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LETTERS

Aerosols and Global Warming

While the notion that the addition by mankind of infrared-absorbing (greenhouse) gases can cause a global warming is now well established, the search for some possible counterbalancng effect continues. In their article "Climate forcing by anthropogenic aerosols" (24 Jan., p. 423), R. J. Charlson *et al.* maintain that anthropogenic aerosols could conceivably cause enough cooling to overcome greenhouse warming, and they discuss two possible mechanisms. These aerosols could directly influence the heat balance of the cloudless atmosphere; and such particles, because of their nucleating properties, could increase the albedo of clouds. The latter effect is justified by a well-stated handwaving (nonquantitative) argument (on which I will not attempt to comment), but the first effect, which involves the optical properties of industrial or anthropogenic aerosols, needs to be reconsidered.

The crucial optical parameters that determine whether aerosols in the lower troposphere will warm or cool the surface-plus-lower-atmosphere (called here simply, "the system") are their absorption-to-backscatter ratio, *a*/*b* (not explicitly discussed by Charlson *et al.*), and the albedo of the underlying surface. The physics of *a*/*b* can be understood by way of a phenomenon that airplane travelers often observe. A plume of smog extending over a dark body of water (with an albedo typically less than 0.1) will appear lighter than the water because more sunlight is scattered or reflected back to space by the smog than by the water, and a radiative cooling results. A plume over a light desert or snowcovered surface (with an albedo of 0.5 or more) will appear darker than the surface, hence more sunlight is absorbed by the system and a "warming" results. In this situation, it would be misleading to consider only the reduction of sunlight reaching the surface because of the aerosol layer, yet this was done by Charlson *et al.* The critical value of *a*/*b* above which an aerosol layer will cause a warming effect is about 5 over water, about 1.0 to 2.5 over farmland or forest, and about 0.4 to 0.6 over desert (*1–4*).

Ambient industrial aerosols, with mean radii of 0.5 μm, have been identified as mostly sulfates (probably ammonium sulfate), with a real part of the index of refraction of about 1.5 (*2, 5, 6*). Values of *a*/*b* for "urban-industrial" sites were found to range from 8.0 to 9.2, while for "urban-residential" areas they ranged from 2.9 to 4.0 (*6*). Industrial sulfate particles absorb so much more light than do pure sulfate salts (such as ammonium sulfate or calcium sulfate) because they have carbon or soot particles attached to or included in them (*7*). A filter used to collect industrial aerosols will turn gray or brown, testimony to the presence of light-absorbing soot.

Charlson *et al.* correctly point out that the distribution of anthropogenic aerosols is highly variable because after a few days they are rained out of the lower atmosphere. The greatest concentrations of aerosols are over land near the urban areas of the world, most of which are in the Northern Hemisphere (*7*). Another anthropogenic aerosol that is common in the tropics is smoke from burning forests (slash-and-burn agriculture). This soot absorbs even more short-wavelength solar radiation than do the industrial sulfates. It too is found mostly over the land from which it originated.

To summarize, it appears that, under clear-sky conditions, anthropogenic aerosols probably contribute further to the warming that results from greenhouse gases. Thus it seems unlikely that these aerosols could even partially counteract the greenhouse warming effect.

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Response: First, we did not say that cooling from the scattering of solar radiation by aerosols could conceivably overcome warming from greenhouse gases. Rather, we emphasized that, even though our data indicate that globally averaged climate forcings may be comparable, differences in geographical and temporal distributions of each effect preclude any simple compensation.

Certainly the relative amount of absorption and backscatter of solar radiation is an important determinant of radiative forcing of climate by anthropogenic atmospheric aerosols. We explicitly considered the relative contributions of these processes (reference 21 of our article) and concluded that light scattering by anthropogenic sulfate dominates globally over absorption by anthropogenic elemental carbon. The urban measurements cited by Kellogg are inappropriate for estimating the absorption to backscatter ratio, a/b, on hemispheric or global scales (1). Urban measurements are strongly influenced by local sources of soot such as diesel exhausts. Because sulfate is mainly a secondary aerosol (with a formation time constant of about a day) and derives predominantly from elevated sources located outside cities, urban air has a much greater ratio of soot to sulfate than is represented on regional or global scales. Single scattering albedos for rural U.S. locations are mainly in the range from 0.9 to 0.95; these values are consistent with the measurements we cited and lead to cooling rather than warming (2, 3), except over surfaces with very high albedo, as we noted in our article. It seems likely that single scattering albedos are even greater in remote areas. Further, the a/b ratios cited by Kellogg, derived from scattering measurements at low relative humidity, are overestimates by about a factor of 2 of values pertinent to typical ambient relative humidities of 70 to 80%. With respect to the influence of aerosols on cloud radiative forcing, we note that the a/b for a cloud is expected to be much less than for a clear-air aerosol for a given loading of light-absorbing material. When a cloud is formed on ambient aerosol, the scattering cross-section increases enormously as submicrometer aerosol particles are converted to supermicrometer cloud droplets, whereas absorption remains nearly constant. This view is supported by available measurements of composition (4) and reflectivity (5) of marine clouds.

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Household Composition and Children's Income

The article "America's children: Economic perspectives and policy options" by Victor R. Fuchs and Diane M. Reklis (3 Jan., p. 41) mentions one issue that the authors do not follow up on. Reference 21 presents a computation to approximate how the income of children is correlated with the presence or absence of an adult male member in a household. While the authors note that the 1988 income per child would have been about 9% higher with an adult male member present, they do not appear to have checked the effect of this small increase on the average annual rate of change in per child income from 1960 to 1988.

With the figures in reference 21, one can calculate that the increase in 1988 income per child would have been 9.47% had an adult male been present. Increasing the 1988 median value for each child by 9.47% would yield a value of $7572 and would result in an average rate of change over the 28 years of 2.19%—a value *greater* than that shown for adults (2.04%). This seems to say that when one considers the median income, the increasing number of households with children but without an adult male member accounts for the entire gap in rate of change of income.

The computations for the first quartile income group include the income values from figure 1 and the percentages from reference 21. These yield a 10.29% increase in 1988 income per child. This increase would account for 61% of the gap between the rate of change for children and for adults. If, however, the percent of first-quartile children living in a household without an adult male increased from 7% in 1960 to 26% in 1988 (rather than 19%, as shown in reference 21), the increase in income would be such that there would be no gap in the rate of change between adults and children. It would appear that the policy options the authors present may have to be reconsidered or at least expanded in light of the above computations.

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Response: Schaaf's point is well taken. The increase in the number of children in households without an adult male undoubtedly contributed to their material problems and probably had other adverse effects as well. It is not, however, the entire explanation. The most straightforward way to see this is to limit the analysis to households with at least one adult male. Even in such households children became increasingly dependent on their mothers obtaining paid employment. For example, between 1960 and 1988 the rate of change (percent per annum) of median income per child was 2.1 on the basis of total income, but only 1.5 when mothers' earnings are subtracted. At the first quartile, the effect when mothers' earnings are subtracted is even more dramatic—the rate of change drops from 2.0 to only 1.2. When both parents have paid jobs, children receive fewer household-produced goods and services.

With respect to public policy, we reiterate that a major challenge is to devise programs to help children without encouraging an increase in the proportion living in households without an adult male.

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