EDITORIAL

Evolution of Atmospheres

An atmosphere is the dynamic gaseous boundary layer between a planet and space. Many complex interactions affect the composition and time evolution of an atmosphere and control the environment—or climate—at a planet's surface. These include both reactions within the atmosphere as well as exchange of energy, gases, and dust with the planet below and the solar system above; for Earth today, interactions with the biosphere and oceans are paramount. In view of the large changes in inputs of energy and gases that have occurred since planets began to form and the complexity of the chemistry, it is not surprising that planetary climates have changed greatly and are continuing to change.

Knowledge of the interactions controlling climate and, in particular, an understanding of the sensitivity of the climate system to abrupt perturbations is needed for predicting future climates. Of particular concern is the relatively short-term evolution of Earth's atmosphere in response to anthropogenic inputs of greenhouse gases, chlorofluorocarbons, and other pollutants. Much of our understanding of the likely response comes from study of how past climates responded to changes in composition and energy inputs. In this issue of *Science*, we highlight aspects of this record, current understanding of the processes controlling climate, and some of the means used to monitor atmospheric evolution.

The most dramatic changes occurred during the early evolution of the planetary atmospheres. Two articles focus on the early atmospheres of Earth, its moon, and the neighboring terrestrial planets—Mercury, Venus, and Mars. Comparison of these planetary atmospheres, which are quite different today but most likely had similar initial compositions, illuminates many of the large-scale interactions affecting climates. Hunten, focusing on the atmospheres of Venus and Mars, discusses the importance of blowoff, in which escape of light gases to space also carries along some heavier gases; large impacts; and variations in solar energy in modifying planetary atmospheres. Kasting describes Earth's early atmosphere, which both allowed life to develop and was then greatly affected by life's evolution. Mars, in particular, seems to have experienced dramatic climate changes. Periodic release of water stored in its crust apparently caused large floods and perhaps even formed transient oceans. As Kerr explains in a news story, study of this history is a main objective of the Mars Observer spacecraft, which is en route to Mars.

One of the major problems in evaluating causes of past climate changes is that data on the composition of the atmosphere, and thus the role of changing levels of greenhouse gases, are scarce or indirect for most of the geologic record. In news stories, Appenzeller reviews attempts and prospects for reconstructing the record, and Culotta considers the difficulties in applying the record to calibrate climate models.

A nearly continuous record is available, however, for the most recent continental glaciation from air trapped in the polar ice sheets in Antarctica and Greenland. Raynaud *et al.* review the reliability of the record obtained from ice cores for carbon dioxide, methane, and nitrous oxide and discuss the implications for revealing the relation between atmospheric composition and climate. The data show that changes in levels of CO_2 and CH_4 closely tracked changes in atmospheric temperature through the last glacial cycle and also reveal the rapid increases in levels accompanying the industrial revolution.

The ice core data form the starting point for attempts to understand and ultimately to balance the CO_2 budget. This budget is a description of the chemical exchanges among the atmosphere, oceans, land surface, rocks, and biosphere that act to control CO_2 levels in the atmosphere. As pointed out in a review by Sundquist, the main problem is that recently and during the past deglaciation, large amounts of CO_2 seem to have been taken up by an enigmatic terrestrial reservoir. Sundquist cautions that one important difference between the deglacial and recent CO_2 budgets is the rapidity of the recent increase in CO_2 levels. As a result, the ways in which the reservoirs interact may be different from those in the past.

Understanding the effects of recent perturbations will require monitoring over the next few decades of small changes occurring in the atmosphere. In a news story, Taubes considers the fate of one program designed for that purpose, the Earth Observing System.

The record from past climates clarifies the pace and fundamental controls on atmospheric evolution on time scales from billions of years to a few years. Although problems remain in applying this record to predict ongoing and future changes, the record, nevertheless, provides not only a perspective on current changes but also a necessary basis for making any predictions.

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