CRYOSPHERIC SCIENCE

Vulnerable ice in the Weddell Sea

Of the West Antarctic ice shelves, those in the Amundsen Sea sector have given the most cause for concern. Ocean modelling of the Weddell Sea region, together with a detailed survey of the ice bed morphology, indicates that this region, too, may change soon.

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As a marine ice sheet, the West Antarctic ice sheet rests on ground that is below sea level and has a bed that slopes down, going inland. In the 1970s, concerns about a potential instability of these types of ice sheets were raised — in particular, about the largest one that covers West Antarctica[1,2]. Global-mean sea level could rise by approximately 3.3 m if the entire West Antarctic ice sheet were to disintegrate[3]. So far, indication for accelerating ice loss[4] has mainly been found in the Amundsen embayment at the root of the Antarctic Peninsula. Two papers, published in *Nature Geoscience*[5] and *Nature*[6], indicate that the Weddell Sea sector to the east of the peninsula may soon become susceptible to fast change, too.

An understanding of the current and future development of the West Antarctic ice sheet requires detailed knowledge of the various factors that affect ice sheets. For example, the location of the grounding line — the transition between ice that sits on the bed and ice connected to the sheet but floating on the ocean — plays a key role in the stability of a marine ice sheet, as does the topography of the ice bed[7]. When the grounding line retreats, more ice is discharged from the sheet, because the ice upstream is thicker. This, in turn, leads to further increase of the ice flux into the sea — a positive feedback. Basal melting of the floating part of the ice mass, the ice shelf, plays a particularly important role in this feedback: a warming ocean may change the temperature beneath an ice shelf, leading to enhanced basal melting and, potentially, grounding line retreat. On the other hand, a rough bed topography with small ridges might offer support for a marine ice sheet in retreat, and may thus prevent or delay further disintegration.

Yet before any warm water masses — usually found at intermediate ocean depths between 300 and 700 m — can interact with ice shelves, they must first drain onto the continental shelves. One possible mechanism to push the warm water masses onto the shelves is the momentum transferred between wind and ocean, which drives ocean circulation. A less consolidated cover of sea ice can achieve such a push of warm water onto the shelves.

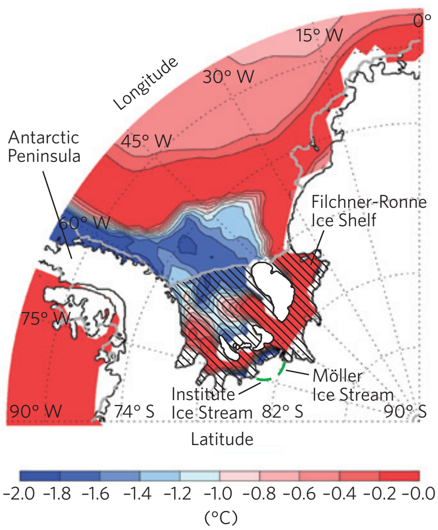

Figure 1 | Warm waters off West Antarctica. In simulations with a coupled ice–ocean model, Hellmer and colleagues[6] show that, later in the twenty-first century, warm ocean currents (red) could reach far beneath the Filchner-Ronne Ice Shelf in the Weddell Sea (hatched), which could lead, in turn, to basal melting. For the Institute and Möller ice streams (green) that feed into the Weddell Sea, Ross and colleagues[5] detected a smooth bed with a relatively steep, retrograde slope — a bed that would offer little resistance to any instability that might arise. The solid grey line behind the coastline (black) indicates the ice-shelf front.

Over the past few years, glaciologists and oceanographers have been studying these processes, with emphasis on the Amundsen Sea sector, where basal melting, grounding line retreat and accelerating ice flow has been diagnosed[8–10].

Now, Ross *et al.*[5] and Hellmer *et al.*[6] focus their attention on the Filchner-Ronne Ice Shelf in the Weddell Sea sector, which has so far seemed stable. Worryingly, Hellmer and colleagues conclude that, over the course of the twenty-first century, warm pulses of ocean currents are likely to reach this ice shelf and induce basal melt, whereas Ross and colleagues find that beneath the grounded ice streams that feed the Filchner-Ronne Ice Shelf, the bed has steep retrograde slopes.

Specifically, Hellmer and co-workers[6] used a regional coupled ice-ocean model to study the response of the ocean to variations in the atmosphere over the next two centuries, as projected by the state-of-the-art global climate model HadCM3. In their simulations, from the year 2036 onwards, pulses of warm water reach up onto the continental shelf in the Weddell Sea sector of Antarctica. From 2070 onwards, warm currents reach sufficiently far south to drain into the cavity beneath the ice shelf, reaching the grounding line less than a decade later (Fig. 1). By the 2090s, the entire Filchner trough is filled with warm water, with ocean temperatures below the ice shelf up to 2 °C warmer than at present. These findings are consolidated with an independent model of different architecture and higher resolution. In the simulations by Hellmer and colleagues, the transport of warm water to the base of the ice shelf is achieved through faster sea-ice drift that results from decreasing sea-ice thickness and concentration. This mechanism contrasts with the previously held view that changes in the sea-ice cover primarily affect the formation of dense shelf water masses[11].

The findings by Hellmer and co-workers[6] highlight the importance of the ocean circulation in the Weddell Sea for the fate of the ice in this sector, and eventually also for the entire West Antarctic ice sheet. They also suggest that the Filchner-Ronne Ice Shelf — hitherto known as one that accretes ice from underneath — could transform into a basal melt regime during the second half of the twenty-first century. In the simulations presented, the warming of the water beneath the ice shelf enhances the reductions in ice thickness by melting from the current 0.2 m per year to 4 m per year — averaged over the shelf — by the end of the twenty-first century. The maximum melt is predicted at the location of the grounding lines and is, in places, as high as 50 m per year.

Such fast melting at the grounding lines could drive rapid grounding line retreat, making the slope and roughness of the bed beneath the Filchner-Ronne Ice Shelf critical factors in the stability of this part of the West Antarctic ice sheet.

A complementary study by Ross and colleagues[5] assesses these factors. They surveyed the ice thickness of two grounded ice streams that feed the Filchner-Ronne Ice Shelf using radio echo sounding. They gathered data over a distance of more than 25,000 km, criss-crossing the downstream areas of the Institute and Möller ice streams in 2010/11. These data allow a highly accurate determination of the basal topography over a densely spaced grid. The survey unveils a retrograde bed with a steeper slope than found in other ice streams of the West Antarctic ice sheet. Furthermore, there are no small-scale undulations that could act as pinning points for retreating grounding lines in this area of the bed.

From the smooth quality of the bed, Ross and colleagues[5] infer that soft sediments are underlying these two ice streams. If so, the smooth bed indicates that the area has probably been free of ice cover in the past. They also find that the shape of the underlying landscape gives evidence that, in the past, a grounded ice-sheet margin existed upstream of the approximately 20,000-km^2-large basin that currently underlies the mouth of the Institute and Möller ice streams of the West Antarctic ice sheet.

The projections of increasing basal melt rates by Hellmer and colleagues[6], together with the smooth, steep and retrograde bed topography diagnosed by Ross and co-workers[5], make the Weddell Sea sector of the West Antarctic ice sheet a region of concern. In light of these results, future assessments of West Antarctic ice sheet stability cannot ignore the Weddell Sea. ❐

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Published online: 9 May 2012