Paleoceanography

LESSONS FOR A CHANGING WORLD

By Amelia Shevenell, Peggy Delaney, Katrin Meissner, Laurie Menviel, and Alan C. Mix

This special issue of *Oceanography* on "Paleoceanography—Lessons for a Changing World" celebrates the field of paleoceanography and paleoclimatology at a time when future climate changes are projected to be larger than within the range of instrumental variation detected to date. The Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6), due for release in 2022, is integrating paleoceanography and paleoclimatology studies across all of its chapters, rather than featuring them in one chapter, in order to integrate what we know about the past and what we need to know about processes that will impact our future. The research highlighted in this special issue provides evidence of past large-scale climate changes preserved in marine and terrestrial sediment archives and documents associated impacts on carbon and nutrient cycles. Studying the impacts of such past climate variability at geologic timescales helps us to better understand how projected future increases in air and ocean temperatures will affect the Earth system, including ocean circulation, sea level, marine ecosystem health, and the occurrence and intensity of flooding and droughts, storms, and wildfires.

Much of what we know about the response of the Earth system during warm climate intervals comes from studying ice cores and the chemistry and assemblages of phytoplankton and zooplankton preserved in marine sediments. From these records, we are learning that the long-term sensitivity of the global climate system to greenhouse forcing (known as Earth system sensitivity) is substantially greater than the short-term sensitivity (Charney sensitivity). A combination of these processes on different timescales is now being included in Earth system models. Although the exact mechanisms involved in this higher sensitivity remain poorly constrained, they likely include the slow-responding components of the Earth system, such as the ocean and the cryosphere—topics highlighted in this special issue of *Oceanography*. These slower processes don't occur in isolation, however, and may influence the way shorter-term climate changes operate.

Every three years, the paleoceanographic community gathers to highlight research advances that reflect the current status of the field and to take a forward look at research opportunities (**Box 1**). Many of the papers and sidebars in this special issue are written by speakers and presenters at the Thirteenth International Conference on Paleoceanography (ICP13), held in Sydney, Australia, in September 2019. The meeting focused on several broad topics that served to organize the special issue, including: (1) tool development, (2) geobiology, (3) carbon-climate feedbacks, (4) ocean circulation and climate system dynamics, and (5) ice-ocean interactions. The papers presented here highlight major advances and document unresolved controversies within the paleoceanographic discipline. They also identify opportunities for new research paths and collaborations and point out important insights gained from studies of past climate that can inform studies of future climate.

BOX 1. History of the International Conference on Paleoceanography (ICP)

UNDER THE SOUTHERN CROSS

ICP13

2–6 SEPTEMBER 2019
SYDNEY, AUSTRALIA

ICP1
1983, Zürich, Switzerland

ICP2
1986, Woods Hole, USA

ICP3
1989, Cambridge, UK

ICP4
1992, Kiel, Germany

ICP5
1995, Halifax, Canada

ICP6
1998, Lisbon, Portugal

ICP7
2001, Sapporo, Japan

ICP8
2004, Biarritz, France

ICP9
2007, Shanghai, China

ICP10
2010, La Jolla, USA

ICP11
2013, Sitges, Spain

ICP12
2016, Utrecht, The Netherlands

ICP13
2019, Sydney, Australia

ICP14
2022, Bergen, Norway (pending)

Proxy Development, New Models, and Statistical Tools

Paleoceanography has made steady progress since the middle of the twentieth century, developing new tools that include the calibration and application of new proxies (**Crumpton-Banks and Rae**, **McCave**) and emerging statistical evaluation and chronologic modeling approaches (**Mix**). Each new tool expands our ability to interpret paleoenvironmental information and quantify uncertainties in available archives and model experiments. Of particular interest to the IPCC assessment is the potential for paleo-model simulations and sensitivity tests to constrain the long-term sensitivity of climate change and to illuminate the roles of ocean, cryosphere, and carbon-cycle feedbacks in past large-scale climate changes and those projected for the future. It is important to leverage more complete process information from paleo data that may have some gaps in space or time.

Geobiology—New Frontiers in Paleoceanography Linking Paleoclimatic Changes with Biology and Evolution

Geobiology describes the interaction between the physical Earth and the biosphere. By combining information about the past development of more than one species, geobiology offers opportunities to explore the dynamics of biological communities and its relation to climate change. Papers in this special issue address the evolution of marine biological communities and their environments based on many types of biological proxy records that range from standard paleoecological methods to new proxy developments (**Yasuhara et al.**, **Fietz**, **Armbrecht**, **Lam**, **Leventer**). This topic is of special interest to policymakers as they consider the likely ecosystem impacts of large-scale climate change that will inescapably modify the distribution and diversity of life on Earth and bring together new and unprecedented associations of species at the same time that the results of human activities impose a global mass extinction event.

Carbon-Climate Feedbacks Across Timescales

Earth's climate history is characterized by long-term gradual changes interrupted by more abrupt transitions, referred to as tipping points. The potential for crossing practically irreversible thresholds is difficult to address beyond the hypothetical absent historical examples of such events. Here, paleo records provide essential insights into extreme changes that have occurred in Earth's history. Abrupt climate changes were, in some cases, accompanied by significant variations in atmospheric pCO_2 related to carbon cycle perturbations. However, in spite of dramatic progress in some areas, the mechanistic links and feedbacks between climate and reorganizations of the carbon cycle remain elusive. The special issue highlights contributions that improve understanding of carbon-climate feedbacks across all timescales (**Matsumoto et al.**, **Crumpton-Banks and Rae**). Understanding the natural variations of the carbon cycle is an essential part of projecting long-term future changes, changes which may be initiated by anthropogenic emissions but which may also trigger natural feedback mechanisms that will either exacerbate or mitigate change (**Miller et al.**).

Ocean Circulation and Climate System Dynamics

Climate variability is largely governed by ocean dynamics over a wide range of spatial and temporal scales. In particular, ocean circulation plays a central role in climate dynamics through air-sea interactions, global transport of heat and salt in ocean currents, and storage of heat and carbon in the subsurface ocean. Reconstructing the ocean's past is critical for understanding the dynamics of the climate system as a whole. Contributions to this special issue synthesize knowledge about changes in ocean circulation and its links with climate system dynamics. They encompass observational, theoretical, and modeling studies of ocean circulation in the past, present, and future, with a particular focus on: (1) paleoceanographic reconstructions on various timescales derived from marine paleoproxies (**Tachikawa et al.**, **McCave**), (2) key processes that could force or generate changes in ocean circulation, (3) the impact of changes in oceanic circulation on climate system dynamics (e.g., El Niño-Southern Oscillation, monsoons; **Dixit**), and (4) development and application of numerical models to simulate changes in ocean circulation and its impact on climatic changes (**Felis**, **Ford and Chalk**). The paleo record illustrates how variability, in particular extreme events, may dominate impacts on regional and global systems.

Ice-Ocean Interactions: Drivers and Impacts

Sea level rise is perhaps one of the most alarming repercussions of present-day climate change, one that we are beginning to experience in coastal communities, where the majority of the human population lives. Now that it has started, sea level rise may become unstoppable for centuries or millennia. The early stages of sea level rise we are currently experiencing relate mostly to thermal expansion of seawater associated with warming and changes in net ocean heat content, as well as regional differences in sea level changes due to dynamic circulation effects. These phenomena are superimposed on slower effects such as glacial isostatic rebound, both as residuals from the end of the last ice age and as new impacts related to ongoing loss of ice. Due to thermal expansion and ice melting, current sea level rise is accelerating. It is therefore imperative that we gain a more thorough understanding of the dynamics of changes in global ocean heat content and the responses of continental ice sheets, including the complex interactions between buttressing ice shelves, ocean circulation, and warming ocean waters in polar regions. It is particularly important to determine the rates of change in these systems, which will increase our confidence in future sea level and climate projections and better inform policy decisions. The responses we make as human societies to environmental changes, for example, whether we strive to protect coastal cities from sea level rise or begin the process of moving some of our activities out of harm's way, depend on detailed process-level understanding of the rates and magnitudes of changes. Moreover, the slow changes to the sizes and geographic distributions of continental ice sheets determine an important feedback in the radiative balance of climate. This topic is a focal point for studies of ice sheet variability, ice-ocean interactions, crustal deformation, and ice sheet impacts on climate, from radiative feedbacks to changes in ocean and atmospheric circulation, marine productivity, and the carbon cycle. Articles included in this special issue highlight contributions from both reconstruction and modeling studies to shed light on the role of ice sheets in climate sensitivity and ice-ocean interactions from regional to global scales, on rates of change, and on potential long-term irreversibility of sea level rise originating from ice loss (**Miller et al.**, **Gasson and Keisling**, **Neff**, **Leventer**).

Finally, this issue also includes a book review of *A Memory of Ice: The Antarctic Voyage of the Glomar Challenger* by Elizabeth Truswell. **Webb and Barrett** describe how the book interleaves diary-based personal recollections of scientific ocean drilling from five decades ago, the significant events in polar exploration and science of the preceding two centuries, and the significant south polar Earth science achievements that have occurred since 1973. Some of us have been in the field all of those nearly five decades, and it is easy to forget that our early work in such a quickly changing field on a fast-changing planet is rapidly becoming instructive history.

We hope this special issue of *Oceanography* provides a useful "touchstone" of interest to research paleoceanographers, to students who may build the future of paleoceanography and paleoclimatology, and to the broader community of scientists and policymakers who can witness the progress made as the field of paleoceanography and paleoclimatology has advanced. These state-of-the-art contributions also provide a signpost toward future research directions and highlight the value of paleoceanography in illuminating key processes that must be understood by humanity in order to coexist with a world that is changing, both naturally and due to the impact of human activities.

AUTHORS

Amelia Shevenell (ashevenell@usf.edu) is Associate Professor, University of South Florida College of Marine Science, St. Petersburg, FL, USA. **Peggy Delaney** is Professor Emerita, University of California, Santa Cruz, CA, USA. **Katrin Meissner** is Professor and Director, Climate Change Research Centre, University of New South Wales, Sydney, Australia. **Laurie Menviel** is Australian Research Council Future Fellow and UNSW Scientia Senior Lecturer, Climate Change Research Centre, University of New South Wales, Sydney, Australia. **Alan C. Mix** is Professor, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA.

ARTICLE CITATION

Shevenell, A., P. Delaney, K. Meissner, L. Menviel, and A.C. Mix. 2020. Introduction to the special issue: Paleoceanography—Lessons for a changing world. *Oceanography* 33(2):13–15, https://doi.org/10.5670/oceanog.2020.226.