Testing a New Cirrus Cloud Parameterization in NCAR CCM3

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Introduction

Cirrus cloud cover and ice water content (IWC) are the two most important properties of cirrus clouds. However, in general circulation models (GCMs), their treatment is very crude. For example, in the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3), IWC is prescribed as a function of column-integrated water vapor and height (Hack 1998). The in situ observations in the tropics indicate that the cirrus IWC is an order of magnitude larger than what is prescribed in the model (McFarquhar and Heymsfield 1996). The comparison with the International Satellite Cloud Climatology Project (ISCCP) data indicates that the modeled cover is on the average 40 to 50 percent larger than observed. To understand the impact of cirrus clouds on the climate, we have developed a more sophisticated, diagnostic cirrus scheme that takes into account both model large-scale dynamics and basic microphysical properties of cirrus.

The Cirrus Parameterization Scheme

We define all model clouds formed at temperatures below -35°C as cirrus, consisting solely of ice crystals. The scheme is based on the work of Zurovac-Jevtic (1999). It assumes that the water vapor needed for cirrus ice formation is supplied by a number of sources, such as detrainment of convective clouds (Zhang and McFarlane 1995); convergence due to large-scale circulation; and as a result of temperature changes due to advection, radiative heating, and diffusion. The equilibrium conditions controlling the deposition of vapor use two thresholds for the relative humidity (Heymsfield and Miloshevich 1995): A temperature dependent threshold for the homogeneous nucleation (cirrus initiation in clear-sky) and a quasi steady-state relative humidity corresponding to the slight supersaturation frequently seen in well-developed cirrus. The total vapor deposited is divided into two parts: One part has negligible fall velocity and constitutes the body of the cirrus, and the other part is the precipitating ice. The former is estimated assuming that this amount of ice is required by the cloud to act as a catalyst for deposition of vapor to ice at the same rate at which the available vapor is supplied (Zurovac-Jevtic 1999). The deposition of bulk ice is calculated based on the rate of diffusional growth of the whole ice crystal spectrum, represented by the tropical ice crystal spectra parameterized by McFarquhar and Heymsfield (1997).

Two different versions of precipitation treatment are defined. In the first version, the precipitating ice crystals are assumed to have an "infinite" fall velocity (a traditional GCM precipitation treatment). Precipitation from all cloud levels within the same column are added and discharged at the cloud base. In the layers below the cloud, the ice is assumed to evaporate as a function of environmental relative humidity (Sundqvist et al. 1989) affecting the humidity levels throughout the column. In the second version, a fraction of ice precipitation is sent to the layer below. This fraction is determined assuming that a mass-weighted bulk velocity can be calculated employing the assumed ice crystal spectra and crystal terminal velocities proposed by Heymsfield and Iaquinta (2000).

The scheme is diagnostic, making use of the model specific humidity as the only prognostic variable for all water phases. All cirrus ice that is not discharged as precipitation is returned back to the humidity field in the end of each time step allowing the ice to be treated as a passive tracer. In order to distinguish initial formation from already existing cirrus, a memory mask is used. In case of continued existence, a slight instead of high supersaturation (as in clear-sky) is required. No fractional cirrus cover is allowed in the scheme and the diagnosed cloud cover, IWC, and effective radius are used in radiative transfer calculations.

Results

Description of Model Runs

In this section we present the results from model integrations with standard NCAR CCM3.6.6 and two versions of the new cirrus scheme. We will refer to the standard run as CTRL, the experiment with instant precipitation as INSPR, and the experiment with delayed precipitation as DELPR. Cirrus model fields over the tropical warm pool (WP) region (140E-220E and 30S-30N) are compared with the ISCPP satellite data and in situ observations collected during the Central Equatorial Pacific Experiment (CEPEX).

Cirrus Cover

Cirrus clouds are created at four model levels, the lowest being around 10.8 km and the highest being around 16.5 km, close to the tropical tropopause. January means of cirrus cover for the different experiments are shown in Figure 1.

In the CTRL run the cloud cover is around 25 percent in the lowest two layers and it decreases with height. In the INSPR experiment a significantly smaller cover, ~17 percent, is produced at the lowest level, but the cover increases to about the same as in CTRL at higher altitudes, except close to the tropopause level where more cirrus are generated. In the DELPR experiment the mean cloud profile is inverted compared to CTRL, steadily increasing from about 15 percent at the lowest level to about 30 percent at the highest level. It is interesting to note that by delaying the precipitation process, the cloud cover does not change much in the lowest two levels where thicker cirrus are expected, whereas at the highest two levels significantly more thin cirrus clouds are produced. Comparison with the ISCCP high cloud amount for the same region indicates that the observed high cloud is slightly above 17 percent and the pattern of the mean January 1993 ISCCP high cloud cover remarkably resembles the cloud pattern at the lowest level in the DELPR experiment (not shown here).

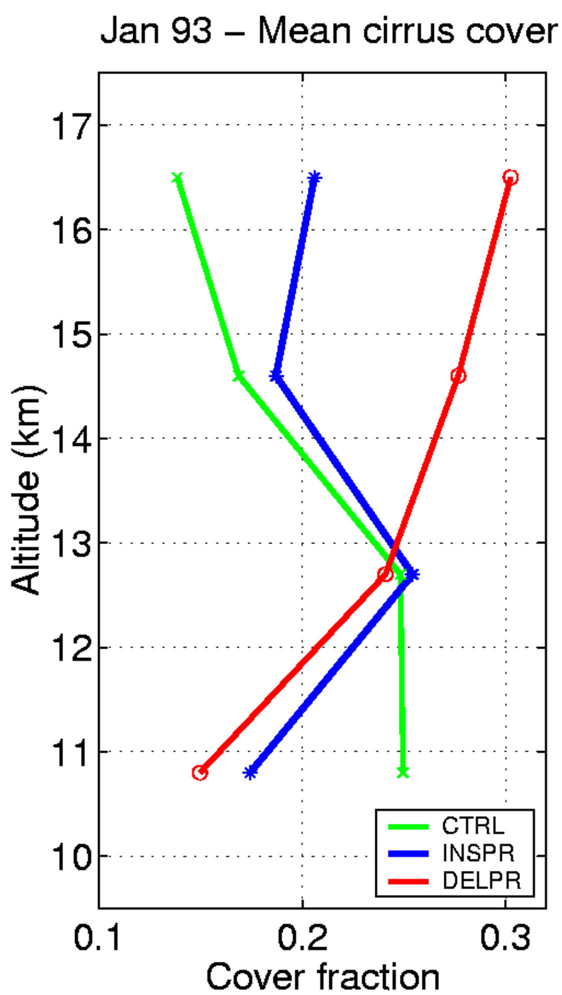

Figure 1. Vertical profiles of mean January 1993 cirrus cover in the WP region from model simulations.

Cirrus Ice Water Content

The mean model-produced ice-mixing ratio in the WP region for the different experiments is shown in Figure 2. The differences between the experiments are obvious. The mean ice content in the CTRL run is very low at all altitudes, decreasing from 4 mg/kg around 11 km to around 0.4 mg/kg in cirrus close to the tropopause. The new cirrus scheme simulates cirrus with notably higher IWC in the lowest two cirrus layers (reaching around 15 mg/kg), but with little change above. Introduction of the new precipitation treatment significantly increases the IWC throughout the cirrus layer, particularly at warm temperatures, where the mean ice content is increased by a factor of 10 compared to CTRL, reaching almost 50 mg/kg near 11 km.

A sample of the corresponding in-cloud IWCs created at each time step is shown in Figure 3. Whereas the IWC in the CTRL run shows small variability within each model layer, the variability is enhanced significantly in the experiments. In the DELPR run the mean IWC at -40° to -45°C is close to 16 mg/m^3, which is in very good agreement with the observed median of about 20 mg/m^3 in the corresponding temperature interval (McFarquhar and Heymsfield 1997). A good general agreement is seen at colder temperatures as well: the DELPR run simulates around 5 mg/m^3 at temperatures near -55°C and the observed medians are between 3 and 10 mg/m^3. The lowest temperatures measured in CEPEX are around -75°C and the spread between the median and the average values lies between 0.5 and 2 mg/m^3, while the model cirrus in the layer with similar temperature shows a mean of about 0.9 mg/m^3.

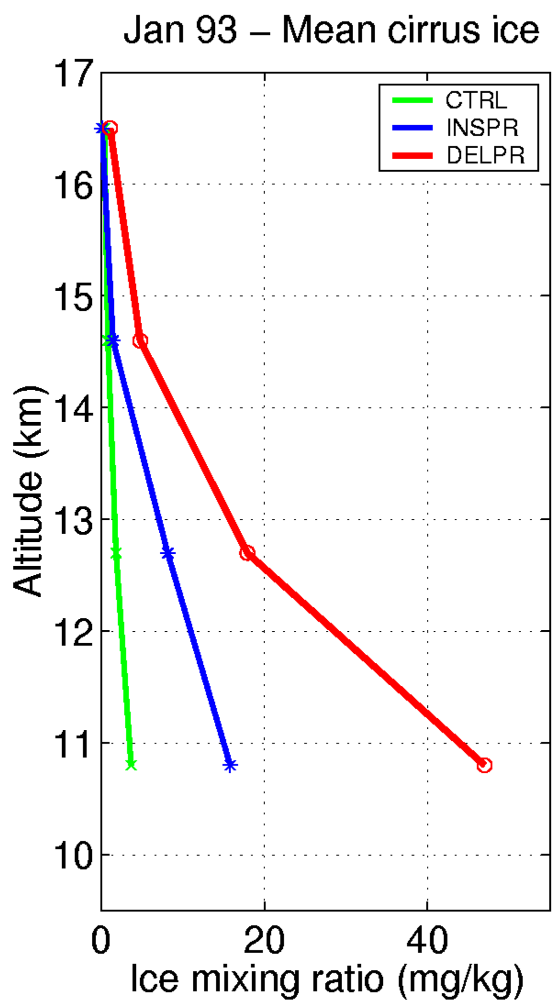

Figure 2. Vertical profiles of mean January 1993 cirrus ice mixing ration (mg/kg) in the WP region from model simulations.

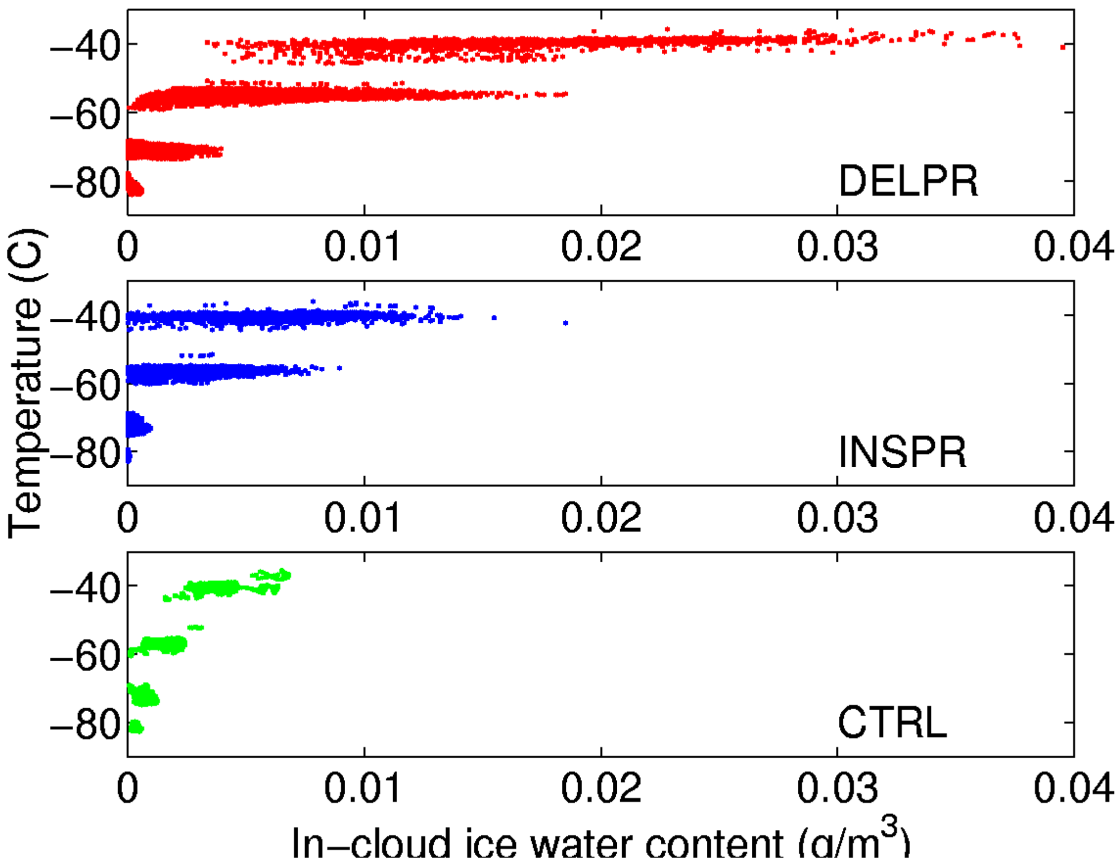

Figure 3. Scatter diagrams from a sample of grid box IWCs for the different experiments.

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