Comparison of Convection Characteristics at the Tropical Western Pacific Darwin Site Between Observation and Global Climate Models Simulations

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Introduction

One of the scientific objectives of the ARM Tropical Warm Pool International Cloud Experiment (TWP-ICE) planned for early 2006 at Darwin, Australia, is to describe convection characteristics and its interaction with the large-scale fields. In view of the short duration of the experiment, it is important to determine the long-term statistics of convection and its associated clouds from the observations and global climate models (GCMs) so as to put the experiment results in proper climate perspective. For this purpose, we examine several important fields associated with the characteristics of convection and the relationships between convection and clouds using GCM simulations and available satellite and surface observations. These include the seasonal variation of convection, the relationships between convection and the upper-level cloud amount, cloud ice water content and cloud radiative forcing. One major goal of the Atmospheric Radiation Measurement (ARM) Program is to improve GCM cloud and convection parameterizations. Using NCAR Community Atmosphere Model (CAM3), we demonstrate that GCM simulations in the tropical western Pacific including Darwin can be significantly improved by improving convection parameterization.

Data and Model

The data used in this study include surface observations of winds and precipitation at the TWP Darwin site of the ARM Program from March 2002 to December 2004, Tropical Rainfall Measurement Mission (TRMM) hourly rainfall gridded to GCM resolution (T42), climatological annual cycle of International Satellite Cloud Climatology Project (ISCCP) high-cloud amount, Earth Radiation Budget Experiment (ERBE) shortwave and longwave cloud radiative forcing, and Xie-Arkin precipitation. The global model is the NCAR CAM3, with the new convection closure developed using the ARM SGP data (Zhang 2002). The model simulation with the new convection parameterization improvement is run for 16 years from 1979 to 1995. The last 15 years is used in the analysis. The model simulation without the new convection scheme modification is from the standard CAM3 AMIP (Atmospheric Model Intercomparison Project) run obtained from NCAR database.

Results

Before presenting results at the TWP Darwin site, we first demonstrate that the simulation of the global climate using the NCAR CAM3 and the new convection closure of Zhang (2002) is in good agreement with the observations. Figure 1 shows the global distribution of precipitation for boreal winter (DJF).

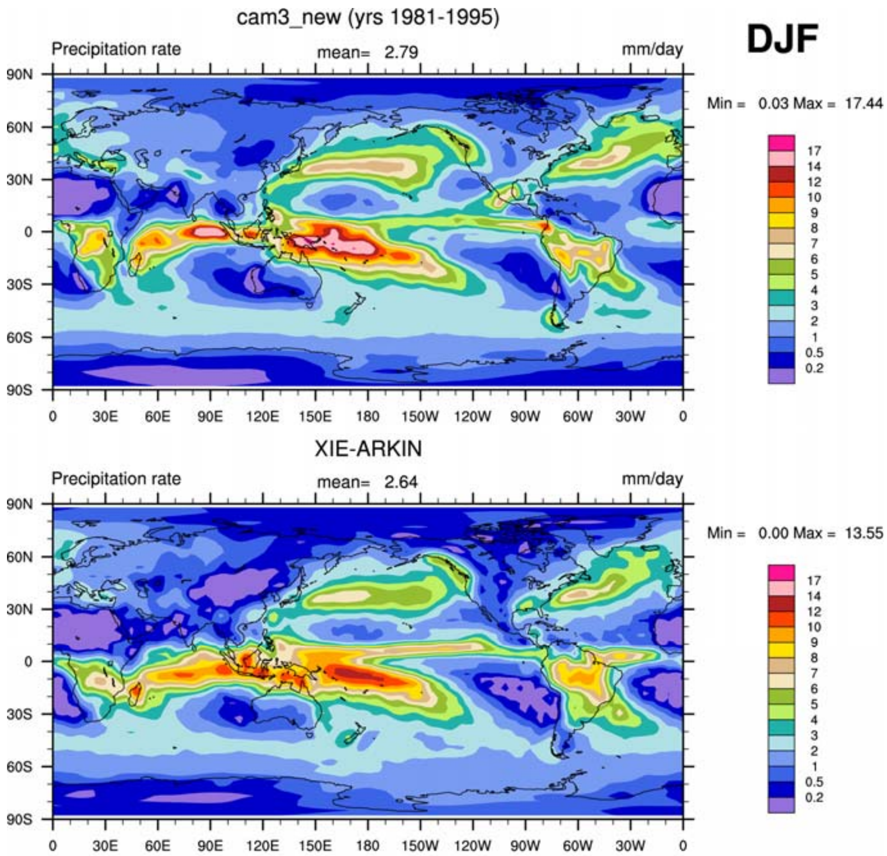

Figure 1. Climatological precipitation distribution for boreal winter (DJF) from (top) the CAM3 simulation with the new convection closure and (bottom) the Xie-Arkin observations, respectively. The units are in mm day^{-1}.

Both the Southern Pacific Convergence Zone (SPCZ) and the Indian Ocean Inter-tropical Convergence Zone (ITCZ) are well simulated. The longstanding problem of the primary precipitation belt in the Pacific staying north of the Equator during the winter season in CAM3 is resolved. This can be seen by comparing Figure 1 with the DJF climate in the standard CAM3 simulation (Figure 2).

Next, we compare the model simulation with the observations at the TWP Darwin site. Figure 3 shows the probability distribution function (PDF) of hourly rainfall intensity and its contribution to the total rainfall at Darwin from the CAM3 model simulations and the two observation sources, TRMM and ARM. Since ARM observations are at a single surface station while CAM3 and TRMM are averages over a GCM grid box, the ARM data are averaged over 24-hrs to account for the spatial mismatch. With the mean wind speed at Darwin near 3 m/s, 24-hr average roughly corresponds to spatial average over a

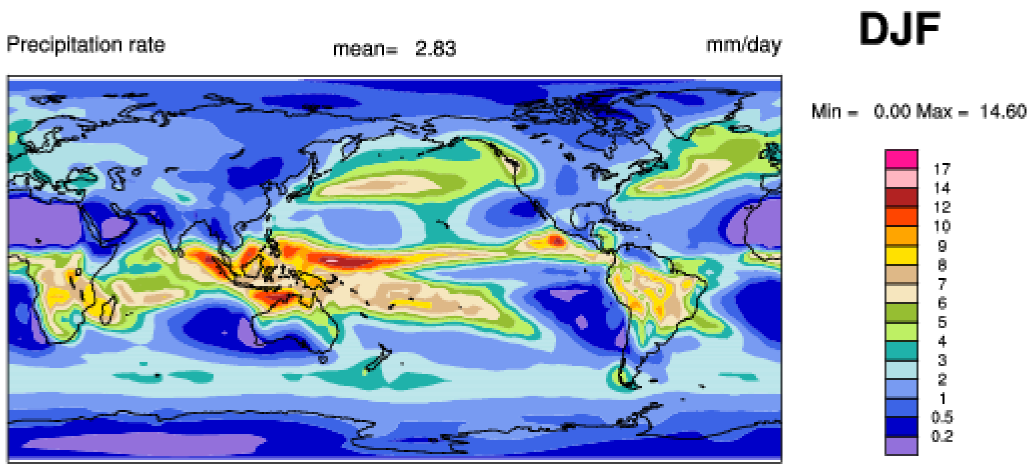

Figure 2. Same as in Figure 1, but from the standard CAM3 simulation.

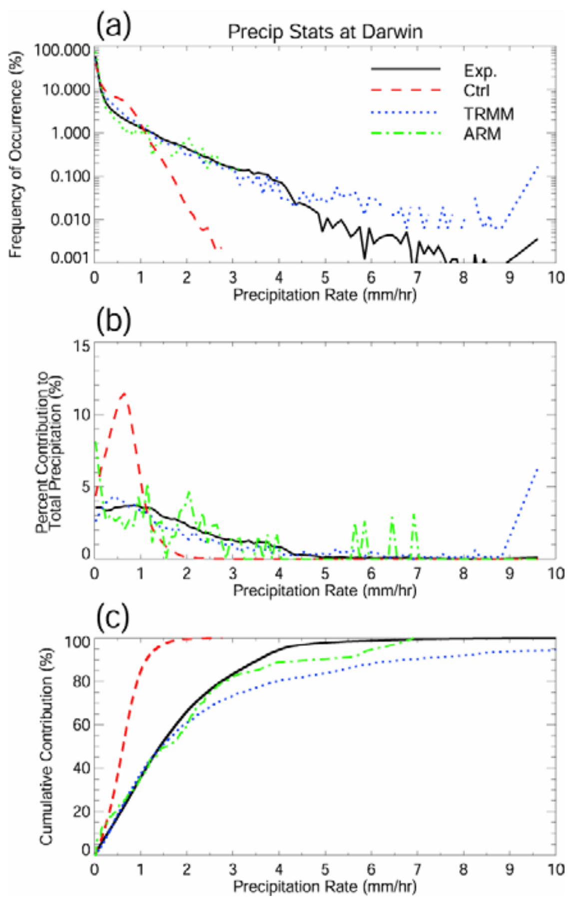

Figure 3. Frequency distributions of (a) precipitation rate, (b) relative contribution to total precipitation, and (c) cumulative contribution from each binned precipitation rate based on hourly mean precipitation data at the TWP Darwin site. The ARM surface observations are 24-hr averages (see text for details).

GCM grid box for a steady-state system. In the figure, the range of precipitation rates is divided into 0.1 mm hr^{-1} bins from 0 to 9 mm hr^{-1}, with precipitation rates higher than 8 mm hr^{-1} lumped into the last bin. The probability distribution of the precipitation intensity (Figure 3a) shows that precipitation in the standard CAM3 run (labeled ctrl in the figure) has a very narrow distribution, occurring much more frequently at precipitation rates below 1 mm hr^{-1}, and much less frequently at precipitation rates above 1 mm hr^{-1} than those in the new CAM3 run (labeled Exp in the figure) and the TRMM and ARM observations. The probability distributions for the new CAM3 run and the observations are much closer. The relative contribution to the total precipitation from each bin (Figure 3b), which is the product of the frequency of occurrence and the mean precipitation rate within the bin divided by the total precipitation, and the cumulative contribution plots (Figure 3c) show that for the standard CAM3 run, about 90% of the total precipitation is from precipitation events with intensities less than 1 mm hr^{-1}. Within this narrow band, the peak contribution comes from precipitation rates near 0.5 mm hr^{-1}. Contributions from precipitation intensities greater than 2 mm hr^{-1} are negligible. In comparison, in the new CAM3 simulation, as well as in the TRMM and ARM observations, contributions from rainfall rates greater than 2 mm hr^{-1} account for about 40% of the total rain. The improvement in the precipitation intensity PDF is similar in the global tropical belt (Zhang and Mu 2005).

Using the multi-year CAM3 simulations, we examined the annual cycle of precipitation, high-cloud amount, shortwave and longwave cloud radiative forcing at the ARM TWP Darwin site. Figure 4 shows that during the Australian monsoon season (DJF) precipitation, high-cloud amount, and shortwave cloud forcing at Darwin are all well simulated with the new convection closure compared with the available observations. The standard CAM3 produces too much precipitation, high-level clouds and shortwave cloud forcing. However, longwave cloud forcing in the new CAM3 simulation is degraded. This seems to suggest that convective cloud tops may be too low in the model in the new simulation.

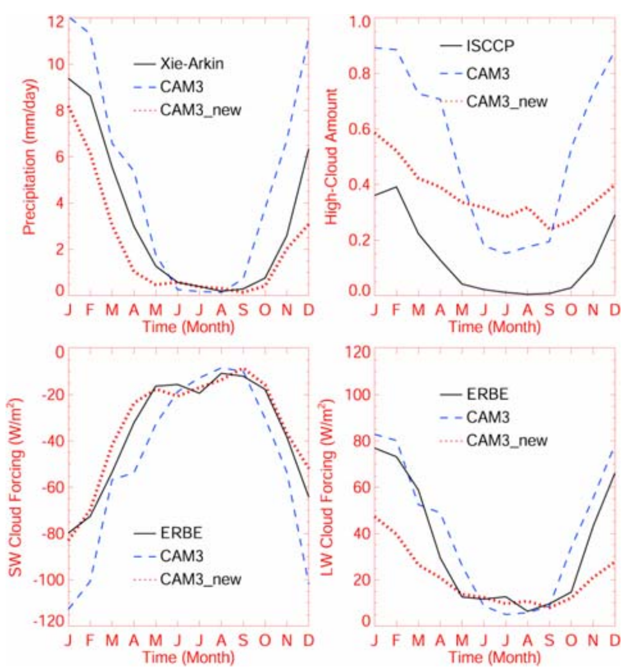

Figure 4. Annual cycle of precipitation, high-level cloud amount, shortwave and longwave cloud radiative forcing at Darwin from CAM3 simulations and observations.

To demonstrate importance of convection in determining the cloud microphysical and radiative properties, Figure 5 shows the layer averaged cloud ice water content from 500 mb to 100 mb, shortwave cloud forcing, in-cloud ice water path and cloud fraction as functions of convective heating rate at 500 mb from the new CAM3 simulation at the Darwin site during the monsoon season. There is a strong dependence of all these fields on the intensity of convective heating. When there is more convection, there is more upper-level cloud amount, more ice water in the clouds, and thus more cloud radiative forcing.

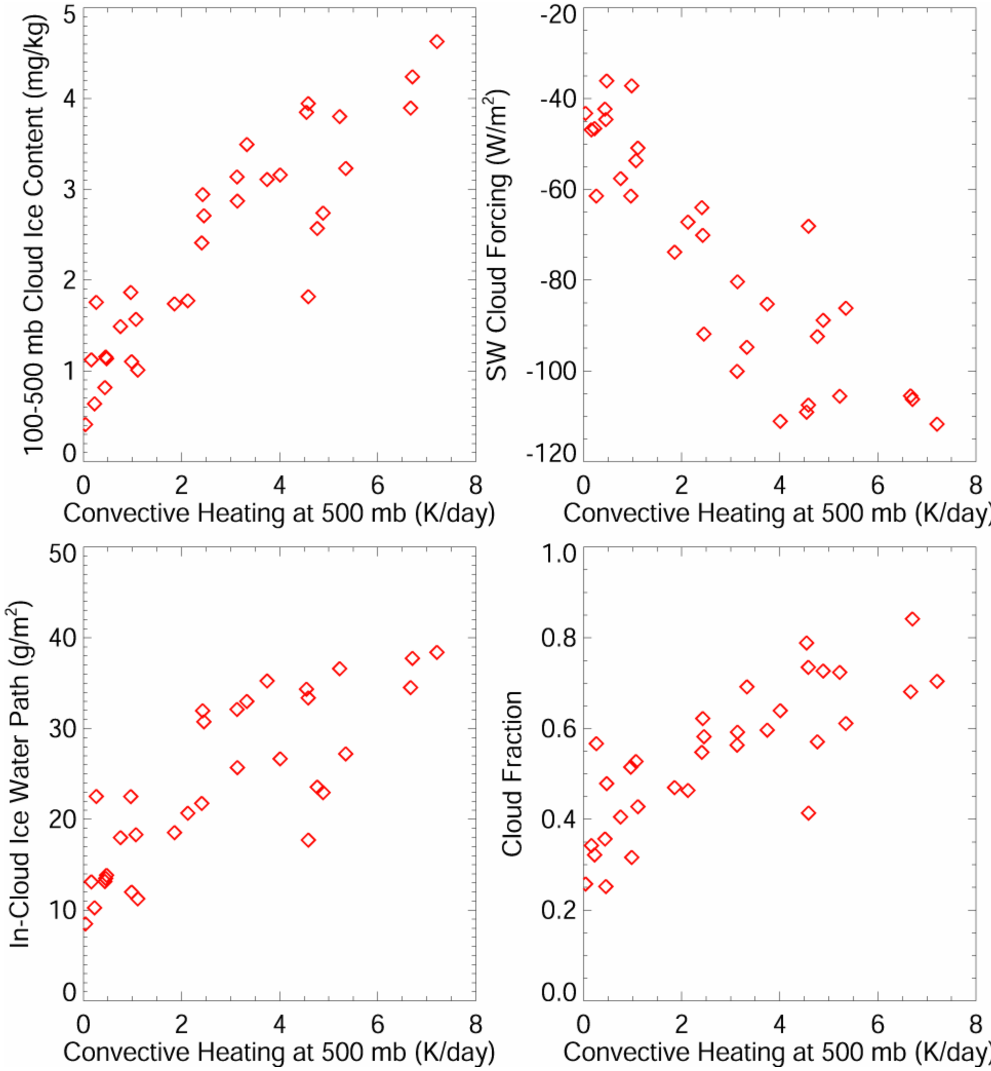

Figure 5. Upper troposphere cloud ice content averaged between 500 and 100 mb, SW cloud forcing, in-cloud ice water path and high-cloud amount as functions of convective heating at 500 mb, showing the dependence of these quantities on the intensity of convection. Each point represents a monthly average.

Conclusions

The NCAR CAM3 simulations with and without the improvement in convection parameterization are compared with observations at the ARM TWP Darwin site. It shows that significant improvement in the simulated DJF precipitation and rainfall intensity PDF can be achieved both locally at Darwin and globally by modifying convection parameterization. The relationships between convective heating and the high-level cloud properties in the model indicate that convection is very important in determining the cirrus/anvil cloud properties at Darwin.

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