GLACIOLOGY

# Vulnerable Antarctic ice shelves

The decay of floating ice shelves around Antarctica speeds up ice flow from the continent and contributes to increased sea-level rise. Now, meltwater attributed to warm winds has been discovered on an East Antarctic ice shelf, suggesting greater vulnerability than previously thought.

Martin Siegert

The giant grounded ice sheets of East and West Antarctica, which contain enough ice to raise sea levels by around 60 m, are protected from direct contact with the open ocean by a series of floating ice shelves[1]. The health of these ice shelves is affected by oceanic heat that melts their undersides and thins the ice. Surface meltwater can also cause ice shelves to break up suddenly and catastrophically. Now, writing in *Nature Climate Change*, Jan Lenaerts and colleagues[2] report a substantial accumulation of meltwater at and around the grounding zone of the Roi Baudouin ice shelf in East Antarctica, which they link to warm winds and not ocean temperatures. These processes, previously unseen in East Antarctica, indicate that further warming may amplify the risk of ice shelf collapse and subsequent rapid ice loss.

In general, wasting of the ice shelf takes place by the calving of icebergs at the ice shelf edge and by melting at the boundary between the ice shelf and the water it floats in. Ice shelves are highly sensitive to oceanic warmth, as exemplified by satellite measurements of thinning within floating ice in front of Pine Island Glacier[3]. This loss is offset, to a greater or lesser extent, by the flow of ice, which transfers mass from the grounded ice sheet to the floating ice shelf across a grounding zone connecting the two. Continued ocean-driven melting could act to decay the ice shelves completely, but it seems unlikely that they will diminish at a steady rate. Break up of an ice shelf, if it occurs, is more likely to be abrupt and dramatic.

For example, on the eastern side of the Antarctic Peninsula, the Larsen B ice shelf underwent a rapid and catastrophic mechanical failure in 2002. Here, meltwater collected in hundreds of lakes atop the ice surface, which, on draining, caused buoyancy driven uplift that allowed fractures to form through the ice shelf. This triggered a chain reaction of further lake drainage and ice fracturing, leading to sudden ice-shelf collapse[4].

Surface melting of ice is believed to be a negligible or very small term in the mass budget in Antarctica (in contrast to Greenland, where it is significant), but the break-up of Larsen B tells us that surface melting can be critical to the structural integrity of ice shelves. When ice shelves disappear, an important back-force on the upstream grounded ice is lost, resulting in increased flow of grounded ice to the ocean[5].

Melting on Larsen B was influenced by foehn wind action: westerly winds deliver heat to the ice surface on the lee side of the Antarctic Peninsula as air descends over the mountains. In summers, when the ambient temperature is unusually high, such winds can cause noticeable melting that can either weaken the ice shelf through crevassing or warm it if the water refreezes[6]. As the topography and atmospheric conditions of both East and West Antarctica are different from those on the Antarctic Peninsula, wind activity has not thus far been considered significant as a destabilizing influence on the majority of Antarctic ice shelves.

Now, Lenaerts *et al.* have measured substantial subsurface meltwater accumulations at and around the grounding zone of the Roi Baudouin ice shelf in East Antarctica, which they interpret to be the consequence of katabatic winds — the density-driven flow of air from the high altitude Antarctic interior to the coast. On descent, air temperatures increase due to changes in pressure and mixing with warmer air parcels (Fig. 1), resulting in the temperature of the ice surface being up to 3 °C hotter than the surrounding ice sheet. The katabatic flow also scours the surface snow, exposing glacier ice. As glacier ice is darker than snow, it acts to absorb rather than reflect solar radiation, causing further melting. The melt water flows to the grounding zone where it seeps through the snow and accumulates as a layer within the ice shelf.

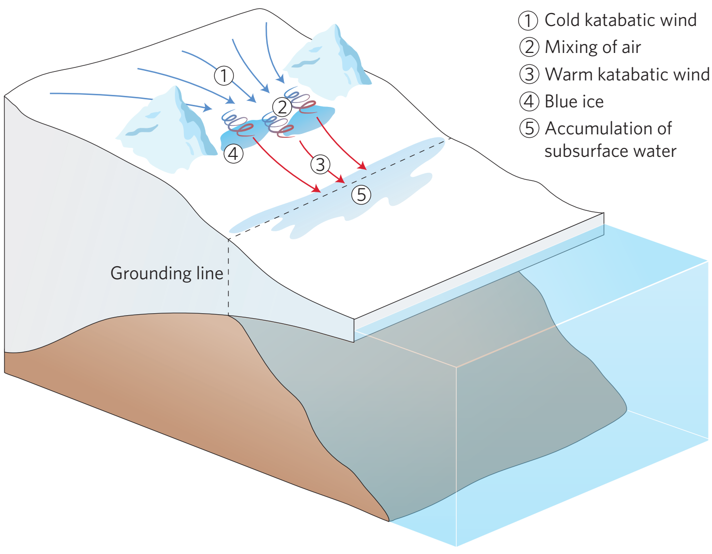


**Figure 1 |** Schematic illustration of how katabatic winds emanating from the ice-sheet interior are funnelled by topography along the flow of outlet glaciers, causing exposure of dense (blue) ice at the surface and mixing of air. The warming effect of air mixing, added to the enhanced ability of ice to absorb solar radiation compared with snow, leads to sufficient heat to melt snow and ice. The meltwater flows toward the grounding line, where it accumulates beneath the snow surface.

The Roi Baudouin ice shelf measurements are important for three reasons. First, they demonstrate that katabatic winds can drive melting in East Antarctica. Second, the meltwater formation is restricted to the grounding zone and is thus focused on a critical region of the ice sheet. Third, some of the meltwater has been observed to drain, implying a connection between the surface and the ocean beneath the ice shelf and, hence, the initiation of a potential structural weakness.

As Lenaerts *et al.* point out, atmospheric warming, as observed globally, could lead to increased surface melting in Antarctica across other grounding zones[6], including some particularly vulnerable locations. One example is the Thwaites Glacier in West Antarctica, which rests on a bed hundreds of metres below sea level and is protected by an ice shelf that is currently losing mass[7]. Another is Totten Glacier in East Antarctica, which contains as much ice as the bulk of West Antarctica (in sea level equivalent terms) and is similarly exposed to a thinning ice shelf[8]. If Antarctic ice shelves decay more rapidly than the flow of ice is able to adjust to, the grounding zone could become unstable, leading to the rapid collapse of grounded ice into the ocean[9]. This could cause sea level to rise at rates much greater than observed today (around 20 cm in total since the middle of the nineteenth century) and greater than generally predicted for this century (between 40–80 cm)[10].

Ocean-driven melting of ice shelves remains the principle way in which they may lose mass. However, changes induced by surface melting cannot be ignored, especially under further atmospheric warming. These changes demand study across the vulnerable ice-sheet margins of Antarctica. ❐

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