SEA-LEVEL RISE

Ice-sheet uncertainty

Gravity measurements of the ice-mass loss in Greenland and Antarctica are complicated by glacial isostatic adjustment. Simultaneous estimates of both signals confirm the negative trends in ice-sheet mass balance, but not their magnitude.

David H. Bromwich and Julien P. Nicolas

Satellite gravimetry has been playing an increasingly important role in monitoring the state of the polar ice sheets since 2002. A suite of mass-balance studies[1–3] based on the Gravity Recovery and Climate Experiment (GRACE) mission has revealed substantial losses of ice-sheet mass in Greenland and West Antarctica. What's more, the contribution of the ice sheets to global mean sea-level rise has accelerated over the past few years[2]. Writing in *Nature Geoscience*, Wu and colleagues[4] describe an innovative approach employed to derive ice-mass changes from GRACE data and suggest significantly smaller ice-mass loss overall than earlier GRACE-based estimates.

Variations in the mass of the polar ice sheets — and more generally in the storage of water or ice on land — affect the Earth's gravitational field. This effect is detected by the twin GRACE satellites. However, other phenomena also contribute to the geodetic signal measured by GRACE. These further contributions comprise the response of the lithosphere to past variations of the ice load at the Earth's surface, termed glacial isostatic adjustment, as well as changes in the spatial distribution of the atmospheric and oceanic masses. Disentangling these different signals is key to accurately assessing ice-sheet mass balance.

The atmospheric and oceanic contributions are commonly derived from global reanalyses or other global climate models that assimilate observations. However, the contribution from glacial isostatic adjustment is more difficult to evaluate because the Earth's mantle is viscoelastic and therefore responds to changes in surface loading with a long delay. Indeed, the variations of the mass and extent of the ice sheets since the Last Glacial Maximum, about 20,000 years ago, continue to affect present-day changes in bedrock elevation. Assessments of the glacial isostatic adjustment typically rely on deglaciation models — which simulate the evolution of the ice sheets since the Last Glacial Maximum — together with assumptions about the viscosity profile of the mantle. Much is still unknown regarding the history of the ice sheets, and even less is known about the behaviour of the mantle in response to loading and unloading.

The originality of the method used by Wu and colleagues[4] consists of estimating ice-mass changes and glacial isostatic adjustment simultaneously, as opposed to quantifying the latter separately from deglaciation models as had been done before. The problem is expressed in terms of a single matrix equation, with the observed surface-height changes decomposed into their different contributions. The equation is ultimately solved for ice-mass changes through matrix inversion. The glacial isostatic adjustment is thus not directly retrieved from deglaciation models, but the inversion method still requires a first-guess estimate of this value and the related statistical information. These are derived from deglaciation models. A similar approach has been previously applied to studying temporal variations in land-water storage in low- and mid-latitude regions[5], which are much better constrained by present models than the polar regions. To refine and correct the first-guess estimate for glacial isostatic adjustment, Wu and colleagues use ground-based global positioning system (GPS) data.

Two important results come out of this study. First, compared with the glacial isostatic adjustment simulated by deglaciation models, larger subsidence rates are found over Greenland whereas West Antarctica exhibits lower uplift rates. In both cases, one may conclude that an excessive part of the geodetic signal may have been ascribed to modern ice-mass loss in previous studies. Hence the second result: for the period spanning April 2002 to December 2008, Wu and colleagues find an average annual ice-mass change of -104 ± 23 Gt yr^{-1} for Greenland and -64 ± 32 Gt yr^{-1} for West Antarctica. These findings confirm the ongoing shrinkage of the polar ice sheets. However, and most importantly, the newly estimated ice-sheet mass losses represent less than half of other recent GRACE-based estimates[2–3] for the same time interval: -230 ± 33 Gt yr^{-1} for Greenland[2] and -132 ± 26 Gt yr^{-1} for West Antarctica[3] (Fig. 1). It is noteworthy that, unlike the two quoted studies, the results from Wu and colleagues are not corrected for the atmospheric mass contribution, but this correction is small, within ± 5 Gt yr^{-1}, over Greenland and West Antarctica.

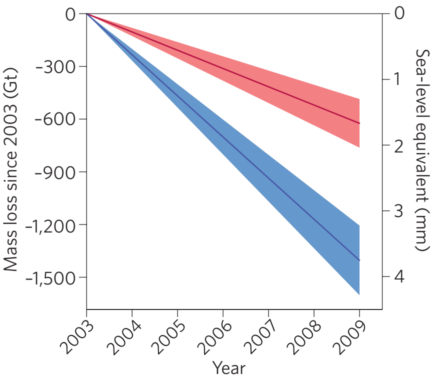

Figure 1 | Cumulative mass loss of Greenland's ice sheet. The estimate by Wu and colleagues[4] of Greenland ice-mass loss since 2003 (red) is considerably lower than an earlier predicted value[2] (blue), owing in part to larger than previously estimated subsidence rates of the underlying bedrock. Only the blue curve was corrected for changes in atmospheric mass, but these corrections are small over Greenland, and the curves and their differences can thus be interpreted in terms of contribution to global mean sea level (right-hand scale). The shaded areas reflect stated uncertainties.

The significant scatter among the GRACE-based estimates published thus far[1] results not only from the differing processing methods, but also from the shortness of the GRACE time series, the differing length of the series used in various publications, and the recent acceleration in ice-mass loss. And despite significant uncertainties regarding the glacial isostatic adjustment, combinations of the GRACE data with, for example, altimetry[6] or climate model results and ice-discharge measurements[7], have enhanced our confidence in the GRACE-based estimates of mass balance. But the calculations by Wu and colleagues significantly broaden the range of present ice-sheet mass-loss estimates and the associated impact on global sea level.

The differences between the work by Wu and colleagues[4] and earlier studies may reflect errors in present deglaciation models with respect to the ice-load history and response of the Earth's mantle. However, the revised estimates of glacial isostatic adjustment carry their own uncertainties: they depend strongly on a small number of GPS records that are all located on the ice-sheet margins.

The network of ground-based GPS sites has been considerably expanded in Greenland and Antarctica since 2007 as part of an International Polar Year project[8]. These extra GPS data will be instrumental in improving our present knowledge of the glacial isostatic adjustment over the polar ice sheets[9], with the promise of enhanced constraints on GRACE data. ❐

David H. Bromwich and Julien P. Nicolas are in the Polar Meteorology Group, Byrd Polar Research Center, Ohio State University, 1090 Carmack Road, 108 Scott Hall, Columbus, Ohio 43210, USA.
e-mail: bromwich@polarmet1.mps.ohio-state.edu

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