Late-Quaternary Paleoclimatic Data and Climate Models

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Some very important advances in our understanding of climate - past, present and future - are coming from computer models of atmospheric circulation, reviewed briefly in this article. One task for Quaternarists is to check these models with paleoclimatic data from other studies involving, for example, pollen, marine plankton and lake levels. The authors summarize some areas of agreement and some findings that are in discord. (Ed.)

Modelling Atmospheric Circulation

General circulation models of the atmosphere are major tools for estimating the patterns of future climates that may result from increased concentrations of carbon dioxide (Manabe and Wetherald, 1975; Schlesinger and Mitchell, in MacCracken and Luther, 1985) or from increased smoke and dust after major nuclear or volcanic explosions (Covey et al., 1985). Such changes in atmospheric composition and

turbidity can cause significant variations in the earth's radiation balance. The general circulation models not only estimate the changes in radiation but also translate them into different patterns of temperature, moisture, and atmospheric circulation. Tests of the model results are needed, however, before the simulated patterns should be considered accurate predictions of future climates.

Instrumental records of climate provide only limited tests of the accuracy of these models, but records of past climates can allow a broad testing of the capabilities of the climate models over a range of known changes in orbitally induced radiation (Webb and Wigley, in MacCracken and Luther, 1985). To be useful in such testing, the data should cover large variations in climate, be accurately dated, have broad geographic coverage, and provide quantitative estimates of climatic variables. The general causes of the past changes in climate should also be known.

Paleoclimatic data from pollen, marine plankton, and lake levels for the past 18,000 years fulfill these criteria. During this period, the climatic changes record the switch from full-glacial to interglacial conditions. The stratigraphic levels involved have many radiocarbon dates, which yield an accuracy between cores of ± 300 years (Webb, 1982). Sets combining these three types of data are nearly global in coverage (Street-Perrott and Harrison, 1985; Webb, 1985), and methods exist for transforming each type into estimates of past climatic variables (Kutzbach, 1980; Imbrie and Kipp, 1971; Bartlein et al., 1984).

Boundary Conditions

In addition, the major atmospheric boundary conditions for the climate changes during this period are well known (Berger, 1978a, b; CLIMAP, 1981). These conditions include the seasonal and latitudinal changes in solar radiation at the top of the atmosphere (resulting from modifications in the earth's orbit about the sun), as well as variations in sea-surface temperatures (CLIMAP, 1981), major ice sheets (Denton and Hughes, 1981), and atmospheric composition and turbidity (Lorius et al., 1984). Over the past 18,000 years, this set of boundary conditions has altered significantly at 3,000-year intervals (Fig. 1), providing a framework for numerical experimentation with general circulation models. For selected dates in the past (18,000, 15,000 years . . .), these models simulate "snapshots" of the climate in equilibrium with the boundary conditions (Kutzbach, 1981; Kutzbach and Guetter, 1986).

This kind of study follows from the work of Williams and others, (1974), Gates (1976), and Manabe and Hahn (1977), who used a specific set of surface boundary conditions to model the climate of 18,000 yBP. It also builds on the zonal and global-average models of Suarez and Held (1976) and Imbrie and Imbrie (1980) that showed the possible role of orbital parameter variations in changing the climate.

An examination of the variations in the earth's orbit shows that over the past 18,000 years the time of perihelion has shifted from January to July (at about 10,000 yBP) and then back to January, the current situation. This paralleled a modification in tilt, from 23.5° at 18,000 yBP to 24.5° at about 10,000 yBP and then back to the present value of 23.5° . These two changes combined to produce increased seasonality in northern hemisphere climates between 12,000 and 9,000 years ago. Compared to modern conditions, solar radiation at the top of the atmosphere at 10,000 yBP was increased by about 8% in June through August and decreased by about 8% in December through February over the northern hemisphere. Figure 1 shows these and other changes in the last 18,000 years, with reference to seven sets of simulation experiments (arrows) with the U.S. National Center of Atmospheric Research Community Climate Model.

Experiments with both low- and high-resolution circulation models show that the increased seasonality at 9,000 yBP resulted in continental interiors that were warmer in summer and cooler in winter than they are today. This intensified the summer monsoon circulation of Africa and southern Asia, because ocean temperatures during these seasons were much the same as today (Kutzbach, 1981; Kutzbach and Otto-Bliesner, 1982; Kutzbach and Guetter, 1986; Fairbridge, 1986). Evidence from latitudes 9°N to 27°N show that the water levels in lakes were higher then and that the increase and decrease in these levels generally paralleled the changes in precipitation minus evaporation, simulated by the general circulation model for the land areas in this latitudinal belt (Kutzbach and Street-Perrott, 1985).

The model results have also provided new insights about the variations in past climates. They have produced, for example, estimates for past changes in circulation that can only be guessed at from paleoclimatic data. The models

Figure 1: Schematic diagram from Kutzbach and Street-Perrott (1985) of major changes since 18,000 yBP in (1) external forcing (Northern Hemisphere solar radiation in June-August (S_{JJA}) and December-February (S_{DJF}), as percentage difference from present); (2) land ice as percentage of 18,000 yBP ice volume; (3) global mean annual sea-surface temperature (SST) in degrees K (including calculated surface temperature over sea ice) as departure from present; (4) excess glacial-age AEROSOL, arbitrary scale; and (5) atmospheric CO_2 concentration in ppmv.

illustrate how the contrast between land and ocean amplifies the orbitally driven changes in seasonal radiation by varying the intensity of the monsoons. Such variations provide a possible mechanism by which relatively small changes in radiation can have a large influence on global climates, throughout all of the geological record (Olson, 1986; Berger et al., 1984) and particularly so in the tropics. Studies are still being pursued on the effect of changes in tropical climates on mid- to high-latitude climates and of the orbital variations on the growth and retreat of ice sheets (Ruddiman and McIntyre, 1981; Ritchie et al., 1983; Heusser et al., 1985).

Checking the Models Against the Data

Comparisons between model results and paleoclimatic data in mid- to high-latitudes have also been made. For 18,000 yBP, these show that the Laurentide ice sheet at full height may have acted to split the flow of the jet stream across the continent with a branch to the north over Alaska and a second branch dipping south to flow across the southwest (Kutzbach and Wright, 1985). This result is compatible with the geographic patterns of lake level and vegetation changes inferred from the data. More recent work that compares model results with pollen data (Webb et al., and Barnosky et al., in Ruddiman and Wright, in press) involves detailed regional comparisons between the predicted temperature and moisture conditions.

Some comparisons between the model results and the data reveal areas of discordance. For example, the model showed moisture increases in the northern tropics at 15,000 and 12,000 years ago when the data indicated relatively dry conditions (Kutzbach and Street-Perrott, 1985). Work is now in progress to study these areas and times of discordance and to use them to suggest improvements to the data, to the model, to the boundary conditions used and to the methods for comparing the data to the model results. The work is iterative and will not only provide critical tests of

the models but will also yield major insights about past climates and thus increase general understanding of how the climate system operates.

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