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Satellite data shows Antarctic Peninsula glaciers flow faster in summer

Satellite observations reveal that glaciers on the west coast of the Antarctic Peninsula flow 12% faster on average in summer than in winter. These increased flow speeds are attributed to a combination of seasonal atmospheric and oceanographic forcing mechanisms.

The question

The Antarctic Ice Sheet is the largest reservoir of frozen water on Earth and from 1992 to 2017 it contributed to a 7.6 ± 3.9 mm rise in global sea-levels[1]. Ice mass loss in Antarctica is dominated by dynamic processes, which influence the flow of ice into the ocean, rather than surface mass processes such as melting, precipitation, and snow drift. The magnitude and timing of the response of ice sheets to a changing climate is one of the largest uncertainties in sea-level projections.

Since the 1990s, satellite observations of ice flow have revolutionised our understanding of the Earth's Polar regions and are key to monitoring how ice discharge into the ocean is changing. The Antarctic Peninsula is the warmest region of the continent and has undergone substantial glaciological changes in the last century. The catastrophic collapse of floating ice shelves, such as Larsen A in 1995 (ref. [2]), led to the loss of the buttressing force provided by the shelves, which opposes glacier flow, and a fourfold increase in the rate of ice mass loss[3]. In addition to long-term acceleration, ice speeds can also vary on shorter timescales. Seasonal ice speed variations are widespread across Greenland[4]; however, in Antarctica, there have been few observations of such variations.

The discovery

We used Sentinel-1 satellite data to measure the ice speed of 105 glaciers on the west coast of the Antarctic Peninsula, from 2014 to 2021. Our observations revealed a widespread pattern of seasonal ice speed variability across the west Antarctic Peninsula, with glaciers flowing more quickly in summer than in winter. We found an average summer speed-up of 12.4 ± 4.2%, with a maximum speed change of up to 22.3 ± 3.2% on the most seasonal glaciers (Fig. 1a). These seasonal speed fluctuations were observed from Marguerite Bay northwards. Neighbouring glaciers often have speed fluctuations with different timings and magnitudes, showing the importance of glacier geometry and local conditions.

We compared the timing of the ice speed maxima with patterns in environmental data to investigate the mechanisms driving these speed fluctuations (Figs. 1b,1c). Direct observations of the calving front locations of the glaciers and ocean temperature reanalysis data were used to study the effect of warm ocean water on the glacier termini, where increased melt and calving rates cause retreat and reduce the buttressing force. Using a regional climate model, we calculated the amount of meltwater and rain that can reach the glacier bed to enhance sliding at the ice–bed interface. We found that the ice speed maxima coincide with maxima in the upper ocean temperature and meltwater and rain runoff. Peak surface melt occurred two months before the summer speed maximum; the time taken for meltwater runoff to percolate through the snowpack can explain this lag. These results suggest that a complex mix of atmospheric and oceanographic factors influence the seasonal speed-up.

The implications

Although we observed strong seasonal ice speed variability during our 6-year study, our results do not show when this pattern began, nor project its future evolution. Atmospheric temperatures and meltwater availability on the Antarctic Peninsula are forecasted to increase[5]. Therefore, further work is required to understand how the region will respond.

Oceanic processes are largely responsible for driving long-term ice dynamics in Antarctica, unlike Greenland where atmospheric processes dominate. Antarctica may respond to increased meltwater availability differently to Greenland owing to differences in snowpack properties, glacier and ice sheet bed conditions, and ocean forcing. Processes that limit the summer speed-up in Greenland, such as efficient sub-glacial drainage pathways, have not yet been observed in Antarctica. Further fieldwork and modelling are needed to better understand these differences.

Mass balance studies using the input–output method rely on ice speed measurements for calculating ice mass loss and its contribution to rising sea levels. However, owing to the availability of historical satellite observations annual average speed measurements are often used. If peak summer or winter minimum ice speeds are assumed to represent the annual average, ice flow into the ocean will be over or underestimated, respectively. Seasonal speed variations must be accounted for in future ice sheet mass balance studies, which may allow differences between estimates to be reconciled.

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EXPERT OPINION

"Evidence of seasonality in glacier speeds on the west Antarctic Peninsula is an important finding as there has not been much documented evidence of short-term variability in ice flow in Antarctica. This work was only possible thanks to consistent and frequent coverage of the area with satellite data and the results highlight the need for continuous coverage of coastal Antarctica going forward." **Bernd Scheuchl, University of California Irvine, Irvine, CA, USA.**

FIGURE

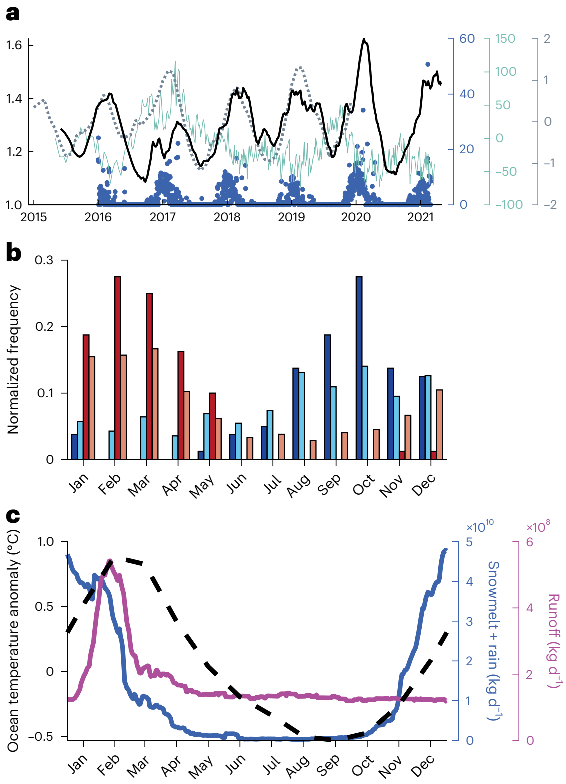

Fig. 1 | Seasonal patterns in ice speed and its environmental drivers. a, Seasonal variation of ice speed and environmental factors at Hotine Glacier, where the black, blue, grey and green data indicate the ice speed (km yr^{-1}), surface water flux (mm water equivalent day^{-1}), upper ocean potential temperature anomaly (°C), and terminus position (m), respectively. **b**, A histogram of the months in which ice speed maxima (red) and minima (blue) occurred for all 105 study glaciers (pale) and the top 20 most seasonal glaciers (dark). **c**, The monthly variation of the basin scale environmental forcings: total modelled snowmelt plus rain (blue) and runoff (mauve), and the mean ocean temperature anomaly (black dashed line). © 2023, Wallis, B. J. et al.

BEHIND THE PAPER

The success of this study is thanks to the European Space Agency and European Commission's Copernicus programme, which acquires Sentinel-1 Synthetic Aperture Radar imagery over the Antarctic Ice Sheet margins. In this study we processed 37.6 TB of this freely available satellite data and used 10,000 image pairs to measure the ice speed. High performance computer facilities were essential, giving us the capacity to process these large volumes of satellite data at the finest spatial and temporal resolution possible. This study pushed us to develop new approaches to data analysis, leading to discoveries in remote sensing glaciology. We did not initially aim to focus on the west coast of the Peninsula, but after seeing interesting seasonal signals on the Breguet Glacier we investigated further. We found that the pattern of summertime ice speed-up was widespread across the region, which was not previously known. **B.J.W. & A.E.H.**

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FROM THE EDITOR

"This work by Wallis et al. stood out because it shows just how important it is to consider short, seasonal timescales when looking at the behaviour of massive ice sheets. The progress made here brings the field closer to understanding just how much these surprisingly variable systems will contribute to sea level rise as the world continues to warm." **James Super, Senior Editor, *Nature Geoscience*.**