in Australia, have created new large-scale climate model experiments that include meltwater effects. Here, we present key findings from these simulations and explore what additional Antarctic meltwater could mean for the Australian climate.

How does the Antarctic Ice Sheet melt?

The Antarctic Ice Sheet forms as snow accumulates over thousands of years and turns into ice. This land ice slowly flows toward the edge of Antarctica and begins to float on the ocean, forming so-called ice shelves (Figure 1). These floating extensions act as dam walls, holding back the flow of glaciers behind them.

Occasionally, ice breaks off from the ice shelves, forming icebergs that travel away from Antarctica and melt in the Southern Ocean (Figure 1). Ice shelves also melt from below, when relatively warm ocean water reaches beneath them – a process known as basal melting (Figure 1).

If basal melting increases, it can cause ice shelves to thin so much that the glaciers behind them accelerate their flow into the ocean, adding more ice to the ocean. When this extra ice melts, even more meltwater is created.

Antarctic melting is speeding up

Over the past decades, basal melting has significantly increased due to warmer ocean water reaching beneath the ice shelves[4]. This, in turn, has led to significant extra meltwater entering the Southern Ocean.

Antarctic meltwater is cold and fresh, and it influences ocean circulation and temperature, thereby impacting all components of the climate system, including air temperature and rainfall[3,5]. Some of these impacts extend high into the atmosphere and even reach the Northern Hemisphere[3,5,6]. Importantly, they often act differently to other climate change signals, such as warming, making them particularly relevant to assess.

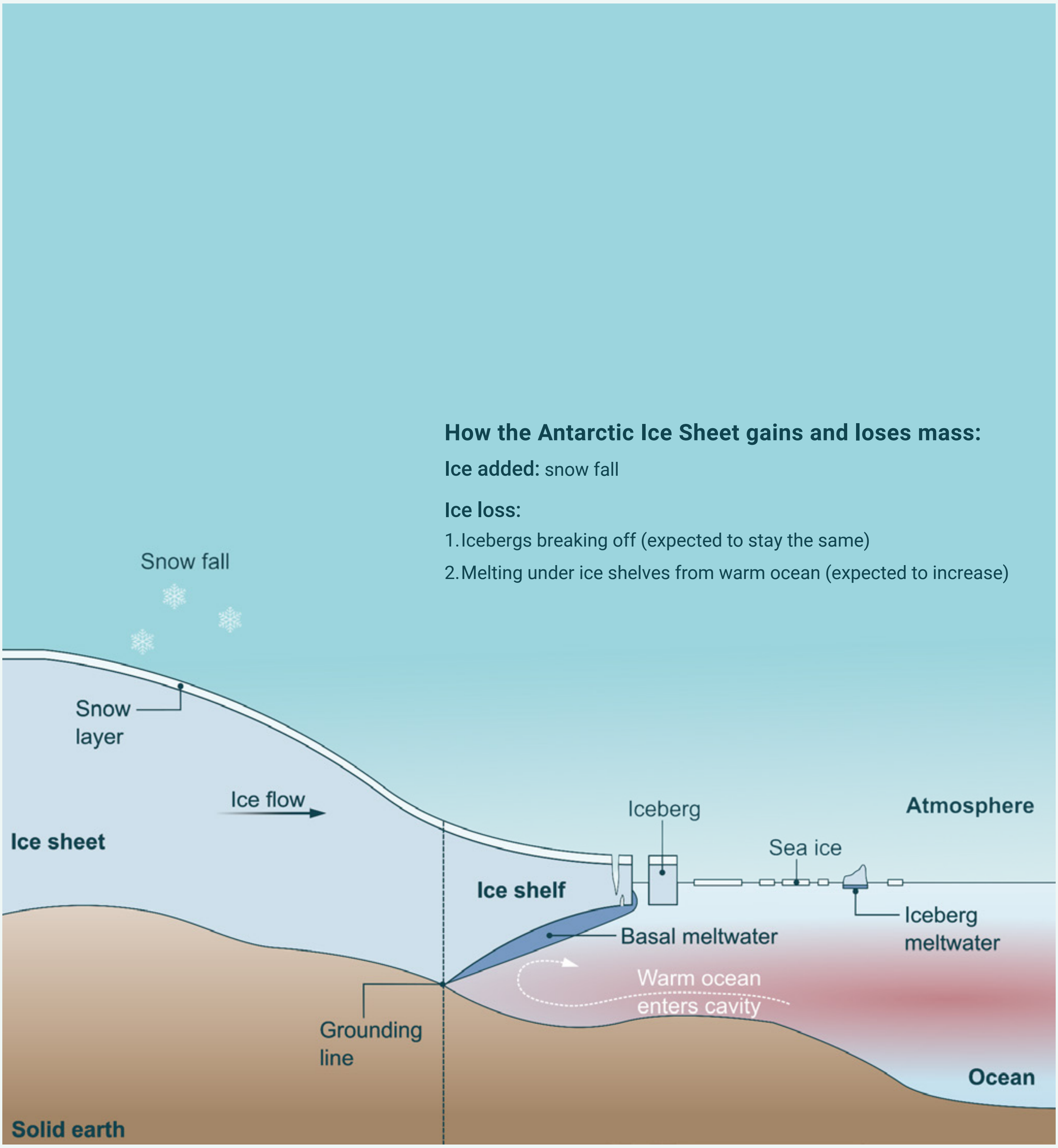

Figure1. Mechanisms driving ice sheet mass gain and loss. Credit: Wilma Huneke

Antarctic meltwater is not included in climate models

Despite its important effects on the climate system, Antarctic meltwater is not included in most current climate models – such as those used to inform the Intergovernmental Panel on Climate Change (IPCC) reports – leaving a critical gap in our climate projections.

This is because climate models integrate multiple components, including the atmosphere, land surface, ocean and sea ice, but generally do not yet include ice sheet and ice shelf dynamics (Figure 2).

To bridge this gap, scientists worldwide, including those from Australia, have participated in the Southern Ocean Freshwater Input From Antarctica (SOFIA) initiative – a multi-model meltwater experiment project, where different climate models are used to simulate what happens when extra meltwater from Antarctica is added to the ocean surface[7]. By running the same experiment across multiple climate models, with their own strengths and weaknesses, researchers can better quantify how the climate might respond to additional Antarctic meltwater.

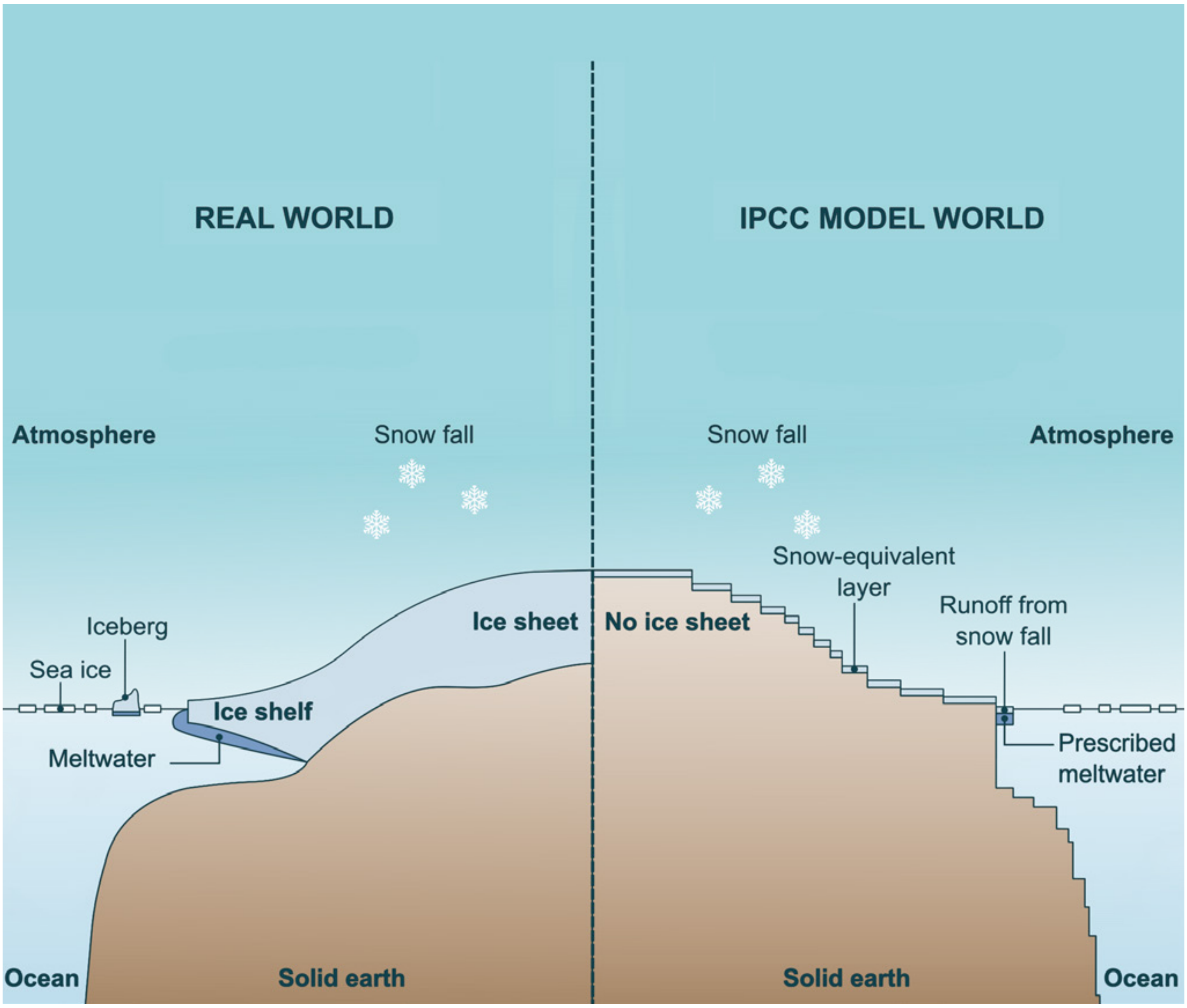

Figure 2. Schematic of different climate components near Antarctica (left) and their representation in a climate model (right). Not to scale. Credit: Wilma Huneke

How does Antarctic meltwater impact the Australian climate?

a) Impacts on temperature

Current climate projections show that Australia could warm by over 4°C compared with pre-industrial levels (1850–1900) by the end of the century under an intermediate emissions scenario (Figure 3, left).

However, the meltwater experiments consistently show that additional Antarctic meltwater is likely to reduce this warming, but not offset it, meaning Australia would still experience a net warming (Figure 3, right). This is because Antarctic meltwater induces a cooling effect in Australia (Figure 3, middle), with surface air temperatures on average around 0.5°C lower by 2100 compared with pre-industrial levels (Figure 3, middle). This cooling is fairly consistent year-round and more pronounced over land than over the ocean.

The cooling effect occurs because the cold, fresh Antarctic meltwater is less dense than the surrounding waters and spreads like a thin blanket at the ocean surface, keeping warmer water trapped below. As a result, the ocean interior warms, while the surface and the air above it cool[8,9].

b) Impacts on rainfall

Current climate projections for Australian rainfall vary between models, with inconsistent signals of both increased and decreased rainfall by the end of the century. The only consistent trend is a robust drying response in part of southwest Australia[10].

In the Antarctic meltwater models, the results are even more unclear, including in southwest Australia. Figure 4 shows the changes in rainfall observed in the meltwater experiments with the model average (top left) alongside each individual model. Individual models show a mixed rainfall signal, with some models showing an increase in rainfall and others a decrease (of more than 15%).

These uncertainties arise because climate models used in these experiments struggle to represent rainfall. The results from the meltwater experiments add to the already large uncertainties in projected precipitation for Australia.

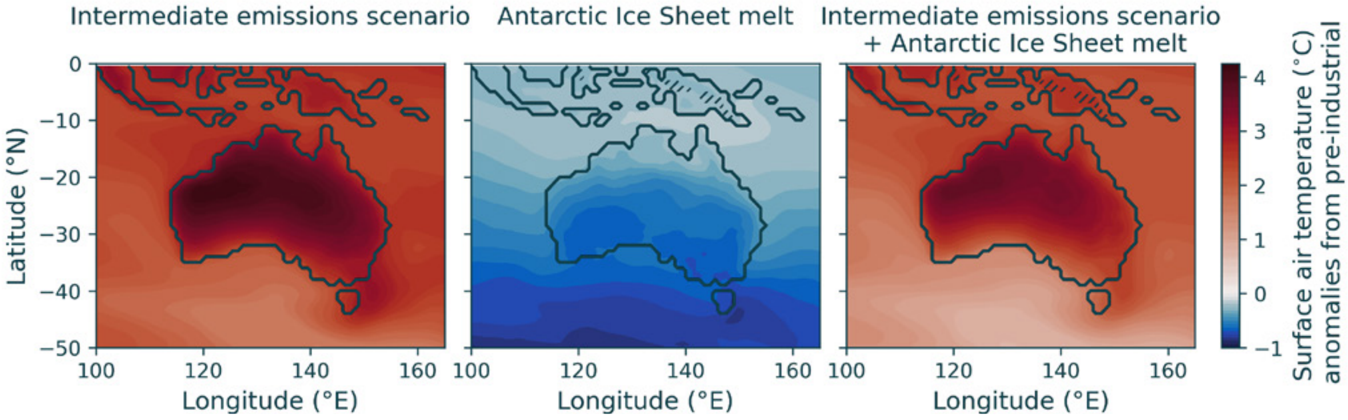

Figure 3. Warming relative to pre-industrial surface air temperatures under an intermediate emissions scenario by the end of the century (left). Cooling relative to pre-industrial surface air temperatures in Antarctic meltwater experiments (middle). The combined response from both experiments (right) provides an estimate of corrected future simulations, assuming no interactions.

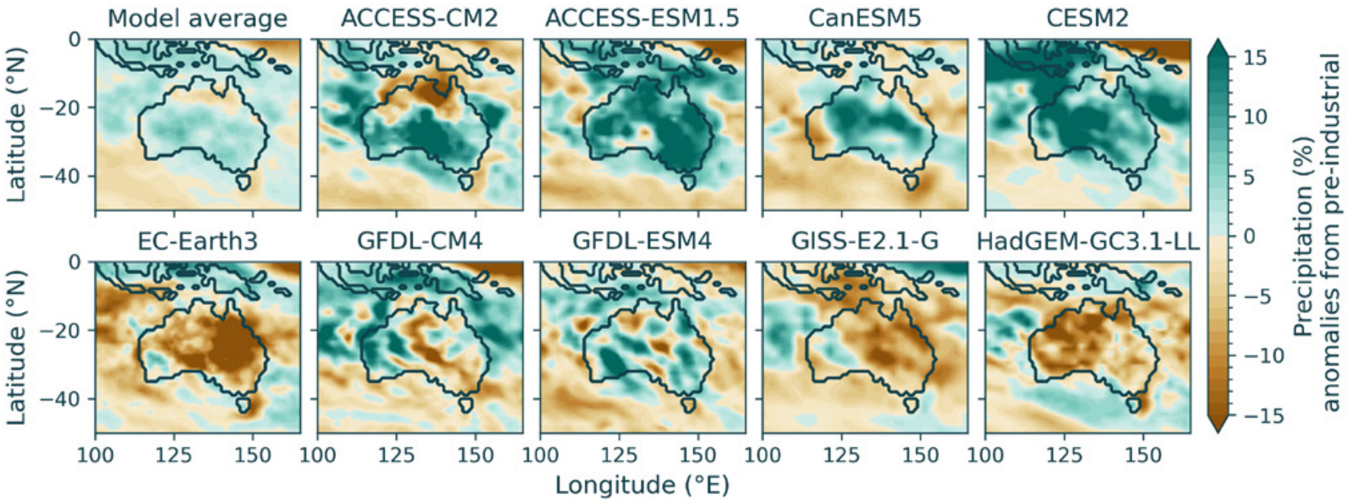

Figure 4. Rainfall responses in Antarctic meltwater experiments relative to pre-industrial levels. Green represents an increase in rainfall compared to preindustrial levels (wetting response), while brown represents a decrease (drying response). The models show a large spread that mostly cancels out in the model average, making the signal difficult to detect in Australia's highly variable climate. However, some models suggest that large changes in rainfall remain possible.

Why continued model development is important

The meltwater experiments show that accounting for the impacts of Antarctic meltwater could lead to substantially different climate projections compared with those that currently exclude them. They indicate that Antarctic melting may reduce projected warming in Australia, but not offset it, meaning that Australia would still face a much hotter future and must prepare accordingly. On the other hand, rainfall responses remain uncertain due to known limitations in how climate models represent rainfall.

These findings have significant implications for our agriculture, water security, and drought and flood risk, and highlight the need for improved climate projections integrating the impact of Antarctic meltwater and better representing rainfall.

As the only country in the Southern Hemisphere fully contributing to the IPCC, Australia has a unique responsibility and opportunity to deliver these vital improvements. This will require sustained support and new resources for the National Computational Infrastructure (NCI), as well as sustained funding for Antarctic monitoring programs, which are key for enhancing the accuracy of ice sheet melt projections.

Shackleton Ice Shelf. Credit: Pete Harmsen / AAD

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