al. argue that Ne isotopes in the mantle are not genuinely solar-type as commonly assumed, but likely to be Ne-B, which may be a component of the early solar system having the $^{20}Ne/^{22}Ne$ value of about 12.5, as inferred from the results from most gas-rich meteorites (*8*). The clear, consistent findings of Trieloff *et al.* indicating an atmospheric origin of mantle noble gases can be attributed to several factors: their selection of the most gas-rich samples from these locations, analyses with high-precision mass spectrometry, and the stepwise crushing method for degassing.

Their results support the idea that the whole mantle contains pristine heavier noble gases with isotopic compositions that are indistinguishable from those of the atmosphere, except for the radiogenic components. Furthermore, they suggest that Ne-B is a possible candidate for the mantle Ne. Consistent with this suggestion is the fact that the reported values for Ne isotopic compositions in mid-ocean ridge basalts and oceanic island basalts rarely exceed the value of Ne-B; any examples exceeding this value are associated with large analytical uncertainties. If the pristine noble gases of Earth do in fact contain Ne-B, it suggests that the accretion process to form Earth might have occurred in an environment similar to that of some other meteorite parent bodies. Earth's atmospheric noble gas isotopic compositions could have been established afterwards in an environment different from that of meteoritic parent bodies. Such a scenario is quite different from the model that assumes trapping of the primary atmosphere from the dense solar nebula (*9*). After incorporation of such a component, partial atmospheric loss with the isotopic fractionation might have established the pattern of the atmosphere (*10*).

Trieloff *et al.*'s proposal would require that atmospheric noble gas components had been incorporated into the mantle by processes like subduction before the last homogenization of the two mantle reservoirs (within a few hundred million years after the formation of Earth) represented by mid-ocean ridge basalts and oceanic island basalts. It is not certain, however, whether such complete homogenization might have been possible, even in early Earth. If terrestrial noble gas isotopic compositions had almost been established during accretion of planetesimals to form Earth, the difference of the atmospheric Ne ($^{20}Ne/^{22}Ne = 9.80$) from the mantle Ne needs to be explained by some later process that did not affect the isotopic compositions of heavier noble gases. Although Ne-B is suggested as a likely candidate for the pristine component in the mantle (*1*), additional confirmation is needed to settle this problem. In addition, Trieloff *et al.*'s data have added to the evidence indicating decoupling between the He and Ne isotopes. Hence, a detailed examination is required to reevaluate its importance. Our knowledge about the pristine noble gas isotopes in the mantle has been greatly increased by these new data, but many problems remain to be solved.

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PERSPECTIVES: ATMOSPHERIC SCIENCE

Absorbing Phenomena

Stephen E. Schwartz and Peter R. Buseck

Most considerations of global climate change caused by human activities, including the Kyoto convention (*1*), have focused on the warming influence of greenhouse gases (*2*). However, aerosols are another important atmospheric constituent that influences climate and has been affected by human activities (*3*, *4*). Aerosol particles increase scattering and absorption of shortwave (solar) radiation (*5*, *6*), increase cloud reflectance (*5*, *7*), enhance cloud lifetimes (*8*), and suppress precipitation (*9*, *10*). These phenomena are all thought to exert a cooling influence on climate. Recently, Rosenfeld (*9*) presented results demonstrating that anthropogenic aerosols reduce cloud droplet size and suppress precipitation downwind of major urban areas and industrial facilities, consistent with earlier hypotheses (*7*, *8*). Now, a major study, the Indian Ocean Experiment (INDOEX) (*11*), has extensively documented several of these phenomena and a report from this group (*12*) has identified yet another important effect of anthropogenic aerosols on clouds.

The influences of aerosols on climate are much more complex than those of greenhouse gases. Bulk aerosol composition is highly variable spatially and temporally, because of different sources and production mechanisms and short atmospheric residence times, from less than a day to more than a month. Particle sizes range from nanometers to micrometers; within the same size class, particles can exhibit widely different compositions and morphologies (*13*), with different constituents commonly present even within the same particle. For example, 10-nm soot carbon spherules can be found embedded within much larger sulfate particles (*14*). The inhomogeneous in properties and geographical distributions of aerosols make it difficult to characterize their influences on climate and to represent these influences in models. INDOEX examined the chemical and physical properties and geographical distribution of natural and anthropogenic aerosols and their precursors, the effects of these aerosols on clouds and radiation, and the resultant influences on regional and global climate. The study focused on a geographical region that has not received much prior attention, the northern and equatorial Indian Ocean. The 1998 and 1999 field studies were conducted during the winter monsoonal months January through March, when air flow over the region is dominated by transport from the Indian and south Asian subcontinents. Aerosols and other atmospheric and radiative quantities were documented by a wide range of measurements from aircraft, ships, satellites, and island stations.

In an initial study coming out of the 1999 campaign, Satheesh and Ramanathan reported recently (*15*) that anthropogenic aerosols exhibit substantial loading over much of the North Indian Ocean, the Arabian Sea and the Bay of Bengal, and even somewhat south of the equator. Model calculations showed that this aerosol had been transported thousands of kilometers from source regions in the heavily populated areas of the Indian subcontinent. The aerosol (see figure) was surprisingly absorbing. The absorption resulted mainly from carbon from fossil fuel and biomass combustion, with a smaller con-

S. E. Schwartz is in the Atmospheric Sciences Division, Brookhaven National Laboratory, Upton, NY 11973, USA. E-mail ses@bnl.gov P. R. Buseck is in the Departments of Geology and Chemistry/Biochemistry, Arizona State University, Tempe, AZ 85287–1404, USA. E-mail: pbuseck@asu.edu.

tribution from mineral dust. The conventional measure of aerosol climatic influence is radiative forcing at the top of the atmosphere, that is, the change in the amount of solar radiation absorbed by Earth and its atmosphere due to the aerosol. Because of the high absorption, the top of the atmosphere radiative forcing by the aerosol over the Indian Ocean was much less than for a nonabsorbing, purely scattering aerosol. However, Satheesh and Ramanathan point out (*15*) that a decrease in radiative forcing at the top of the atmosphere is only one measure of aerosol influence. In particular, they find that heavy aerosol loadings substantially decreased the shortwave irradiance at the surface, another key climatic variable.

Measurements at Kaashidhoo Island, Republic of Maldives, about 500 km southwest of the southern tip of India (4.96°N, 73.5°E), showed that aerosols decreased diurnal-mean shortwave irradiance at the surface by 15 and 29 W m^{-2} under cloud-free conditions in February to March 1998 and 1999, respectively (*15*). Model calculations indicate that at least 60% of this forcing resulted from anthropogenic aerosol. This anthropogenic aerosol forcing was three to seven times as great as global average longwave (infrared) radiative forcing by increases in greenhouse gases over the industrial period, 2.6 W m^{-2} (*3*), but opposite in sign. This radiative forcing by aerosols must exert an enormous influence on the energy budget of the tropical ocean, decreasing evaporation and the rate of the hydrological cycle relative to that of the preindustrial era as well as that represented in current climate models. Such an absorbing aerosol might also account for the unknown atmospheric absorption that has been inferred from budget studies (*16*). The aerosol forcing at the top of the atmosphere, measured by satellite-borne radiometer, was only about one-third as great as that at the surface (*15*). The difference goes into heating of the atmosphere. The heating rate of the lowest 3 km of the atmosphere, where the aerosol was principally located, was increased by 0.5 and 1 K day^{-1} for February to March 1998 and 1999, respectively. Satheesh and Ramanathan (*15*) note that this heating can affect local vertical circulations and suggest further that north-south gradients in atmospheric heating arising from the geographical distribution of aerosols may even modify large-scale monsoonal circulations.

On page 1042 of this issue, Ackerman and colleagues (*12*) report yet another consequence of absorption of shortwave radiation by aerosols, namely, that the heating of the atmosphere can evaporate clouds. Clouds exert both cooling and warming influences on climate—cooling in the shortwave (because of their reflectance) and warming in the longwave (because of absorption and reemission of thermal infrared radiation). The shortwave component dominates, so a reduction in cloud coverage would result in a net warming influence. The effect of atmospheric heating by absorbing aerosols on shallow trade-wind cumulus clouds in the marine boundary layer was examined by Ackerman *et al.* (*12*) in model calculations in which INDOEX measurements were used as input variables. For heating corresponding to the INDOEX 1998 and 1999 campaigns, the calculated fractional cloud coverage was reduced relative to baseline conditions by 25 and 40%, respectively. Other things being equal, this reduction in cloudiness would reduce the diurnal average outgoing top-of-atmosphere flux by about 5 W m^{-2} in both cases; that is, it would exert a warming influence. However, these estimates neglect the cooling influence of enhanced cloud albedo and lifetime resulting from increased cloud droplet concentrations. Because the increase in cloud droplet concentrations relative to unperturbed baseline clouds was not known, it was necessary to make assumptions about this increase; it was found that even the sign of the overall influence, warming or cooling, depends on these assumptions. Refining the uncertainties in estimates of aerosol influences on clouds will be difficult because of the variability of aerosol loading and properties and in part the difficulty of finding unperturbed clouds that can serve as models for baseline conditions. Rosenfeld (*9*) noted that the influence of pollution aerosols on cloud-drop radius was much more readily discerned by satellite observations in the Southern than in the Northern Hemisphere. He attributed the difference to the greater contrast with pristine clouds compared with the Northern Hemisphere, where clouds are affected by anthropogenic aerosols over large scales. Perhaps some pristine Southern Hemisphere location can meet the requirement of unperturbed clouds.

Strong absorption. This photo from aircraft during INDOEX 1999 (25 March 1999; 3.0°N, 74.5°E) over the tropical Indian Ocean north of the Intertropical Convergence Zone shows small cumulus clouds embedded in an absorbing aerosol layer. Absorption of solar radiation by the aerosol heats the air surrounding the clouds, causing them to evaporate.

These recent studies demonstrate both the importance of aerosol effects on climate and the complexity of aerosol-cloud interactions. Unfortunately for those who would like a quick and accurate assessment of anthropogenic climate forcing over the industrial period, the studies also demonstrate that there is much to be learned before such an assessment can confidently be given.

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