OCEANOGRAPHY

Detecting sea-level rise

Over short periods of time, it can be difficult to isolate sea-level increase in observations as it is hidden by natural shifts in rainfall quantities over ocean and land, which cause temporary drops in the global sea-level curve. Now research shows how to detect the signal, even in short records, by estimating these variations.

Carmen Boening

Over the past 20 years, satellite observations show that global sea level has been steadily increasing at a rate of 3.3 mm yr^{-1} (ref. 1). A continuing rise threatens to impact coastal communities through shoreline erosion, saltwater intrusion on freshwater supplies and a general increased risk of flooding[2]. To determine the rate of rise over short periods of time, such as the past five to ten years, we must take into account natural fluctuations such as increased rainfall over land compared with the ocean, which causes global sea level to temporarily go down[3]. Nevertheless, as the rain water returns to the ocean through rivers and runoff, the rate of sea-level rise will soon bounce back. As they report in *Nature Climate Change*, Anny Cazenave and colleagues have detected this variability by employing hydrological models that can simulate land water storage and thereby can remove this variable from the sea-level curve[4].

Sea level can change through a number of processes, such as thermal expansion (the warming or cooling of the ocean water), the addition of water from melting land ice such as ice sheets and glaciers, precipitation over the ocean or removal of water through evaporation. Although these processes have been observed to lead to a net increase in global sea level on long timescales, fluctuations over five- to ten-year periods can still be significant and — when in the negative phase — may be wrongfully interpreted as a slowdown of the overall rise. When most of the warming signal in the ocean is steady[5], most larger sea-level fluctuations occur when precipitation spatially shifts[6]. Over a period of a few months we might, for example, have more rain over the continents, leading to a decrease in total water in the ocean. This would result in a drop in global sea level during this time. However, as most of the water will run off back into the ocean again, sea level will soon return to its previous state on top of the continuing rise. Thus, it is important to take these variations into account when drawing conclusions about present-day sea-level change.

MARK A. JOHNSON / ALAMY

The accumulation of water associated with massive floods in Australia during 2010–2011 contributed significantly to the simultaneous global mean sea-level drop.

Now, Cazenave *et al.*[4] report a method for distinguishing between the variability that is introduced on short timescales versus the long-term trend. They use hydrological models that provide an estimate of how much water is on land during a certain amount of time and how much runs off back into the ocean. This provides a means to estimate the short-term variability in the satellite records of sea-level rise. By subtracting the model estimates from the observations, the team are able to determine the trend in sea-level rise for the past ten years. They find that estimating the trend without accounting for the short-term variability gives a low estimate of 2.4 mm yr^{-1} sea-level rise. This number is increased, bringing it into alignment with the long-term rate (3.3 mm yr^{-1}), when short-term variability is taken into account. The importance of accounting for fluctuations in the climate system has also recently been debated in the discussion of the present 'warming hiatus'. Studies (for example, ref. 7) have suggested that a slowdown in the surface warming trend is indeed related to this type of natural variability.

Thus, bearing this in mind, the work of Cazenave and colleagues[4] improves our understanding of the future of sea-level rise, even considering only the short period (since 1992) for which we have satellite observations. Over the past few decades, satellite observations have generally enhanced our knowledge of change on a global scale by a significant amount. We are able to detect sea-level rise with an accuracy of a few millimetres. Nevertheless, for periods of the record — that is, up to ten years — it is important to find ways to distinguish between natural fluctuations and the longer-term trend. Although models help to solve this issue, as this study shows[4], observations 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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Acknowledgements

The writing of this article was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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