MEETINGS

Geoclimate: Probing the Earth's Climate Record at All Temporal and Spatial Scales

PAGES 471, 472

Why study Earth's "deep-time" (loosely, "pre-Quaternary") climate? Simply put, the climatic record must be studied at all spatial and temporal scales, in order to comprehend the full range of variability of Earth's climate system, and the physical, biological, and chemical processes that control this variability. The modern and recent record of climate variability is much better documented and understood than is the longer, deep-time record. Similarly, whereas some of the more dramatic, larger changes in Earth's climate are reasonably well known from the longer-term geologic record, the higher-frequency record is less well documented and certainly not understood.

Our goal as Earth scientists is to utilize a thorough understanding of the geologic context of past climate change to help the broader community more fully understand the drivers of such change in the future. For example, atmospheric CO_2 levels are now higher than at any time in the last 420,000 years, and they are likely higher than at any time in the last 20 million years, according to the 2001 International Panel on Climate Change report. Even given emissions reductions to 1990 levels, the report states that Earth is headed for pre-Miocene atmospheric CO_2 levels likely topping 600 ppm within a century. What were the drivers and paleo-environmental consequences of such past changes, and how long did periods of warmth last? These questions require answers because they bear on our assessment of the causes and implications of recent changes in atmospheric CO_2. The deep-time context is prerequisite to a better understanding of Earth's climate system in general, and modern climate change in particular.

To explore ways to improve the collaboration between modelers and geologists in deep-time paleoclimatology, and in order to understand just what deep-time paleoclimatology entails, a workshop was held last spring at the Marymount University in Arlington, Virginia. The workshop was attended by 22 scientists from as many different colleges, universities, research organizations, museums, and government agencies across the United States.

Workshop Results

What is "deep time"?

Most workshop participants viewed deep time as pertaining to Earth's pre-Quaternary record. In general, Quaternary deposits represent climate states related to the cyclical transitioning between glacial and interglacial states. The sediments are commonly unlithified, can be dated, and/or correlated reasonably well, and contain fossils of extant species. However, Earth's climate system operates on a continuum of temporal, spatial, and parametric scales, and climate variability represented in deep-time records is much greater than is captured in the Quaternary record alone. Ultimately, Earth's climate system must be studied through all of Earth history, at all temporal scales, and at all resolutions.

Communication Issues

The deep-time paleoclimate research community remains divided along methodological lines; most strikingly, between climate modelers and those who reconstruct climate using proxy data. The groups read different literature, attend different meetings, conduct their research in different ways, and focus on different temporal and spatial scales. Whereas modelers study climate by setting the processes and then viewing the results, geologists view the results and attempt to extract the processes. Furthermore, there are many more geologists and climatically relevant geologic problems and states through Earth history than there are paleoclimate modelers with whom to collaborate.

Large-scale global climate models constructed to predict the future are complex. Although changes in some paleoclimatically significant parameters can be made relatively easily (for example, CO_2 levels), significant changes in boundary conditions, such as vegetation cover or continental position, require substantial effort. Moreover, climate computer modeling runs are time-consuming and expensive. Thus, the justification for new model experiments must be strong and consistent with the mission of predicting future global climate.

Paleoclimate models allow testing of hypotheses, particularly interactions and feedbacks—key issues for understanding climate variation—among the components of Earth's climate system. Models formulated to address deep-time paleoclimate could shed light on tectonic-climatic feedbacks; variability in modes of atmospheric and oceanic circulation, evolution of the atmosphere, hydrologic cycle, and biosphere; biosphere-climate interactions; and solar and orbital forcing, among other processes.

To test hypotheses, however, the models require boundary conditions and diverse verification data sets. This is where opportunities for synergistic collaborations between modelers and geologists can be fruitful, but currently are hampered, owing to the barriers noted above. Geologists who work in Earth's past typically deal with coarser time resolution, but finer spatial (geographic) resolution than is used in global climate models (GCMs). Although geologists can offer modelers data on the time-averaged (10^3–10^6yr) climate states of a specific region, these data are not integrated easily with a high temporal resolution GCM.

Science Themes: The Key Issues

Numerous science issues were discussed during the workshop. Many were deemed particularly critical to a holistic understanding of Earth's complex climate system. These included:

- Can thresholds of climate change be predicted? Do rates matter? Do thresholds change if rates of change are different? How and why does Earth's climate system transition between greenhouse and icehouse states, or veer to hothouse extremes, or undergo abrupt excursions? What drives different rates of change? What is climate stasis, and has it ever existed? What responses are linear/nonlinear?
- What gases, in addition to CO_2, are important in the greenhouse gas-climate link? What feedbacks multiply or mitigate the effects of greenhouse gases on climate? How has atmospheric composition evolved through time? What role has atmospheric evolution played in climate transitions and in equilibrium climate states identified in the geologic record? What are the effects of sudden and large methane clathrate releases? Has the role of changes in the hydrologic cycle been underestimated, or do we simply lack effective tools for studying this in ancient records?
- What is the role of altered atmospheric and oceanic circulation in climate change? How has the redistribution of ocean energy altered Earth's radiation balance and climate? What is the relative importance of atmospheric composition versus altered ocean circulation in driving climate change?
- What is the long-term record of the ecosystem-climate relationship, and what feedbacks have operated on geologic time scales? How have the biosphere and atmosphere co-evolved and interacted?
- How do climate components interact at different spatial and temporal scales?
- What are the sensitivities and thermostats that drive changes in meridional thermal gradients?
- How are tectonic-climatic interactions expressed in the geologic record, and how important are they? Can climatic effects of such tectonic drivers (for example, changes in gateways, weathering, relief, elevation, and continental position) be quantified better? Can climatic processes drive tectonic responses?
- Are climatic-eustatic feedbacks, the involvement of the hydrologic cycle in such feedbacks, and the effects of epi-continental seas at various latitudes quantifiable?
- Can models be refined to incorporate simultaneous coupling of more components?
- What are the effects of changes in solar and orbital controls at all scales, including changes in solar activity (over short time scales), solar luminosity (through deep time), and orbital variations?

Many of the issues are well suited to modeling investigations, given the appropriate infrastructure and input data availability, but they will also benefit from the study of paleoclimate data; in particular, data-model collaborations. Other issues will require data collection and analysis of paleoclimate proxy indicators. For both, refinements in both dating and correlation are crucial, as well as focused efforts in climate proxy and modeling development.

The Path Forward

The workshop proceedings underscored a clear need for additional community discussion and action aimed at resolution of research issues in both computation-based paleoclimate modeling and data-based paleoclimate reconstruction. Such communication could occur at professional meetings; for example, town-hall style meetings at the AGU Fall and Spring Meetings, and through a community-based Web site. The last of these has already been established; see http://geoclimate.ou.edu.

Communication and Infrastructure Needs

Climate reconstruction of the pre-Quaternary, in particular, has progressed rapidly. Geologists increasingly are able to integrate precise geochronology, targeted laboratory analyses, and systematic field investigations to develop detailed accounts of ancient climate. In particular, various geochemical, magnetic, low-temperature fluid-inclusion, and other laboratory approaches are continuing to expand our capabilities. These advances demonstrate that Earth's deep-time record can be mined to enable climate study and reconstruction at unprecedented scales and resolution. The key is to push technology forward, to decrease ambiguity in existing proxies, and to develop new and more accurate proxies for past climatic parameters. Proxies on the horizon include use of compound-specific isotopes, elemental ratios, and leaf-margin/stomatal-density analyses, to name a few.

The value of collaboration between modelers and geologists is clear; but as was noted by the workshop participants, it will require progress on several fronts.

Geographically extensive data sets will have to be developed in a manner consistent with the digital input requirements of climate models. Models will need to be developed that are capable of accommodating the scales, resolutions, and issues typically encountered in (deep-time) geologic data sets, such as Earth Models of Intermediate Complexity (EMICS), regional climate models, and GCMs, without compromising results relevant for process studies and issues being addressed by the broader model development community. Cross-training must be encouraged such that, for example, geologists could learn the skills necessary to collaborate effectively with climate modelers.

In addition to expanding model types and availability, modelers and geologists need more opportunities to interact and collaborate. Such interaction could and should be promoted through mutual meetings, workshops, publications, and the like.

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