Greenland Ice Sheet mass balance

By Dr Tom Slater, University of Leeds, UK

How does mass balance vary over Greenland?

The mass balance of the Greenland Ice Sheet is the net difference between ice gains through snowfall, and ice losses through melting at its surface or underneath its floating ice tongues, and through the calving of icebergs from glaciers flowing into the ocean.

How is Greenland Ice Sheet mass balance changing?

Contemporary changes in Greenland Ice Sheet mass balance

Between 1992 and 2018, the Greenland Ice Sheet lost more ice through ablation than it gained through accumulation, losing 3.9 trillion tonnes of ice in total at an average rate of 150 billion tonnes per year[5]. During this period the rate of ice loss from Greenland increased seven-fold, rising from 34 billion tonnes per year in the 1990s to 234 billion tonnes per year in the 2010s. Approximately 360 billion tonnes of ice loss will raise global sea levels by 1 mm.

Unlike Antarctica, which is losing almost all of its mass through ice dynamics, recent losses in Greenland have been almost equally split between **dynamic losses** and **decreasing surface mass balance**[5]. While ice discharge has increased[6], the acceleration in ice losses has been mainly driven by increased runoff as the atmosphere above Greenland has warmed, melting more of the surface during the summer[7].

How is Greenland Ice Sheet mass balance expected to change in the future?

Climate models predict that Greenland will continue to lose ice this century[8]. As observed over the past three decades, surface melting and runoff will continue to increase in Greenland as the climate warms and dominate its mass balance in future. The largest losses are expected from southwest Greenland[9] which typically experiences the most melting due to how warm air is transported over the ice sheet.

As more of Greenland's surface melts it becomes darker, reduces the surface albedo and absorbs more solar radiation, creating a positive-feedback loop which exacerbates melt. Although Greenland's surface mass balance will be the main source of ice loss in future, ice flow through its marine terminating glaciers is also expected to speed-up, increasing rates of iceberg calving and ice retreat[9].

Based on an ensemble of 256 ice sheet models, Greenland is expected to raise global sea levels by between 2 and 10 cm by 2100[8].

What are the different components of mass balance in Greenland?

In order to understand how Greenland is changing now and how it might change in the future, we must account for each individual component of its mass balance.

Surface mass balance

Greenland Ice Sheet **surface mass balance** is the net difference between ice gains (accumulation) and losses (ablation) at the ice sheet surface[1]. Greenland gains ice through precipitation, mainly as snowfall.

Ice is lost through melting of snow and ice at the surface when temperatures exceed 0 °C, most of which flows downhill into the ocean (runoff), and to a lesser extent through sublimation (the change of solid ice to vapour), evaporation (the change of liquid water on the surface to vapour), and the erosion of snow in windy weather.

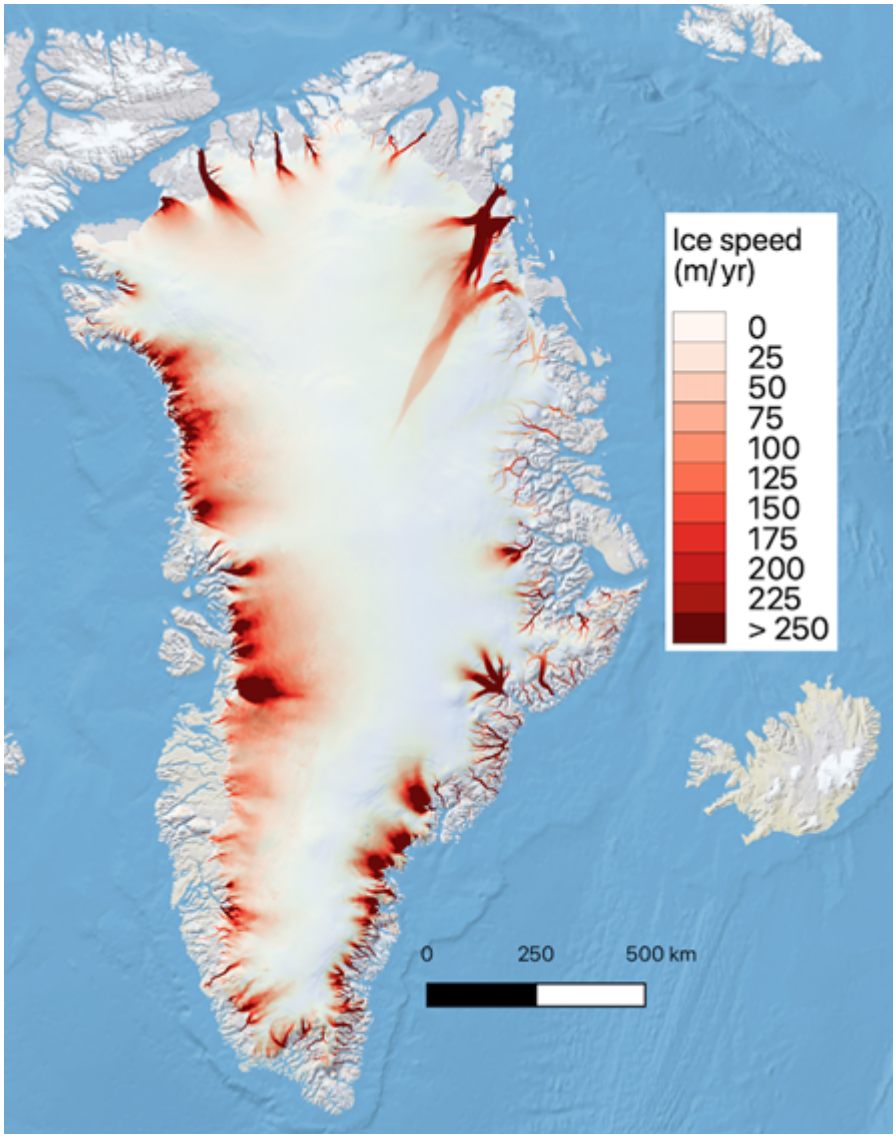
Unlike Antarctica, runoff is a much larger component of Greenland's surface mass balance, which is further away from the poles and warms above 0 °C during the summer at low altitudes[2].

Surface meltwater flows off the Greenland Ice Sheet and into the ocean through channels, which form over several summers. Credit: Ian Joughin

Ice dynamical changes

Ice dynamical changes relate to changes in ice discharge into the ocean and in the speed of ice flow. The Greenland Ice Sheet is drained by a series of narrow marine terminating glaciers dotted along the coast, where ice is lost to the ocean through the calving of icebergs and ocean driven melting underneath their floating ice tongues[3]. If calving increases, then there is more mass lost to the oceans. Calving may increase because ice velocity increases, because ocean currents change, or

because the glaciers are thinning and increasingly floating.

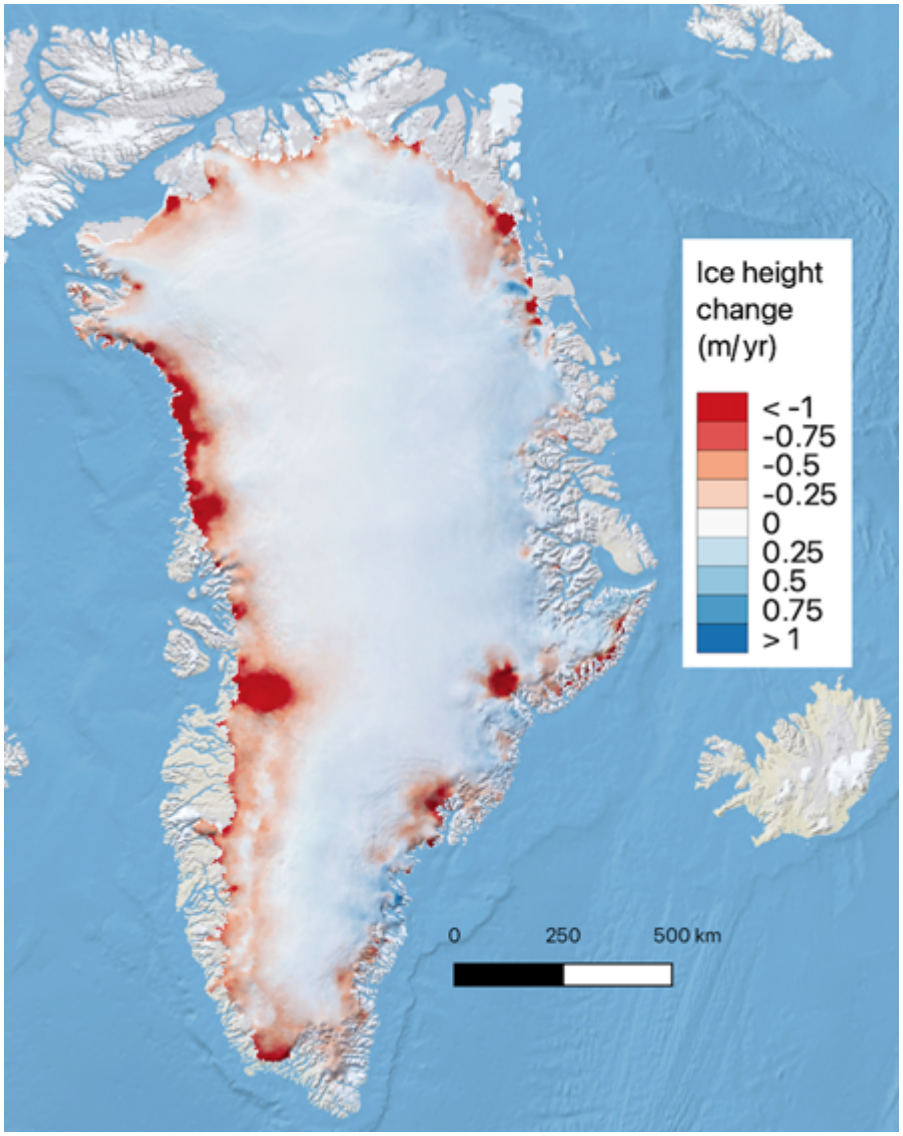


Map showing the locations of Greenland's ice streams and marine terminating glaciers from ice speed measured through satellite optical imagery. Data taken from Gardner et al., 2019[4]

How do we measure Greenland Ice Sheet mass balance?

The Greenland Ice Sheet is massive (about 9 times bigger than the UK, for example) and remote – how do we measure it's mass balance? This is only possible through satellites orbiting the Earth, which provide repeat observations and comprehensive coverage over the polar ice sheets. Satellites launched by the European Space Agency and NASA have continuously monitored the ice sheets since the 1990s and allow scientists to measure Greenland Ice Sheet mass balance in 3 ways:

- **Altimetry** reveals changes in ice sheet volume through measuring the height of the surface, which can be related to mass through the density of the ice lost or gained[10].
- **Optical/Radar imagery** provide measurements of ice speed which can be used to measure ice discharge through Greenland's marine terminating glaciers[11].
- **Gravimetry** measures changes in ice mass through changes in Earth's gravity field[12].



Maps of elevation change from satellite altimetry reveal where the Greenland Ice Sheet is changing mass. Map created using data acquired by the CryoSat-2 satellite radar altimeter. Credit: CPOM.

Validating satellite measurements in the field

To increase confidence in satellite measurements, we can validate them by travelling to the Greenland Ice Sheet and conducting field campaigns. On the ground, we can collect ice cores to measure snow properties such as density and stratigraphy, which improve our understanding of the surface conditions observed by the satellite[13]. We can also quantify the accuracy of satellite measurements directly, by acquiring overlapping measurements from similar sensors mounted on aircraft[14].

Scientists acquire ice cores on the Greenland Ice Sheet to help validate satellite measurements. Credit: Anna Hogg.

About the author

Dr Tom Slater is a research fellow at the NERC Centre for Polar Observation at the University of Leeds. His research focusses on using satellite radar altimetry to study the Antarctic and Greenland ice sheets, and measure their contribution to global sea levels.

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