Antarctica

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Ice shelves guarded by snow shields

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Floating ice shelves that fringe Antarctica are at risk from warming ocean water and from above by warming air. Work now reveals that snow accumulation on ice shelves can minimize surface melt and ponding, but that future atmospheric warming will likely overpower this protection that snow provides, leaving ice shelves vulnerable to collapse.

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Dams impede flowing rivers. Similarly, floating ice shelves around Antarctica, formed as the ice sheet drains into the ocean, are physical barriers that can impede upstream ice flow and thus reduce potential ice-sheet contributions to global sea-level rise[1]. Knowing the viability of ice shelves in a warming world is vital to predicting ice-sheet and sea-level change in the coming decades, centuries and millennia. A majority of Antarctic ice shelves holding back the ice sheet are vulnerable to water-induced fracturing that can lead to cracks that migrate from the top of the ice shelf to its base and even full-scale disaggregation (that is, collapse) of the ice shelf[2], yet the conditions required for appreciable surface melt are commonly expressed in terms of air temperature alone. Reporting in *Nature Climate Change*, Jan Melchior van Wessem and co-authors[3] find that the air temperature thresholds at which ice shelves experience surface melting are controlled by snow accumulation, where enhanced snow shielding minimizes surface melting at warmer temperatures compared with where snow shielding is lacking even at colder temperatures.

Even the coldest and most remote places in Antarctica are not safe from human-induced climate change. The South Pole, for example, has warmed by 0.6 °C per decade over the past 30 years, which is three times the global average rate of warming[4]. While surface ice melt is nowhere near as extensive in Antarctica as in Greenland today, continued warming above the fringing ice shelves will lead to more than double the volume of surface meltwater[5]. Ultimately, this water has a few potential fates: infiltrate downward into the top, permeable layers (that is, fluffy to lightly compressed snow) of the ice shelf, or, if the surface is impermeable (that is, a slab of ice), the water can accumulate into ponds or streams. The pressure of the water on the ice can create cracks that propagate downward to the base of the floating ice shelf via a process called hydrofracture[6]. Satellites in space have observed ice shelves in the Antarctic Peninsula collapse and disintegrate entirely following periods of meltwater ponding at the ice-shelf surface[7,8], removing the natural dams and unleashing ice flow downstream into the ocean that contributes to sea-level rise[9].

The viability of ice shelves in the relatively warm Antarctic Peninsula has previously been defined by threshold mean annual air temperature between −9 °C and −5 °C, where ice shelves persist at temperatures colder than this threshold[10]. If we assume ice shelves elsewhere in Antarctica behave similarly to the ones in the Antarctic Peninsula, we could track the future demise of ice shelves as warmer temperatures migrate south. Yet, some ice shelves outside the Antarctic Peninsula are now suffering in regions where air temperatures have yet to meet this threshold due to attack from below as warm ocean water melts the base of the floating ice[11] and from above by the ponding of surface meltwater and hydrofracture[3]. These findings indicate that the thresholds found for the Antarctic Peninsula cannot be used universally across the continent, but what causes these deviations is not well understood. One potential driver of these differences is the impact of snow accumulation on the potential for meltwater generation and ponding, conditions required for hydrofracture-induced demise of Antarctic ice shelves. Precipitation is projected to increase as warming air increases the moisture capacity[12]; whether the precipitation falls as snow or rain matters greatly for the ice sheet and fringing ice shelves across the continent.

The authors consider the conditions required to initiate meltwater ponding on ice shelves based on the formation and demise of a permeable snow (or lightly compacted snow called firn) layer on the top of ice shelves. A metric for whether meltwater ponding occurs is the melt-over-accumulation (MoA) ratio. The air pockets within snow and firn can no longer evacuate water and runoff and ponding initiates if the MoA ratio exceeds 0.7. Using a high-resolution regional climate model fitted to snow accumulation and melt observations, simulations of historical, present and future MoA ratios for all Antarctic ice shelves constrain distinctly different temperature thresholds for ice shelves that experience different conditions. Dry, cold ice shelves, such as the Amery Ice Shelf in East Antarctica and the two largest ice shelves in the world, the Ross Ice Shelf and the Filchner-Ronne Ice Shelf, reach conditions for meltwater ponding at around −13 °C due to a lack of permeable snow that acts as a sponge for meltwater. Wet, mild ice shelves, such as those in the Antarctic Peninsula and Thwaites Glacier, do indeed experience meltwater ponding at −9 °C as previously found by Morris and Vaughan[10]. The work of van Wessem and co-authors highlights that snow accumulation controls the air temperature thresholds for meltwater ponding and thus ice-shelf viability and that ice shelves in

East Antarctica are more susceptible to disintegration and collapse than previously thought.

The ice shelves around Antarctica currently restrain the ice flow into the ocean. Therefore, more vulnerable ice shelves, even in the relatively colder East Antarctica, could cause a faster flow of ice into the ocean and thus accelerate Antarctica's contribution to global sea-level rise. Coupling this study with satellite images of meltwater ponding on ice shelves could test the implications presented by van Wessem and co-authors, essentially is meltwater ponding happening where we think it should happen based on historical and current temperature and snowfall conditions? Meteorological stations on ice shelves and in coastal regions around Antarctica and other monitoring mechanisms, such as seasonal to annual autonomous underwater vehicle surveys, to monitor conditions above, on top and below ice shelves are imminently needed. While there are many components to consider when projecting ice-sheet mass balance and their sea-level contributions, ice shelves that hold back the ice sheet are a fundamental part of the puzzle.

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Competing interests

The author declares no competing interests.