Uncertainty in Climate Change Caused by Aerosols

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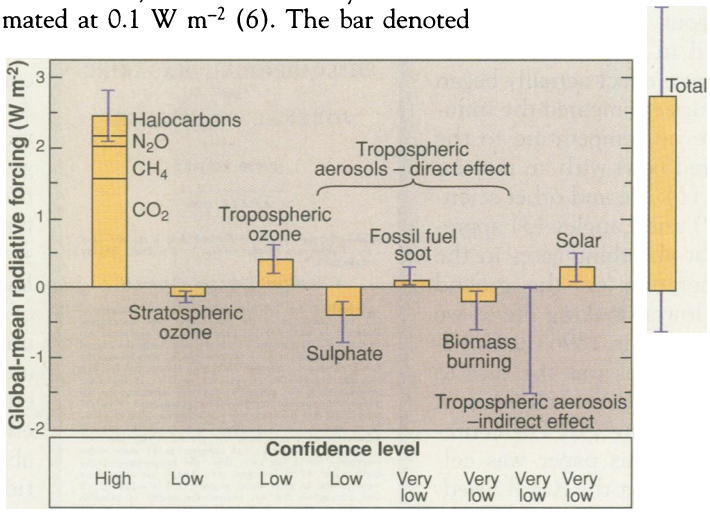
The National Research Council (NRC) recently issued a report "A Plan for a Research Program on Aerosol Radiative Forcing and Climate Change" (*1*) that underscores the importance of anthropogenic aerosols as agents of climate change. Atmospheric aerosols are suspensions of microscopic and submicroscopic particles; in industrial regions and over much of the Northern Hemisphere, their sources are dominated by human activity. Anthropogenic aerosols influence climate directly, by scattering solar radiation, and indirectly, by modifying cloud properties. Of all atmospheric pollutants, aerosols are the most evident because they restrict visibility and whiten the otherwise deep blue of the sky, yet understanding of their influence on climate change is beset with uncertainty. Although the NRC report stresses the need to reduce these uncertainties, in our view it does not go far enough.

The climatic influence of aerosols is complex. Light scattering by aerosols decreases penetration of solar radiation through the atmosphere and absorption at the surface, thereby exerting a cooling influence. This scattering by aerosols can readily be observed from aircraft as a whitish veil over the landscape. The presence of anthropogenic aerosols is thought to have roughly doubled the amount of light scattered back into space by particles in the atmosphere (*2*). In addition, increased aerosol particle concentrations, by increasing cloud droplet concentrations, enhance cloud reflectivity and inhibit precipitation development, causing clouds to persist longer and resulting in still more reflection of sunlight (*3*). The decrease in absorption of solar radiation due to anthropogenic aerosols, the "forcing" of climate by these aerosols, is estimated to be comparable, but of opposite sign, to climate forcing resulting from increased absorption of terrestrial infrared radiation by enhanced atmospheric concentrations of CO_2 and other polyatomic molecules, the anthropogenic "greenhouse" forcing (*4*).

This situation is illustrated in the figure, which shows current estimates by the Intergovernmental Panel on Climate Change (IPCC) (*5*) of global and annual mean radiative forcing over the industrial period. The cooling influence attributed to stratospheric ozone is attributable mainly to a decrease in the concentration of this greenhouse gas. A slight warming influence is ascribed to soot aerosols, which are efficient light absorbers. The IPCC gave no estimate for the indirect aerosol effect, only an uncertainty range. Not shown is forcing due to dust aerosols, which has recently been estimated at 0.1 W m^{-2} (*6*). The bar denoted "Total," which we have added, is roughly the same as that for the long-lived greenhouse gases alone.



Forcing the issue. Estimates of the globally and annually averaged anthropogenic radiative forcing of climate due to (i) changes in concentrations of greenhouse gases and aerosols from preindustrial times to the present and (ii) natural changes in solar output from 1850 to the present (*5*). The bars denote a mid-range estimate for each forcing (an upward bar denotes a positive forcing or warming influence; a downward bar, a cooling influence); the I-beams show an estimate of the uncertainty range. Bar at right shows the total forcing as the algebraic sum of the individual component forcings and the uncertainty range for the total forcing as the sums of the upper and lower ends of the individual uncertainty ranges. The lower panel indicates the IPCC's subjective confidence that the actual forcing lies within the indicated uncertainty range.

The picture changes markedly, however, when the very large uncertainties in current estimates of aerosol forcing are considered. If the magnitude of aerosol forcing is at the low end of the uncertainty range, aerosols are negating only a small fraction of the greenhouse forcing. However, if the aerosol forcing is at the high end of the uncertainty range, aerosols could be negating virtually all of the present greenhouse forcing.

Let us suppose that aerosols are in fact negating much of the greenhouse forcing, a possibility wholly consistent with present uncertainties. Then the temperature increase over the industrial period, about 0.5 K for the global and annual average (*5*), if due to these forcings at all, must be due to the rather slight residual, indicating a much greater planetary temperature sensitivity than if the aerosol forcing is small. And if temperature sensitivity is high, global warming may accelerate sharply in the future. Climate models do not help much to narrow this uncertainty, as global and annual mean temperature sensitivities of current climate models vary by a factor of 3 (*7*). Paleoclimate studies yield comparable uncertainties (*8*).

The NRC panel report (*1*) provides a clear and concise summary of the current state of knowledge about aerosol forcing of climate, finally concurring in the IPCC estimates of forcing and uncertainty. It then outlines a detailed and well-thought-out plan of process-related research and satellite-based measurements to reduce the uncertainty in aerosol forcing to some ±15% globally and locally, comparable to the uncertainty in greenhouse gas forcing.

Although we concur in this objective, we are concerned that the report does not adequately convey a sense of urgency in reaching it. Without greatly narrowing the uncertainty in aerosol forcing, there will exist little observational basis for the nature and magnitude of climate response to increasing concentrations of greenhouse gases. We wish the authors of the NRC report had emphasized more strongly that because of the vastly different residence times of greenhouse gases (decades to centuries) and tropospheric aerosols (about a week), negation of greenhouse forcing by aerosol forcing means that forcing due to one week's emissions of aerosol precursors is negating forcing due to decades of past CO_2 emissions, whereas each week's co-emitted CO_2 is adding to an ever accumulating burden of this greenhouse gas. Clearly, the longer we postpone getting the knowledge of the aerosol forcing that is required to address the policy implications of this realization, the deeper the hole we are digging for

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ourselves with respect to the greenhouse effect and its potential repercussions on future generations.

In our view, the NRC panel seriously underestimates the research effort required to reduce the uncertainty in aerosol forcing to the specified level. The task of characterizing tropospheric aerosols, their spatial and temporal variability, their size-dependent chemical and physical properties, and their optical and cloud-nucleating effects; of understanding the processes controlling these properties and effects; of representing these processes in models; of evaluating the performance of these models; and of representing these effects in climate models requires a research effort several-fold greater than that outlined in the report. In the absence of this research, knowledge of climate response to greenhouse forcing necessary for confident policymaking will be reliant entirely on climate models having little credible empirical confirmation.

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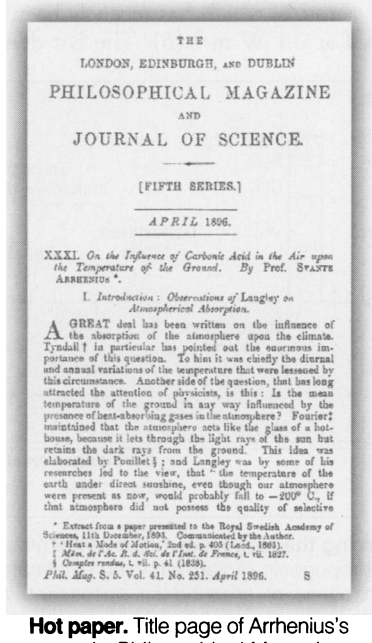
9. S.E.S. acknowledges support from the U.S. Department of Energy.

Arrhenius and Global Warming

Although concern about global atmospheric warming has intensified in recent decades, research into the greenhouse effect actually began in the 19th century. Fourier compared the influence of the atmosphere on temperature to the heating of a glass-covered bowl with an interior coated with black cork (*1*). He and other scientists such as Tyndall (*2*) and Langley (*3*) appreciated that without heat-absorbing gases in the atmosphere, the temperature on the ground would be considerably lower, making life as we know it impossible. However, in 1896 the Swedish scientist Svante Arrhenius was the first to make a quantitative link between changes in CO_2 concentration and climate (*4*). The centenary of the publication of his paper was celebrated at a recent workshop at the Royal Swedish Academy of Sciences (*5*).



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet§; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† "Heat a Mode of Motion," 2nd ed. p. 405 (Lond., 1863).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
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Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. S

Hot paper. Title page of Arrhenius's paper in *Philosophical Magazine*.

Although he had a wide range of interests, Arrhenius is best known for his work on electrolytic dissociation, for which he received the Nobel prize in Chemistry in 1903, and on the theory of reaction kinetics. In his work on the effect of CO_2 on global climate (*4*), Arrhenius made clever use of data provided by Langley (*6*), who had measured the emission spectrum of the moon for different lunar heights and seasons. This data allowed the calculation of the absorption coefficients of CO_2 and H_2O and of the total heat absorbed in the atmosphere of the Earth for a variety of CO_2 concentrations, as well as the corresponding temperature change.

After an estimated 10,000 to 100,000 calculations by hand (*7*), Arrhenius predicted a temperature rise of 5° to 6°C for a doubling of CO_2, not too different from recent estimates of 1.5° to 4.5°C (*8*). Arrhenius primarily ascribed changes in CO_2 levels to changes in volcanic activity and concluded that they could be the cause of glacial cycles on a geological time scale. In a lecture in 1896 (*9*), he estimated that a doubling of CO_2 as a result of fossil fuel burning would take 3000 years. At the time, he was rather in favor of the resulting slow warming, which in his view would result in better living conditions and higher crop yields.

Arrhenius's work, and that of his contemporaries, showed remarkable insight into many factors influencing climate, such as aerosols, ice fields, clouds, and the oceans as a sink for CO_2. In the 1930s, human forcing of climate through fossil fuel emissions began to be considered as a cause of significant temperature increases in the short term (*10*). Today, sophisticated atmospheric models (general circulation models) incorporate a growing number of factors (*11*). Compared to the real climate, these models are still crude: typical parameters are a time step of 1 hour, a spatial grid size of 250 km, and up to 20 vertical levels (*12*). Reliable long-term observational data of climate system variables and detailed physical understanding of feedback mechanisms associated with, for example, clouds, oceans, and vegetation are often lacking. However, there is general agreement among many different studies about the detection of change and its attribution to natural or human-induced influences.

Last year, the Intergovernmental Panel on Climate Change (IPCC) concluded that "the balance of evidence suggests that there is a discernible human influence on climate" (*13*). Despite uncertainties in climate predictions and a highly political climate, perhaps it is reassuring that 100 years of research have affirmed Arrhenius's initial considerations.

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