BOOK REVIEWS

Atmospheric Interplay

Aerosol–Cloud–Climate Interactions. PETER V. HOBBS, Ed. Academic Press, San Diego, CA, 1993. xii, 233 pp., illus. $65 or £50. International Geophysics Series, vol. 54.

The planetary albedo of the Earth is about 30 percent. Thus, of the sunlight intercepted by the Earth, only about 70 percent is available to power the climate system. The rest is reflected away, mainly by clouds, which cover some 60 percent of the surface of the planet. Put differently, clouds reduce the global average absorbed solar radiation by about 50 watts per square meter. They also contribute significantly to the trapping of terrestrial radiation, the infrared energy emitted by the Earth, contributing about 30 W m^{-2} to the natural greenhouse effect. The net cloud radiative forcing is the difference, some 20 W m^{-2}. On average, therefore, the albedo effect dominates, and clouds cool the Earth at present. All of these quantities can be measured from satellites and are known to have large seasonal and geographical variations.

The direct radiative effect of doubling the concentration of atmospheric carbon dioxide would be to add about 4 W m^{-2} to the energy budget of the climate system. Thus, if a climate change caused by increased carbon dioxide were to result in even a small change in the cloud amount, the feedback effect of the altered clouds on the transfer of solar and terrestrial radiation through the atmosphere might well be important. Furthermore, even if global average cloud amount did not change appreciably in response to a change in climate, the spatial and temporal distribution of clouds might well be altered, as might other critical quantities, such as cloud altitude and cloud radiative properties. All of these changes in clouds could lead to significant feedback effects.

The world's leading climate models, each a computational behemoth, differ substantially in their sensitivity to atmospheric CO_2. When they are subjected to a doubling of CO_2 concentration, all the models equilibrate to a warmer climate, but each produces a different warmer climate. Those most sensitive to CO_2 tend to warm by some 4° to 5°C, on global average. The least sensitive warm by only 1° to 2°C. Enough analyses of and comparisons among these models have now been done to establish that the difference in sensitivity is due to the models' different treatment of clouds. In fact, four versions of the leading British model were recently created by making four different cloud algorithms, each of which was quite plausible. The four versions, identical in every respect other than their treatment of clouds, yielded global warming in response to doubled CO_2 ranging from 1.9° to 5.4°C (C. A. Senior and J. F. B. Mitchell, *J. Climate* **6**, 393 [1993]).

The atmospheric CO_2 concentration today is some 30 percent higher than it was in the late 19th century, mainly because of fossil-fuel burning. The concentrations of other gases that contribute to the greenhouse effect have also increased, predominantly owing to human activities. This enhancement of the natural greenhouse effect is thought to have increased the radiative forcing by about 2 W m^{-2} over the last century or so. Have the clouds meanwhile changed so as to amplify or reduce the resulting climate change? We do not know. In fact, we lack a basic understanding of why the global cloud amount is about 60 percent, why the planetary albedo is about 30 percent, how these and other fundamental quantities may have changed along with climate over geological time, and how they may change in the future.

One intriguing possibility is that our inadvertent intensification of the greenhouse effect may have been compensated for, at least in part, by an equally inadvertent cooling due to anthropogenic aerosols. In addition to their important natural sources such as volcanoes, soil, and biogenic particles, atmospheric aerosols originate in many human activities ranging from biomass burning to industrial production. Like clouds, aerosols have a substantial direct effect on both solar and terrestrial radiation. They can have indirect effects as well, because they can influence clouds in several ways, including by acting as condensation nuclei for cloud droplets and by altering the radiative properties of clouds. In turn, clouds can affect aerosols. Indeed, the scavenging of aerosols by cloud droplets and their removal by precipitation constitute an important sink for aerosols.

Aerosol–cloud–climate interactions have become a subject of intensive research; thus the publication of a comprehensive and authoritative overview is especially timely. This attractive and well-edited book highlights the discrepancy between the rich complexity of actual cloud and aerosol processes and the stark simplicity with which they are treated in even the most ambitious global climate models. For example, Hobbs summarizes recent progress in exploring the proposed feedback link between climate, clouds, and dimethylsulfide (DMS). Over much of the world's oceans DMS, a product of phytoplankton, may be the dominant source of cloud condensation nuclei. Hobbs and Harshvardhan both cite recent work indicating that aerosols from fossil-fuel and biomass burning may well have important regional climatic effects. Yet these processes are missing from virtually all the global models on which we base our best estimates of the climatic consequences of an enhanced greenhouse effect. Indeed, as Sundqvist points out, global climate models today generally treat cloud cover by ad hoc approaches, and most neglect cloud water content altogether, although it is well known that the radiative properties of clouds depend strongly on their water content. Most of Sundqvist's contribution is devoted to setting out the elements of a rational and consistent scheme for the parameterization of the many processes involved in the cloud water budget. Hartmann summarizes the importance of satellite remote sensing in providing an observational basis for validating climate-model treatments of clouds and for developing improved parameterizations. He points out the need for a combination of observational, theoretical, and modeling studies if we are to advance our understanding of cloud radiative effects and evaluate possible cloud feedbacks.

In fact, a number of field observational programs have been mounted in an effort to shore up the empirical foundation of our understanding. The research community appears to have reached something of a consensus that in situ and remote-sensing observational technologies must be brought to bear on the outstanding problems if real progress is to be made. As Hobbs remarks, at present "too many theories are chasing too few measurements!" All of the contributions to *Aerosol–Cloud–Climate Interactions* are up-to-date, with some containing references through 1993, as well as accessible to the nonspecialist. The book should be useful not only to researchers in this active, interdisciplinary field but to all who wish to be better informed about our rapidly evolving conception of climate.

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