Learning from past climates

Anthony J. Broccoli

CAN information about the Earth's climate in the distant past really help us to predict the direction and magnitude of future climate change? That was the question addressed at a recent workshop* that brought together scientists from the United States and Russia, and afforded them an opportunity to compare their records of past climate. With the former Soviet Union comprising roughly one-fourth of the Northern Hemisphere land area, much of it in the climatically sensitive high latitudes, information from this vast region is important to the strategy of using palaeoclimate data to understand how the climate system responds to changes such as increases in greenhouse gases.

Information about past climates is inferred from a diverse array of biological, chemical and geological indicators such as fossil pollen grains, the shells of marine microorganisms and landforms associated with glaciation. Evidence of past radiative forcing (for example, changes in infrared-absorbing gases such as carbon dioxide, or in the reflectivity of continental surfaces) is recorded in a similar manner. Climate modellers now commonly use such information to test how well their numerical models can simulate the climate of the Last Glacial Maximum, which occurred about 20,000 years ago. Success in reproducing past climates such as this enhances the credibility of simulations of future climate change.

Sensitivity

A rather different way of estimating the magnitude of future climate change is to use reconstructions of past temperature and radiative forcing to estimate directly the global climate sensitivity, defined as the ratio of the global temperature change to the change in radiative forcing. This method, dubbed 'palaeocalibration', assumes that the relationship between global temperature and radiative forcing is nearly linear for the range of climates the Earth has experienced since the mid-Cretaceous period (about 10^8 years ago). Using information from a cold period (the last glacial) and a warm period (the mid-Cretaceous), one palaeocalibration estimate yields a climate sensitivity that would result in a warming of 2.3 °C for a doubling of atmospheric carbon dioxide (M. Hoffert, New York Univ.; C. Covey, Lawrence Livermore National Laboratory)[1]. This is within the sensitivity range of 1.5–4.5 °C for CO_2 doubling that has been estimated from global climate models[2].

A more controversial hypothesis, which has emerged from work in the former Soviet Union, is that spatial patterns of climate change may be largely independent of the nature of forcing. This 'palaeoanalogue hypothesis' is supported by climate reconstructions for a number of time periods since the mid-Cretaceous (A. Lapenis, New York Univ.). These reconstructions are unique because of the wide spatial coverage they provide and their availability for time periods much earlier than the last glacial–interglacial cycle.

The hypothesis is intriguing, as it implies that the pattern of response is an intrinsic property of the climate system and does not depend on the spatial pattern of the forcing. Furthermore, it would allow the empirical prediction of future climate change, including its spatial distribution, from predicted changes in radiative forcing due to greenhouse gases without the use of climate models[3,4]. As described at the meeting, the 'universal temperature response' implied by the palaeoanalogue hypothesis has been compared with climate changes simulated by models, and potentially significant differences are indicated. The universal temperature response tends to be larger than that of climate models in polar regions and smaller than the model response at low latitudes (K. Selyakov, State Hydrological Institute, St Petersburg).

But we shouldn't throw out our climate models yet. Some are sceptical of the climate reconstructions that have been used to develop the palaeoanalogue hypothesis, for a number of reasons. First, the temperature estimates are typically presented as contoured maps or averages around the latitude circles. Do enough data really exist to reconstruct past global temperature distributions, particularly for distant time periods such as the Cretaceous and early Tertiary? Second, as raw palaeoclimate data consist of proxies that are assumed to respond to climate, a concern is whether the procedures for deriving temperature estimates from these proxies are objective and well documented. Finally, both the basic data (such as pollen counts in lake sediments) and stratigraphic information required to establish their chronology have not been readily available to palaeoclimate specialists outside the former Soviet Union.

The verdict on the palaeoanalogue hypothesis must await the resolution of these issues, as it depends heavily on the reconstructions developed in the former Soviet Union. This cuts both ways: the utility of palaeocalibration also depends on the same reconstructions, because they are a potential source of information about additional episodes in the Earth's climate history. The more information we have, the better we can quantify the relationship between global radiative forcing and temperature response. Climate modellers would also benefit from the availability of quantitative climate reconstructions from times when the Earth was warmer than today. These would supplement the better-documented variations that have occurred during the last glacial–interglacial cycle.

Integration

For full value to be obtained from the palaeoclimate information developed in the former Soviet Union, the data will need to be converted into computer-accessible forms and integrated with existing worldwide archives; and methods for deriving climate variables such as temperature and precipitation must be compared, to resolve possible conflicts in interpretation. Support for such research is in short supply, given the economic difficulties faced by present-day Russia, and workshop participants asked that their expression of support be directed to those United States government agencies funding climate research.

If successful, will the palaeoclimate data produced by such an effort help us to quantify global climate sensitivity, and what are the alternatives? Perhaps the best way to calibrate sensitivity would be through the contemporaneous simulation and monitoring of ongoing changes in climate, but because of inadequacies in measurements of past variations in both climate forcing and response, improved systems for climate monitoring would be required before we could adopt this strategy[5]. Even if such systems existed today, several more decades might be required to collect enough data. In the meantime, we may need to look to the prehistoric past to assess the quality of current estimates of climate sensitivity. Although the uncertainties in attempting to deduce variations in climate during such distant times probably preclude fine-tuning these estimates, careful examination of palaeoclimate data should increase either our confidence or our scepticism. □

Anthony J. Broccoli is in the NOAA Geophysical Fluid Dynamics Laboratory, P.O. Box 308, Princeton, New Jersey 08542, USA.

* *Workshop on Paleocalibration of Climate Sensitivity*, Silver Spring, Maryland, USA, 15–17 August 1994.

1. Hoffert, M. I. & Covey, C. *Nature* **360**, 573–576 (1992).
2. Houghton, J. T., Jenkins, G. J. & Ephraums, J. J. (eds) *Climate Change. The IPCC Scientific Assessment* (Cambridge Univ. Press, 1990).
3. Budyko, M. I. & Izrael, Y. A. *Anthropogenic Climate Change* (Univ. Arizona Press, 1987).
4. MacCracken, M. C., Budyko, M. I., Hecht, A. D. & Izrael, Y. A. (eds) *Prospects for Future Climate* (Lewis, Chelsea, Michigan, 1990).
5. Hansen, J., Rossow, W. & Fung, I. *Iss. Sci. Technol.* **7**, 62–69 (1990).