Cloud/Aerosol Parameterization: Comparison of Model Predictions with ARM Data

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Introduction

Cloud parcel models have been used to parameterize the activation of aerosol particles to form cloud droplets, and these parameterizations have been used in climate models to estimate the indirect forcing by anthropogenic aerosols (Chuang et al. 1997; Penner et al. 1996). Results indicate that the indirect forcing by anthropogenic sulfate aerosols from an increase in droplet number is ~-0.4 Wm^{-2} to -1.5 Wm^{-2} with the smaller number more likely because most models indicate that most sulfate is formed within cloud droplets and, hence, would not form additional cloud condensation nucleus (CCN). Carbonaceous aerosols, on the other hand, may result in forcing ~-2.4 Wm^{-2} to -4.4 Wm^{-2} (Penner et al. 1996). These analyses demonstrate that the potential total negative forcing from the indirect effect of anthropogenic aerosols is large compared to the positive forcing by greenhouse gases. In contrast, however, analysis of the magnitude of indirect forcing for aerosols from biomass burning using satellite data gives estimates that are substantially less than the forcing estimated in climate models (Kaufman and Fraser 1997). We have used data from the Atmospheric Radiation Measurement (ARM) Intensive Observation Period (IOP) of April 1996 to characterize the reflected radiation from clouds as a function of aerosol number concentration at cloud base. These data can then be used to test the parameterizations in climate models.

We have developed a parameterization for the indirect effect that is based on a mechanistic description of droplet formation and the chemical processes controlling the formation of sulfate (Chuang and Penner 1995). It has been evaluated by comparing the predicted droplet size from our coupled climate-aerosol model with those measured by satellite (Chuang et al. 1997). However, a much more thorough test of the parameterization is needed. We are evaluating our parameterization using data available through the ARM Program. In particular, we use readily available data for cloud top and cloud base (inferred from satellite data) and cloud liquid water content (inferred from microwave radiometer) to sort ARM data by the parameter $p = h\left[\frac{9\pi w_L^2}{2\rho_w^2}\right]^{\frac{1}{3}}$, where h is the depth of the cloud, w_L is the liquid water content, and ρ_ω is the density of water. For a constant value of p and constant solar zenith angle, the reflected shortwave radiation measured by the satellite should increase as the number concentration of drops within the cloud increases, and the number concentration of drops within the cloud should increase if the aerosol concentration at cloud base is increased until saturation (which occurs near N_a = 5000 particles/cm^3 for typical aerosol conditions). Thus, we use data sorted by the parameter p as well as solar zenith angle to plot reflected radiation against aerosol concentration. This allows us to determine whether the measured relationship corresponds to that given by the parameterized relationship. Because we only have aerosol concentrations at the surface, we must limit our study to cases where the cloud forms at the top of the boundary layer and the layer below is well-mixed. Also, for this scheme to work, it is important to limit the number of cases examined to include only those in which the cloud has not undergone a significant amount of entrainment and mixing of dry air with cloudy air. We must also limit our examination to clouds that are entirely liquid. Thus, we have developed the following criteria in selecting the time periods and data for examination:

1. the cloud thickness estimated from the sonde data is within 200 m of that estimated from the satellite.

2. the mixing ratio of water vapor is approximately constant below cloud base.

3. cloud base is less than 3 km.

4. the mixing ratio of water below the cloud is approximately equal to the sum of the mixing ratio of cloud water and water vapor within cloud.

5. cloud cover determined from the satellite is larger than 95%.

Initially, we have only the one month of data in which all the parameters that are needed for this analysis were available (April 1996), and the above criteria severely limits the number of data points available for analysis. Therefore, we are in the process of extending the data available for analysis by normalizing the reflected solar radiation to that for a single solar zenith angle. As a further test of the parameterization, we will also compare directly the measured and calculated reflected radiation.

References

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