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Mass balance of the Greenland and Antarctic ice sheets from the 1970s to 2023

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The Greenland and Antarctic ice sheets are major drivers of global mean sea level rise and are predicted to continue to do so in the future. However, they also represent the largest source of uncertainty in projections of future sea level rise making robust estimates of observed ice sheet mass changes critical. Here, we compare and combine 42 independent estimates of ice sheet mass balance derived from satellite observations of temporal changes in ice sheet flow, volume, and gravitational attraction to determine the ice sheet mass balance from 1972 (Greenland) and 1979 (Antarctica) until 2023. We then use regional climate models to partition the total mass balance into contributions associated with surface mass balance and ice dynamical imbalance. The ice sheets lost 11,309 ± 565 billion tonnes of ice between 1979 and 2023, with glacier dynamical imbalance driving 84% of the ice loss and surface mass balance the remainder. This dataset can be used to track the contribution of the ice sheets to sea level rise and constrain projections of future sea level rise.

Background & Summary

Since the 1990s, the pace of ice loss from the Antarctic and Greenland ice sheets has accelerated, contributing to the increase in global mean sea level rise[1], with the ice sheets now representing almost a quarter of global sea level rise[2]. As ice losses from the ice sheets are predicted to further increase over the coming decades and centuries[3], quantifying ice sheet mass balance – the rate of change in ice sheet mass – is thus critical to assess the ice sheets' contribution to rising sea levels and the risks associated for coastal communities around the world[4,5]. The ice sheets also dominate uncertainties in future sea level rise, and high-end sea-level rise projections increase by a factor 2.6 by 2150 if ice sheet instability processes are included[5]. Maintaining the long-term observational record of ice sheet mass balance is a critical step towards improved ice sheet model skill[6,7] and realistic projections of sea level rise[8,9].

Fluctuations in ice sheet mass are the results of ice dynamical, surface mass balance (SMB), and basal mass balance processes. While ice sheets gain mass primarily from snowfall accumulation, they lose mass through several processes, including solid ice discharge at the grounding line, melting at the bed and at the ice-ocean interface, and through surface meltwater runoff, sublimation, evaporation, and blowing snow erosion. Ice velocity measured by radar and optical imaging sensors, volume changes measured by radar and laser altimeters, and Earth's gravity field variations measured by microwave ranging interferometers are the key satellite records used to monitor the state of the ice sheets[10]. When combined with models of SMB, firn processes, basal mass balance, and glacial isostatic adjustment (GIA), they provide estimates of ice sheet mass balance. In the input-output method[11–13] (also called mass budget method), mass balance within glacier drainage basins is derived from combining solid ice discharge estimates (derived from ice velocity measurements and estimates of ice thickness at the grounding line) and regional climate model estimates of the individual SMB components[14,15]. In marine-terminating glacier basins, ice discharge is calculated at flux gates defined in the vicinity of the grounding line, either at a fixed distance upstream from the grounding line, inland of the most retreated grounding line location recorded or where airborne measurements of ice thickness are available. The grounding line flux is then calculated by combining ice velocity and ice thickness measurements and is adjusted by adding the average SMB for the area between the flux gate and ice front. A correction is further applied to time-series of grounding line flux to account for temporal changes in ice thickness using surface elevation change measurements. Finally, mass balance is derived by differencing this ice discharge estimate and the basin integrated SMB. Altimetry-derived mass balance estimates[16–18] are derived by correcting ice sheet volume changes (estimated from repeated elevation surveys) for firn

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