CLIMATE REGULATION BY MARINE PHYTOPLANKTON? A TEST BY ANTHROPOGENIC SO_2 EMISSIONS

BNL--42744

DE89 014708

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May 1989

Submitted to
28th Liege International
Astrophysical Colloquium,
"Our Changing Atmosphere",
Liege, Belgium
June 26-30, 1989

This work was performed under the auspices of the U.S. Department of Energy, under Contract No. DE-AC02-76CH00016.

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Because of their high albedo relative to the underlying land or ocean surfaces, clouds exert a major influence on the short-wave (solar) forcing of the earth radiation budget. Ramanathan et al. (1989) report from satellite measurements for April 1985 that the cloud enhancement of planetary albedo results in a global average decrease of solar heating of 45 W m^{-2}. This compares with a calculated increase in infrared radiative forcing due to a doubling of CO_2 concentration of 4 W m^{-2}. Consequently, even a minor perturbation of cloud albedo would alter the earth radiation budget substantially compared to changes due to increases in CO_2 and other "greenhouse" gases.

A possible mechanism for perturbing cloud albedo noted by Twomey (1977) was a change in the number density of cloud droplets, N. An increase in N would increase cloud albedo even if all other cloud properties remained constant. Such a perturbation might result from industrial emissions producing a greater number density of aerosol particles (AP) that serve as cloud condensation nuclei (CCN). Instances have been reported of marked enhancement of albedo of marine stratus clouds due to urban pollution (Durkee, 1989) or ship effluent (Porch et al., 1989; Radke, 1989; and references therein). Twomey et al. (1984) suggest an approximately logarithmic dependence of planetary albedo on N; a 50% increase in N would lead, according to their calculation, to an increase in mean planetary albedo of 1.0% (absolute) provided all other cloud properties remained constant. This increase in planetary albedo would decrease solar radiative forcing by 3.4 W m^{-2}; the resulting equilibrium global cooling would be 1.9 K, uncertain to a factor of 2 because of uncertainty in the climate sensitivity factor λ. Here I have employed λ = 1.8 W m^{-2} K^{-1}; current estimates for λ range from 0.9 to 3.6 W m^{-2} K^{-1} (Ramanathan et al., 1987).

The potential sensitivity of global mean albedo and temperature to N prompted a novel suggestion (Charlson et al., 1987) consistent with the Gaia hypothesis (Lovelock, 1979, 1987) for regulation of global climate by marine phytoplankton. Certain species of coccolithophores excrete dimethylsulfide (DMS), and this DMS is arguably the principal source of reduced sulfur gases in the global atmosphere and, in the absence of anthropogenic SO_2, the principal source of atmospheric gaseous sulfur species. Such gaseous sulfur species are oxidized in the atmosphere to form sulfuric acid, which rapidly forms an aerosol. Since sulfate-containing AP are highly efficient CCN, it is argued that an increase in DMS production by marine phytoplankton would yield increased concentrations of CCN, resulting in increased cloud albedo, decreased surface insolation, and decreased planetary temperature. It is further hypothesized that such decreased insolation or temperature might result in decreased production of DMS by marine phytoplankton, i.e., that the process might constitute a negative feedback loop for regulation of planetary climate by marine microorganisms.

The DMS hypothesis of Charlson et al. (1987) has been questioned on a number of fronts. Legrand et al. (1987) present measurements from the Vostok ice core suggesting that non-sea-salt (NSS) sulfate concentration is negatively correlated with temperature over the 160 000 year record, and hence that the overall sign of the feedback loop would be positive, not negative as required for a regulatory system. Caldeira (1989), from a consideration of the cost to the organism of DMS production concludes that neither climate modulation nor altruism could have been significant factors in the evolution of DMS production by marine microorganisms.

A further challenge to the DMS hypothesis comes from an examination for a climatic influence of anthropogenic SO_2 emissions (Schwartz, 1980). The challenge is based on the following reasoning: a) Present SO_2 emissions substantially exceed DMS emissions globally, are confined largely to the Northern Hemisphere (NH) (Figure 1), and have reached their present levels within the past 100 years; b) SO_2 is a suitable surrogate for DMS both chemically and geographically. This assertion gains support in the fact that atmospheric $SO_4^=$ concentrations are elevated over much of the NH compared to the Southern Hemisphere (SH) (Figure 2); c) Interhemispheric differences that would be anticipated according to the sensitivity to CCN concentrations given by Twomey (1977) and by Charlson et al. (1987) to arise from interhemispheric difference in gaseous sulfur emission rates or NSS $SO_4^=$ concentrations are not observed either in cloud contribution to hemispheric albedo (Figure 3) or in the rate of increase of hemispheric mean temperature over the past 100 years (Table 1); d) Since global- or hemispheric-scale climatic influences of anthropogenic SO_2 emissions are not observed, it seems unlikely that the sensitivity of these climatic variables to gaseous sulfur emissions is insufficient to sustain the hypothesis that the earth climate system is regulated by marine DMS emissions.

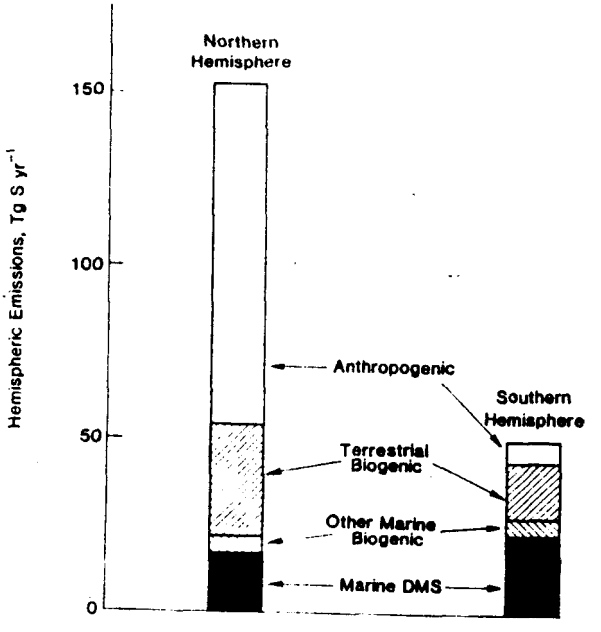

Figure 1. Gaseous sulfur emission rates for Northern and Southern Hemispheres. From Cullis and Hirschler (1980) except for marine DMS (Andreae, 1985) apportioned according to ocean surface area.

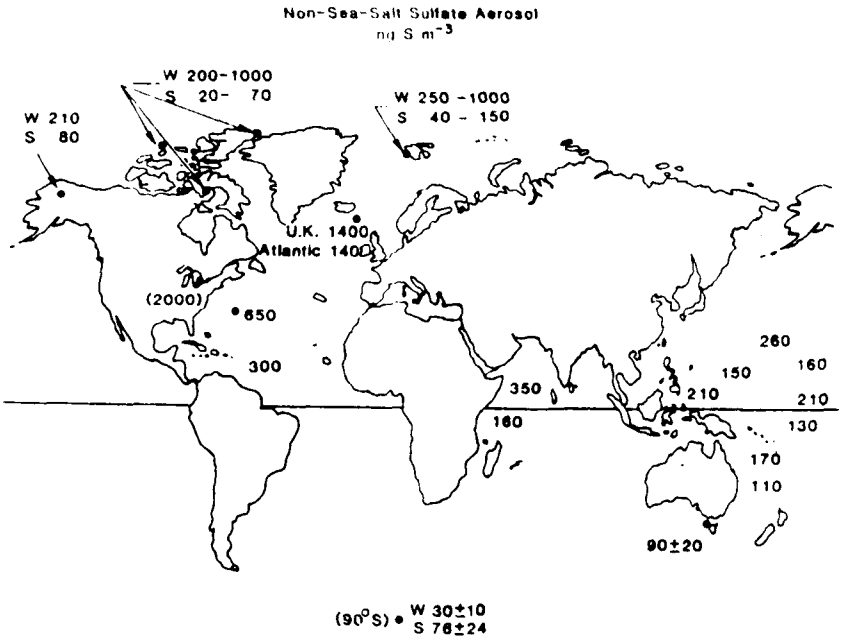

Figure 2. Concentrations of aerosol sulfate (ng S m^{-3}) measured over extended sampling periods at remote sites. W and S denote winter and summer, respectively. For Faeroe Islands "U.K." and "Atlantic" denote direction of air trajectory. For citations to the measurements see Schwartz (1988).

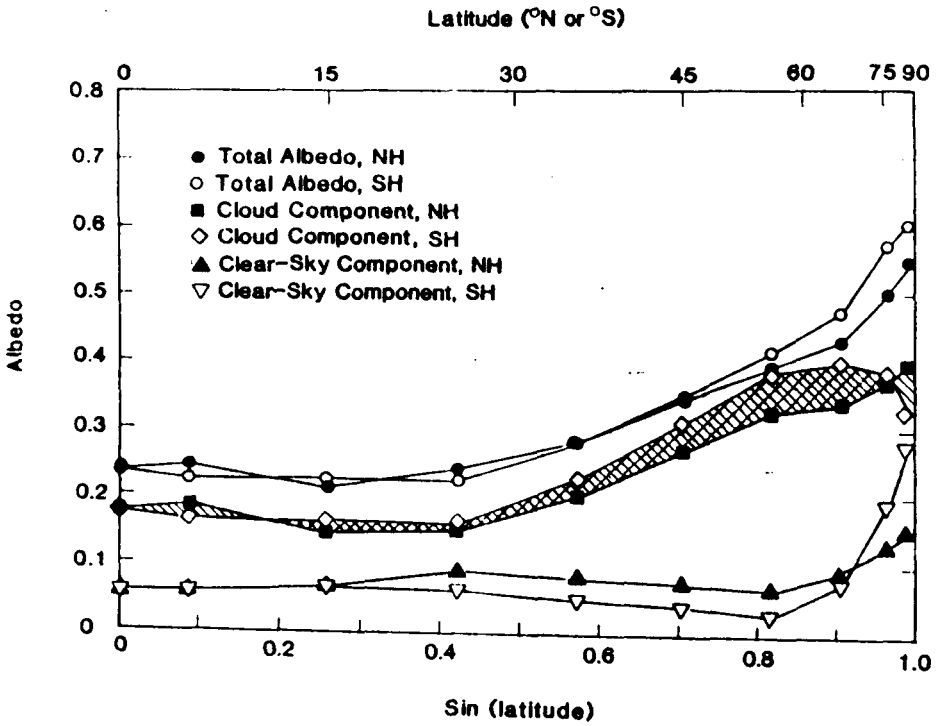

Figure 3. Average annual zonal mean over 10° latitude bands for northern and southern hemispheres of total planetary albedo and of cloud and clear-sky components. Single hatching: NH cloud component exceeds SH; cross hatching: SH exceeds NH.

Table 1. Time-average rate of change of hemispheric or zonal mean temperature for different data sets.

Latitude Range	Data Set	Period	Temperature Change Rate K/100 yr	Reference
NH	Surface Air	1881-1984	0.51	a
SH	Surface Air	1881-1984	0.49	b
NH	Sea Surface	1904-1984	0.60	a
SH	Sea Surface	1904-1984	0.57	b
NH	Surface Air	1890-1985	0.80 ± 0.12	c
SH	Surface Air	1890-1985	0.59 ± 0.14	c
22-44°N	Surface Air	1890-1985	0.63 ± 0.09	c
22-44°S	Surface Air	1890-1985	0.49 ± 0.15	c

References:
a. Jones et al., 1986a
b. Jones et al., 1986b
c. Hansen and Lebedeff, 1987, with uncertainties estimated by the present author.

The apparent lack of observable influence of emissions of gaseous sulfur compounds on climate is puzzling. There is little doubt that SO_2 and reduced sulfur compounds are precursors to aerosol sulfate. It is also well established that sulfate-containing aerosol particles are effective cloud condensation nuclei. There is also persuasive theoretical and observational evidence that the albedo of liquid-water clouds increases with cloud droplet number density. It thus seems reasonable that an influence on the cloud contribution to global mean albedo and temperature might be expected, as Twomey et al. (1984) and Charlson et al. (1987) have suggested. The observational evidence, however, indicates otherwise, although the possibility of an interhemispheric difference in cloud liquid water path that compensates a difference in cloud albedo cannot be entirely ruled out (Slingo, 1988). Thus, it seems unlikely that global cloud albedo and temperature are controlled by emissions of gaseous sulfur compounds.

In conclusion, it would seem that the lack of discernible response of mean global or hemispheric albedo or temperature to anthropogenic SO_2 emissions indicates that control of these properties is too complex to be governed by a single variable of this type. Nonetheless, the potential for a substantial human influence on global climate by the mechanism examined here makes it mandatory to gain a thorough understanding of the processes that control cloud albedo and its influence on global climate.

Acknowledgement. This work was supported by the National Acid Precipitation Assessment Program through the PRECP Program funded by the U.S. Department of Energy.

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