News & views

Climate science

Crevasse analysis reveals endangered ice shelves

Jeremy N. Bassis

An ingenious combination of satellite imaging, machine learning and stress analysis has revealed the Antarctic ice shelves that are most at risk of disintegrating as a result of atmospheric warming. **See p.574**

In 2002, a large part of the Larsen B ice shelf – one of the freely floating platforms of ice that surround the Antarctic ice sheet – disintegrated in less than six weeks. This allowed the glaciers that previously fed it to flow more quickly to the ocean[1]. Neither the speed nor the timing of the disintegration was predicted by ice-sheet models used to project future sea-level rise. Glaciologists have spent the past two decades looking at the aftermath of ice-shelf disintegrations, to learn lessons that will help them predict which ice shelf will be the next to fall, and how this will contribute to the discharge of grounded ice to the ocean[2,3]. On page 574, Lai *et al.*[4] report progress in this area. The authors combined simple theories of fracture formation with machine-learning techniques to determine which portions of an ice shelf are most vulnerable to break-up and most likely to lead to sustained drawdown of the grounded ice sheet on collapse.

Ice shelves restrain the flow of ice from the grounded portions of the ice sheet into the ocean. The boundary between a grounded ice sheet and a floating ice shelf is called the grounding line. The demise of ice shelves around parts of the ice sheet where the underlying bedrock slopes downwards from the grounding-line sheet as it passes beneath the sheet can lead to an irreversible cycle of increased discharge of grounded ice to the ocean (Fig. 1). This cycle is called a marine ice-sheet instability[5], and directly contributes to global sea-level rise.

The two main suspects in the ongoing demise of ice shelves are atmospheric and oceanic warming, but atmospheric warming is suspect number one in the collapse of Larsen B. The disintegration of Larsen B and its neighbouring ice shelves was preceded by substantial atmospheric warming that melted the top of the ice, inundating the surface of the shelf with meltwater[1]. This resulted in the formation of pervasive ponds that filled fractures in the ice (crevasses), creating additional stress that caused the crevasses to deepen. The crevasses are thought to have eventually broken through all the way from the surface to the bottom of the ice sheet, a process called hydrofracturing[6]. So, can the mapping of existing crevasses on ice shelves be used to assess the likelihood of future collapses?

Enter Lai *et al.*, who have used a machine-learning algorithm to analyse satellite images of all Antarctic ice shelves, and thereby to accurately map the locations of crevasses. This provided an unprecedented data set that reveals where ice is visibly broken and where it remains intact. The authors then used a decades-old theory known as linear elastic fracture mechanics[7] to predict where the stress in the ice shelves is large enough to allow fractures to penetrate the entire ice-shelf

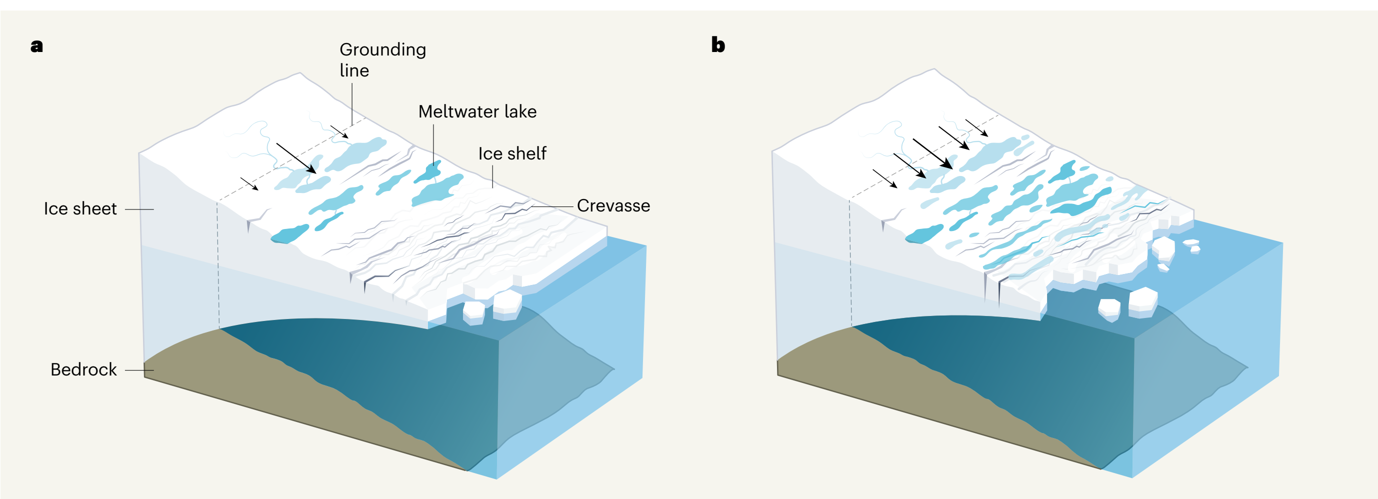

Figure 1 | The effect of global warming on ice shelves. a, The flow of ice (arrows) from the Antarctic ice sheet to the ocean is reduced by ice shelves that buttress (provide resistance to) the flow. Lai and colleagues' analysis[4] reveals that most of the ice shelves are currently stable, because the stresses in the ice that pull apart surface crevasses are mostly too small to allow the crevasses to penetrate the entire ice-shelf thickness, and because compressive stresses in the regions where meltwater accumulates on the surface prevent hydrofracturing (the process by which water fills crevasses and propagates fractures to the bottom of the shelf). The grounding line is the boundary at which the grounded ice sheet becomes a free-floating ice shelf. **b**, However, global warming will increase the amount of meltwater on ice-shelf surfaces, allowing meltwater to fill crevasses and cause hydrofracturing. The authors find that up to 60% of the area of ice shelves could become destabilized if they are inundated with meltwater, causing the shelves to disintegrate and increasing ice flow to the ocean.

thickness, and directly compared the results with their data set of where fractures are observed to occur.

The researchers find that the stress pulling apart most water-free surface crevasses is currently too small to allow the crevasses to penetrate the entire ice-shelf thickness. Similarly, the stress in the few parts of the ice shelf at which water regularly accumulates on the surface is often compressive, and therefore prevents the water from squeezing its way through hydrofractures to the bottom of the ice shelf. Under present conditions, these regions of the ice shelf are stable and unlikely to collapse rapidly.

However, as atmospheric temperatures continue to rise, larger portions of the ice shelves are expected to undergo surface melting than at present. Lai *et al.* find that up to 60% of the area of ice shelves that buttress (block the flow of) the ice sheet could be destabilized if they become inundated with meltwater, as a result of crevasses being filled by the water. Taken together, the authors' findings pinpoint the portions of ice shelves that are most vulnerable to atmospheric warming, and show that large sections that are currently stable could collapse as atmospheric temperatures continue to rise.

Lai *et al.* focus on atmospheric warming as suspect number one, but it remains unclear how tightly the fate of ice shelves is tied to suspect number two: oceanic warming. At present, atmospheric temperatures remain too cold over much of the Antarctic ice sheet to promote substantial surface melting[6]. By contrast, a warming ocean has been linked[8,9] to the thinning and retreat of ice shelves in the Amundsen Sea Embayment in West Antarctica. This is especially true for the ice shelves fed by the Pine Island and Thwaites glaciers — warm ocean water is rapidly thinning these shelves and sculpting deep basal channels into their undersides. These channels have been linked to increased fracturing of the ice shelf[10], but surface melt can also drain into surface depressions associated with the channels, forming rivers that efficiently remove water from the surface of the ice shelf and thereby prevent widespread inundation of the ice shelf[11]. What happens on the top of an ice shelf is thus tightly linked to what happens at the bottom.

Increasingly sophisticated models have been used to simulate (or re-enact) the retreat and disintegration of ice shelves in response to atmospheric warming (see refs 2 and 3, for example). However, a deeper understanding of the effects of both the ocean and the atmosphere is needed to accurately predict the fate of ice shelves in a warming climate, because ice shelves are vulnerable to attack from above and below. In other words, the chief suspects in the destabilization of ice shelves do not act in isolation — they are co-conspirators.

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Insect behaviour

Catching plague locusts with their own scent

Leslie B. Vosshall

A pheromone molecule that makes crop-damaging locusts swarm has been identified. Could this pheromone, which is sensed by odorant receptors, be used to trap these insects and prevent the agricultural devastation that they cause? **See p.584**

This year is a plague year. The COVID-19 pandemic, caused by the coronavirus SARS-CoV-2, is burning across the globe as we anxiously await an effective vaccine or drug to control it. Another plague, of a much older kind — one that is not curable with vaccines or medicine — is currently raging in Africa (Fig. 1) and the Middle East. Seasons of unusually heavy rains, driven by climate change (see go.nature.com/3fchnrm), have created population explosions of swarming desert locusts (*Schistocerca gregaria*). Swarms can contain billions of insects and cover hundreds of square kilometres. These insects strip vegetation and crops, threatening the precarious existence of subsistence farmers and contributing to food insecurity in vulnerable regions. The only effective weapon for fighting such locust plagues is the aerial spraying of pesticides, but the swarms are fast-moving and unpredictable, and spraying devastates beneficial insects.

How do these vast swarms of voracious insects form, and what can be done to stop them? On page 584, Guo *et al.*[1] identify a pheromone molecule of the migratory locust (*Locusta migratoria*) that might hold the key to swarming behaviour, and the authors' discovery raises the possibility of using locusts' own pheromone to combat this threat.

L. migratoria is a species of grasshopper that begins its life as a benign individual leading a solitary existence. But solitary locusts can attract each other to create ever-larger groups of gregarious locusts. During the process of joining a group, the pigmentation of solitary locusts changes from green to black, in an alteration regulated by a neuropeptide molecule[2]. The gregarious insects also begin to produce the molecule phenylacetonitrile, which is metabolized into cyanide and used as a type of chemical warfare against predators[3].

Researchers have long assumed that an aggregation pheromone was the trigger for swarms, but no molecule had yet satisfied the conditions of being a candidate pheromone. For this, it would need to be a single type of molecule isolated from a natural source that, by itself, has the biological activity of interest — and that, when chemically synthesized in the laboratory, has the same activity as the biological substance[4,5].

From a collection of 35 compounds emitted by locusts[6], the authors identified 6 that are highly enriched in gregarious but not in solitary insects. Guo and colleagues tested each compound for its ability to entice locusts. Only the molecule 4-vinylanisole proved to be highly potent, and it attracted male and female locusts at both juvenile and adult developmental stages. Crucially, 4-vinylanisole was equally attractive to both solitary and gregarious locusts. This suggests that the ability to sense this proposed aggregation pheromone is innate.

The concentration of 4-vinylanisole in the air increased markedly when the population density of locusts rose. This is consistent with the molecule having a role in triggering the positive-feedback loop that gathers gregarious locusts as a swarm grows. The authors carried out a clever experiment to determine how many solitary locusts need to be crowded together to induce the production of this aggregation pheromone. The answer