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Perspectives

PALEOCLIMATE:

Mid-Holocene Climate Change

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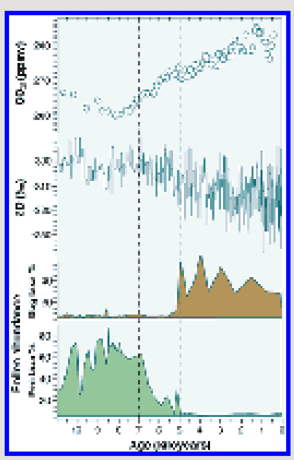
Large-magnitude, rapid climate change events--some taking place within just a few decades, less than the span of a single human lifetime (1)--characterized the last glacial period, between about 50,000 and 10,000 years ago (2). Such events result in a big signal in the geologic record through the modification of the landscape by glaciers, changes in atmospheric and ocean chemistry, and altered distributions of marine and terrestrial biota. By comparison, the "signal" of climate change in our current interglacial period, the Holocene, is relatively muted. Nevertheless, many paleoclimatologists, armed with techniques that permit the examination of past climate at unprecedented temporal and spatial resolution, are now turning their attention to the Holocene.

The new focus on the Holocene is motivated in part by the recognition that substantial and possibly global climate oscillations have occurred during the past 10,000 years, with pacing similar to the larger magnitude glacial events (3). Because these oscillations occurred under conditions similar to those of today--that is, in a time of overall warmth and in the absence of large Northern Hemisphere ice sheets--they bear more directly on our understanding of contemporary climate change than do the events of the last glacial period. Moreover, the relatively subtle changes of the Holocene provide a challenging benchmark against which to test the numerical climate models that guide our understanding of how the climate system functions.

Several recent studies highlight the mid-Holocene (7000 to 5000 years ago) as a period of particularly profound change. During this interval, land air temperatures appear to have declined across much of the globe. This can be seen most clearly in the polar regions, as documented by data from Antarctica, Greenland, and the eastern Canadian Arctic (4, 5). The evidence at lower latitudes is more ambiguous, but paleobotanical data show that most tropical and subtropical land areas either cooled or became more arid, or both; at temperate latitudes, some areas experienced a mid-Holocene dry period followed by increasingly cool and wet conditions (6). In some cases, the mid-Holocene shift in climate appears to have been quite abrupt (see the figure).



Records of Holocene climate change. Global atmospheric CO_2 concentrations (10) and stable isotope (δD) ratios (4) are from the Taylor Dome ice core, Antarctica. Stable isotopes are a proxy for local temperature. Pollen percentage data are from Rio Rubens Bog, southern Patagonia, and show an abrupt change attributed to increasing moisture (6).

In addition to these changes in land air temperatures and precipitation, the mid-Holocene also saw substantial change in atmospheric and ocean circulation patterns. In the North Atlantic, a prominent increase in abundances of warm-water planktonic foraminifera in some marine sediment cores suggests that sea surface temperatures warmed between 8000 and 5000 years ago (3). This warming trend is significant, comparable in amplitude to the periodic ~1500-year cycles, which are documented in the same cores and attributed to major changes in the North Atlantic thermohaline circulation (3). Other studies show cooling of tropical Pacific (7) and Antarctic (4) surface waters between 7000 and 5000 years ago, weakening of the Australian monsoon (8), and an increase in the frequency of storms events in the tropical Andes (9). The storm-frequency data--although controversial--are especially intriguing because they suggest a relation between mid-Holocene climate change and the modern El Niño-Southern Oscillation periodicity. This may have implications for the frequency of El Niño-type events under possible future global warming scenarios.

The mid-Holocene changes in temperature and circulation patterns were accompanied by increasing greenhouse gas concentrations. Atmospheric CO_2 increased by just over 10 parts per million (ppm) between 7000 and 5000 years ago, a rate of ~0.5 ppm per century (10). This pales in comparison with modern anthropogenic CO_2 increases (which amount to more than 60 ppm in the last century), but it does not differ greatly from the rate of CO_2 change during the last deglaciation and implies a major redistribution among the terrestrial, marine, and atmospheric carbon pools. According to one plausible scenario (11), total terrestrial biomass decreased at low latitudes as aridity increased and temperatures cooled, resulting in a net release of carbon into the atmosphere. Limited carbon isotopic evidence (10) does indeed suggest that the observed CO_2 increase can be attributed to terrestrial sources, rather than the oceans, but the details remain to be investigated with higher resolution data.

Understanding mid-Holocene climate change will not be straightforward. As in the case of glacial-age climate, changes in Earth's orbital parameters and in the ocean thermohaline circulation are probably important. Northern Hemisphere insolation has been decreasing since the early Holocene, with the steepest decline about 6000 years ago, while deep ocean nutrient and isotope data suggest a concomitant decline in North Atlantic deep water formation (12). But whereas conventional wisdom holds that Atlantic thermohaline variations tend to promote opposing climate changes at high northern and southern latitudes (13), the evidence from ice cores suggests that both hemispheres cooled during the mid-Holocene. A possible solution is suggested by numerical modeling efforts. In one set of simulations (14), a reasonable match with the available data is obtained only when ocean thermohaline changes and insolation changes are combined with the influence of the terrestrial biosphere, which produces strong feedbacks on temperature and precipitation patterns. Evidently, the terrestrial biosphere, which is often ignored in climate models, plays a more active role in the climate system when large, Northern Hemisphere ice sheets are absent.

Although the mid-Holocene represents a period of change in the climate system under conditions not all that different from today, two temptations must be resisted. The first is to use the mid-Holocene as a direct analog for contemporary climate change. Although, like today, CO_2 concentrations increased during this time, it must be reiterated that the rate of CO_2 increase was more than two orders of magnitude smaller and was very likely a response to, rather than a forcing of, climate change. The second is to assume that we have sufficient data to confidently characterize mid-Holocene climate. Because the signal of Holocene climate change is small, the noise is correspondingly large, and in consequence Holocene climate is effectively more complex than glacial climate (15). The "complexity" in this case is spatial variability, which can be addressed only by obtaining high-quality, high-resolution

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paleoclimate data from many, widely distributed locations.

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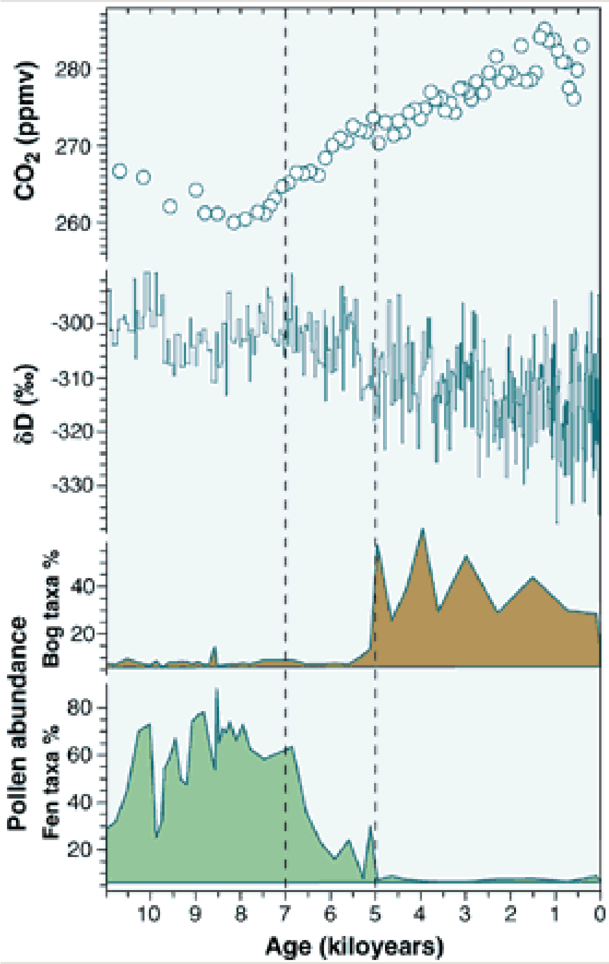

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