Lessons from a hot past

Warm intervals in the geological record potentially hold the key to understanding ongoing changes in Earth's climate. Our ability to unlock this information depends on continued technical and conceptual progress.

Ice-free Antarctic shores. Tropics hot enough to exclude plant life. Ocean circulation patterns reversed compared to the present. These aren't predictions of a dire future Earth but rather glimpses of conditions during warm climate states. These intervals reveal how the Earth system responded to past drivers of change, often involving elevated atmospheric carbon dioxide levels, and, as imperfect analogues, what might lay in store in the future due to ongoing climate change. Learning lessons from the past depends on continuing to refine the fidelity of palaeoclimate reconstruction tools (proxies), as well as grappling with uncertainties across time and space[1].

Indirectly observing using proxies can illuminate how the Earth system responded to past climate extremes. The early Eocene (~56 to 50 million years ago) is a prime example, when extremely warm global temperatures coincided with carbon dioxide levels well over 1,000 ppm. Palaeoclimate proxy-based work has indicated that a likely feature of the early Eocene was a reduced temperature difference between the tropics and the poles. Often difficult to reproduce in palaeoclimate models, this lower temperature gradient, often associated with other warm intervals too, would have required heat flow to the higher latitudes to be greater than modern flows, with knock-on effects to circulation patterns in the oceans and atmosphere.

Determining the relevance of past warm periods to the future depends, in large part, on the accuracy of the proxy methods used to reconstruct ancient environmental conditions. Each proxy, be it geochemical or palaeontological, has limitations, but technical advances continue to expand the toolbox available for this type of work. For instance, van Dijk et al.[2] apply the clumped isotope proxy to terrestrial iron carbonates (siderites) from the early Eocene across a range of latitudes, an approach particularly well suited to determining the temperature at the time of formation for carbonate minerals that doesn't require knowing the often poorly constrained isotopic composition of precipitation — a key difficulty with other methods. They confirmed the presence of a shallower latitudinal temperature gradient while also identifying humidity as a critical factor in atmospheric heat transport that supported this gradient. Although gathered from a small number of sites, low-latitude data indicating mean annual temperatures in excess of ~40 °C add support to the concerning prospect of the tropics becoming inhospitable to most plants once CO_2 levels get high enough.

The Miocene Climatic Optimum (MCO; 17 to 14.7 million years ago) represents another case study of a warm interval when atmospheric CO_2 levels encompassed a range between the modern atmosphere (~400 ppm) and the probable atmosphere of the coming decades or centuries (~600 ppm)[3]. Unlike the more extreme early Eocene, there was also a relatively compact but substantial ice sheet in Antarctica at this time, which only began to approach its modern extent following cooling that bookended the MCO. In this issue, Bradshaw et al.[4] use palaeoclimate models to test the factors that controlled the behaviour of this ice sheet in the midst of a period of global warmth. They found that the smaller ice sheet not reaching the coastline was the key to explaining previous indications of a highly dynamic, fluctuating ice sheet at the time. Coastal vegetation expansion along these shores elevated water fluxes from the land to the atmosphere, which in turn enhanced hydrological cycling over the continent and increased the sensitivity of the ice sheet to small background changes in the Earth's orbital configurations (which tweak the amount of incoming solar radiation) on timescales of tens of thousands of years. Emerging understanding of the MCO[3] shows that drastic changes in the Antarctic region occur when CO_2 is higher than today, keeping in mind that proxy and model limitations mean the scale and pace of these shifts is only really confidently known averaged out over thousands of years.

The early Eocene and MCO show how far the Earth system can move when pushed, but not how fast changes might happen on the decadal to centennial timescales relevant to human societies. Proxy records with this sort of time resolution, for a host of analytical and practical reasons, are hard to come by during intervals of extreme warmth millions of years ago. However, constraints can be provided by less extreme but more recent intervals of relative warmth between Pleistocene glacial periods or even just the last several thousand years. Bauska et al.[5] use atmospheric CO_2 trapped in Antarctic ice cores to show how the global carbon cycle was controlled by different processes on centennial compared to millennial timescales, implying that the Northern Hemisphere will be an important source of carbon in coming centuries. Zooming in even further, Büntgen et al.[6] use tree rings from central Europe to track year-to-year changes in drought conditions over the last two thousand years, providing a practical baseline that could help plan for future droughts.

Investigating past warm climates can help constrain the magnitude and speed of future climate change, but there is still work to be done. Integrating new proxies with existing records is necessary to keep advancing understanding of key processes that operate when the Earth warms and pushing high temporal- and spatial-resolution sampling ever further back in time. Consistent and transparent data reporting (for instance, adhering to FAIR standards) and a unified approach to uncertainty treatment will also make results more useable across studies and disciplines. Clearer discussion of the specific, well-supported ways in which palaeoclimate work predicts future change will also aid in the translation of insights to policymakers and organizations like the Intergovernmental Panel on Climate Change, especially for those time intervals deeper in the geological record. ❐

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