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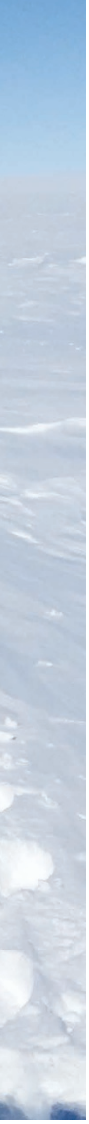
# THE THREAT BENEATH ANTARCTICA

**THE GIANT EAST ANTARCTIC ICE SHEET LOOKS STABLE FROM ABOVE — BUT IT'S A DANGEROUSLY DIFFERENT STORY BELOW.**

BY JANE QIU

On a glorious January morning in 2015, the Australian icebreaker RSV *Aurora Australis* was losing a battle off the coast of East Antarctica. For days, the ship had been trying to push through heavy sea ice. It rammed into the pack, backed up and crashed forward again. But the ice, several metres thick, hardly budged. Stephen Rintoul, an oceanographer at the University of Tasmania in Hobart, Australia, nearly gave up his goal — to reach a part of the continent that had thwarted all previous expeditions. "I really thought that would be it," he says. "It'd be another failed attempt."

Then the weather came to the rescue, with a wind change that blew the ice away from the shore, opening a path through the pack. The ship managed to break free and wove its way through 100 kilometres of ice, reaching the edge of the frozen continent shortly after midnight. Rintoul and his team were the first



**A research team probes for crevasses on Totten glacier, the largest in East Antarctica.**

scientists to reach the Totten Ice Shelf — a vast floating ice ledge that fronts the largest glacier in East Antarctica. "It was a really exhilarating experience," says Rintoul, chief scientist of the expedition.

The team had to work fast before the ice closed again and blocked any escape. For more than 12 hours, Rintoul and his colleagues carried on non-stop, probing the temperature and salinity of the water, the speed and direction of ocean currents as well as the shape and depth of the ocean floor. They also deployed instruments that would continue taking measurements after the ship had departed.

These first direct observations confirmed a fear that researchers had long harboured: that warm waters from the surrounding ocean can sneak underneath the floating glacier tongue and eat the ice away from below[1]. "This could explain why Totten has been thinning in the past few decades," says Rintoul.

Findings such as these are revealing some scary truths about East Antarctica — the vast, remote landmass to the east of the Transantarctic Mountains (see 'Ice king'). This region is about as big as the entire United States and the majority of it stands on a high plateau up to 4,093 metres above sea level, where temperatures can plunge to −95 °C. Because the East Antarctic Ice Sheet seems so cold and isolated, researchers thought that it had been stable in the past and was unlikely to change in the future — a stark contrast to the much smaller West Antarctic Ice Sheet, which has raised alarms because many of its glaciers are rapidly retreating.

In the past few years, however, "almost everything we thought we knew about East Antarctica has turned out to be wrong", says Tas van Ommen, a glaciologist at the Australian Antarctic Division in Kingston, near Hobart. By flying across the continent on planes with instruments that probe beneath the ice, his team found that a large fraction of East Antarctica is well below sea level, which makes it more vulnerable to the warming ocean than previously thought. The researchers also uncovered clues that the massive Totten glacier, which holds about as much ice as West Antarctica, has repeatedly shrunk and grown in the past[2] — another sign that it could retreat in the future.

Although East Antarctica doesn't seem to be losing much ice today, there are indications that it is feeling the heat of climate change and is responding in measurable ways. This is disconcerting because its ice sheet is more than ten times bigger than the one in the west. If all the ice below sea level in East Antarctica were to disappear, the height of the world's oceans would swell by nearly 20 metres.

Researchers are now trying to gather as much information as possible about East Antarctica to better predict what's to come. Their concern is that over the next few centuries, the ice sheet there might reach a tipping point. "Once glaciers retreat beyond a certain point, things may go downhill very quickly and cause rapid sea level rise," says Eric Rignot, a glaciologist at the University of California, Irvine. "We don't want to sleepwalk into a calamity like this."

## DEEP DANGER

Rignot was one of the first scientists to warn about possible trouble in East Antarctica — a region long neglected by climate researchers. In 2013, his team detailed the behaviour of ice around the margin of Antarctica by combining satellite imagery, airborne surveys and climate models. The researchers found evidence that six East Antarctic ice shelves, including Totten, were melting from below at rates much higher than expected — with some even rivalling those of fast-retreating glaciers in West Antarctica[3].

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More surprises emerged when the researchers took a closer look at some of those East Antarctic glaciers. Satellite imagery and airborne surveys between 1996 and 2013 showed that the surface of the Totten glacier dropped by 12 metres and that its grounding line — the point at which the ice flowing off the continent begins to float on the ocean — retreated inland by a shocking amount of up to 3 kilometres[4].

"This is not an isolated incidence," says Chris Stokes, a glaciologist at Durham University, UK. His team analysed satellite imagery obtained between 1974 and 2012 that covers all the coastal regions in East Antarctica. Most areas had no net ice gain or loss. The only exception is the Wilkes Land region — an area larger than Greenland that includes Totten glacier[5]. Three-quarters of the glaciers there retreated between 2000 and 2012. "Wilkes Land may be East Antarctica's weak underbelly," says Stokes.

As researchers were pondering the surprising retreat of East Antarctic glaciers, van Ommen and his colleagues were flying over Totten to probe its underside. "The landscape underneath the ice is fundamentally important for how glaciers flow and how they respond to climate change," he says. When the team launched an international initiative called ICECAP (International Collaboration for Exploration of the Cryosphere through Aerogeophysical Profiling) a decade ago to systematically survey the hidden landscape of East Antarctica, "we almost knew nothing about what's going on down there", he says.

Every Antarctic summer since then, ICECAP's aircraft have been criss-crossing the vast continent to peer through the ice using radar as well as gravitational and magnetic sensors. "They are the best flights in the world," says Martin Siegert, a glaciologist at Imperial College London and a principal investigator of the project. The seemingly featureless ice sheet is ever-changing — with wind-sculpted snow dunes and ice shimmering in thousands of shades under the unearthly Antarctic light. "It's just like another planet," he says.

The flights have revealed an astoundingly dramatic landscape hidden beneath the relatively flat ice sheet. Preliminary results from airborne surveys this January, led by glaciologist Sun Bo at the Polar Research Institute of China in Shanghai, confirmed the existence of a 1,100-kilometre-long canyon — the longest in the world, and almost as deep as the Grand Canyon in the United States. In previous flights over Wilkes Land, van Ommen's team discovered that 21% of the Totten glacier catchment is more than 1 kilometre below sea level — an area 100 times larger than previous estimates. "We really didn't expect it to be as extensive as it has turned out to be," says Donald Blankenship, a geophysicist at the University of Texas at Austin and another ICECAP principal investigator.

The team also found underwater troughs that extend all the way from the edge of the Totten Ice Shelf to the grounding line 125 kilometres inland, and as deep as 2.7 kilometres below sea level[6]. This deeply contoured landscape could allow warming waters from offshore to quickly reach and erode the ice.

The first chance to study the fate of that water came when the RSV *Aurora Australis* reached Totten in 2015. Near the glacier tongue, Rintoul and his colleagues detected waters as warm as 0.3 °C — much warmer than the −2 °C freezing point of sea water[1]. "They are driving rapid rates of melt," says Rintoul. The instruments he and his team left behind show that warm waters are present all year round. If these waters follow the recently discovered channel beneath Totten to the grounding line, they will be at least 3.2 °C warmer than the freezing point at that depth. "That would be really bad news," he says.

Threats to ice shelves could also come from the Antarctic interior — from lakes under the ice sheet that periodically send flood waters towards the coast. A decade ago, Lake Cook beneath the ice sheet in Wilkes Land suddenly drained, gushing 5.2 billion cubic metres of flood water — the largest event of this type

ever reported in Antarctica. Such floods could be another destabilizing factor, causing faster ice flow and more iceberg calving, says Leigh Stearns, a glaciologist at the University of Kansas in Lawrence.

## TROUBLED PAST

These scenarios are not just hypothetical, say researchers. Studies in the past few years have revealed that East Antarctica has lost a lot of ice in the past, and could do so again in the near future.

Some of the evidence for that comes from a 2010 expedition supported by the Integrated Ocean Drilling Program, which retrieved sediments from the sea floor off the coast of East Antarctica. Getting those sediments was a dangerous endeavour. The ship had to repeatedly stop drilling and dodge massive icebergs. "The waters around Antarctica present some of the most challenging environments for ocean drilling," says Tina van de Flierdt, a geochemist at Imperial College London and a principal investigator of the expedition.

The efforts paid off, however, by revealing surprising changes in the ice sheet's history. "We had long thought when the East Antarctic Ice Sheet grew to the current size about 14 million years ago, it's the end of the story," says van de Flierdt. "It's this big stable block of ice that isn't really doing anything in the face of climate change."

Instead, the sea-floor sediments revealed that the ice sheet waxed and waned many times between 5.3 million and 3.3 million years ago[7] — an epoch called the Pliocene, when air temperatures were up to 2 °C higher than today. "We got a clear signal every time it was warm, suggesting that the ice sheet was sensitive to climate warming," says van de Flierdt.

The researchers say that they have some intriguing preliminary results from the most recent interglacial period, between 129,000 and 116,000 years ago — when the globe was as warm as it is today. The ice sheet retreated just slightly less at that time than it did during the much warmer Pliocene. "That's a big surprise," says van de Flierdt.

"If the results prove to be robust, I'd say it's really interesting," says Maureen Raymo, a geochemist at the Lamont-Doherty Earth Observatory in Palisades, New York. "This may mean that you can lose a certain amount of ice quite easily with a little bit of warming," she says.

## FAST FORWARD

As East Antarctica's vulnerability comes into focus, researchers are increasingly concerned about the future. The only way to forecast decades or centuries ahead is to use computer models that simulate how ice sheets respond to a changing climate. But the models are relatively simplistic, and until recently they couldn't accurately reproduce some past events, such as the significant glacial retreats that scientists have been discovering in East Antarctica's history.


**ICE KING**

The East Antarctic Ice Sheet is about as big as the entire United States and is up to 5 kilometres thick in places. If it melted completely, it would raise sea levels by about 50 metres — more than 10 times the impact of losing the West Antarctic Ice Sheet.

Climate researchers Robert DeConto of the University of Massachusetts in Amherst and David Pollard of Pennsylvania State University in University Park have tried to make the simulations more realistic by factoring in some processes that were left out of earlier studies. Their model allows meltwater on the ice surface to deepen crevasses and splinter the ice shelves, and it simulates how ice cliffs collapse once they lose the ice shelves that buttress them.

When DeConto and Pollard included these processes, their model showed East Antarctica's glaciers retreating substantially during the last interglacial period and in the Pliocene[8]. "It's really the first successful attempt to roughly match ice-sheet simulations with our best understanding of past glacier retreat and sea-level rise," says van Ommen.

After looking back in time, the researchers turned their model to the future. There, they saw a mix of good and bad news. In their simulations, the entire Antarctic Ice Sheet does not change much in the next 500 years if global warming is limited to less than about 1.6 °C above pre-industrial levels by the end of the century — roughly in line with what the Paris climate agreement aims to achieve.

But if temperatures rise more than about 2.5°C above pre-industrial levels by 2100 and continue climbing, Antarctic ice melt will raise ocean levels by 5 metres by 2500 (ref. 8), with nearly half of that coming from East Antarctica. With Greenland ice also melting, the global sea level would rise by at least 7 metres — enough to inundate large parts of major coastal cities such as Mumbai, Shanghai, Vancouver and New York. "This would drastically reshape the world's coastline and affect millions," says DeConto.

He cautions that the model is still rather crude — mainly because observations of East Antarctica are so limited. "Most of the coastline is simply unmapped," he says.

The lack of data has also resulted in extremely poor ocean models that grossly underestimate the amount of warm water reaching the ice shelves, says DeConto. "This really calls for long-term monitoring of ocean conditions."

In East Antarctica now, temperatures are dropping rapidly as the austral winter sets in; researchers are cosy at home reviewing the latest haul of data from the field season. A priority for the future is to map the bedrock beneath all major ice shelves. That will help researchers to identify other glaciers that might be eaten away by warm ocean waters, and to predict how the interior might respond once the ice on the coastal margins disappears.

One of the scariest finds would be large valleys in the continental interior that get deeper as they slope towards the ocean. These could destabilize large sections of East Antarctica's glacial cap when its margins start to disintegrate over the coming decades and centuries. "Then the entire ice sheet could slide off easily," says Blankenship. "There would be nothing to hold it back." ■

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