Sensitivity Tests on the Microphysical Parameters of a 2-Dimensional Cirrus Model

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Introduction

Radiatively induced convection may serve a key role in the evolution of cirrus. A 2-dimensional cirrus model with a spatial resolution of 100 m is developed to investigate dynamical-radiative-microphysical interactions. It is assumed that the model domain represents part of a cross-section of cirrus outflow that intrudes into a stably stratified upper troposphere and is advected by the mean horizontal wind.

This study tests some of the most uncertain microphysical parameters in this model, namely, the initial values of the microphysical properties of ice crystals, and the shape of ice crystals.

A Brief Description of the Model

The dynamics module of the model basically follows Starr and Cox's framework (1985). It is a finite difference model of second-order accuracy in space and time. The major improvements are the use of Smagorinsky's parameterization scheme for eddy coefficients and the incorporation of a high-resolution, positive definite scheme for particle transport (Allen et al. 1991).

The parameterization scheme that Ebert and Curry (1992) developed for the optical properties of ice clouds is adopted with a modification for effective radius smaller than 20 m. In their scheme, for infrared radiation the mean mass absorption coefficient of a distribution of ice crystals is roughly inversely proportional to the effective radius. This may be a proper approximation for a large effective radius but not for an effective radius less than 20. It is possible that the effective radius can be smaller than 20 in long-lasting high cold cirrus. Therefore, the scheme is modified to better represent the mass absorption coefficient for smaller ice crystals. A narrow-band delta 2-stream code is used to calculate irradiances (Toon et al. 1989).

An explicit microphysics module, which conserves both the number and mass, is used in the simulations (Chen and Lamb 1994). There are three types of hydrometeors in the model: ice crystals, unactivated solution particles, and activated solution particles. Twenty-five bins ranging from 1 to 1000 are used for the ice crystals. Aqueous particles are categorized by their solute mass. Homogeneous freezing of aqueous particles, the diffusional growth of ice crystals and aerosols, the sedimentation of ice crystals, and the aggregation of ice crystals are explicitly calculated. The parameterization of deposition nucleation is also included.

Simulations

Ice microphysics for the simulations varies according co Table 1. A nearly neutrally stratified cloud deck of a depth of 1 km is placed between 13 and 14 km (centered at -58 C) in height in a standard tropical atmosphere profile. The background vertical wind is set to be zero. All of these simulations are run for night time conditions (no solar heating).

Table 1. Summary of the simulations.

Run	**1**	**2**	**3**
Shape	Column	Column	Sphere
Mean Radius (micrometers)	20	40	40
Number density (L^{-1})	640	80	80
Optical depth (IR windows)	1.2	0.54	0.68

Run 1 has the most favorable conditions to create a radiatively driven mixed layer. First, the initial value of the optical depth in Run l is the highest because its mass absorption coefficient is the largest. Therefore, the radiatively induced convection will be the strongest.

Second, the fall speed of ice crystals increases with the size of ice crystals. Therefore, the growth rate of the depth of the cloud is closely related to the initial ice crystal size. The optimal condition to deepen the mixed layer takes place when the growth rate of the cloud extent is about the same speed as the growth rate of the mixed layer; that is to say, when the maximum radiative cooling/warming occurs at the top/bottom of the mixed layer (Figure 1). From the horizontal mean potential temperature profile (Figure 2), the depth of the mixed layer increases with simulation time. The mean temperature of the mixed layer increases slightly after 60 minutes of simulation. Unlike the other two runs, the horizontal mean ice mixing ratio of Run 1 peaks at the upper portion of the cloud deck after 25 minutes of simulation (not shown), which is close to a conceptual mixed layer model.

Third, the absolute humidity is low at this low temperature. The high ice number density in Run 1 entails a high competition for water vapor. Hence, the growth of ice crystals is rather limited. Indeed, in updrafts in Run 1, ice crystals are not able to grow to a size so that the crystals fall relative to the updraft speed, which can reach values as large as 3 m/s.

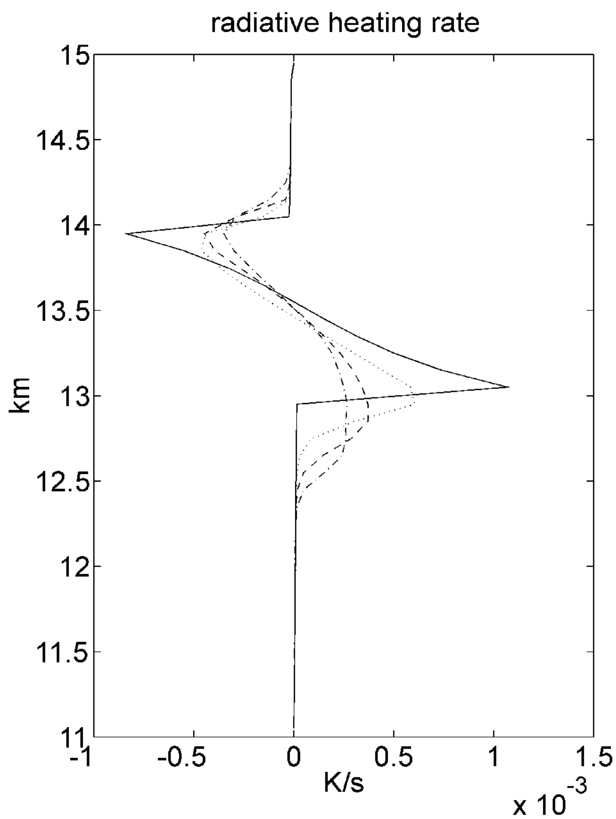

Figure 1. The horizontal mean radiative heating rate profile of Run 1. The solid line is at simulation time 0 min; the dotted line is at time 20 min; the dashed line is at time 40 min; the dash-dotted line is at time 60 min.

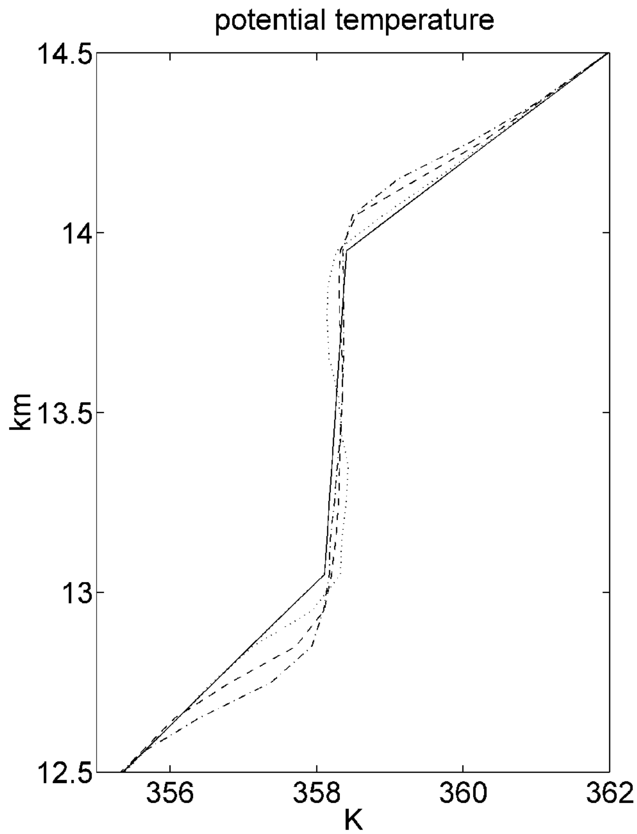

Figure 2. The horizontal mean potential temperature profile of Run 1. The line conventions are the same as in Figure 1.

The cloud rapidly deepens as ice crystals fall into the sub-saturated sub-cloud layer in both Run 2 and Run 3. The values of radiative heating rate decrease as the ice water path decreases due to sublimation in the sub-saturated layer. After 30 minutes of simulation, the originally neutrally stratified layer covers only the upper portion of the cloud and is radiatively cooled (Figure 3). The radiative destabilization weakens; as a matter of fact, the buoyancy production of resolvable turbulent kinetic energy (TKE) becomes negative from run time 35 minutes to 55 minutes in both cases.

For the horizontal mean temperature profile (not shown), the temperature of the originally neutrally stratified layer decreases about 0.2 K in Run 3 and 0.3 K in Run 2 after 60 minutes, which is mainly caused by radiative cooling. The temperature tendency is in the right direction for the freeze drying mechanism proposed by Danielson (1982).

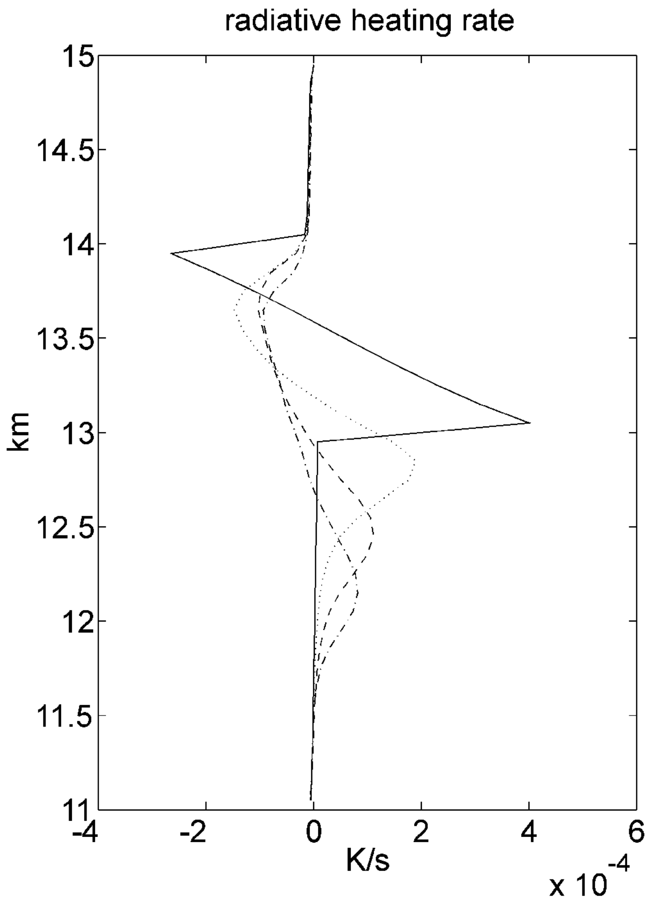

Figure 3. The radiative heating rate profile of Run 2. The line conventions are the same as Figure 1.

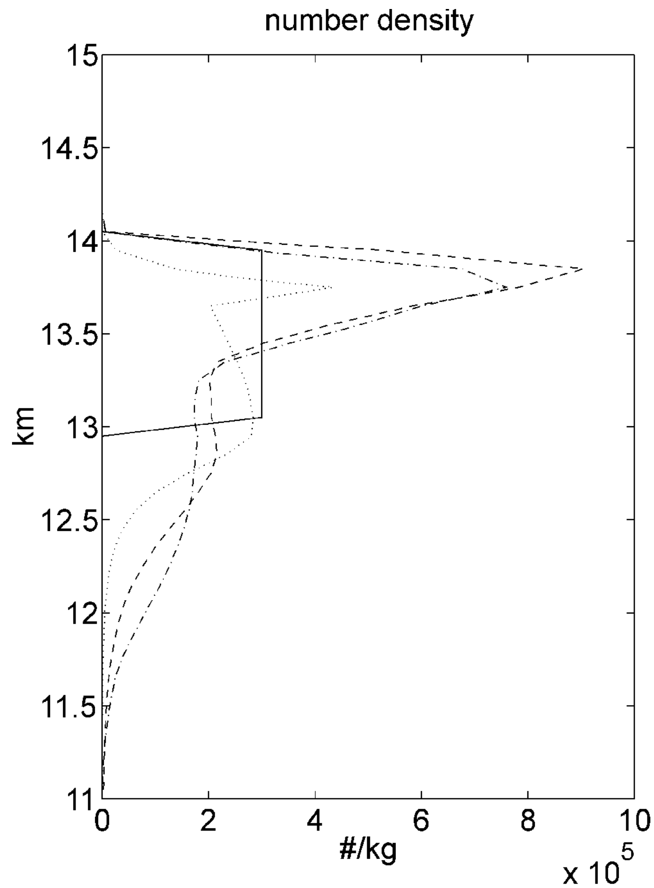

Figure 4. The horizontal mean ice number density profile of Run 3. The line conventions are the same as Figure 1.

The shape of ice particles affects 1) the rate of diffusional growth, 2) terminal velocity, and 3) optical depth. Compared with a spherical ice crystal of the same mass, a columnar crystal has a faster diffusional growth rate, a smaller terminal velocity, and a smaller mass absorption coefficient. Therefore, after the first 20 minutes of the simulations, the domain mean resolvable TKE is larger in Run 3 than in Run 2. However, the vertical extent of the cloud elongates faster in Run 3 because of a faster terminal velocity and slower sublimation rate. After a larger portion of ice mass sediments into the sub-cloud layer, the mean TKE of Run 2 becomes less than Run 3. A drastic difference between Run 2 and 3 (Figure 4) is that regions of high ice supersaturation (45) are produced only in Run 3. Homogeneous nucleation of haze particles occurs only for spheres because updrafts are relatively depleted of ice due to rapid settling of spheres and relatively enriched in water vapor due to slow diffusional growth.

Conclusions

A 2-D cloud resolving model (CRM) with explicit microphysics is developed to study the evolution of cirrus clouds. We show that the evolution of cirrus is sensitive to the presumed shape of ice crystals. We also show that when the growth rate of the mixed layer is comparable to that of the cloud depth, convective overturning is maintained.

Relatively simple differences in initial microphysics lead to substantially different cirrus decks after 1 hour of simulation. This suggests the need for additional simulations as well as in situ observations of cloud microphysics in tropical cirrus.

Acknowledgment

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