Control of global warming?

SIR—Is it quantitatively feasible to introduce in a controlled manner into the atmosphere particulate material, to change the characteristics of natural low-level clouds in such a way as to inhibit or neutralize global warming? The idea that small changes in cloud cover (or cloud properties) can produce temperature changes of a few degrees Celsius comparable with those associated with enhanced long-wave absorption accompanying increased carbon dioxide concentrations is consistent with recent calculations[1]. These showed that climate changes equivalent to those produced by doubling the carbon dioxide in the atmosphere can be produced by relatively small changes in the extent of cloud cover C, the liquid-water path L, and the droplet equivalent radius r in the clouds. Specifically, it was predicted that the warming produced by the carbon dioxide content can be balanced by increases of 15–20% in C and 20–35% in L, and by decreases of 15–20% in r.

In the lower atmosphere there is an ample supply of natural cloud condensation nuclei (CCN), which act as centres on which cloud droplets are nucleated[2], in the sense that sufficient concentrations exist everywhere (at temperatures where condensation occurs in preference to ice nucleation) to initiate cloud formation when the relative humidity H achieves a value of about 100%. The introduction of further, highly effective CCN can, however, increase the droplet concentration N with a corresponding reduction in droplet equivalent radius r and an associated increase in cloud albedo. To a first approximation, $r/r_0 = (N/N_0)^{-1/3}$, where r_0 and N_0 are the initial values of droplet equivalent radius and droplet concentration, respectively.

The number concentrations of droplets in clouds over land are characteristically several hundred per cubic centimetre, whereas over the oceans they are about an order of magnitude less. I take $N_0 = 50$ cm^{-3} as a typical maritime droplet concentration. From the above equation, if the concentration of droplets in maritime clouds (low-level stratus) is doubled to $N = 100$ cm^{-3}, the cloud droplet equivalent radius r would be decreased by about 25%, which is more than sufficient[3] to offset the warming effect of a doubling in the concentration of carbon dioxide.

I assume first that the CCN particles advertently introduced into the atmosphere are each of mass $m = 10^{-13}$ g (radius, 0.6 μm), and that they are present in concentrations of 100 cm^{-3} over the entire area of the Earth to an altitude H of 1 km. Thus the total mass of these CCN per unit area of the Earth's surface would be $M = HNm = 100$ kg km^{-2}.

The average longevity τ of these particles in the atmosphere is likely to be about one day. To maintain the stipulated enhancement in N, CCN need to be disseminated into the atmosphere at about 4 kg km^{-2} h^{-1}. If m were $= 10^{-19}$ g (radius $\sim$ 0.3 μm), the dissemination rate required would be about 0.4 kg km^{-2} h^{-1}.

A discussion of the technology required for the generation of CCN on the required scale is beyond the scope of this correspondence. Note, however, that these dissemination rates are modest, and that the ocean surface provides an excellent site for the production (by bubble bursting, for example) of very efficient hygroscopic condensation nuclei in the form of droplets of sea water, the primary constituent of which is NaCl. In the radius range considered, such particles will be more efficient as CCN (that is, will be activated at lower supersaturations) than those originating from dimethylsulphide, which are believed[3] to be the main source of CCN over the oceans. The above dissemination rates correspond to deposition rates of sea water into the oceans of about 40 and 4 μm yr^{-1}, respectively.

It seems feasible to conduct an experiment in which CCN are introduced in a controlled manner into marine stratus, and in-cloud microphysical measurements and above-cloud radiative observations made. It would also be possible to assess these ideas by incorporating them into an established cloud model, which treats the salient microphysical processes explicitly. The most propitious situation for effecting the proposed radiative changes would involve fields of stable boundary-layer clouds with low droplet concentrations, occurring under highs over the tropical oceans.

Increasing the droplet concentration in clouds is likely to enhance their colloidal stability, making the coalescence process that leads to rainfall more difficult to initiate and thereby, in some situations, prolonging the lifetime of the clouds. The introduction of ice-forming nuclei into colder clouds could increase or decrease their lifetimes, depending on the circumstances.

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