The Role of Aerosols in Cloud Drop Parameterizations and Its Application in Global Climate Models

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Introduction

The characteristics of the cloud drop size distribution near cloud base are initially determined by aerosols that serve as cloud condensation nuclei and the updraft velocity. We have developed parameterizations relating cloud drop number concentration to aerosol number and sulfate mass concentrations and used them in a coupled global aerosol/general circulation model (GCM) to estimate the indirect aerosol forcing. The global aerosol model made use of our detailed emissions inventories for the amount of particulate matter from biomass burning sources and from fossil fuel sources as well as emissions inventories of the gas-phase anthropogenic SO_2. This work is aimed at validating the coupled model with the Atmospheric Radiation Measurement (ARM) Program measurements and assessing the possible magnitude of the aerosol-induced cloud effects on climate.

Global Emissions Inventory

In order to provide a global understanding of the effects of aerosols on clouds, one must first understand the global concentrations of the different aerosol components or types. This task consists of the development of a source emissions inventory for aerosols and for gas-phase species that form aerosols. In particular, we are interested in natural and anthropogenic emissions of gaseous sulfur species (which form sulfate in the aerosol), soot or black carbon emissions, emissions of particulate organic carbon and of gas phase non-methane hydrocarbon species which produce aerosols during photooxidation, nitrogen oxides (which form nitrate in the aerosol), and ammonium. For some of these species we already have relatively well-developed emissions inventories [e.g., global emissions of sulfur have been developed by Spiro et al. (1992) and global emissions of NO_x have been developed by Penner et al. (1991)]. Also, we updated both anthropogenic NO_x and SO_2 emissions through the International Global Atmospheric Chemistry Global Emissions Inventory Activity (Penner et al. 1994). The global emissions inventories for black carbon and organic aerosols we have developed include 1) detailed emissions inventories for the amount of particulate matter (e.g., black carbon, organic carbon, and minor species) produced from wood and dung fuel, charcoal burning and charcoal production, agricultural fires, and savannahs and forests burning, 2) an organic matter inventory produced from the diesel and coal sources, and 3) natural organic matter emissions (Liousse et al. 1995). We have also developed an initial representation for aerolian dust (Rau 1994).

Lawrence Livermore National Laboratory Global Aerosol Model Development

At present, several aerosol types (organic aerosols from biomass burning, black carbon, nitrate, sulfate, and dust) are treated by our global aerosol transport and removal model, called GRANTOUR. This Lagrangian model may be run either off-line, using the wind and precipitation fields from a general circulation model, or interactively, in a mode that allows alterations of the wind and precipitation fields consistent with currently calculated species or aerosol concentrations. The model has been run in a coupled mode with several GCMs, including, most recently, the Hamburg GCM. Additionally, a version of the model which treats the gas phase chemistry of tropospheric O_3 has recently been developed. Such capability is important for treating the gas to particle conversion of aerosol components whose gas phase sources react with OH prior to forming aerosol species. The accuracy of those new inventories is being tested by comparing the model simulations with observations. Sensitivity analyses have also been performed by varying the aerosol precipitation scavenging rates.

Aerosol-Cloud Interactions

We have worked on parameterizing the effects of anthropogenic sulfate-containing aerosols on initial cloud drop number concentration (Chuang and Penner 1995).

We refined our treatment of the aerosol size distributions by specifically calculating the processes by which aerosol sulfate is produced in the atmosphere, condensation of H_2SO_4 on pre-existing particles, and the formation of sulfate by in-cloud oxidation of SO_2. The pre-existing particles with a prescribed size distribution are assumed to mainly consist of organic matter, black carbon, and natural sulfate. The resulting anthropogenic sulfate-containing aerosol size distribution is then used in a detailed microphysical model to provide a parameterization of the cloud drop number concentration for use in the climate model. This parameterization is being introduced into the coupled model of GRANTOUR/National Center for Atmospheric Research Community Climate Model (NCAR CCMI) to test the adequacy and range of the predicted anthropogenic sulfate-containing aerosol cloud forcings and to compare with its direct forcing at different relative humidity. Results which have been multiplied by fraction of surface area are listed in Table 1.

Table 1. Annual average anthropogenic sulfate forcing (Wm^{-2}).

	Indirect	Direct (RH = 80%)	Direct (dry)
S. Hemis	0.144	0.107	0.063
Land	0.047	0.037	0.022
Ocean	0.097	0.070	0.041
N. Hemis	0.449	0.493	0.290
Land	0.199	0.268	0.158
Ocean	0.250	0.225	0.132
Global	0.593	0.600	0.353

Our simulations indicate that current concentrations of anthropogenic sulfate have direct and indirect effects that may be comparable in magnitude and at least locally will tend to mask the warming effects of increased greenhouse gases (Figure 1).

Continuation of Work

The earth's radiation balance is highly sensitive to changes in aerosol characteristics. The direct effects of aerosols on the earth's radiation depend on their single scattering albedo and therefore on their composition. A potentially more important effect of aerosols, however, comes through their impact on cloud microphysical characteristics. Because aerosol concentrations vary, both naturally and because of human activities, it is important to include both effects in GCMs. The goal of the ARM Program is to improve general circulation models and, in particular, the representation of clouds in GCMs; therefore, we plan to couple our aerosol model to the ECHAM model to gain a thorough understanding of aerosol effect on cloud lifetime and its influence on global climate. We will also use the ARM measurements to test and improve the coupled global aerosol, cloud, and general circulation model.

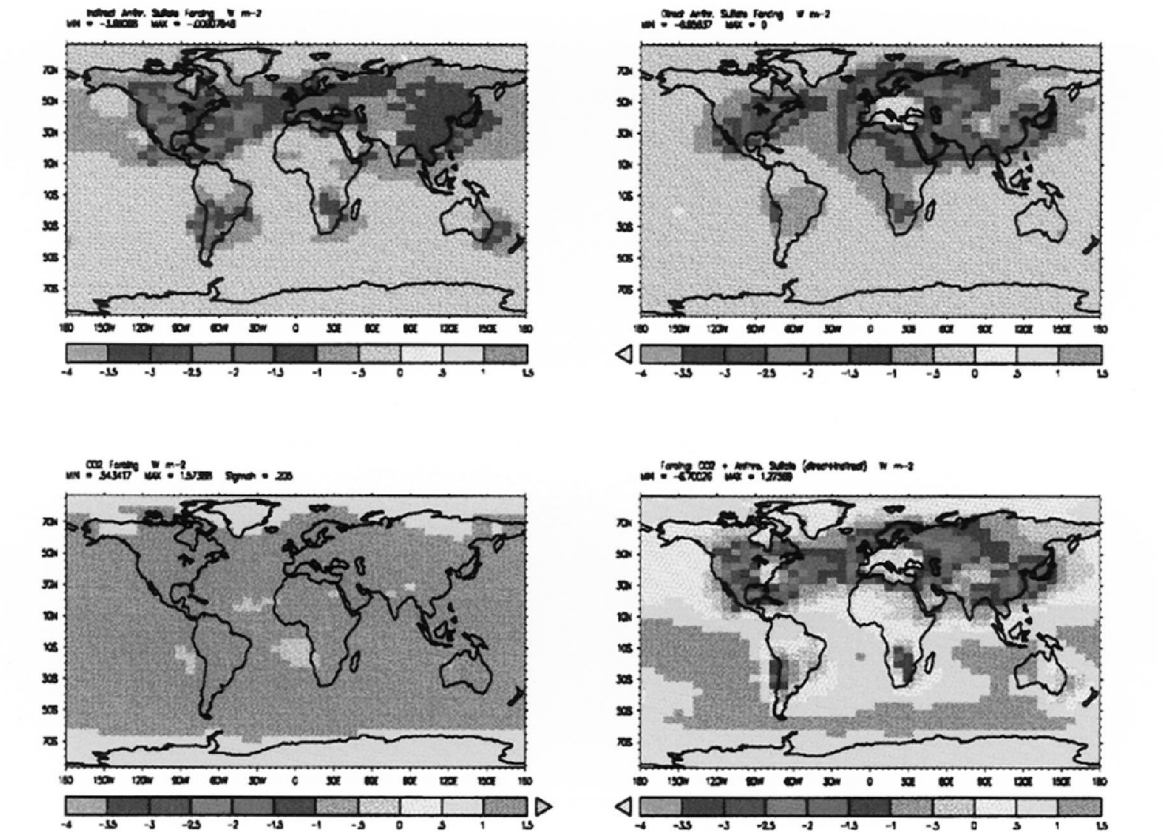

Figure 1. Global distribution of annual average indirect and direct forcing by anthropogenic sulfate-containing aerosols (upper left and right), CO_2 forcing (lower left, from Taylor and Penner 1994) and the total forcing (lower right).

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