The Greenland Ice Sheet is shrinking, as glaciers discharge increasing amounts of ice into the ocean and raise sea levels globally. Ocean warming has been implicated as a driver of glacier retreat, with submarine melting as the presumed link. However, in Greenland the evidence for this ocean–glacier connection has been largely circumstantial: much remains to be discovered about how the ocean interacts with glaciers. Writing in *Nature Geoscience*, Khazendar et al.¹ present observations of Jakobshavn Isbræ, Greenland’s most prolific glacier in terms of both its ice flux and its contribution to sea-level rise. They show that a reversal in the glacier’s behaviour coincided with ocean cooling, adding a new piece of evidence that links glacier changes to ocean variability.

Like many other glaciers, Jakobshavn Isbræ has undergone a well-documented retreat. Before 2003, the glacier had a floating ice tongue that extended many kilometres into the ocean. The arrival of warmer waters is thought to have eroded this ice tongue and eventually led to its disintegration, which left the glacier with a relatively vertical face at its marine terminus and triggered more than a decade of acceleration, thinning and retreat²–⁶.

That ocean warming can erode an ice tongue and destabilize a glacier is both supported by evidence and fairly intuitive: a glacier with a floating ice tongue, such as Jakobshavn before its retreat, has a large submarine surface area exposed to ocean warming. However, one might not expect the reverse to be true — that ocean cooling can stabilize a glacier without an ice tongue. Instead, one might suspect that the glacier becomes indifferent to fluctuations in ocean temperature.

Khazendar et al.¹ suggest that the ocean continues to exert influence on the glacier, even after the disintegration of its ice tongue. They have compiled an extensive set of ocean and glacier datasets to study Jakobshavn Isbræ. Using radar and laser altimetry along with satellite imagery, they show that the trends of acceleration, thinning and retreat slowed in 2014 and started to reverse in 2016. These transitions in glacier behaviour coincided with regional ocean cooling in Disko Bay (the bay outside the long, narrow fjord into which the glacier drains) and further upstream in Davis Strait.

To explore the impact of this cooling on the glacier, they model submarine melting by combining the observed ocean temperatures with estimates of subglacial discharge, which is freshwater that drains at the base of the glacier and drives vigorous upwelling along the terminus. Khazendar et al. find that the modelled melt rate is correlated with their glacier records, and conclude that ocean cooling has caused the glacier to slow and thicken. Furthermore, they trace the origins of ocean cooling using a data-constrained ocean model, ECCO (Estimating the Circulation and Climate of the Ocean), and propose that the regional ocean cooling since 2016 — against a backdrop of substantial ocean warming globally — was a consequence of wintertime heat loss to the atmosphere in the boundary current that circulates around Greenland.

Put together, these observations highlight a complex web of connections between the ocean, atmosphere and ice sheet. A common metric for predicting glacier stability is the bed-slope beneath the glacier. However, Khazendar et al. point out that Jakobshavn Isbræ is currently stabilizing on an unstable bed-slope, which they interpret as another piece of evidence that external forcing is driving the glacier changes. They focus on submarine melting as the dominant external force, but there are other potential controls that require further examination, such as the
role of the ice melange in stabilizing the glacier. A limitation shared by all studies that correlate ocean variability with Greenland’s glaciers is that there are many missing links between the large-scale ocean and glacier dynamics. Observations of far-field ocean temperature — 100 km from the glacier terminus, in the case of this study (Fig. 1) — might not reflect the ocean conditions near the glacier. Jakobshavn Isbrae is one of the best studied glaciers, but observations within its fjord are sparse due to an unusually high concentration of icebergs. The limited observations show strong temperature gradients along the fjord, suggesting that temperatures measured outside the fjord in Disko Bay might be a poor proxy for near-glacier temperatures.

Connecting the large-scale ocean to submarine melting involves many poorly-understood processes in coastal currents, submarine troughs, fjords and plumes, including winds, mixing, waves, tides and sills. At the ocean–ice boundary, we do not even know the magnitude of melting nor how it varies with nearby ocean conditions; we have no direct measurements of melting at tidewater glaciers so we rely on untested models. On the glacier side, many open questions remain about how (or whether) submarine melting can trigger changes in glacier dynamics.

The intertwined web of glacier, ocean and atmosphere dynamics complicates our efforts to move from correlation to causation. We know that marine-terminating glaciers are not simple linear systems and exhibit many proven and potential feedbacks. Isolating one piece as the driver of another is a difficult, or sometimes impossible, task. Interestingly, temperature records near Helheim Glacier — the most comprehensive ocean records from inside a Greenlandic fjord — have not shown any significant correlation with glacier behaviour.

Ocean–glacier research in Greenland is limited by the length and quality of our observational records. These timeseries often have long decorrelation timescales and few degrees of freedom. In studying interannual and decadal processes, we are constrained by the fact that our records are, at best, only getting longer at a rate of one year per year (ref. 10). However, there is potential for rapid progress if we can combine our slowly growing timeseries — like the novel ones presented by Khazendar et al. — with targeted process studies to better understand the dynamics that connect the ocean, atmosphere and cryosphere.

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