provide even better accuracy. Since 2002 we have direct observations of water mass fluctuations from the Gravity Recovery and Climate Experiment (GRACE)[8]. This satellite mission 'weighs' all parts of the Earth by measuring changes in the gravity field, which gives us an estimate of the variability in water storage that can then be used to adjust for the interannual to decadal changes in sea level. The authors discuss how, for the second period of their sea-level data set starting in 2003, the information from this mission can be used to remove the short-term variability. Thus, employing this data set to determine the future rise and fall of sea level will be essential to detect any possible long-term change in the rate of sea-level rise and distinguish it from the short-term ups and downs.

Overall, the paper by Cazenave *et al.* provides an important first step towards identifying rapid changes in the rate of sea-level rise. Combining information on short-term change with the overall record of sea level, as exemplified in this study[4], might be a useful way to provide an early warning system for abrupt changes in sea-level rise in the future. ❐

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PALAEOCLIMATE

A southern misfit

Temperature reconstructions of the past millennium rely heavily on Northern Hemisphere data. Now a Southern Hemisphere temperature reconstruction is available and sheds light on the complexity of the interhemispheric temperature relationship.

Kim M. Cobb

For far too long the climate science community has grappled with an inconvenient truth: the vast majority of the datasets used to constrain temperature trends of the recent past come from the Northern Hemisphere. Over a dozen reconstructions of Northern Hemisphere temperature spanning the past millennium exist and have played a critical role in distinguishing natural from anthropogenic climate change. However, the extent to which recent temperature variations in the Northern Hemisphere resemble those in the Southern Hemisphere remains unclear. Such information is critical to a complete understanding of the mechanisms of global, rather than hemispheric, climate change. Writing in *Nature Climate Change*, Raphael Neukom and co-authors[1] present a new, millennium-long reconstruction of Southern Hemisphere temperature by combining information from a wide variety of palaeoclimate sources. Although the new reconstruction resembles the Northern Hemisphere reconstructions in some key aspects — the anomalous nature of twentieth century warming being one of them — it also suggests that temperatures in the two hemispheres may have differed more than they have agreed over the past millennium.

The best-dated, highest-resolution records of past climate variability rarely extend beyond the past millennium, making this time period an important test bed for quantitative comparisons between climate field reconstructions and numerical climate model simulations of past climate[2,3]. Yearly temperature can be reconstructed from archives, such as corals, ice cores, tree rings, lake sediments and cave stalagmites, by calibrating their geochemical or physical signals against the instrumental record of climate, where they overlap over the past century. In this regard, extremely poor data coverage for Southern Hemisphere ocean temperature observations makes this calibration more difficult (Fig. 1). Scientists use a variety of advanced statistical techniques to extract the shared signals across a given network of palaeoclimate records. The uncertainties associated with reconstructed temperature estimates inevitably increase further back in time, as the number of available records decreases, but can be quantified using a variety of approaches.

One of the first such reconstructions was the so-called hockey stick, published by Mann *et al.* in 1999[4]. As a reconstruction of Northern Hemisphere temperature spanning the past millennium, the hockey stick graph reflected a long-term cooling into the seventeenth century, the stick, followed by a sharp warming that began in the late nineteenth century, the blade. Multiple teams of scientists have subsequently generated dozens of alternative Northern Hemisphere temperature reconstructions, each using slightly different methods and data networks[5]. Climate model simulations that include natural forcings from volcanic eruptions and solar variability, as well as anthropogenic forcings such as greenhouse gases, reproduce many of the key features seen in the collection of Northern Hemisphere temperature reconstructions, within the combined uncertainties of the forcings and the reconstructions[5]. Such features include multi-year, hemispheric-scale cooling associated with large volcanic eruptions, as well as pronounced warming over the industrial era. The high level of data–model agreement suggests that scientists have a good grasp of the dominant mechanisms of climate change on decadal to centennial timescales, and that such mechanisms are fairly well represented in the current suite of climate models used to project future temperature.

However, the new reconstruction of Southern Hemisphere temperature[1] suggests that the climate model simulations of past climate systematically underestimate the magnitude of natural climate variability in the Southern Hemisphere. At first glance, the reconstruction contains the same basic features of the Northern Hemisphere family of reconstructions — a centuries-long cooling into the seventeenth century, and a twentieth-century warming of unprecedented duration and magnitude. But a close comparison

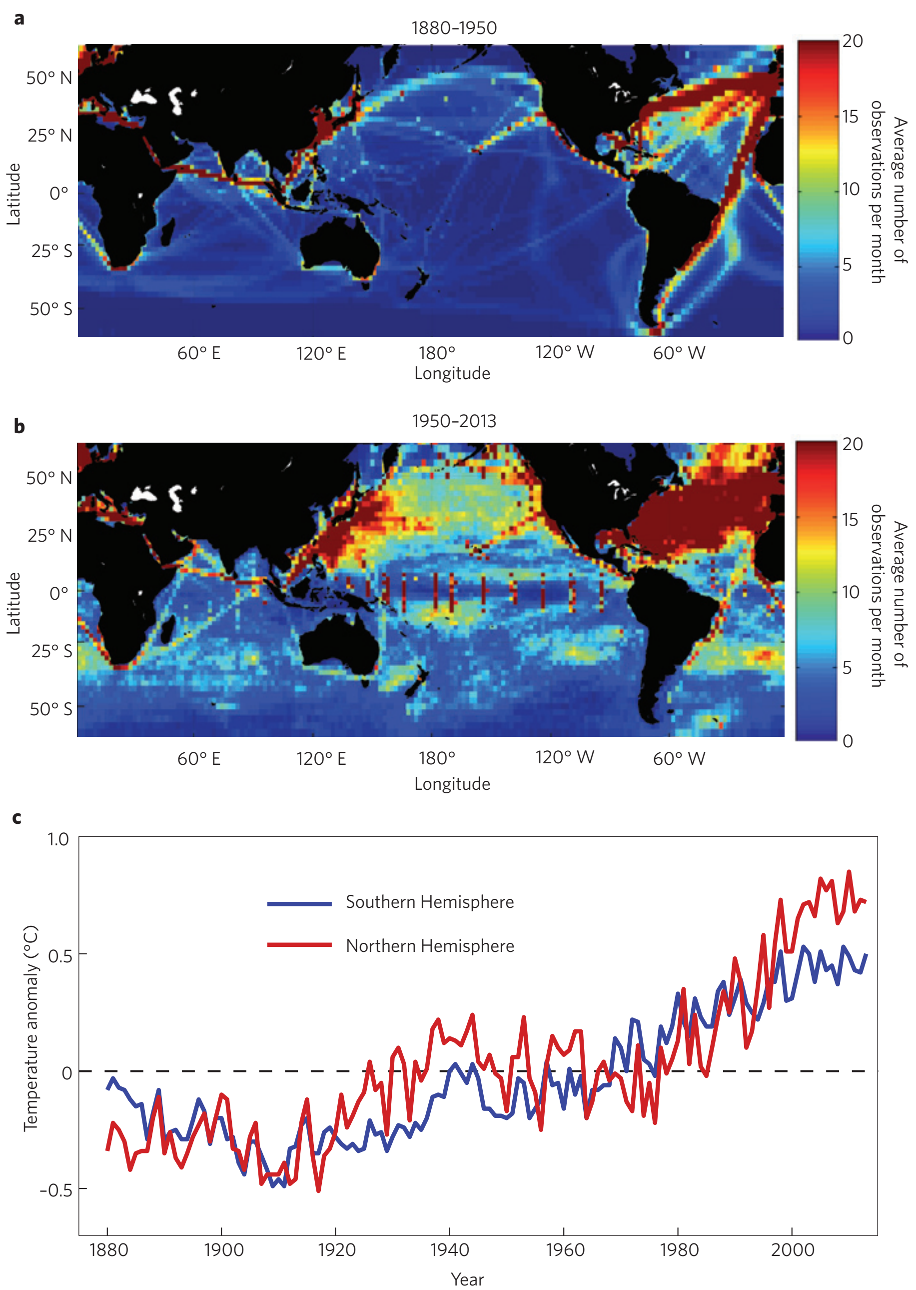

Figure 1 | Instrumental temperature observations over the twentieth century. **a**, Map showing the average number of marine temperature observations per month from the International Comprehensive Ocean–Atmosphere Data Set (http://go.nature.com/qlA4c6) in the interval 1880–1950. Spatial coverage: 2.0° latitude × 2.0° longitude global grid. **b**, Same as panel **a**, but for the 1950–2013 interval. **c**, Northern and Southern Hemisphere yearly temperature anomalies over the the period 1880–2013, computed with respect to 1951–1980, from the GISTEMP dataset (ref. 13 and references therein, http://go.nature.com/8iUuVX and http://go.nature.com/yy2NLB).

between the Northern and Southern Hemisphere reconstructions reveals many intervals when the two series diverge for decades at a time. Notably, some of these differences occur following large volcanic eruptions, when the Northern Hemisphere cools significantly but the Southern Hemisphere does not, at least according to the new reconstruction[1]. The fact that many of these differences occur within the past 400 years, when the data networks from both hemispheres are most robust, makes it less likely that such temperature differences are artifacts of poor data coverage. That said, it is possible that small but cumulative age errors in single palaeoclimate records may smear out interannual variability in large-scale temperature reconstructions[6,7] — currently the topic of vigorous debate[8,9].

If the new reconstruction of Southern Hemisphere temperature is accurate, then estimates of climate sensitivity — the response of global temperature change to a given amount of external radiative forcing — may be lower than those calculated based solely on Northern Hemisphere reconstructions[10]. Indeed, instrumental temperature data suggest that warming in the Northern Hemisphere has been greater than that observed in the Southern Hemisphere over the past two decades (Fig. 1c) — a feature reproduced in the current suite of climate models[11]. Therefore, this hemispheric asymmetry may be a fundamental feature of the climate system's response to a change in radiative forcing[12], whereby the ocean-dominated Southern Hemisphere acts as a buffer of sorts to global temperature change on decadal to centennial timescales. On the other hand, Neukom *et al.* propose that divergent hemispheric temperatures arise from strong natural climate variability in the Southern Hemisphere, and have been a constant feature of the past millennium.

Given the new information now available from the Southern Hemisphere, climate scientists must consider a larger role for natural climate variability in contributing to global temperature changes over the past millennium. While the new reconstruction brings strong additional support to the phrase 'anthropogenic global warming', it also highlights the limits of our current ability to understand, and predict, global temperature variations from decade to decade. In other words, global temperatures will warm appreciably by 2100, but the road may be bumpy and full of surprises. ❐

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