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Understanding sea-level change is impossible without both insights from paleo studies and working across disciplines

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ABSTRACT

In recent years, there have been significant advances in the observational and modeling techniques used, respectively, to reconstruct and interpret paleo records that relate to changes in sea-level and/or ice extent. This special issue, which presents contributions from the PALeo constraints on Sea-level (PALSEA) PAGES/IMAGES/WUN[1] working group, reflects a number of these developments. Here, we provide an overview of the papers presented in this special issue within the context of the aims introduced above. By combining insights from very different paleo-archives and methodologies in one special issue we hope that this special issue will encourage new ideas and collaborations in this area of climate science.

1. Introduction

Ice sheets and sea-level respond on a number of different time scales from tidal to centennial to multi-millennial up to millions of years and therefore records that span these periods are vital to understand why ice sheets and sea-level are changing today and how they will change in the future (Alley et al., 2005; Allison et al., 2009). Instrumental records of ice sheet changes are only of several decades duration or less (e.g. Cazenave and Llovel, 2010) and for sea-level a little over a century (Church and White, 2011; Jevrejeva et al., 2010) and so paleo data are required to study and understand the processes that cause ice sheets and sea-level to change on multi-decadal and longer time scales. For example, the present-day temperature distribution within the Greenland and Antarctic ice sheets, which is a control on the ice rheology and therefore the dynamical evolution of these systems, is influenced by climate changes that occurred hundreds to hundreds of thousands of years ago (e.g. Huybrechts, 1994; 1996). Consideration of paleo sea-level and ice extent data is helping to improve our understanding of how and why ice sheets and sea-level have changed in the past in response to different climatic forcings, and this understanding underpins our ability to project future changes given specific climate evolution scenarios (e.g. Grinsted et al., 2010; Kemp et al., 2011; Price et al., 2011).

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2. The late Holocene benchmark

The late Holocene period was relatively stable but does include some significant regional climate fluctuations, such as the Medieval Warm Period and the Little Ice Age (Jansen et al., 2007). These events present the opportunity to assess the sensitivity of ice sheets and sea-level to these climate perturbations and to assess whether sea-level rise since the industrial revolution is anomalous against the background natural sub-centennial to millennial variability. Two of the papers consider observations of sea-level change over the last two millennia at locations distant from contemporary and past land ice, the coast of Israel (Toker et al., 2011) and the SW Pacific (Gehrels et al., 2011). Using archaeological indicators, Toker et al. (2011) present evidence for relatively large and rapid variations in sea-level on the Israeli coast and discuss the possibility that these changes were driven by dynamic topographical effects related to the effect of the North Atlantic Oscillation on a marginal basin. Gehrels et al. (2011) present a high resolution proxy record that clearly show a distinct acceleration in the rate of rise during the early 20th century and that the rate of rise since this time is significantly greater than the mean rate during late Holocene in this region. This result confirms a growing number of such records around the globe that isolate an acceleration in the rate of sea-level rise associated with recent climate warming.

Three other papers consider high-resolution sea-level records close to glaciated regions during the late Holocene and to what extent they contain information about the response of the Greenland Ice Sheet (Long et al., 2011; Wake et al., 2011) or Alaskan glaciers (Barlow et al., 2011) to climate variability. These studies illustrate the difficulty in interpreting high resolution sea-level data from near-field regions, particularly when tectonic processes are active (Barlow et al., 2011).

3. Ice sheet and sea-level changes during previous interglacial periods

Sea-level observations that span previous interglacial periods provide useful constraints on the sensitivity of ice sheets and sea-level to differences in climate forcing. However, interpreting the relative sea-level record from benchmark coral indicators requires careful consideration of the response to glacial isostatic adjustment (GIA) at different sites (e.g. Kopp et al., 2009). Lambeck et al. (in press) consider this issue through a model sensitivity analysis and demonstrate that interpreting observations without accounting for isostatic effects can lead to a large bias in the interpretation of these data for global ice volume. Evidence for sea-level fluctuations during the last interglacial period is nevertheless compelling and Thompson et al. (in press) give new evidence for sea-level fluctuations based on a combination of careful dating and rigorous stratigraphy of fossil coral reefs in the Bahamas.

4. Catastrophic ice-sheet change

Little is known about rapid modes of ice sheet response to climate change. Even though the satellite record captures short-term accelerations and rapid ice-sheet events, the forcing of these changes and the governing processes are not well understood. Furthermore, it is not clear if these changes represent natural variability in the system or are a response to recent warming. As monitoring periods lengthen, the answers to these questions will become clearer but an understanding of underlying natural variability will still be required. Periods of rapid and large changes in ice sheets and sea-level in the past have the potential to improve our understanding of ice sheet dynamical responses to climate change. Carlson et al. (2011) take a modeling approach to examine the contribution of the Laurentide ice sheet to the large and rapid sea-level rise known as meltwater pulse 1A, during which rates of eustatic sea-level rise exceeded values of 40 mm/yr (Deschamps et al., in press). They conclude that this ice sheet was not the dominant source of melt water pulse 1A and, in doing so, contribute to a growing literature that is divided between a dominant North American or Antarctic contribution to this highly enigmatic event. Once the melt partitioning of this event is better constrained, potential forcing and feedback mechanisms can be identified and the potential for such rapid events occurring in the future can be more accurately assessed.

5. New approaches

New approaches and tools are vital to better understand paleo-archives of ice sheet and sea-level change. Tarasov et al. (2011) use a novel approach that combines Bayesian statistics with a Monte Carlo modeling method coupled with Neural Network theory to arrive at a data-calibrated model for North American deglaciation which includes rigorously defined uncertainties. Siddall et al. (2011) take a fresh look at temperature proxies from Antarctic ice cores to consider the impact of GIA (vertical land motion) on these records. They find that the isostatic signal can be significant during interglacial periods when the changes in ice extent are relatively small (and are preceded by relatively large changes). They also conclude that the ice core temperature reconstructions are not compatible with models of Antarctic deglaciation that include a relatively large thinning (order 1000 m) in West Antarctica.

6. Summary

The new research presented in this Special Issue represents novel modeling and observational studies of the causes and signatures of sea-level change. Combined, these efforts are helping to advance our understanding of, and place in context, the ongoing changes to ice sheets and sea-level resulting from anthropogenic climate change. By bringing diverse approaches, data and time scales together with carefully posed questions, it is clear that the paleo archive is an effective and crucial resource to better understand the rate and nature of contemporary and future ice sheet and sea-level evolution.

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