lessons can be learnt by studying evidence for Holocene sea level and ice sheet change in the context of regional climate change, such as the Medieval Warm Period and the Little Ice Age (see Kelly and Long, and Yu et al., this issue). In turn, Holocene changes must be considered in the light of the large changes in ice volume and sea level during the termination of the last glacial period (T1). During T1, the interaction between ice sheets, ocean circulation and global warming greatly perturbed the ice sheets and can be regarded as a case study for large changes in global climate on decadal to centennial timescales (see PALSEA, 2009). In particular, relative sea level variations during this period may help reveal which ice sheets collapsed in response to climate change during T1 (see Milne, this issue). Other periods in the past also have lessons for millennial-scale climate variability (see Gonzalez and Dupont, this issue).

Paleodata can help constrain the sensitivity of ice volume and sea level change to broader climate change. It can help place limits on future rates of change and it can give a multi-decadal and multi-centennial context to sea level and ice sheet change. The contributions in this edition of PAGES news will give recent examples of this work.

Note

For more information on the PALSEA Working Group please visit www.climate.unibe.ch/~siddall/working_group.html

References


For full references please consult: www.pages-igbp.org/products/newsletters/ref2009_2.html

Recent Antarctic and Greenland ice-mass fluxes from satellite observations and their significance

JONATHAN BAMBER
Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, UK; j.bamber@bristol.ac.uk

Understanding contemporary ice sheet behavior is crucial for estimating future trends but the useful satellite observation period of ~20 years is too short. Paleodata, especially from the Holocene, have the potential to help us interpret the contemporary observations.

Reliable, large-scale observations of the mass trends of the ice sheets do not extend very far back in time. The earliest data set covering the whole of Greenland and 80% of Antarctica began with the launch of ERS-1 in 1991. Since then, other satellites and sensors have provided unique insights into the time-evolving behavior of the ice sheets. Two pressing issues emerge from these observations. The first is the lack of consistency between estimates of the mass balance (Fig. 1), and the second is whether the large and rapid fluctuations in ice dynamics observed are a secular response (i.e., a one-way trend) to external forcing or just part of the “normal” variability in flow that is constantly taking place. Considerable weight and importance has been placed on the apparent increasing mass loss from both Greenland and West Antarctica over the last decade (e.g., Fig. 1). The implication is that this trend is a secular response to external forcing (Hansen, 2007) but the record is too short to confirm this with any certainty. Resolving this issue is crucial, and this is where the paleo record of ice sheet variability, particularly during the Holocene, could, and perhaps must, provide some of the answers.

Since the mid 1990s, our view of ice sheet dynamics has undergone a profound paradigm shift (Bamber et al., 2007). The conventional wisdom was that the response time of ice sheet dynamics was on the order of $10^3$-10$^4$ years. The numerical ice sheet models developed during the 1980s supported this “wisdom” (Huybrechts and de Wolde, 1999). These models operated at relatively coarse resolution, typically 40 km, with certain simplifications to the physics employed that were considered reasonable at the continental scale. As a consequence, the models were not able to resolve individual ice streams (Fig. 2). During the last decade, with the advent of satellite-based repeat pass synthetic aperture radar interferometry (InSAR), a radically different view has emerged. For example, between 1997 and 2000, the largest outlet glacier (by discharge volume) in Greenland, Jakobshavn...
Isbrae, doubled in velocity from around 6 km/a to 12 km/a (Joughin et al., 2004) (Fig. 3). Interestingly, similar observations, for a slightly different time period, showed the same rapid, simultaneous speed-up of two glaciers on the southeast coast of Greenland (Luckman et al., 2006). Smaller, but still substantial, speed-ups have also been observed for ice streams draining the West Antarctic Ice Sheet (WAIS) (Fig. 2). Some of these, in particular Pine Island Glacier (Fig. 1), have continued their acceleration, resulting in an increasingly negative mass balance since 1996 (Rignot et al., 2008).

Thus, although there is a lack of consensus about the absolute value for the mass balance of the ice sheets, there is agreement that the trend has become increasingly negative for both Greenland and the WAIS (Shepherd and Wingham, 2007).

It has become clear over the last decade that parts of the ice sheets can respond rapidly to external forcing and that there is variability in flow over a range of timescales from minutes to millennia (Bindschadler, 2006). What is not known, however, is whether the recent observations of rapid and large changes in motion are in any way unusual. Do they represent a secular trend in response to atmospheric and/or oceanic warming, as some have implied (Hansen, 2007), or is this simply normal ice sheet variability on a decadal timescale? The answer to this question is fundamental to i) our understanding of ice sheet behavior, ii) interpretation of the short, satellite-derived mass trends, and iii) predicting future ice sheet behavior. It would be fortuitous that we started our measurements at just the right time to observe the start of a secular, monotonic trend. On the other hand, it is noteworthy that similar trends are seen for both Greenland and the WAIS, and that they are not restricted to single drainage basins but appear to have a common forcing. It is important to note, however, that the ice sheets are also still likely to be responding to changes in forcing at the end of the last glacial around 12 ka BP. As a consequence, they will be out of equilibrium with respect to the modern-day climate, and their reaction to external forcing is an integrated response to changes over multiple millennia.

A reasonable contention would be that the resolution of this question is well suited to a numerical modeling experiment. The models are, however, currently playing "catch up" with the observations. Considerable effort is being invested in the development of higher-order models that contain a more detailed representation of the physical processes that are now believed to be important for reproducing the observed behavior (Pattyn, 2003). There are, however, other issues that may render this problem difficult for numerical models to address in the medium term. In particular, the basal boundary conditions are an important constraint for the models but are poorly known. Geothermal heat flux, for example, may vary by a factor of twenty across Greenland and Antarctica (Fahnestock et al., 2001), yet the models generally assume a global mean value. Ice has an anisotropic rheology (i.e., its flow properties vary with direction) and can be a factor of ten weaker in one plane as opposed to another but, again, the models currently cannot deal with this. Further, for large swathes of East Antarctica there are no direct observations of ice thickness; a critical boundary condition for numerical modeling, as ice velocity is proportional to the fourth power of thickness.

The question then is can paleodata capture past variability in dynamics and ice sheet extent with sufficient fidelity to be able to address the pressing and important questions that have emerged from the contemporary record? Pilot stud-
U-series dating of fossil coral reefs: Consensus and controversy

MORTEN B. ANDERSEN1, C.D. GALLUP2, D. SCHOLZ3, C.H. STIRLING4 and W.G. THOMPSON5

1Department of Earth Sciences, University of Bristol, UK; 2Department of Geological Sciences, University of Minnesota Duluth, USA; 3School of Geographical Sciences, University of Bristol, UK; 4Department of Chemistry, University of Otago, New Zealand; 5Department of Geology and Geophysics, Woods Hole Oceanographic Institution, USA; wr Thompson@whoi.edu

New developments in U-series coral dating are sparking a healthy debate over how best to interpret coral ages from older fossil coral reefs, reinvigorating research in sea level changes during previous interglacial periods, and fostering a new appreciation of the challenges ahead.

Understanding potential magnitudes and rates of future sea level change is an urgent societal and scientific problem. The history of sea level change provides crucial information about the links between climate forcing, response, and sea level change; as well as critical constraints on future sea level rise. The most direct method for reconstructing sea level history is uranium/thorium (U/Th) dating of fossil corals that once grew near the sea surface. This method has the potential to provide a detailed and well-dated record of sea level change for the last 700 ka. Given the relatively continuous growth of coral reefs in tropical seas and the precision of U- Th dating, the construction of a detailed and accurate sea level history should be a straightforward task. Despite decades of effort, this crucial goal remains elusive because many U/Th ages are unreliable due to mobility of the relevant isotopes, a problem that worsens with increasing coral age. Recently, sea level research has been reinvigorated by new insight into the mechanisms of U-series isotope mobility in fossil corals and by significant improvements in analytical techniques.

Identifying reliable coral ages

Recent advances in analytical techniques have improved the precision of U/Th dating, extending the dating range to at least 700 ka (see Stirling and Andersen, this issue). Unfortunately, analytical challenges (some of) the data we need to help place the modern observations in a longer-term context. There are currently no equivalent studies for WAIS catchments or on a larger scale in Greenland. In fact, even the gross deglacial evolution of the WAIS is poorly known (Ackert et al., 2007). Let’s hope this changes soon!

References


For full references please consult: www.pages-igbp.org/products/newsletters/ef0009_2.html