poles apart

What's happening to the Greenland ice sheet?

Surface lakes created by seasonal melt on the Greenland ice sheet, July 2006

The Greenland ice sheet — that enormous mass of ice stretching from 60 to 85°N — contains enough ice to raise sea level by up to 7 m if it were all to melt. Such a sea-level rise is unlikely in the very near future but the Greenland ice sheet has now been shrinking for some years. This Poles Apart looks at how the ice sheet is losing mass, the reasons for its decline, and what might happen in the future.

Measuring mass balance

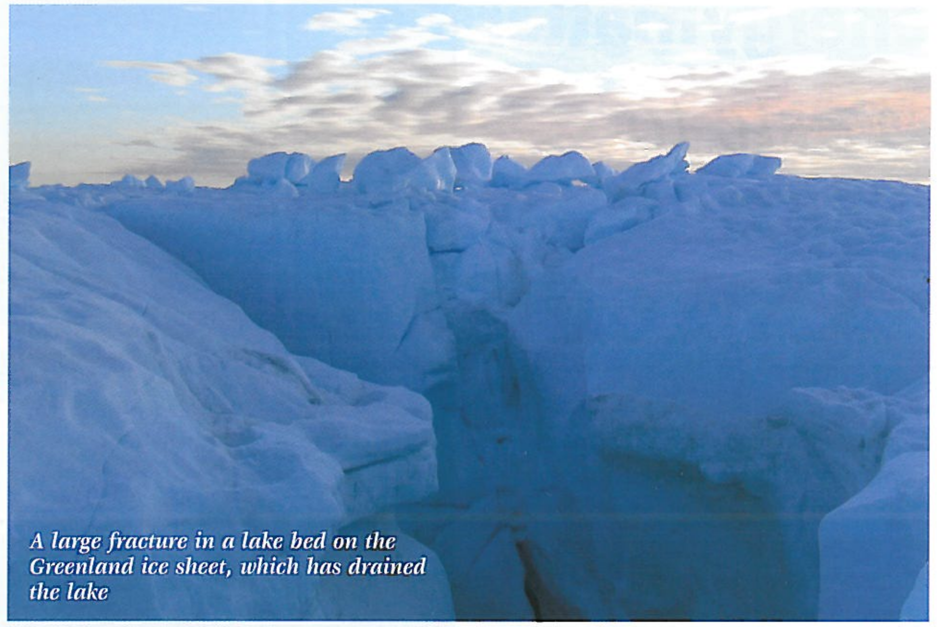
The 'health' of any glacier or ice sheet can be described by its mass balance. This is the net difference between gains (snowfall) and losses (melting, calving of icebergs). A glacier with a positive mass balance is gaining mass and growing bigger; a glacier with a negative mass balance is shrinking due to mass loss. Calculating the mass balance is difficult because we need to know about the snowfall over the whole ice sheet, as well as calving and melting rates around the margins. Measurements of these on the ice sheet are difficult, expensive, and it is impossible to make enough measurements on the ground to cover anything more than a tiny fraction of the ice-sheet surface.

It has only been with the advent of satellites — making millions of measurements each year — that we have been able to reliably measure ice-sheet changes. The satellites only really began being used in the 1970s and 1980s and for this reason we do not have very long measurements of the whole of Greenland's mass balance. What we do have for the pre-satellite era are decades of observations of ice-sheet behaviour, and some very good records of changes to some individual outlet glaciers that drain the ice sheet.

In the case of Greenland, the satellite data show that the mass balance has become increasingly negative over recent years. In 1996, for example the ice sheet had a negative mass balance of approximately 90 km^3 of ice. That is a staggering volume of ice, equivalent to 0.23 mm y^{-1} of global sea-level rise. But in 2000 the figure approached 150 km^3 and by 2005 the ice sheet had a net loss of 220 km^3 of ice (equivalent to 0.57 mm y^{-1}). In other words, by 2005, Greenland was contributing nearly one fifth of the global sea-level rise of about 3 mm y^{-1}. Most of the rest comes from thermal expansion of the oceans and the melting of small ice caps in places like Alaska and Patagonia.

Why is ice being lost?

The obvious questions for glaciologists are: where is this ice being lost from, and why is it being lost at an increasing rate? Recent work has shown that a range of different processes — some of them not previously known to science — are contributing to the loss of ice. The first and most obvious change is that the Greenland ice sheet has responded to the severe warming of the Arctic region — nearly 3°C in a decade, according to some estimates. This warming has caused increased melting on the surface of the ice sheet, at least at low elevations around its margin. For example, in 1979 about 400,000 km^2 of the ice sheet used to have some melting each summer. By 2005 nearly double the area was affected — 700,000 km^2 — and the melting reached as high as 2,000 m elevation. The melting creates slushy snow and meltwater, much of which collects in large melt lakes on the ice surface or eventually runs off the side of the ice sheet to the ocean. This meltwater flow over the surface has been known about and well understood for many years, but one discovery about the melt lakes caused shock waves in the glaciological community.



A large fracture in a lake bed on the Greenland ice sheet, which has drained the lake

Measurements of the speed of some of the outlet glaciers showed that they were speeding up in summer much more than expected. Because they are made up of kilometres-thick ice, there is no way that the summer warmth could reach the lowermost layers of the ice sheet, and so glaciologists had to consider the possibility that some other process was speeding them up. This process seemed to occur close to melt lakes and so scientists focused their attention on these areas. After careful monitoring of the ice velocity and the melt lakes simultaneously, they were able to show that individual lakes can drain through crevasses in the ice very suddenly — disappearing completely in just a few hours. This water penetrates the full thickness of the ice-sheet bed and at the base lubricates the ice, allowing the ice sheet to speed up. These rapid 'pulses' of glacier motion can lead to more ice reaching the sea in summer. What astonished glaciologists was the speed of the process; no one had suspected that water could drain through kilometres of an ice sheet so quickly. Fortunately, the process only occurs for a few weeks during the summer and so in winter the glaciers return to their former velocity.

Jakobshavn Isbrae

Most of the very large outlet glaciers draining Greenland terminate in the ocean, and observations have shown that many have retreated, thinned and accelerated in recent decades. Of particular interest is the northern hemisphere's largest glacier, Jakobshavn Isbrae. This glacier flows out of the western side of Greenland, and drains about 7% of the ice sheet. Each year, it produces about 35 billion tonnes of ice, or about 10% of all Greenland icebergs. (Because of this and because it tends to produce particularly thick icebergs that survive for long periods in the North Atlantic, it is often speculated that the iceberg hit by the *Titanic* might have come from Jakobshavn Isbrae.)

Jakobshavn has for some time held the record as Greenland's fastest outlet glacier, but in 1997 it accelerated even more, nearly doubled its discharge of ice, and began thinning rapidly. The cause of this initially puzzled glaciologists but seemed to be related to the collapse of a floating tongue in front of the glacier, and consequent loss of a buttressing effect. This is similar to the mechanism proposed for the speed-up of glaciers in the Antarctic Peninsula after ice-shelf collapse (see GEOGRAPHY REVIEW Vol. 18, No. 2).

However, one recent study has gone even further and managed to identify why the floating tongue may have collapsed. Oceanographers looked back through old records of water temperature taken as part of the management of a major shrimp fishery in West Greenland. These records show that a tongue of warm water, at a few hundred metres depth, penetrated north along Greenland's coast in 1997 and so Jakobshavn Isbrae began to melt from underneath. It is likely this melting caused the loss of the ice tongue and sudden acceleration of the glacier.

Many other glaciers around Greenland have also thinned, accelerated, retreated and may have similar mechanisms for change. However, Jakobshavn has been particularly well-studied because it is one of the few sites for which there are excellent records of the position of the glacier front during the last 150 years, thanks largely to various expeditions to the region. This means we are able to place some of the changes in a longer-term context. In the case of Jakobshavn, it now seems to be at its greatest retreat since 1850, and is over 40 km back from this earliest recorded position.

Predicting future change

To answer the earlier questions: the loss of ice is coming from melting around the edge, and from acceleration of some outlet glaciers, driven by oceanic change and penetration of surface meltwater to the bed. Glaciologists are still studying these processes, and in doing so trying to provide better predictions of what the ice sheet might do in future decades. The omens are not reassuring. Many of the outlets being studied still seem to be accelerating and thinning at the coast, and in some cases the thinning is spreading inland. This is a problem because the beds of some of these inland glaciers are below sea level and so they may retreat large distances inland, discharging much ice to the ocean in the process. Furthermore, melting of large areas of the ice-sheet margin continues in response to rising temperatures in the Arctic.

Most predictions of ice-sheet change come from computer models. These are becoming increasingly sophisticated but cannot yet capture all of the processes that glaciologists have observed at work in the ice sheet. Some models suggest that the Greenland ice sheet may split into two with a smaller southern dome and larger northern dome. Other models suggest that warming of as little as 3°C could trigger almost complete loss of the ice sheet. No glaciologist expects metres of sea-level rise in the immediate future but the concern is that the decay is likely to be irreversible. In other words, it may take centuries for the ice sheet to disappear, but the point at which it is 'set on that path' may be close and it is highly unlikely we could ever stop the process. Looking into the immediate future, Greenland already makes a substantial contribution to sea-level rise and it seems likely to do so, perhaps at an increasing rate, for some time to come.

Further reading

Bentley, M. (2005) 'Poles Apart: Antarctic ice-shelf collapse', GEOGRAPHY REVIEW Vol. 18, No. 2 pp. 36–38.

For an animation showing how the Jakobshavn Isbrae glacier has receded see:

http://svs.gsfc.nasa.gov/vis/a000000/a003300/a003395/

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Key words

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