Sulphate aerosol and climate

SIR—Wigley has suggested in Scientific Correspondence[1] that the Northern Hemisphere may be warming more slowly than the Southern Hemisphere, possibly due to an anthropogenic increase of cloud condensation nuclei of about 20% in the Northern Hemisphere. We wish to propose an alternative yet complementary explanation for the suggested difference — that backscatter of solar radiation by non-cloud, anthropogenic SO_4^{2-} aerosol particles in cloud-free air significantly reduces the incoming solar radiation over much of the Northern Hemisphere. A simple box-model calculation illustrates the expected magnitude of the mean column burden of anthropogenic sulphate, $B_{SO_4^{2-}}$:

$$B_{SO_4^{2-}} = \frac{F_{SO_4^{2-}} \tau_{SO_4^{2-}}}{A} \sim \frac{(3.3\times10^6\ \mathrm{g\,s^{-1}})\,(5\times10^5\ \mathrm{s})}{2.5\times10^{14}\ \mathrm{m^2}}$$

$$\sim 6.6\times10^{-3}\ \mathrm{g\,m^{-2}}$$

where $F_{SO_4^{2-}}$ is the average flux of this SO_4^{2-} through the atmosphere in the Northern Hemisphere (equivalent to about half of 70 Tg yr^{-1} of sulphur emitted as SO_2); $\tau_{SO_4^{2-}}$ is the mean sulphate aerosol particle lifetime (about 6 days) and A is the area of the Northern Hemisphere. We assume that all anthropogenic SO_4^{2-} originates and stays in the Northern Hemisphere. An empirical optical scattering efficiency, α (10 $m^2\ g^{-1}$, ref. 2), then yields an estimate of optical depth, $\delta_{SO_4^{2-}}$, for solar wavelengths due to anthropogenic SO_4^{2-}:

$$\delta_{SO_4^{2-}} = \alpha\, B_{SO_4^{2-}} \sim 0.066$$

Finally, an empirical backscatter fraction, β (0.15, ref. 3), and estimated cloud fraction, f (~ 0.6), allow for estimation of the energy lost from the Earth's surface, L (we disregard the effect of aerosols above cloudy areas):

$$L \sim (1-f)\,\beta_{SO_4^{2-}}\,(2\delta_{SO_4^{2-}}) \sim 0.8\%$$

where the factor of two is the secant of solar zenith angle averaged over the sunlit hemisphere.

If the solar irradiance incident on this low-altitude aerosol is about 240 W m^{-2}, irradiance (direct plus diffuse solar radiation) is lost at a rate of about 2 W m^{-2}. The solar energy lost from the Earth–atmosphere system would be somewhat less — approximately 1.6 W m^{-2} — due to the albedo (reflectivity) of the underlying surface. This radiative forcing is comparable in magnitude but opposite in sign to the current forcing by anthropogenic CO_2 of about 1.5 W m^{-2} (ref. 4). Hence, backscatter of solar radiation by SO_4^{2-} aerosol cannot be ignored and could account for some or all of the difference in temperature trends between the two hemispheres[1]. In addition to this direct effect, anthropogenic SO_4^{2-} may have an indirect effect by acting as cloud condensation nuclei which can influence cloud albedo[5]. However, this cannot be quantified because there is no known/accepted relationship of SO_4^{2-} mass concentration to the number concentration of cloud condensation nuclei.

Refinements are possible in the calculation of the non-cloud aerosol radiative forcing. Sulphur chemistry has been included in a three-dimensional global model[6] to estimate the geographical dependence of $\delta_{SO_4^{2-}}$. We already know that anthropogenic SO_4^{2-} concentrations and loss of solar irradiance are highest in industrial regions, low over the North Pacific and essentially absent in the Southern Hemisphere. The radiative transfer calculation also can be refined with the addition of well-developed models, including a full treatment of the angular scattering characteristics, seasonality, as well as the geographical distribution of cloud fraction, vertical distribution of aerosol and surface albedo.

Uncertainties will remain even when such a coupled chemical/radiative transfer model is done, because the geographical nonuniformity and asymmetry of the Northern and Southern Hemisphere forcing may cause shifts in meteorological parameters unlike those due to the geographically uniform forcing by greenhouse gases. It does seem unlikely, however, that the magnitude of irradiance loss estimated above will change radically in a refined model calculation. Thus, the effect of anthropogenic aerosol has to be taken into account in any assessment of climate change.

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Differences in hair and fleece loss

SIR—Paul Bowden in his excellent News and Views article[1] on gene expression and hair loss made an oversight in his passing comment that sheep have a mosaic pattern of wool replacement as is the case for hair growth in man. Most mammals have a seasonal pattern of coat replacement in which the skin follicles are dormant during the winter (telogen) and active during the summer (anagen) after a spring moult. This annual cycle of growth is controlled by changes in day length and is universal among the hoofed animals, including the wild ancestor of domestic sheep[2].

Shortening days in autumn trigger changes called catagen, leading to the winter resting period (telogen), whereas lengthening days in the spring stimulate re-growth (anagen), leading to the loss of the old coat. This re-growth before loss of the old coat is a mechanism, like that found in mosaic replacement, which ensures that the animal is never naked as a result of the moult.

The shorter cycles of hair replacement in mice discussed by Bowden, which occur in waves across the body, and the mosaic replacement in man (and guinea pigs) are highly specialized. The lack of a seasonal link in the guinea pig can be interpreted as due to evolution near the equator, where major seasonal climate changes necessitating summer and winter coats do not occur and there is little accompanying variation in day length.

From the Iron Age onwards, sheep were selected for continuous wool growth so that wool could be shorn and not lost during the moult[3], and an evolutionary sequence can be traced from surviving primitive breeds, which have a complete moult, to modern breeds, which have little tendency to shed their wool[4]. Bowden probably had the Merino breed of sheep in mind when he said that man and sheep have a mosaic system of active hair replacement because the Merino more than any other breed has virtually continuous wool growth, mimicking a true mosaic system of wool replacement. But an incidence of dormant follicles of 4 per cent in the Merino, at the time of the year when primitive sheep would also have dormant follicles, does not constitute mosaic replacement[5]. That level of dormancy means that Merino wool fibres are replaced only once every 8 years, and as this is longer than the life of the animal it is not too much of an exaggeration to say that Merino sheep in truth grow wool continuously.

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