Antarctica's changing weather and climate

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Local weather and climate variations impact Antarctica's biodiversity, ice shelf stability, polynya dynamics (open water within sea ice), and hydrological systems. Antarctica's climate is an inextricable part of the complex global processes that drive dynamics in the atmosphere, hydrosphere (water) and cryosphere (ice). Changes in Antarctica are propagated around the globe, with far-reaching effects on weather, sea-level rise, and ocean circulation, for example. A clearer understanding of how global climate change translates to local conditions in Antarctica, particularly the frequency and intensity of extreme events, helps to improve our understanding of the consequences of change.

About this document

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

- shares fundamental information about weather and climate in Antarctica
- highlights climate-change related risks to weather across the Ross Sea region
- provides insights into weather processes that influence ice melt and accumulation
- provides examples of ASP contributions to the refinement of global weather and climate models to understand past, present, and future conditions in Antarctica and the Southern Ocean.

Key points

- Localised Antarctic weather data is crucial because it reveals finer-scale details about climate variability and its impacts, which are often masked by broader regional averages.
- The development and application of the AntAir ICE dataset has enabled ASP researchers to create high resolution, accurate surface temperature reconstruction models across Antarctica. Significant warming trends were detected in parts of the Ross Sea region during 2003–2021.
- West Antarctica's extreme air temperature events are linked to offshore high-pressure systems that cause the horizontal transport of warm moist air onto the continent. Extreme warming events in East Antarctica are associated with inland high-pressure systems and katabatic winds (strong, cold winds that flow down from the high interior ice sheet towards the coast).
- Precipitation dynamics tell us that the moisture sources of snowfall in Victoria Land are in the Southern Ocean, as well as local sources in the Ross Sea during summer, when sea ice is reduced.
- Foehn winds are emerging as an important driver of small-scale climate dynamics. Detection and identification of Foehn wind events with high-resolution, satellite-derived air temperature products has shown how, when localised Foehn winds occur, they can raise temperatures by as much as 40°C in just a few hours.

Antarctica is changing

Climate change impacts have emerged in recent years in Antarctica. Examples include:

- the catastrophic collapse of ice shelves in the Antarctic Peninsula and West Antarctica
- the record decline in Antarctic sea ice
- breeding failure of Emperor penguins.

More recently, we've witnessed the surprising appearance of extreme weather events in Antarctica. In March 2022, large parts of East Antarctica experienced a record-breaking heatwave with temperatures soaring 39°C above normal. While this heatwave lasted only a few days, the event was connected to:

- the collapse of the Conger Ice Shelf (the first ice shelf in East Antarctica to fail)
- changes in sea-ice conditions
- changes in ocean circulation.

A growing network of ocean monitoring stations detected no less than 19 ocean heatwaves. Research teams observed waterfalls gushing off ice shelves, and documented the occurrence of rainbows, which evidence liquid water droplets in the air.

As global temperatures rise, regional and local patterns in Antarctica must be understood to effectively monitor change. Much of our work has focused on downscaling from regional patterns to local processes to help better understand the impacts of changing climate.

Automated weather station network has advanced

The ASP supports a network of automated weather stations — 18 in the McMurdo Dry Valleys and 2 in Northern Victoria Land — that collect data to better understand local conditions.

Paired stations on valley floors and nearby ridges allow researchers to see how local wind patterns affect local temperatures. Local data is critical for downscaling satellite data, modelling simulations, and climate projections to make them more accurate for small areas and relevant to Antarctic ecosystems and glacier melt.

Weather station data have helped the ASP team to create a detailed map of near-surface air temperature across Antarctica from 2003 to 2021, down to 1 square kilometre resolution. To build the AntAir ICE model, the team combined real-world temperature data (from 117 weather stations across the continent) with satellite estimates (from MODIS) to train and validate the temperature model.

The results were close to those from the widely used ERA5 climate model, but AntAir ICE offers higher spatial resolution. This makes it better for studying small-scale patterns and trends over time.

Antarctic warming trends over the past two decades

Using the AntAir ICE dataset, ASP researchers identified air temperature trends and extreme events across Antarctica between 2003–2021. Analysis confirmed a spatial variation across the continent, with a significant cooling over the Antarctic Peninsula and significant warming in the Ross Sea region, especially near coastal Victoria Land and the Transantarctic Mountains.

Different processes drove warming events across the continent. West Antarctica experienced localised extreme temperatures due to the transport of warm, moist air from further north. East Antarctica showed widespread warming driven by a large inland high-pressure system. Northward air flow (katabatic winds) from the interior toward the coastline manifested as additional warmth due to air being heated as it compressed down the elevation gradient.

Another key discovery was the impact of Foehn winds on surface temperature in the McMurdo Dry Valleys, especially in winter. When regional winds are light, cold air can settle in the valleys, causing temperatures to drop below -50°C. But when Foehn winds occur, they push warm air down into the valleys, raising temperatures by as much as 40°C in just a few hours. These warm wind events are becoming more frequent in winter, which explains the slow rise in annual temperatures in the Dry Valleys.

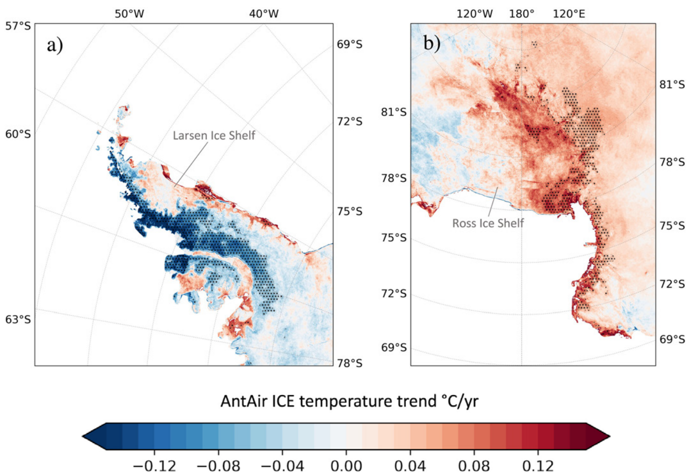

Figure 1: Annual mean temperature trend from AntAIR ICE for a) Antarctic Peninsula and b) Ross Sea region from 2003-2023. Dots mark a significant trend (p<0.05). (Source: Nielsen et al. 2025)

Tropical connections influence sea-ice formation

Polynyas (open water surrounded by sea ice) are areas of intense ocean–atmosphere heat exchange and are sea-ice production factories. Changes to polynya behaviour influences sea-ice extent, ocean circulation and the carbon cycle. Using satellite data, ASP researchers examined how polynyas change in size and location during the winter months when sea ice is at its peak. Polynya changes were closely linked to local wind patterns, which are influenced by large-scale atmospheric systems — especially a low-pressure area known as the Amundsen Sea Low (ASL). The strength and position of the Amundsen Sea Low is driven by changes in the El Niño Southern Oscillation (ENSO), a tropical climate driver, and the Southern Annular Mode (SAM), a measure of the location and strength of the southern hemisphere's westerly winds. Together, ENSO and SAM shape the location and strength of the ASL.

This shows how tropical climate variability can affect polar weather patterns and climate. The ASL plays a key role in driving local wind patterns, sea-ice movement, and polynya variability in the Ross Sea. Each of the three main polynyas in the region — Ross Sea, Terra Nova Bay, and McMurdo Sound reacts differently to these atmospheric drivers, with varied impacts on sea-ice formation. These results highlight the need to understand local consequences and provide insights into the current state of these polynyas.

Meteorological factors drive glacial melt in the McMurdo Dry Valleys

Weather and climate variables driving melt at Taylor and Commonwealth Glaciers in Antarctica's Taylor Valley were investigated using 22 years of weather and energy flux data. Though only 30 km apart, these glaciers have different local climates within the same valley. Taylor Glacier is drier and windier, while Commonwealth Glacier, closer to the coast, receives more snowfall.

Key findings:

- Commonwealth Glacier experiences greater year-to-year melt variability, mainly due to changes in albedo (how much sunlight is reflected) caused by summer snowfall.
- At both glaciers, melt is linked to degree-days above freezing during foehn winds, which are more frequent at Taylor Glacier.
- At Taylor Glacier, melt mostly happens at above-freezing air temperatures, but foehn winds often cause sublimation, cooling the surface and limiting melt.
- At Commonwealth Glacier, melt often occurs even at sub-zero air temperatures, driven by intense solar radiation and relatively low albedo.

Future melt patterns are expected to diverge. Taylor Glacier will likely respond more to changes in foehn event frequency, which will be driven by regional pressure gradients. Conversely, Commonwealth Glacier will be influenced by coastal weather, particularly moisture-driven changes affecting cloud cover, snowfall, and albedo — driven by proximity to increasingly ice-free seawater. These differences, within a single valley, attest to the need for high resolution prediction capabilities to guide spatial planning.

Large-scale weather patterns influence snow sources

Antarctica's Victoria Land has diverse snowfall patterns — some areas like the McMurdo Dry Valleys are extremely dry, while northern Victoria Land gets much more snow. To understand why, ASP researchers looked at the sources of snowfall and associated weather patterns. The study found that most of the moisture for snowfall in Victoria Land comes from the Southern Ocean, especially the area south of Australia and New Zealand.

However, in the north, moisture comes mostly from snowfall occurring when warm, moist air from lower latitudes (closer to the equator) moves south. This often happens when high-pressure systems sit in place for a long time, helping push this air toward Antarctica. These warm air events usually don't reach southern Victoria Land, which lies deeper within the Ross Sea area.

In the south, moisture comes from the east, particularly when the sea ice in the Ross Sea opens up, allowing more moisture to reach land.

Models can predict meltwater generation

The McMurdo Dry Valleys in Antarctica host unique microbial ecosystems, dependent on glacier-derived freshwater. Research by ASP introduces the first use of the WRF-Hydro/Glacier model in the Dry Valleys to simulate the hydrological process — from glacier melt to streamflow reaching terminal lakes. Using weather data from Commonwealth Glacier over a 7-month period (Aug 2021–Feb 2022), researchers refined the model by adjusting parameters to match observed conditions.

These models effectively predict meltwater generation and flow, and are being further developed to translate projected climate changes into estimates of water availability — a critical driver of biological activity. The enhanced model accurately captured melt dynamics, temperature variations, surface elevation changes, and runoff patterns. This information provides a robust foundation for more precise future simulations of McMurdo Dry Valleys hydrology and its ecological consequences.

Our research is an important part of global understanding

Our work contributes to the growing understanding of Antarctic weather and climate, its spatial and temporal variability, regional drivers and long-term trends. Products such as AntAIR ICE provide an updatable, high-resolution picture of near-surface air temperature. This adds to our understanding of ice melt across the continent, and we know that surface melting and floating ice shelves can be a catalyst for ice sheets to rapidly disintegrate.

Our results show that locally-specific information on changes to ice melt and wetness must inform spatial planning and management measures. This information is vital to mitigate climate change effects on Antarctic environments and ecosystems.

Our work on downscaling regional climate projections is designed to address the need for managers to tailor specific management interventions. These interventions are to protect values, as documented in the Climate Change Response Work Programme of the Committee for Environmental Protection, which is part of the Antarctic Treaty System.

For more information, contact

James Renwick
Professor, Victoria University of Wellington
james.renwick@vuw.ac.nz

Marwan Katurji
Associate Professor, University of Canterbury
marwan.katurji@canterbury.ac.nz

Adrian McDonald
Atmospheric Physicist, University of Canterbury
adrian.mcdonald@canterbury.ac.nz

Definitions

Weather: The conditions in the air above the earth, such as wind, rain, or temperature, especially at a particular time over a particular area.

Climate: Long-term patterns and averages of weather conditions — such as temperature, humidity, wind, and precipitation — in a particular region over extended periods, typically 30 years.

Synoptic drivers: Large-scale weather patterns and atmospheric conditions that influence local weather events. These drivers can include atmospheric rivers, blocking events, and variations in the jet stream, all of which can transport moisture and affect precipitation patterns.

Southern Annular Mode (SAM): A climate pattern that describes the north-south movement of the westerly wind belt that circles Antarctica, influencing weather and climate across the Southern Hemisphere, including Aotearoa New Zealand.

Foehn winds: Warm, dry, and gusty winds that occur on the leeward (downwind) side of mountain ranges. They are a result of moist air being forced to rise over the mountains, where it cools and releases precipitation. As the air descends the other side, it is compressed and warms, resulting in the characteristic warm and dry conditions of a foehn wind.

Katabatic winds: Strong, cold winds that flow down from the high interior ice sheet towards the coast, due to gravity. They are caused by the cooling of air over the elevated ice sheet, creating dense, cold air that flows downhill under its own weight.

Polynya: An area of open ocean water that persists within sea ice, either due to wind-driven ice movement or upwelling of warmer water that prevents ice formation.

El Nino Southern Oscillation (ENSO): A climate pattern involving periodic changes in sea surface temperatures and atmospheric pressure in the central and eastern Equatorial Pacific Ocean.

Amundsen Sea Low (ASL): A climatological low-pressure center in the Amundsen Sea that plays a key role in influencing the weather and climate of West Antarctica and the surrounding Southern Ocean, including the Ross Sea region. ASL affects wind patterns, sea-ice distribution, and the flow of warm ocean water toward Antarctic ice shelves.

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