NEWS & VIEWS

doi:10.1038/nature10948

CLIMATE CHANGE

Shrinking glaciers under scrutiny

Melting glaciers contribute to sea-level rise, but measuring their mass loss over time is difficult. An analysis of satellite data on Earth's changing gravity field does just that, and delivers some unexpected results.

JONATHAN BAMBER

Glaciers and ice caps are pivotal features of both water resources and tourism. They are also a significant contributor to sea-level rise. About 1.4 billion people are dependent on the rivers that flow from the Tibetan plateau and Himalayas[1]. Yet significant controversy[2] and uncertainty surround the recent past and future behaviour of glaciers in this region. This is not so surprising when one considers the problem in hand. There are more than 160,000 glaciers and ice caps worldwide. Fewer than 120 (0.075%) have had their mass balance (the sum of the annual mass gains and losses of the glacier or ice cap) directly measured, and for only 37 of these are there records extending beyond 30 years. Extrapolating this tiny sample of observations to all glaciers and ice caps is a challenging task that inevitably leads to large uncertainties.

In an article published on *Nature*'s website today, Jacob and colleagues[3] describe a study based on satellite data for Earth's changing gravity field that tackles this problem. Their results have surprising implications for both the global contribution of glaciers to sea level and the changes occurring in the mountain regions of Asia.

Melting glaciers are an iconic symbol of climate change. On the basis of the limited data mentioned above, they seem to have been receding, largely uninterrupted, almost everywhere around the world for several decades[4]. Scaling up the small sample of ground-based observations to produce global estimates is, however, fraught with difficulty. Size, local topography, altitude range, aspect and microclimate all affect the response of individual glaciers in complex ways. Even the seasonality of changes in temperature and precipitation strongly influence the glaciers' response, and those that terminate in a lake or ocean behave differently again.

Nonetheless, until recently there was little alternative to some form of extrapolation of the terrestrial observations to large regions and numbers of glaciers. One such high-profile assessment[5] concluded that, during the period 1996–2006, the mass loss from glaciers and ice caps (GICs) increased steadily, contributing a sea-level rise of 1.1 ± 0.24 millimetres per year by 2006. In this study[5], the authors concluded that GICs had been the dominant mass contributor to sea-level rise over the study period, and they extrapolated their results forward to argue that this would also be the case in the future.

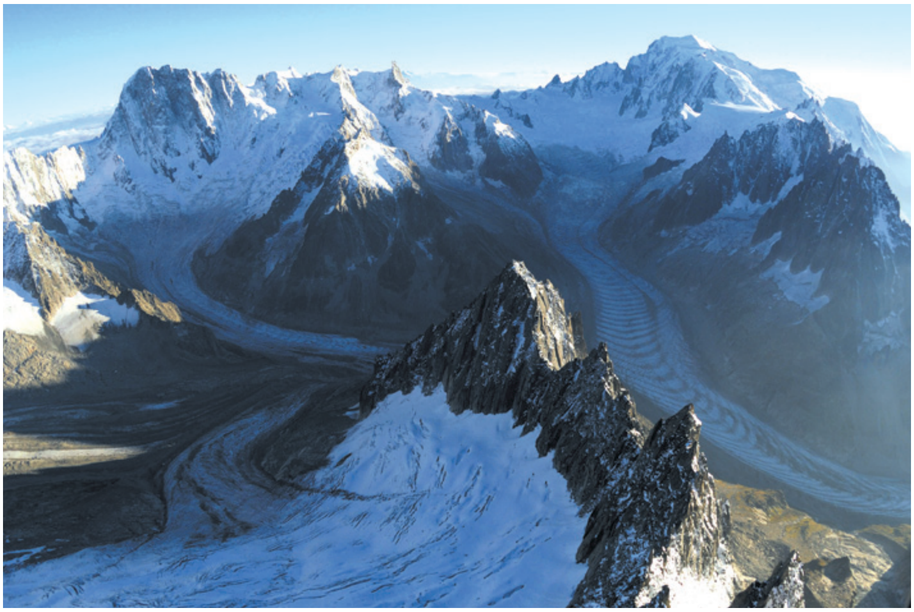

Figure 1 | The Leschaux and Talèfre glaciers in the French Alps. The photograph highlights the complex and intricate topographic setting of these mountain glaciers and the difficulty in extrapolating observations from one glacier to others. Jacob and colleagues[3] avoided these difficulties by using the area-integrated signal from satellite gravity data.

Then along came the Gravity Recovery and Climate Experiment (GRACE), which consists of a pair of satellites that have been making global observations of changes in Earth's gravity field since their launch in 2002. They have been used in various studies to examine the changing mass of the great ice sheets of Antarctica and Greenland[6] and several other large glaciated regions[7]. But, so far, the data have not been analysed simultaneously and consistently for all areas.

The difficulty with doing this is that GRACE measures the gravity field of the complete Earth system. This includes mass exchange and/or mass redistribution in the oceans, atmosphere, solid Earth and land hydrology, in addition to any changes in GIC volume. To determine the latter, it is clearly essential to be able to separate it from the other sources of mass movement that affect the gravity field. A second, related issue is the effective resolution of the observations. The GRACE satellites are sensitive to changes in the gravity field over distances of a few hundred kilometres. They cannot 'see' the difference between the signal from one glacier or small ice cap and another.

To isolate the GIC signal from others at the surface, Jacob and colleagues defined units of mass change — called mass concentrations, or mascons — within each of their 18 GIC regions (including the European Alps; Fig. 1). Each region might have many tens of mascons defining the geographic extent of significant ice volume within the sector[3]. Combined with global models of land hydrology and atmospheric-moisture content, the authors were able to isolate the GIC mass trends over the eight-year (2003–10) period of the observations. What they found was unexpected.

First, the contribution of GICs (excluding the Antarctica and Greenland peripheral GICs) to sea-level rise was less than half the value of the most recent, comprehensive estimate[8] obtained from extrapolation of *in situ* measurements for 2001–05 (0.41 ± 0.08 compared with 1.1 mm yr^{-1}). Second, losses for the High Mountain Asia region — comprising the Himalayas, Karakoram, Tianshan, Pamirs and Tibet — were insignificant. Here, the mass-loss rate was just 4 ± 20 gigatonnes per year (corresponding to 0.01 mm yr^{-1} of sea-level rise), compared with previous estimates that were well over ten times larger. By a careful analysis, the authors discounted a possible tectonic origin for the huge discrepancy, and it seems that this region is more stable than previously believed.

What is the significance of these results[3]? Understanding, and closing, the sea-level budget (the relative contributions of mass and thermal expansion to ocean-volume change) is crucial for testing predictions of future sea-level rise. Estimates of the future response of GICs to climate change are, in general, based on what we know about how they have responded in the past. A better estimate of past behaviour, such as that obtained by Jacob and colleagues, will therefore result in better estimates of future behaviour. Discussion of the demise of the Himalayan glaciers has been mired in controversy, partly because of basic errors[2], but also because of the dearth of reliable data on past trends. Given their role as a water supply for so many people[1], this has been a cause for concern and an outstanding issue.

Of course, eight years is a relatively short observation period. Some of the regions, such as the Gulf of Alaska, experience large inter-annual variations in mass balance that are mainly due to variability in precipitation[7]. This is also true for the High Mountain Asia region[3], and, as a consequence, a different measurement period could significantly alter the estimated trend for this sector. Furthermore, some areas, such as the European Alps and Scandinavia, have been relatively well monitored, and thus constrained, using other approaches. Nonetheless, Jacob and colleagues have dramatically altered our understanding of recent global GIC volume changes and their contribution to sea-level rise. Now we need to work out what this means for estimating their future response. ■

Jonathan Bamber *is at the Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, Bristol BS8 1SS, UK.*
e-mail: j.bamber@bristol.ac.uk

1. Immerzeel, W. W., van Beek, L. P. H. & Bierkens, M. F. P. *Science* **328,** 1382–1385 (2010).
2. Cogley, J. G., Kargel, J. S., Kaser, G. & van der Veen, C. J. *Science* **327,** 522 (2010).
3. Jacob, T., Wahr, J., Pfeffer, W. T. & Swenson, S. *Nature* http://dx.doi.org/10.1038/nature10847 (2012).
4. Kaser, G., Cogley, J. G., Dyurgerov, M. B., Meier, M. F. & Ohmura, A. *Geophys. Res. Lett.* **33,** L19501 (2006).
5. Meier, M. F. *et al. Science* **317,** 1064–1067 (2007).
6. Velicogna, I. *Geophys. Res. Lett.* **36,** L19503 (2009).
7. Luthcke, S. B., Arendt, A. A., Rowlands, D. D., McCarthy, J. J. & Larsen, C. F. *J. Glaciol.* **54,** 767–777 (2008).
8. Cogley, J. G. *Ann. Glaciol.* **50,** 96–100 (2009).