CLIMATE SCIENCE

Ocean thermometer from the past

Noble gases dissolved in an ice core from Antarctica have revealed global mean ocean temperatures for 22,000–8,000 years ago with unprecedented accuracy, providing a crucial benchmark for refining climate models. SEE ARTICLE P.39

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Twenty thousand years ago, Earth was nearing the end of a glacial period. Gigantic ice sheets covered much of North America, Europe and Patagonia, air and water temperatures beyond the tropics were 4–23 degrees colder than today[1–3], depending on location, and atmospheric levels of carbon dioxide were approximately 35% lower[4]. For reasons that are still unclear, the planet then transitioned to the warm, interglacial conditions that have lasted for about the past 11,000 years. On page 39, Bereiter *et al.*[5] report that noble gases trapped in an ice core from Antarctica provide a record of past mean ocean temperature during this transition, with unprecedented accuracy (±0.25 °C) and high temporal resolution (250 years). This remarkable record will enable scientists to better formulate and update hypotheses on the transition between the last ice age and present-day warm conditions.

Much of the previously available information on ocean temperatures during the past thousands of years has come from records produced by organisms that lived in those times — for example, from differences in observed assemblages of the remains of marine biota[6], from ratios of metal ions within preserved shells[7], or from the arrangement of chemical bonds in lipid biomarkers called alkenones[8], all of which have a known temperature dependency. The temperatures obtained from these records are valuable, but are subject to uncertainties due to the complex responses of the organisms to biological and environmental processes. As a result, these temperature proxies are typically accurate to approximately 1 °C. This is a problem, because the mean temperature change of the ocean is thought[9] to have been only about 3 °C.

By contrast, Bereiter and colleagues used a technically challenging method[10] in which noble gases trapped in an ice core (Fig. 1) act as a proxy for temperature changes in the ocean. Noble gases are biologically and chemically inert, and therefore respond mainly to changes in physical conditions and processes, rather than in biological ones. In particular, the solubilities of noble gases — especially those of the heavier gases, such as krypton and xenon — depend on temperature.

Gases are constantly exchanged between the ocean and atmosphere. As the ocean warms, krypton and xenon become less soluble in water, and so the ocean removes less of these gases from the atmosphere. The amount of krypton and xenon in the atmosphere therefore increases. The elemental and isotopic ratios of these elements in air bubbles trapped in land ice thus provide a signal that can be used to deduce ocean temperature. Importantly, the laws that govern the physical processes underpinning this noble-gas proxy are more enduring than those that underpin the biological processes on which most other palaeotemperature proxies are based. Moreover, there is relatively little time delay between changes in ocean temperature and corresponding changes in the noble-gas signal, compared with many other proxies — the 'lag-time' of the noble-gas tracer is less than 100 years. Bereiter and colleagues' temperature record is therefore more accurate and has greater temporal resolution than other records.

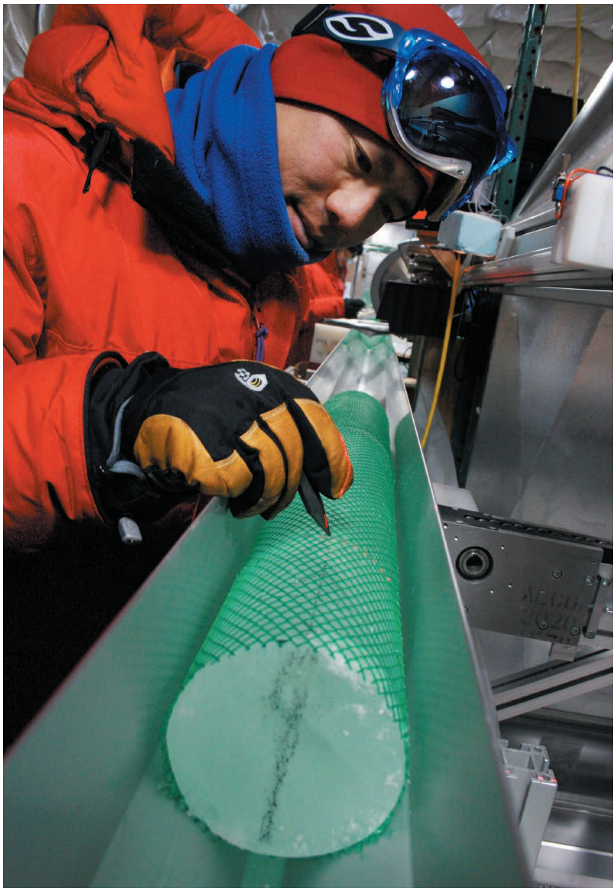

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Figure 1 | Ice core from the West Antarctic Ice Sheet. Measurements of noble gases trapped in the ice core have been used to construct a record of global mean ocean temperatures 22,000–8,000 years ago[5].

The most valuable result of the authors' research is the temperature record itself, which scientists can use to test their climate models and hypotheses. For example, the record reveals that the temperature difference between the cold glacial period and the warm interglacial (up until the industrial period) was 2.57 ± 0.24 °C, a number that models can now aim to replicate. Additionally, the high temporal resolution of the record means that model simulations can be checked at many time points during the transition, and can be used to explore interesting periods in the past in detail.

The most surprising revelation from the temperature record is the extent of ocean warming during an event called the Younger Dryas, which occurred about 13,000–11,500 years ago. This event was an interruption in the overall warming trend, during which scientists think that temperatures dropped by a few degrees in the Northern Hemisphere[11] but continued to increase, perhaps even at an accelerated rate, in the Southern Hemisphere[12]. Bereiter and colleagues report that the mean ocean temperature (which reflects the global ocean, but is weighted towards the Southern Hemisphere) increased substantially during the Younger Dryas, much more than had been estimated: the temperature increase was