PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Role of Palaeoclimate Studies: Modelling

B. J. Hoskins

Phil. Trans. R. Soc. Lond. B 1993 **341**, 341-342
doi: 10.1098/rstb.1993.0119

The role of palaeoclimate studies: modelling

B. J. HOSKINS

Department of Meteorology, University of Reading, Whiteknights, P.O. Box 239, Reading RG6 2AU, U.K.

Stepping back from the topic of the meeting, I should like to begin by addressing the role of palaeoclimate studies in the subject of climate and its prediction. I do not believe that it is only by looking at the past that one can see into the future. However, I do believe that studies of past climates have an important role to play.

To perform climate modelling and to compare the data from models with observations, one must have a conceptual framework. Important elements in this framework are the roles of continents, mountains, solar input and atmospheric composition. It must include notions of rapid change. For example, the response to increasing atmospheric CO_2 may be very slow until a certain critical point when it becomes very rapid: the 'Joker in the pack'. The possibility of multiple equilibria, more than one possible climate for the same external conditions, must be recognized. The average situation is essentially irrelevant in a system that spends almost all of its time in either of two equilibra.

Models, especially those that are to be used for prediction, need to be tested outside the range of parameters for which they have been developed. This does not necessarily mean that they have been consciously tuned by optimizing all the adjustable parameters. It does mean that when there is a choice between two schemes, the one that gives the worse simulation of the average climate of today will be rejected. It is only through a detailed programme of experimentation and diagnosis that sensitivity can be determined.

There are a number of ways that we can be stimulated in our ideas on climate. Firstly, we can take a planetary atmospheres approach. For example, we can look at the atmosphere of Mars and find that it has very regular weather systems, contrasting with the forecasters' nightmare on Earth. We can then see whether our numerical models for the Martian atmosphere do simulate this behaviour and try to understand the essential physical difference between the two planetary atmospheres which gives this contrasting behaviour. Alternatively, we can use our numerical models of the atmosphere like a laboratory apparatus, looking at the sensitivity to rotation rate, planetary radius, swamp covered lower boundary, etc.

The second major approach is to look in detail at the model simulation of 'current' atmospheric behaviour. In models that explicitly include weather systems, how do these compare with those seen in the real atmosphere? How do the models represent the large tropical variability on the intra-seasonal (30–60 day) and interannual (El Niño-Southern Oscillation) timescales? The simulation of the climate of the 20th Century for prescribed sea-surface temperatures can be examined.

The timescales of interest then extend smoothly into the area of palaeoclimate studies, with snapshot simulations of, for example, the Last Glacial Maximum or models of the evolving response to changing orbital parameters. As the period of interest extends further into the past, so the departures from the present system become greater but the quantity and quality of the data to constrain and validate the model decrease. The modelling studies increasingly take on the flavour of the planetary atmosphere studies discussed above. Such studies move modellers into sometimes frustrating, but often exciting, contact with the geological community. They can produce challenges for the models and for our ideas on climate. For geologists the models can provide an integrator of geological information and a stimulus for new or further studies.

There are different categories of climate model embodying different choices of which constituents or processes are fixed, which are represented explicitly and which are represented implicitly (parametrized). For the timescales of changes in the orbital parameters, Dr Berger concentrates on an explicit representation of ice. The weather and even deep ocean processes are parameterized. Even cloud cover is fixed. The atmospheric GCMs as used by Professor Barron, Professor Kutzbach, Dr Mitchell and Dr Valdes for snapshot runs of 1–100 years explicitly represent the weather and, increasingly, even clouds. Sea-surface temperatures are usually fixed. Sometimes the ocean is represented by a slab of a certain thermal capacity. This has the advantage of making the system closed apart from the solar input. It has the disadvantage that artificial horizontal fluxes of heat in the slab have to be included to make the model reproduce today's climate with any accuracy. What should be done with this artificial flux for other climate simulations?

For predictions of the climate impact of enhanced greenhouse gases the atmospheric GCM is these days coupled to an active oceanic model. The large-scale circulation of the ocean is represented explicitly. The eddies, the weather of the ocean, are currently implicit though, with the increasing power of computers, there may or may not be advantages in making them explicit. Unfortunately, the current situation is that to stop a drift of the coupled model away from the present climate, large artificial vertical fluxes of heat and moisture at the ocean–atmosphere interface have to be added to those predicted by the ocean model. Again, there is the question of what should be done

Phil. Trans. R. Soc. Lond. B (1993) **341,** 341–342
Printed in Great Britain

about this so-called 'flux correction' for other climate simulations. Coupled atmosphere–ocean GCMS are only now starting to be considered for palaeoclimate studies.

There is a very real question of what ocean representation should be used in modelling palaeoclimates. How interactive should it be? If foraminifera give a useful estimate of SSTS it is certainly arguable that atmospheric GCM experiments with fixed SSTS will always be very useful. They are now cheap enough that many sensitivity experiments can be performed. The same question arises over the biosphere. Increasingly in GCMS complex interactive biosphere schemes are being included. These require knowledge of stomatal resistance, etc. Would it be better to keep the interaction simple rather than prescribe numerous such parameters for palaeo-vegetation? The extent of the validating data will, perhaps, always be small enough to argue against such complexity.

Finally, I should like to turn to some comments about what we do with the results from GCMS. Often the vast numbers of calculations and results in climate models are interrogated only in the form of long-term means of some basic fields such as surface pressure, temperature and their variance. We have to look at the results in more detail if we are going to learn as much as we can about climate and compare with available data. Climate models should not be black boxes. Rather the design and analysis of experiments must be viewed in the context of theories of climate processes and the characteristics of the particular model used.

The output from climate models should be made closer to the validating data and increased emphasis should be given to extreme events. If deductions about wind are being made from the orientation of fossil trees, then trees can be blown over in the model when a certain wind threshold is exceeded. If there is evidence of lightning activity then such activity can be estimated through the representation of deep convection in the model. If species could be extinguished by extreme conditions lasting for a certain period, the models could predict this.

There is a great deal for the climate modelling and geological communities to learn about getting the most fruitful interaction between them but, as evidenced by this meeting, there are great intellectual and practical rewards to be gained.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES