Editorial

The past climate change heats up

Research during the past decade has provided a shocking new assessment of the speed with which major climate changes can sweep across our planet. The most precise evidence of rapid climate change comes from cores extracted from mountain glaciers and from the larger ice sheets of Greenland and Antarctica. Annual layers in the glacial ice provide the chronology and key data on snowfall, temperature, influx of dust, and trace gases from the ancient atmosphere trapped in air bubbles. There is ominous evidence that, during the past few thousand years, Earth's climate has been anomalously tranquil compared to its behavior during the preceding hundred thousand years. We still live within a glacial interval, albeit at a time of glacial recession. For more than 3 million years, continental glaciers have been expanding and contracting, and in a few tens of thousands of years, if not stifled by human-induced global warming, they will once again spread southward to New Jersey and the Alps.

The Rapid Climate Change special feature includes nine Perspective articles and six research articles. In the first Perspective, Alley (1) reviews evidence from the record of the past 110,000 years indicating that climate shifts as large as those between glacial maxima and times like the present have occurred naturally within fractions of decades. Overpeck and Webb (2) consider the history of environmental changes far from continental glaciation, noting, for example, that records of coral growth reveal previously unrecognized patterns of change for El Niño and the Southern Oscillation. Broecker (3) reviews evidence that the Little Ice Age (≈1650–1890) resulted from a weakening of thermohaline circulation in the ocean: a reduction of the downwelling in the northern Atlantic that drives the great oceanic conveyor belt. Keigwin and Boyle (4) present geochemical evidence that the conveyor belt may have weakened during the Little Ice Age, just as it did during the Younger Dryas (a brief return to full glacial conditions ≈12,700–11,500 years ago, after the Northern Hemisphere's initial emergence from the last glacial maximum). Marotzke (5) analyzes global circulation, noting that if the overall density structure of the ocean remains constant, then a reduction of downwelling in the northern Atlantic should be balanced by an increase in the Antarctic region, and vice versa (the so-called oceanic seesaw); also, any weakening of downwelling in the north will weaken the conveyor belt's transport of heat from the Southern to the Northern Hemisphere. Lowell (6) reviews evidence from radiocarbon dating indicating that, during the last glacial maximum, mountain glaciers throughout the world expanded to their largest size just a few hundred years before their final retreat. Pierrehumbert (7) warns that the complex atmosphere-ocean system of the tropical Pacific region is unstable, poorly understood, and worth watching for signs of change. Peteet (8) shows how, during and since the Northern Hemisphere's emergence from the last glacial maximum, terrestrial plant species have responded quickly to rapid climate change. Stocker and Marchel (9) assess computer models that, despite shortcomings, exhibit hysteresis patterns for downwelling in the northern Atlantic and thus predict nonlinear behavior.

Six research papers in this special feature present historical evidence of rapid climate change and its consequences. Birks and Ammann (10) document rapid, synchronous changes for climates and organisms in Europe during the recent transition from glacial to nonglacial conditions. Dyurgerov and Meier (11) show how, between 1961 and 1997, small glaciers shrank throughout the world, through an increase in rate of summer melting that has outpaced an increase in annual accumulation. Recent acceleration suggests that this trend does not simply represent emergence from the Little Ice Age. Inouye and others (12) show how seasonal aspects of climate change in the Colorado Rockies during the past 25 years have created problems for such aspects of animal ecology as migration and hibernation. Lobitz and others (13) describe evidence that cholera outbreaks are linked to climate conditions favorable to the causal bacteria. Hartmann and others (14) warn that synergistic interactions between stratospheric ozone depletion and greenhouse warming may have caused significant climate change in recent decades and could have a greater impact in the future. Kirschvink and others (15) argue that, twice during Precambrian time (about 2.4 and 0.8–0.6 billion years ago), an entirely glaciated "snowball Earth" developed; they also discuss how these events may have been related to global geochemistry and major episodes in the history of life.

The articles in this special feature make it clear that research from the past decade has yielded major advances in our understanding of rapid climate changes of the past and their effects on life. Research elucidating the complex dynamics of the ocean-atmosphere system has lagged far behind. Both theoretical advances and acquisition of more detailed knowledge of historical patterns will be required for us to better understand the entire system and anticipate future patterns of change.

Steven M. Stanley

1. Alley, R. B. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1331–1334.
2. Overpeck, J. & Webb, R. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1335–1338.
3. Broecker, W. S. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1339–1342.
4. Keigwin, L. D. & Boyle, E. A. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1343–1346.
5. Marotzke, J. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1347–1350.
6. Lowell, T. V. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1351–1354.
7. Pierrehumbert, R. T. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1355–1358.
8. Peteet, D. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1359–1361.
9. Stocker, T. F. & Marchal, O. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1362–1365.
10. Birks, H. H. & Ammann, B. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1390–1394.
11. Dyurgerov, M. B. & Meier, M. F. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1406–1411.
12. Inouye, D. W., Barr, B., Armitage, K. B. & Inouye, B. D. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1630–1633.
13. Lobitz, B., Beck, L., Huq, A., Wood, B., Fuchs, G., Faruque, A. S. G. & Colwell, R. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1438–1443.
14. Hartmann, D. L., Wallace, J. M., Limpasuvan, V., Thompson, D. W. J. & Holton, J. R. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1412–1417.
15. Kirschvink, J. L., Gaidos, E. J., Bertani, L. E., Beukes, N. J., Gutzmer, J., Maepa, L. N. & Steinberger, R. E. (2000) *Proc. Natl. Acad. Sci. USA* **97,** 1400–1405.

EDITORIAL

SPECIAL FEATURE