Climate Since the Ice Began to Melt

Newly mapped climate changes of the past 18,000 years are being simulated in computer models, helping to point toward causes and to verify the models

One of the most dramatic climatic changes in the history of the earth occurred only yesterday, geologically speaking. With the necessary record so close at hand, climate specialists are now piecing together a global, detailed picture of the collapse of the last ice age and the subsequent warmth. This new climate reconstruction is helping to explain why hippopotamus bones turn up in African deserts, among other puzzles.

The new compilation of climate data is also allowing objective tests of theories of climate change. In one test, variations in the shape of the earth's orbit and in the orientation of its rotation axis—variations that had been shown to affect climate during the past million years and earlier—were tied to climate change during the past 10,000 years, the Holocene Epoch. With forecasting in mind, computer models that predict the carbon dioxide greenhouse effect of the next century are being tested against this new climate record rather than merely against each other.

The current effort to reconstruct postglacial climate has gained considerable impetus from an undertaking called the Cooperative Holocene Mapping Project or COHMAP. A consortium of researchers from five institutions,* COHMAP has emulated the milestone CLIMAP (Climate, Long-range Investigation, Mapping, and Prediction) reconstruction of climate of 18,000 years ago, when the last ice age was at its peak. As part of its effort, CLIMAP analyzed microfossils of marine sediment samples; COHMAP is gathering published and unpublished abundances of pollen types recovered from bogs and lake sediments, among other climate indicators. Both convert observed abundances of biological remains into measures of climate by means of an objective calibration based on the present-day relation between species distribution and climate. And, like its predecessor, COHMAP's objective is climate mapping on a global scale. Unlike any other study of the Holocene, though, COHMAP intends to produce a series of global climate reconstructions for every 3000 years since 18,000 years ago.

In the course of generating global climate maps, COHMAP has helped carry Quaternary palynology, the study of pollen from the past 2 million years, into a new era. One COHMAP difference is a matter of scale. Since the 1960's an increasing number of pollen studies have been dated using the radiocarbon technique, which is essential to intersite comparisons. But few correlations over more than a single region were being made. Under COHMAP's auspices, Thompson Webb and his group at Brown University have plotted the abundances of 30 pollen types in eastern North America every 2000 years since 18,000 years ago. Gilbert Peterson of the University of Wisconsin has made a similar compilation for the western U.S.S.R. With COHMAP's encouragement and assistance, Brian Huntley of the University of Durham and John Birks of the University of Cambridge produced comprehensive maps of European pollen distributions. COHMAP work continues on data from Australia, Africa, South America, and East Asia. Such continent-wide reconstructions are necessary if computer models are to test suggested causes for the observed climate changes.

Another COHMAP difference lies in the interpretation of data. In the past, for example, palynologists interpreted a combination of spruce and sedge fossil pollens as an indicator of a cold and dry climate, like that of the present-day Hudson Bay area. Pollen of leafy herbs typical of the prairie suggested a warmer, drier climate. COHMAP is trying to be more quantitative.

A group of COHMAP workers at Brown University consisting of Patrick Bartlein (now at the University of Oregon), Webb, and Edward Fleri (now at Photon Research Associates in La Jolla) used the present-day relation between climate and pollen distributions to calculate paleoclimate from the distributions of fossil pollen in the upper Midwest. From 9000 to 6000 years before present, when the North American ice sheet was shrinking to a nearly insignificant chunk in Laborador, precipitation over much of the Midwest decreased by 10 to 25 percent as the mean July temperature increased by 0.5° to 2.0°C. Bartlein and Webb have made a similar calibration for temperature 6000 years before present in eastern North America. Contrary to the concept of the altithermal, a postglacial period of supposedly pervasive maximum warmth, much of southeastern North America was no warmer 6000 years ago than it is today.

Pollen will be crucial to the eventual global maps, but good pollen records tend to be found in mid and high latitudes, not the tropics. To complete the maps, including the oceans, COHMAP workers are drawing on studies by 20 collaborators that include marine plankton, glacial ice distribution, and even plant macrofossils preserved in pack rat middens. The most useful continental climate indicator other than pollen has turned out to be lake level fluctuations. Just as the amount of recent rain might be deduced from the number and size of the remaining puddles, lakes can act as natural rain gauges. Recovering their ancient readings involves the study of past shorelines and depth indicators such as the mineralogical, floral, and faunal composition of lake sediments. Alayne Street-Perrott of Oxford University and her co-workers have gathered published radiocarbon-dated lake levels from nearly 250 basins in Africa and western Eurasia, as well as from basins in Australia, the United States, and Europe.

The trend of postglacial climate in the tropics as revealed in changing lake levels is hardly one of gradually ameliorating conditions, according to the most recent analysis by Street-Perrott and Neil Roberts of Loughborough University of Technology. As the ice began to shrink following its peak 18,000 years ago, tropical Africa and Arabia began to dry out, culminating in broadly distributed aridity between 14,000 and 12,500 years before present. Then an east-west band of lakes began expanding and the band moved northward until it disintegrated about 5000 years ago.

During this wet period between 10,000 and 5000 years ago, Lake Chad, which lies on the present border of the Sahara, apparently swelled to an area more than ten times its present 25,000 square kilometers and deepened by 40 meters.

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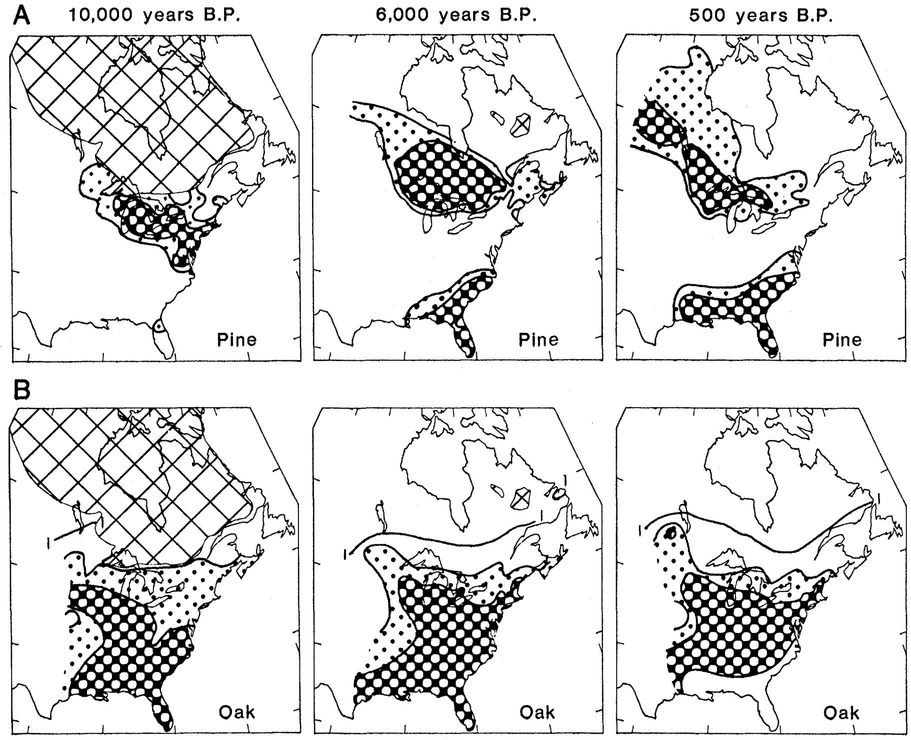
Some of today's sand desert became dotted with lakes. Now-vanished swamps harbored hippopotamuses and crocodiles. According to Street-Perrott, the immediate cause of this long wet spell was a strengthened monsoon, the moisture-laden sea breeze that can carry rain far inland over Africa, India, and Southeast Asia.

The ultimate cause of the greening of North Africa remained uncertain until John Kutzbach of the University of Wisconsin, a COHMAP member, mathematically simulated the behavior of the Holocene atmosphere. In his most recent work, he and Peter Guetter of Wisconsin used the Community Climate Model of the National Center for Atmospheric Research to simulate atmospheric circulation of 9000 years before present. By then, melting had much reduced the size of the ice sheets and the oceans had warmed to near their present temperature.

A potentially significant difference between then and now lies in how sunlight fell on the earth. Nine thousand years ago the earth's axis of rotation was more tilted, the earth came closest to the sun in late July rather than early January, and the annual range of Sun-Earth distances was larger. The net effect was to throw 7 percent more sunlight over much of the Northern Hemisphere during its summer and 7 percent less during its winter. That is, the contrast in radiational heating between seasons was larger. Such changes in seasonality have been shown to control the comings and goings of 100,000-year ice ages and in particular the trend toward warmer summers has been implicated in the demise of the last ice age (*Science*, 8 July 1983, p. 143).

Kutzbach's computer modeling results suggest that orbital variations not only pace the ice ages but also modulated climate since the end of the last ice age. In the computer simulation of climate 9000 years ago, interiors of continents warmed more in the summer, strengthening the monsoon winds and thus increasing rainfall. The water left to moisten the soil and fill lakes after evaporation was about 50 percent greater over North Africa, the Middle East, and south Asia than it was in a simulation that included today's radiation patterns. Both the model's distribution and amount of added moisture fit well the observed pattern of high lake levels, according to Kutzbach and Street-Perrott.

Although orbital variations seem to play a role in Holocene climate, other factors not included in the current climate models must also be important. Kutzbach and Guetter have now simulated climate at 3000-year intervals since 18,000 years ago and find only slightly increased aridity 15,000 to 12,000 years before present, not the extreme aridity evidenced by low African lake levels.



Pollen clues to shifting Holocene climate

These maps illustrate the continuing adjustment of plants to changing climate. A decrease in summer solar radiation and the withdrawal of the cold ice sheet (crosshatch) combined to withdraw the oak and northern pine forests to the north and then to develop the southern pine forest. Light stippling is 5 to 20 percent oak or 20 to 40 percent pine; heavy stippling is greater than 20 percent oak or greater than 40 percent pine.

Computer modelers are helping to get down to the root causes of Holocene climate change, but the growing detail of the postglacial climate record can also do computer modelers a favor. Until recently, they had few ways of reassuring themselves that their models—necessarily grossly simplified imitations of true atmospheric behavior—can produce realistic answers to questions about the future, such as the size of the carbon dioxide greenhouse warming. Tuned to reproduce the present climate and seasons, will models respond faithfully to a large perturbation absent from the present climate? Most models produce a global warming of 1.5° to 4.5°C in response to a doubling of carbon dioxide, but that range is uncomfortably wide and lacks a consensus as to the regional distribution of the warming.

The enhanced monsoon simulation and the first comparisons of computer model simulations with the climate of 18,000 years ago offer some encouragement. In Kutzbach and Guetter's 18,000-year simulation, the high North American ice sheet splits the jet stream into two branches, one passing to the north and the other heading south to Baja California before heading east. This computed circulation pattern, notes Kutzbach, would bring with it the kind of weather needed to produce the observed climate—a wet Southwest and East and a dry Florida to the south, a mild Alaska and a cold, icy North Atlantic to the north. Thus, the model produces a reasonable circulation in response to ice sheets, the major perturbation of the time.

Tests of the global temperature response of two other models, those used by Syukuro Manabe and A. Broccoli of the Geophysical Fluid Dynamics Laboratory (GFDL) and by David Rind and D. Peteet of the Goddard Institute for Space Studies (GISS), have produced some conflicting results. The GFDL results are consistent with the 1.6°C ocean cooling found by CLIMAP, but the GISS simulations suggest that CLIMAP or some continental paleoclimate data may be in error. The forthcoming COHMAP climate maps will obviously find good use.—**Richard A. Kerr**

Additional Reading

1. P. J. Bartlein, T. Webb III, E. Fleri, *Quat. Res.*, in press.
2. J. E. Kutzbach and P. J. Guetter, *Ann. Glaciol.* 5, 85 (1984).
3. F. A. Street-Perrott and N. Roberts, in *Variations in the Global Water Budget*, A. Street-Perrott, M. Beran, R. Ratcliffe, Eds. (Reidel, Boston, 1983), pp. 331–345.