Letters to the Editor

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The Parasol Effect on Climate

BY BACKSCATTERING SOLAR RADIATION, aerosol particles and clouds exert a cooling (parasol) effect on climate, dampening Earth's warming by the greenhouse gases (GHG) (T. L. Anderson *et al.*, "Climate forcing by aerosols—a hazy picture," Perspectives, 16 May, p. 1103) (*1*). Based substantially on uncertain results from chemistry/climate models, Anderson *et al.* postulate large aerosol negative radiative forcing, including even the possibility of negative total (long wave minus short wave) radiative forcing, coinciding with the industrial (anthropocene) period and requiring large (≈3 W m^{-2}) positive internal climate forcing to produce the observed climate warming. Conversely, we present a method to quantify the parasol effect that does not require unproven major internal climate variability.

The change in the energy budget at the "top of the atmosphere" (TOA) during the anthropocene contains the following terms: (i) the global mean radiative forcing of 2.7 ± 0.3 W m^{-2} by GHG and tropospheric ozone (*1*), (ii) the increase in global average surface temperature since the latter half of the 19th century of 0.6 ± 0.2 K, causing an increase in outgoing long wave radiation (OLR), and (iii) the oceanic heat content, which increased on average by about 0.3 W m^{-2} between 1957 and 1994 (*2*). To estimate the change in OLR due to surface warming, we use the OLR sensitivity value (2 ± 0.3 W m^{-2} K^{-1}) obtained from global satellite data (*3*), which yields about 2 ± 0.3 W m^{-2} K^{-1} × (0.6 ± 0.2) K, that is, about 1.2 ± 0.4 W m^{-2} leaves Earth. The OLR sensitivity is consistent with a positive water vapor feedback and a temperature-invariant relative humidity, which is supported by independent data. Water vapor concentrations increased by several percent per decade over many regions of the northern hemisphere (*1*). The assumption of constant relative humidity is becoming a "robust emerging constraint" (*4*).

Thus, out of 2.7 (± 0.3) W m^{-2} of GHG forcing, we can account for 1.5 ± 0.4 W m^{-2}. Because the atmosphere's heat capacity is small, 1.2 (± 0.5) W m^{-2} of solar radiation must have been reflected by aerosols and clouds, yielding an anthropogenic parasol effect of 45 ± 20%. We assumed that the pre-industrial oceanic heat gain was zero and that internal climate variability averaged out over the anthropocene, contrary to the supposition of Anderson *et al.* Observational (*5*) and model studies (*6*) show that GHG warming is moderated by parasol effects on all continents.

We can also perform a similar analysis by comparing changes in Earth's heat budget (*7*) between the periods 1957–94 and 1861–1900. With a GHG forcing of 1.38 ± 0.14 W m^{-2}, a temperature rise of 0.33 ± 0.033 K, and change in the oceanic heat uptake of 0.15 W m^{-2}, we calculate similar values of 40 ± 10% for the parasol effect.

The anthropogenic parasol effect has been 45 ± 20%, probably mainly due to backscattering of solar radiation by aerosol and enhanced cloud brightness, but with smaller contributions from solar variability and land use (surface albedo) changes that seem to largely have cancelled each other out (*1*). Further, there does not appear to have been a long-term trend in volcanic activity (*1*). The effect is equal to 0.65 to 1.6% of the natural parasol effect of 107 W m^{-2} (*1*). The parasol effect increases with any TOA forcing by black carbon, which has been estimated at 0 (*8*), 0.5 (*9*), and 1 W m^{-2} (*10*).

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Response

CRUTZEN AND RAMANATHAN (CR) PROVIDE another inverse calculation of climate forcing by aerosols from observed temperature changes together with knowledge of nonaerosol forcings. Although CR's approach has the advantage of being shorter and perhaps conceptually simpler than others, it requires several assumptions and incorporates unquantified uncertainties such that its true uncertainty range must be substantially greater than claimed. In any event, CR's estimate of aerosol forcing (–1.2 ± 0.5 W m^{-2}) falls right in the middle of the six inverse calculations we cited.

CR do not acknowledge the inherent limitations to the inverse approach. Absent quantification of aerosol forcing (and of all exogenous forcings) in a manner that does not depend on the temperature record, it is not possible to evaluate performance of climate models by comparison with the temperature record or to use this temperature record to empirically estimate climate sensitivity. Thus, there is no escaping the need for the "forward" approach that evaluates aerosol forcing based on knowledge of anthropogenic aerosols and, importantly, their interactions with clouds.

The problem at present is that forward calculations of aerosol forcing admit the possibility of large negative values that are inconsistent with all of the inverse calculations. CR misread our paper on this central point. We did not "postulate" large negative radiative forcing by aerosols. Rather, we stated that present knowledge does not allow this possibility to be precluded. We did not deprecate either the forward or inverse approaches. Rather, we asserted that the disparity between these approaches requires resolution. This disparity can be resolved only by improved understanding and quantification of the relevant aerosol processes, properties, and geographical distribution; it cannot be resolved by models alone—whether they be aerosol chemical transport models or climate models.

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