Cloud Parameterizations in Global Climate Models: The Role of Aerosols

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Introduction

Aerosols influence warm clouds in two ways. First, they determine initial drop size distributions, thereby influencing the albedo of clouds. Second, they determine the lifetime of clouds, thereby possibly changing global cloud cover statistics. At the present time, neither effect of aerosols on clouds is included in general circulation models (GCMs).

The goal of this project is to develop a global aerosol model and to couple it with the cloud/GCM model developed by Ghan[(a)] so that the effects of aerosols on clouds can be treated in a realistic and validated manner. This model development will build on existing codes at Lawrence Livermore National Laboratory (LLNL) that are already able to describe some of the important aerosol types and their climate forcing. These codes will be extended to treat realistic sources of all aerosol types of importance.

Having developed a global aerosol model, we will use measurements at Atmospheric Radiation Measurement (ARM) sites to validate the model in two ways. First, we will use our global aerosol model to study events of particular interest in the ARM data. This effort will allow us to check the accuracy of the model and its ability to reproduce events from particular time periods. Second, we will use the coupled model to study the climatology of aerosol and cloud microphysical predictions at ARM sites. This effort will allow us to check the accuracy of the model's predictions in reproducing a long time series of data. These comparison and tests should provide a stringent test of the model's completeness and prediction capabilities.

(a) Ghan, S. J. 1991. A GCM stratoform cloud parameterization. Proposal submitted and accepted for funding under the ARM Science Team.

Global Emissions Inventory

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 developing a source emissions inventory for aerosols and for gas-phase species that form aerosols. In particular, we consider natural and anthropogenic emissions of gaseous sulfur species (which form sulfate in the aerosol), soot or black carbon, particulate organic carbon and gas phase non-methane hydrocarbon species (which produce aerosols during photo-oxidation), 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 [Spiro et al. 1992] and global emissions of NO_x [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 (IGAC GEIA) (Penner et al. 1993a). An initial inventory for organic aerosols from biomass burning has also been developed (Penner et al., 1992)—though improvements are being further developed through the GEIA—and an initial inventory for black carbon emissions is available (Penner et al., 1993b).

LLNL Aerosol Model Development

At present, several aerosol types (organic aerosols from biomass burning, black carbon, nitrate, and sulfate) are treated by our existing aerosol transport and removal model, 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 general circulation model. Additionally, a version of the model that 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 before forming aerosol species.

We are in the process of developing a module for GRANTOUR that will treat gas-to-particle conversion processes for multicomponent aerosols and aqueous phase transformation processes. In a multicomponent mode, this new gas-to-particle conversion module will take account of the range of possible gas-phase concentrations, temperatures, different relative humidities, and the effects of pre-existing aerosol on the potential for new aerosol formation (nucleation) and aerosol growth by condensation.

We have performed a detailed microphysical study of the effects of anthropogenic sulfate on cloud drop size distribution (Chuang and Penner, in press). We refined our treatment of the aerosol size distribution by specifically calculating the two processes by which aerosol sulfate is produced in the atmosphere: condensation of sulfate on pre-existing particles and the formation of sulfate by in-cloud oxidation of SO_2. The resulting sulfate-containing aerosol size distribution is used in a detailed microphysical model to parameterize the cloud drop concentration. The parameterization was introduced into the LLNL version 1 of the National Center for Atmospheric Research's Community Climate Model (NCAR CCM1) to test the adequacy and range of the predicted aerosol cloud forcings (Chuang et al. 1994). Simulations obtained by coupling with GRANTOUR indicate that current concentrations of anthropogenic sulfate have direct and indirect effects that may be comparable in magnitude (~ -0.45 W m^{-2} on global average) 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 general circulation models.

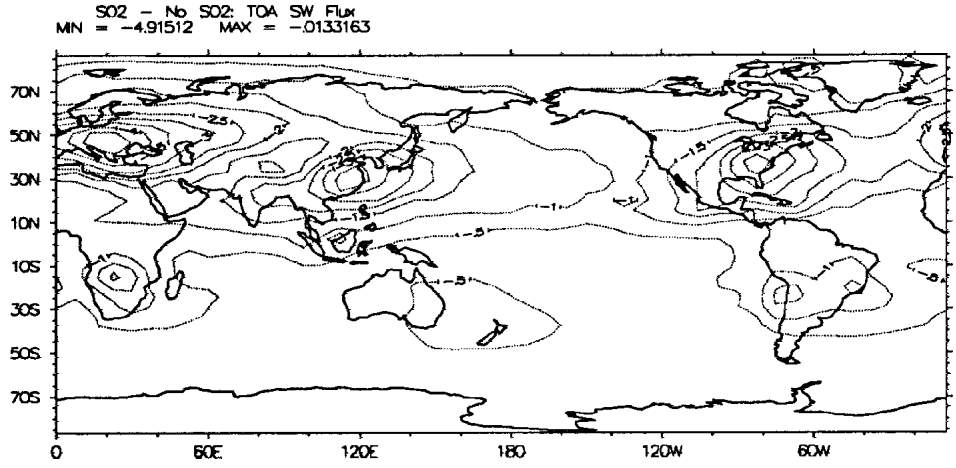

Figure 1. Global distribution of annual average anthropogenic sulfate forcing. Contour is shown every -0.5 W m^{-2}.

The goal of the ARM program is to improve general circulation models and, in particular, the representation of clouds in GCMs. Therefore, as noted, we plan to couple our aerosol model to the cloud/GCM model of Ghan for prediction of cloud optical properties and radiative interactions that result from changes to aerosols. We will also use the ARM measurements to test and improve the coupled global aerosol, cloud, and general circulation model.

Model testing will have two phases: episodic predictions of ARM site events and predictions of climatology. Before a long time series of data become available, we can begin to test our model using the ARM measurements by modeling specific events at these sites. For the episodic studies, we may prefer to run the aerosol and general circulation model at high resolution (e.g., 100- x 100-km horizontal resolution) in order to accurately capture these episodic events. We will also test the model by comparing the time-averaged concentrations and the degree of variability within the month to a long time series of measurements. By testing the ability of the model to reproduce long-term aerosol concentrations, cloud effects, and surface radiative fluxes, we will be able to discern whether changes in aerosols have contributed to a masking of the effects of greenhouse gases on climate and whether they might do so in the future.

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