Single-Column Model and Cumulus Ensemble Model Simulations of GARP[a] Atlantic Tropical Experiment Data

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Introduction

Our ARM project consists of developing and demonstrating improved cloud formation parameterizations by using both a single-column model (SCM) and a cumulus ensemble model (CEM), together with ARM data. These two models can be driven with "large-scale forcing" (e.g., vertical motion) as observed in ARM; each model produces a field of clouds and the associated radiation and precipitation fields. The SCM does so through its physical parameterizations, while the CEM does so by "directly simulating" convective cloud circulations. The improved parameterizations tested in this way will be further tested and applied in the Colorado State University (CSU) general circulation model (GCM). Figure 1 summarizes the approach.

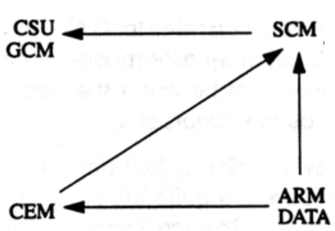

Figure 1. Research strategy followed in this project. ARM data are used to drive the single-column model and the cumulus ensemble model. Parameterizations developed for and tested in the single-column model can then be used in Colorado State University's GCM.

To carry out this research plan, we need to attend to several tasks:

- Develop improved cloudiness parameterizations.
- Develop improvements to the CEM, with emphasis on cloud-radiation interactions.
- Drive both models with the ARM data.
- Transfer the improved parameterizations developed in this way to the CSU GCM.

In this brief report, we mention our efforts and progress in each of these areas.

(a) Global Atmospheric Research Program.

Cloudiness Parameterization Development

Cumulus Convection

Significant progress has been made in developing improved parameterizations of cumulus convection (Randall and Pan 1992), based on generalization of the parameterization of Arakawa and Schubert (1974). The key idea is to introduce the cumulus kinetic energy as a prognostic variable. This approach allows the strict quasi-equilibrium closure to be relaxed, resulting in drastic simplification and computational economy. The temporal and spatial distributions of cumulus precipitation are smoother with the new parameterization than with the standard Arakawa-Schubert implementation. We are currently working to further generalize the parameterization by allowing cloud bases at multiple levels, simultaneously.

Cloud Microphysics

We have developed a new prognostic cloud water parameterization that includes not only cloud water but also cloud ice, rain, and snow, all as prognostic variables (Smith and Randall 1992). Cumulus detrainment acts as a very important source of cloud ice and cloud water. The microphysics parameterization is based on the work of Rutledge and Hobbs (1983).

Cloud Amount

We have begun an attack on the difficult problem of physically determining cloud amount, by extending the work of Xu and Krueger (1991). They used the CEM to simulate cloud distributions in response to prescribed large-scale processes. They estimated the cloud amount for low, medium, and high clouds separately, and obtained semi-empirical relations for stratiform cloud amount as a function of the relative humidity and for convective cloud amount as a function of the cumulus mass flux.

When a prognostic cloud water variable is available, it is natural to include it as a key predictor in such a semi-empirical scheme. Some preliminary work along these lines has already been carried out, using the CEM. An example is shown in Figure 2. Here the cloud amount is plotted against the average liquid water path, with an averaging distance of 128 km, at an altitude of 1.9 km above the sea surface. Moderate scatter is apparent. We have found that most of the remaining variance can be accounted for by adding the area-averaged relative humidity as a second predictor. We are currently pursuing this approach to parameterize cloud amount in the GCM. Further discussion is given by Xu and Randall (1992).

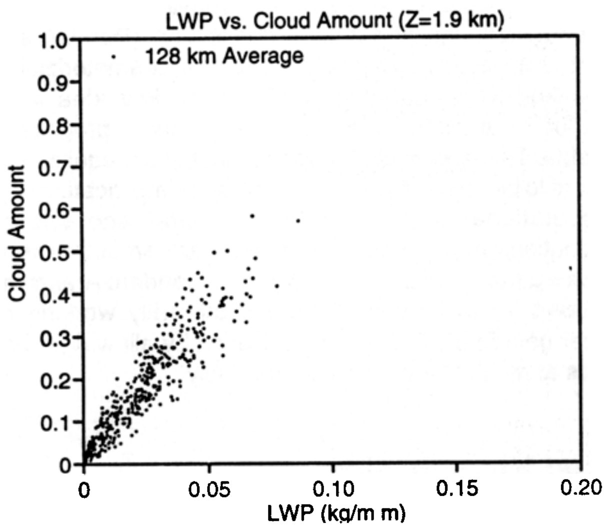

Figure 2. A scatter plot of cloud amount versus liquid water path (LWP), based on high-resolution simulations with the CEM.

CEM Development

We have implemented the radiation parameterization of Harshvardhan et al. (1987) inside the CEM. The cloud optical properties are parameterized following the methods of Stephens (1978). We have performed some sensitivity tests to see the effects of the interactive radiation on the results. These will be discussed below.

In addition, we have modified the CEM to use a more realistic turbulence length scale formulation.

Driving the SCM and the CEM with Data

Until very recently, we did not have ARM data suitable for driving either model. We have, therefore, been "practicing" with the GARP[(a)] Atlantic Tropical Experiment (GATE) data, using both the SCM and the GCM. An example is shown in Figure 3. This shows the observed and SCM-simulated precipitation rates for GATE Phase III. The SCM is run here in a fully prognostic mode—*not* a semi-prognostic test. The agreement between the observations and the simulation is quite encouraging.

Figure 4 shows a similar test performed with the CEM. Again, the results are quite encouraging. Further results were shown at the Science Team meeting.

Tests of the New Parameterizations in the CSU GCM

We have already successfully tested the microphysics and prognostic cumulus kinetic energy (CKE) parameterizations

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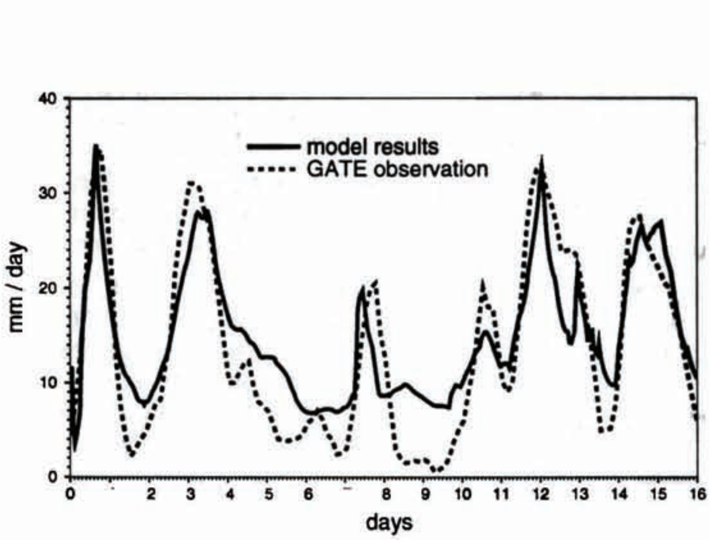

Figure 3. SCM-simulated (solid line) and observed (dashed line) precipitation rate for GATE Phase III.

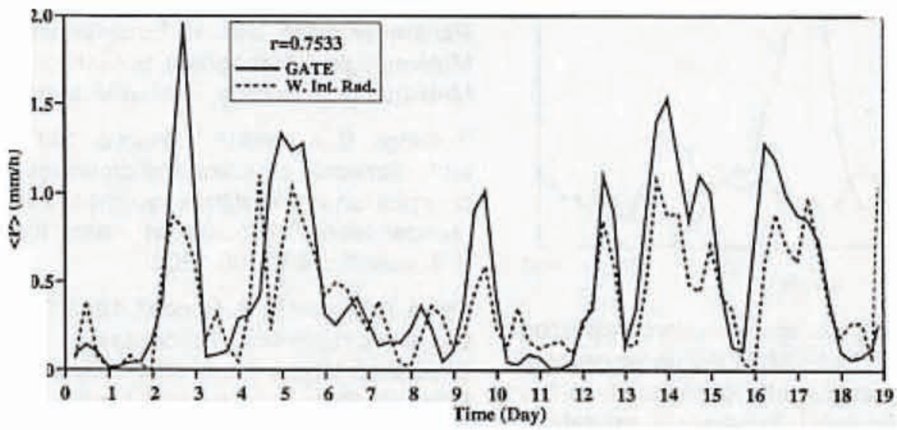

Figure 4. CEM-simulated (dashed line) and observed precipitation rate for GATE Phase III.

in the three-dimensional GCM. At present, we are working on coupling the microphysics parameterization to the radiation parameterization.

For the microphysics, the effects of advection appear to be modest for the resolution currently used (4 x 5 degrees). The distribution of precipitation at the ground is very similar to that obtained with the conventional "large-scale saturation" parameterization that the microphysics parameterization replaced. Some results are shown in Figure 5. Further results are given by Fowler and Randall (1993).

Conclusions and Plans

We have developed new parameterizations of convection, cloud microphysics, and cloud amount. The CEM has been endowed with a radiation parameterization. Both the CEM and the SCM have been driven with GATE data and have produced realistic results. We have also tested our new parameterizations of convection and cloud microphysics in the three-dimensional CSU GCM.

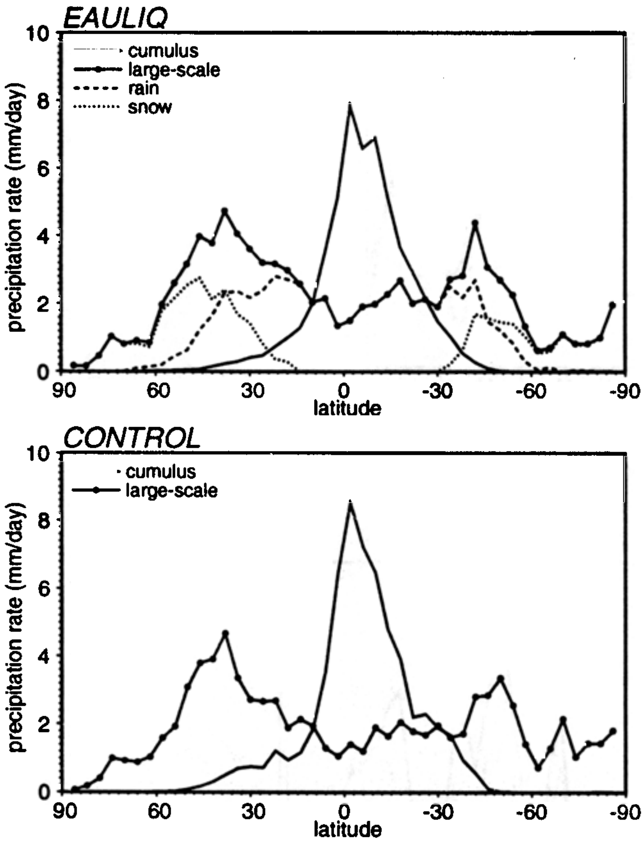

Figure 5. Simulated zonally averaged January precipitation rates obtained with the CSU GCM. In the upper panel, a microphysics parameterization has been used. In the lower panel, the conventional "large-scale saturation" parameterization has been used. Snow and rain are shown separately in the upper panel.

Our highest priority for the coming year is to exercise both the SCM and the CEM extensively using real ARM data. In addition, we plan to couple the microphysics parameterization in the SCM and the CSU GCM with the radiation parameterization. Finally, we hope to test our cloud amount parameterization.

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