A Hierarchical Approach to Improved Cloud Radiation Parameterization for Climate Models Through the Atmospheric Radiation Measurement Program

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Introduction

Improved parameterization of clouds for general circulation models will require both ARM observations and the use of more detailed cloud models. We have adopted a parallel implementation approach to improve cloud parameterizations by including identical cloud radiative processes into three models that span the important spatial and temporal scales for cloud research. These models include a one-dimensional detailed ice microphysical model, the Clark cumulus ensemble model, and the Community Climate Model (CCM2) of the National Center for Atmospheric Research (NCAR).

The development of the detailed ice microphysics model is being carried out under National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) funding, but will be of value in validating the bulk ice parameterization used in the cumulus ensemble model. It employs a vertical resolution of 50 m. The Clark cloud model is currently run in two dimensions with a 1-km horizontal resolution and a variable vertical resolution ($\Delta z = 200$ m in mid to upper troposphere). The domain extent of the cloud model is 1000 km in the horizontal and 30 km in the vertical. The NCAR general circulation model (GCM) is CCM2, the latest version of the CCM. This version of the CCM is a completely new model in both physics implementation and coding structure. Most importantly to the ARM research is the use of a δ-Eddington solar radiation model with 18 spectral intervals (Briegleb 1992), a cumulus mass flux convective parameterization (Hack 1993), and a new cloud prediction scheme, which is an extension of the Slingo (1987) scheme.

Inclusion of Ice Radiative Properties in the Hierarchy of Models

The first parallel development effort was to implement a column version of the CCM2 radiation model in the cirrus cloud model and the cumulus ensemble model. This implementation has now been completed. In particular, the cumulus ensemble model now includes a diurnal cycle. Radiation calculations are performed every 2 min, while the dynamical time step is 7 sec. The same column model has also been implemented in the cloud microphysics model.

The second effort in parallel implementation was the introduction of explicit ice radiative properties into the shortwave and longwave radiative transfer model. For the general circulation model and the cumulus ensemble model, the radiative properties of liquid, mixed phase and ice clouds are parameterized by using the NCAR CCM2 radiation code in conjunction with the radiative optical properties for liquid droplets from Slingo (1989) and for ice from Ebert and Curry (1992).

Mixed phase optical properties are accounted for through the following relation,

$$\tau_{cld} = (1 - f_{ice})\tau_{cld}^{liq} + f_{ice}\tau_{cld}^{ice}$$

$$\omega_{cld} = \frac{(1 - f_{ice})\tau_{cld}^{liq}\omega_{cld}^{liq} + f_{ice}\tau_{cld}^{ice}\omega_{cld}^{ice}}{\tau_{cld}}$$

$$g_{cld} = \frac{(1 - f_{ice})\tau_{cld}^{liq}\omega_{cld}^{liq}g_{cld}^{liq} + f_{ice}\tau_{cld}^{ice}\omega_{cld}^{ice}g_{cld}^{ice}}{\tau_{cld}\omega_{cld}}$$

where for the CCM2 f_{ice} is determined from the following relation,

$$f_{ice} = \begin{cases} 0 & T \geq -5C \\ \frac{T + 5}{15} & -5 \leq T \leq -20C \\ 1 & T \leq -20C \end{cases}$$

based on the observations of Hobbs et al. (1974).

The cumulus ensemble model explicitly calculates the ice water concentration and the liquid water concentration, thus f_{ice} for the cloud model is given by,

$$f_{ice} = \frac{IWC}{IWC + LWC}$$

where IWC is the ice water concentration in a given layer and LWC is the liquid water concentration. The optical properties for liquid drops and ice particles are expressed as (Slingo 1989; Ebert and Curry 1992),

$$\tau_{cld}^{i} = \begin{Bmatrix} LWP \\ IWP \end{Bmatrix}\left(a^{i} + \frac{b^{i}}{r_{eff}}\right)$$

$$\omega_{cld}^{i} = 1 - c^{i} - d^{i}r_{eff}$$

$$g_{cld}^{i} = e^{i} + f^{i}r_{eff}$$

where i denotes either liquid (liq) or ice. The ice values derived by Ebert and Curry for the coefficients a through f are based on Takano and Liou's (1989) optical calculations for hexagonal plates. Note that we must specify r_{eff} for both liquid and ice particles. We use r_{eff} = 10 µm for liquid drops; for the ice particle size in the GCM we plan to use 20 µm. This size is based on the recent results of Baum et al. (1992), but this is one of the parameters we hope to obtain more information on from ARM measurements. In the cumulus ensemble model we diagnose r_{eff} from the predicted ice number and the ice water concentration. Hence, in the cumulus ensemble model r_{eff} is not prescribed as it is in the GCM.

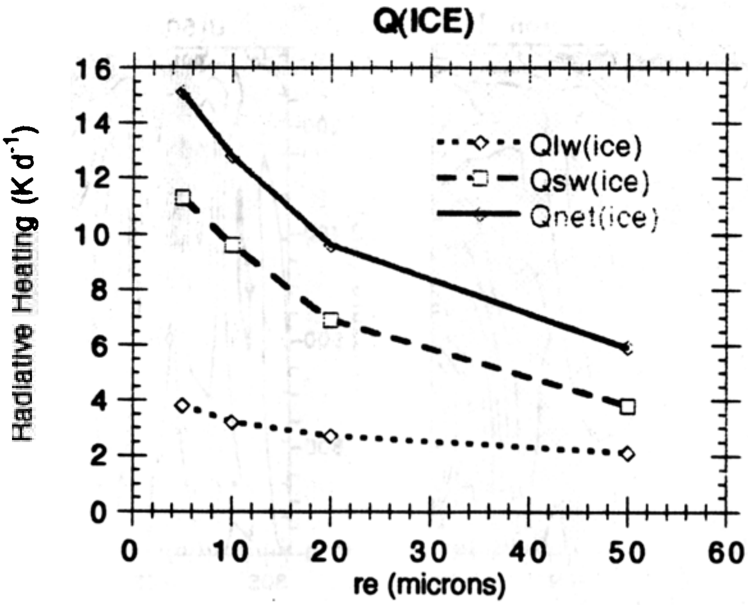
Results from the CCM

Figure 1a shows the dependence of cirrus cloud radiative heating and longwave cooling on the ice particle size. Figure 1b shows the difference between the ice particle heating/cooling from the standard CCM2 heating cloud heating rates. Note that for r_{eff} greater than 20 µm, the net effect is to cool the upper troposphere.

Figure 2 indicates the role of ice particle size in the CCM2. Shown is the difference in zonally averaged temperature and zonal wind, differences that are due to a change in ice particle size from 50 to 10 µm. The use of a 50 µm ice particle size results in a cooling of the upper troposphere of order 5 K (note the interannual variability in this region is around 0.5 K). Associated with the upper tropospheric cooling is a weakening of the upper tropospheric zonal wind. These results indicate that the tropical simulated climate is quite sensitive to ice particle size.

Current Investigations

Currently, the cloud ensemble model is being integrated with the ice optical properties included. We are forcing the model with large scale conditions that are representative of the tropical western Pacific. We intend to integrate this simulation until it comes into an equilibrium balance with the large scale conditions. At this point we will investigate the magnitude of the radiative forcing from the convective and stratiform components of the cloud system. We will then repeat these simulations without the ice optical properties to assess the role of the ice optics on the simulation.



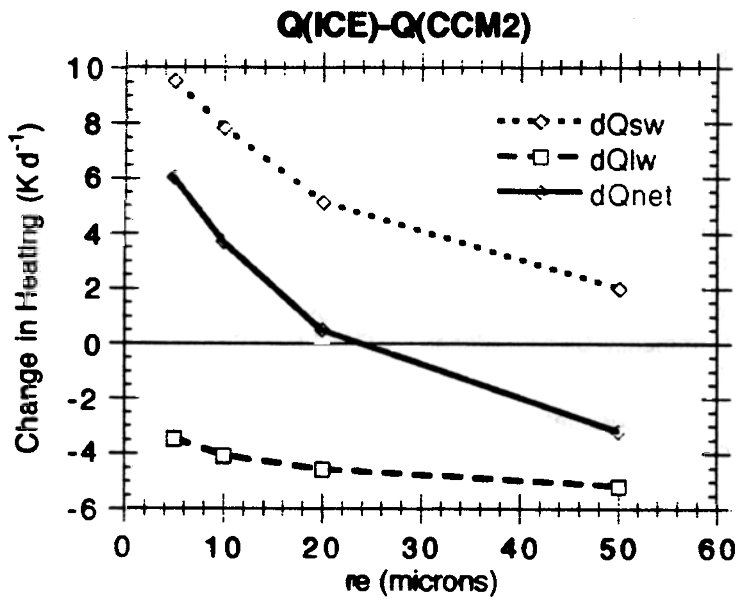


Figure 1. a) Shortwave heating Q_{sw}, longwave heating Q_{lw} and net heating Q_{net} as a function of ice particle size r_{eff} (microns). b) Difference between results in 1a and the standard (liquid phase) CCM2 heating rates.

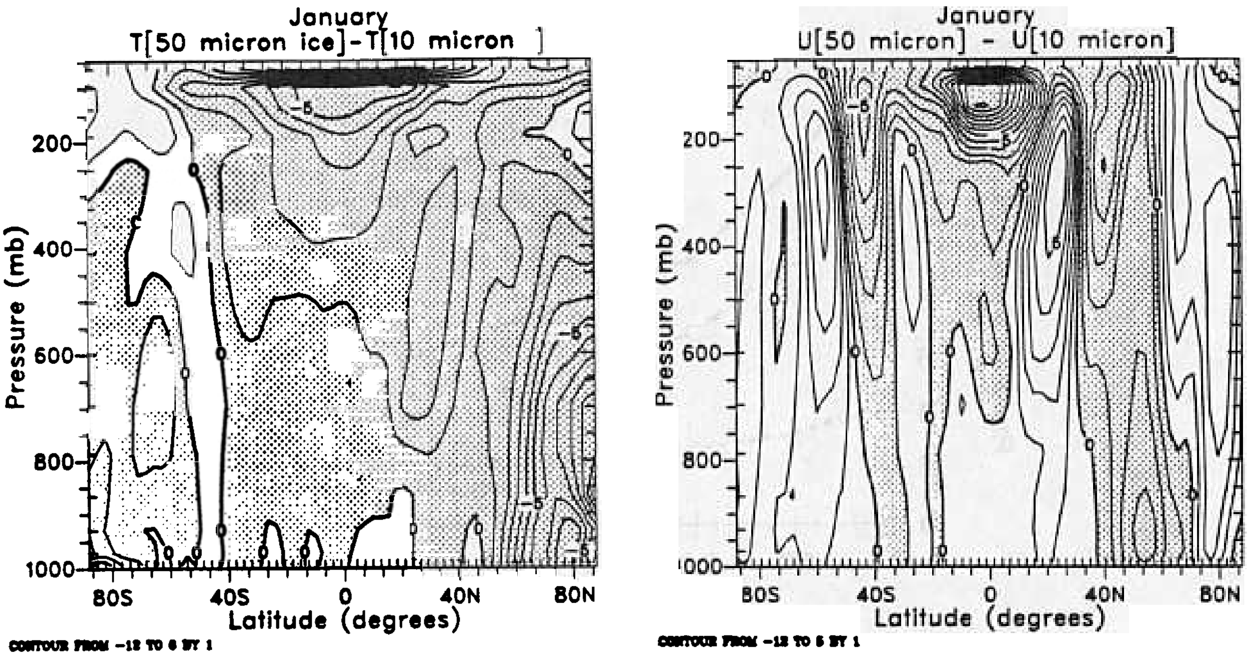


Figure 2. a) Change in CCM2 zonal temperature due to an increase in ice particle size from 10 to 50 microns. b) Change in CCM2 zonal wind due to increase in ice particle size, for January.

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