4. Atmospheric Aerosols and Climate Change

Introduction

Atmospheric aerosol particles are conventionally defined as those particles suspended in air having diameters in the region of 0.001 to 10 microns (millionth of a metre). They are formed by the reaction of gases in the atmosphere, or by the dispersal of material at the surface. Although making up only 1 part in a billion of the mass of the atmosphere, they have the potential to significantly influence the amount of short-wave solar radiation arriving at the Earth's surface. This fact sheet reviews the sources and sinks of atmospheric aerosols and their impact on global climate.

Sources and Sinks of Aerosols

Atmospheric aerosol particles may be emitted as particles (primary sources) or formed in the atmosphere from gaseous precursors (secondary sources). These include sulphates from the oxidation of sulphur-containing gases during fossil fuel combustion, nitrates from gaseous nitrogen species, organic materials from biomass combustion and oxidation of volatile organic compounds (VOCs), soot from combustion, and mineral dust from aeolian (wind-blown) processes. Natural sources of aerosols are probably 4 to 5 times larger than man-made ones on a global scale, but regional variations of man-made emissions may change this ratio significantly in certain areas, particularly in the industrialised Northern Hemisphere.

Removal of aerosols is mainly achieved by rainfall and other forms of precipitation (wet deposition) and by direct uptake at the surface (dry deposition). The efficiency of both these deposition processes, and hence the time spent in the atmosphere by an aerosol particle, is dependent upon the aerosol's physical and chemical characteristics (e.g. particle size), and the time and location of its release.

Explosive volcanic eruptions can inject large quantities of dust and gaseous material, such as sulphur dioxide, into the upper atmosphere (stratosphere). Here, sulphur dioxide is rapidly converted into sulphuric acid aerosols. Whereas volcanic pollution of the lower atmosphere (troposphere) is removed within days by the effects of rainfall and gravity, stratospheric pollution may remain there for several years, gradually spreading to cover much of the globe.

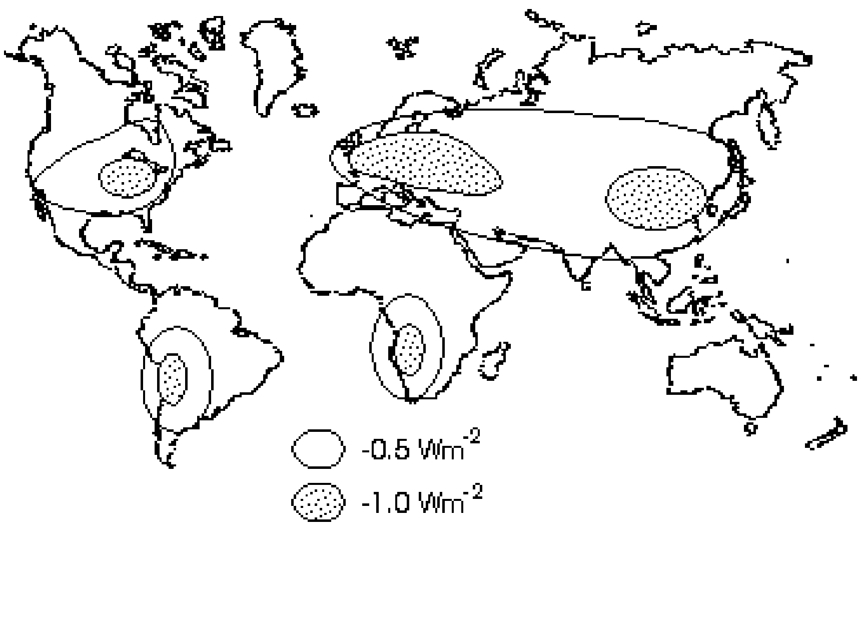
Climate Forcing by Aerosols

Like greenhouse gases, aerosols influence the climate. (Remember, this influence is called climate forcing or radiative forcing.) Atmospheric aerosols influence the transfer of energy in the atmosphere in two ways: directly through the reflection and absorption of solar energy; and indirectly through modifying the optical properties and lifetimes of clouds. Estimation of aerosols' impact on climate is more complex and hence more uncertain than that due to the well-mixed greenhouse gases for several reasons. First, the climate forcing due to aerosol particles is strongly dependent on the particle size and chemical composition. Second, the indirect climatic effects of aerosols depend on complex processes involving aerosol particles and the seeding and growth of cloud droplets. Third, most aerosols have short lifetimes (days to weeks) and therefore their geographical distribution is highly variable and strongly related to their sources.

Direct Climate Forcing

Aerosol particles in the 0.1 to 1.0 micron diameter range are best at disturbing incoming solar radiation due to the similarity of particle size and sunlight wavelength. Sulphate aerosols and organic matter are most effective at scattering and absorbing the short-wave solar radiation, with the effect of negative climate forcing on the global climate. This negative forcing can cause climate cooling. The negative climate forcing due to the formation of sulphur aerosols in the upper atmosphere as a result of volcanic pollution is well known. The volcanic pollution results in a substantial reduction in the direct solar beam, largely through scattering by the highly reflective sulphuric acid aerosols. Overall, there is a net reduction of 5 to 10% in energy received at the Earth's surface. An individual eruption may cause a global cooling of up to 0.3^{o}C, with the effects lasting 1 to 2 years. As for positive climate forcing attributable to greenhouse gases, the negative forcing due to aerosols can be quantified by the amount of solar energy reflected or scattered. Again this is measured in Watts per square metre (Wm^{-2}). The figure below shows how geographically variable the effect on climate can be. Greatest influence occurs close to the source of the precursor emissions, in the highly industrialised regions of the world.

Annual global aerosol climate forcing



Estimations of global negative forcing associated with man-made aerosols are based on computer modelling studies. These show that the global cooling effect of man-made aerosols could offset the warming effect of increased greenhouse gas concentrations by as much as 30%. The regionality of aerosol radiative forcing however, due to localised emission sources and the short lifetimes of the sulphate aerosols in the lower atmosphere, makes calculation of a global average difficult.

Indirect Climate Forcing

The global energy balance is sensitive to cloud reflectivity. Cloud reflectivity is itself sensitive to changes in the cloud droplet number concentration. This droplet number depends, in a complex manner, on the concentration of cloud condensation nuclei (CCN), which, in turn, depends on aerosol concentration. Through this indirect effect, the negative climate forcing caused by man-made aerosol emissions might be further increased. Despite uncertainties, indirect negative climate forcing is believed to be comparable to the direct forcing.

Conclusion

Although making up only 1 part in a billion of the mass of the atmosphere, aerosols have the potential to significantly influence the amount of short-wave solar radiation arriving at the Earth's surface. Aerosols in the atmosphere introduce a negative climate forcing by scattering some of the incoming solar short-wave radiation. This is clearly demonstrated in the aftermath of a volcanic eruption. The recent increase in man-made aerosol emissions has partially offset the enhanced greenhouse effect due to the elevated concentrations of greenhouse gases. This may slow the rate of projected global warming during the 21st century.