10.3 COMPARISON OF THE MULTI-SCALE MODELING FRAMEWORK AND THE NCAR CAM WITH OBSERVATIONS ALONG A PACIFIC OCEAN TRANSECT

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1. INTRODUCTION

Recently, Randall and colleagues (Randall et al., 2003; Khairoutdinov and Randall, 2001) have proposed and developed a substantially different type of global climate model (GCM), called the Multi-scale Modeling Framework (MMF). The MMF consists of a conventional GCM with its cloud parameterizations removed and replaced by an embedded cloud resolving model (CRM). Their model, which we use in this study, consists of the NCAR Community Atmosphere Model (CAM) and an embedded cloud model developed by Khairoutdinov and Randall (2003). The MMF version that we use is the T42 CAM with an embedded 2D (longitude and height) cloud model consisting of 64 columns, each 4 km in width. The MMF is, of course, computationally intensive and requires about 250 times the computer resources of its parent GCM. Its primary advantage is the explicit treatment of cloud dynamics within the CRM and, therefore, a strong potential to improve the representation of cloud processes and properties. The questions that need to be addressed is whether the current model configuration does improve the representation of clouds and, if so, does this result in an improved representation of the climate.

The European Cloud System Studies (EUROCS) Project proposed an interesting approach to the evaluation of cloud properties in dynamical models (Siebesma et al., 2004). They choose to evaluate the properties of nine climate and weather forecasting models along a Pacific Ocean transect stretching from 235E, 35N to 187.5E ,1S (Figure 1). This transect spans the ascending and descending branches of the Hadley circulation and samples three distinct cloud regimes, marine stratocumulus, shallow cumulus, and deep convection in geographically separate areas. Thus, the models can be evaluated on the basis of their ability to simulate the properties of these three different regimes.

The EUROCS group defined 13 locations along the specified track and then selected model output from the nearest model grid box to each location. The period chosen for comparison was June-July-August of 1998. Model output along the transect is then analyzed as a 2D slice of the atmosphere. In the EUROCS study, comparisons are made among the nine models and with a variety of data, particularly data drawn from satellites.

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We have chosen to adopt the EUROCS strategy for an initial evaluation of the MMF against its parent GCM, the CAM. This approach allows us to explore the relative advantages of each model in a controlled environment. In addition, we can draw on the results of the EUROCS comparison study to further clarify our results.

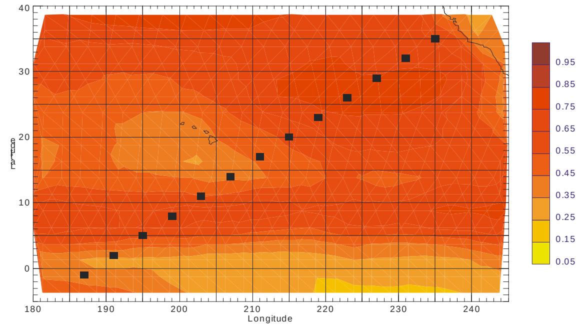

Figure 1. EUROCS Pacific Transect. Black squares indicate points at which model output are selected. The underlying color is the fractional cloud cover determined from International Satellite Cloud Climatology Project (ISCCP) data. (Plot courtesy of the EUROCS Project)

2. MODEL DESCRIPTION

This study uses the MMF as developed by the Colorado State University Group (Khairoutdinov and Randall, 2001). It consists of the NCAR CAM and an embedded 2D cloud resolving model. We began our MMF model run on September 1, 1997 using initial model fields from a CAM spinup simulation and observed monthly sea surface temperature (SST) and sea ice values obtained from the CAM home page (www.ccsm.ucar.edu/models/atm-cam/). CAM model runs were performed for the same period using the same SST values. Model results shown here are averaged over the northern hemisphere summer (JJA) season. CRM results were averaged in both time and space to provide grid-average values consistent with the CAM.

3. RESULTS

We begin with a comparison of pressure vertical velocity, shown in Figure 2. The upper panel is from the MMF, the middle panel from the CAM, and the bottom panel from the ERA40 reanalysis project. All MMF and CAM plots shown here are composites for 1200 GMT. Composite plots done at other hours of the day are very similar. Compared to the CAM, the MMF shows a better developed and deeper core of rising motion in the intertropical convergence zone (ITCZ). This is to be expected given the embedded CRM in the MMF. While both models show substantial subsidence along the northern edge of the transect (35 N), the CAM also shows subsidence in the upper troposphere immediately adjacent to the strong rising motion. This subsidence is not seen in the MMF or in the reanalysis. This subsidence produces drying in the upper troposphere and reduces upper tropospheric cloud cover. The MMF pattern bears a strong resemblance to the ERA40 reanalysis. Maximum values of rising motion are about -0.10 to -0.12 P/sec in both and the vertical structure is quite similar. The CAM values are lower and the core shows less vertical development.

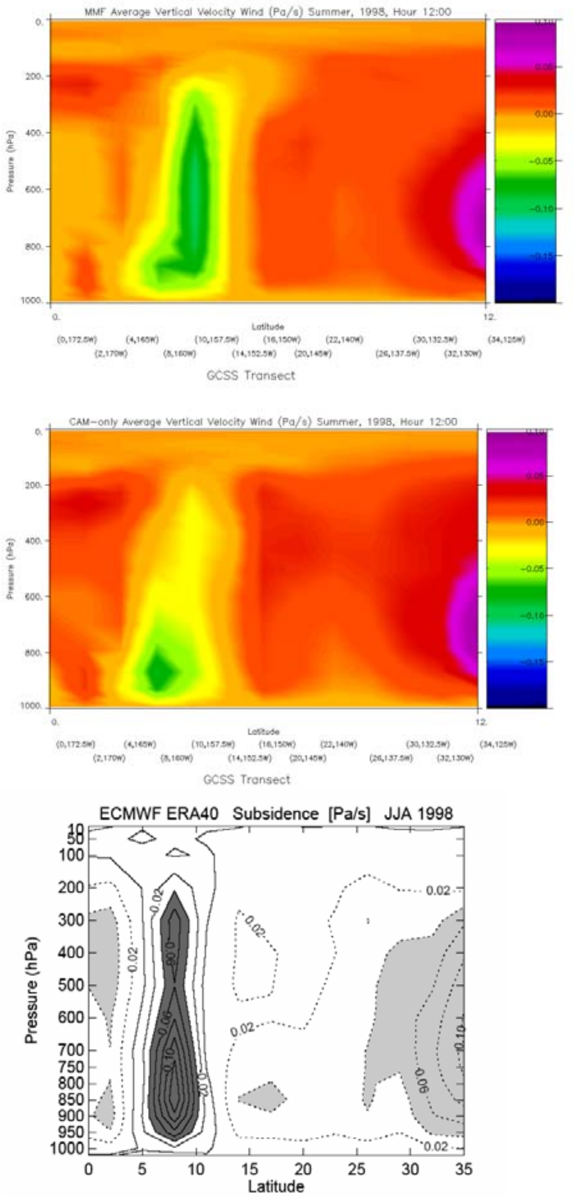

Figure 2. Pressure vertical velocity from the MMF, the CAM, and the ERA40 reanalysis along the transect. Units are Pascals/s. (ERA40 plot courtesy of the EUROCS Project)

Figure 3 shows a similar set of plots for relative humidity (RH). Some care should be exercised here since the RH is with respect to water for temperatures above 273 K but then transitions to a mixed phase RH and, finally, RH with respect to ice for temperatures below 253 K. Both the MMF and CAM produce patterns that are quite similar to that of the ERA40 reanalysis, but both are somewhat too moist in the ITCZ. The MMF has a strong outflow at upper levels that produces an overly moist upper troposphere. The boundary layer is slightly shallower in the CAM but seems to have better development than in the MMF.

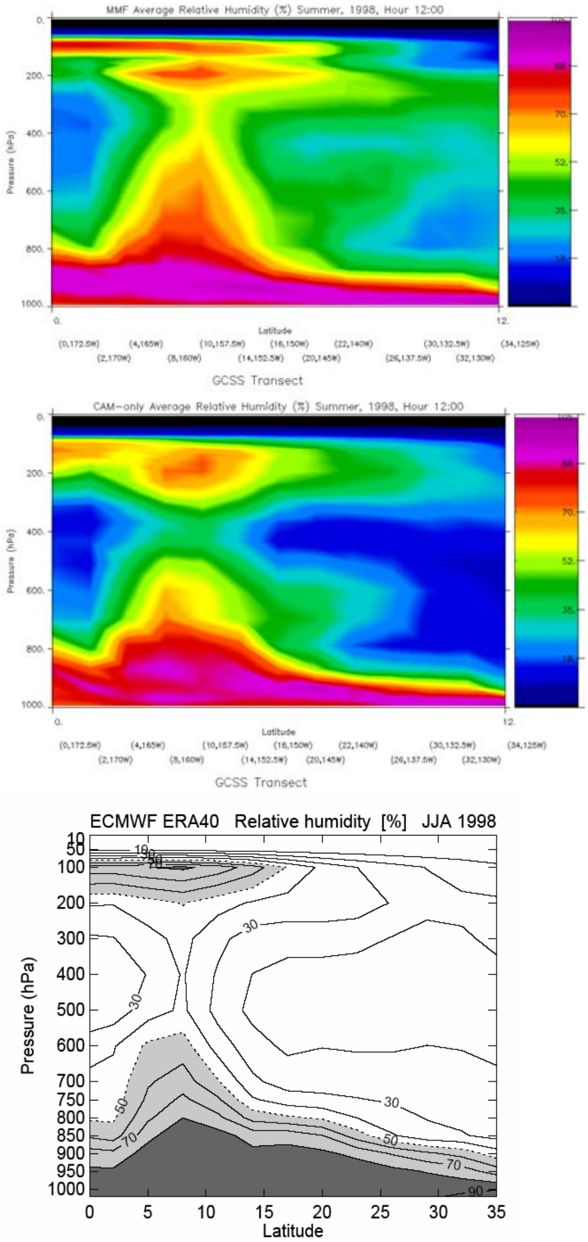

Figure 3. Same as Figure 2, but for relative humidity. (ERA40 plot courtesy of the EUROCS Project)

The next set of plots (Figure 4) shows fractional cloud cover. Unlike fields of state parameters such as vertical velocity and RH, which are heavily influenced by observations in the reanalysis, cloud cover is analyzed from the state fields using the model parameterizations. Therefore, the ECMWF analysis cloud cover is labeled differently in the figure and should not be viewed as representing the true state of the atmosphere.

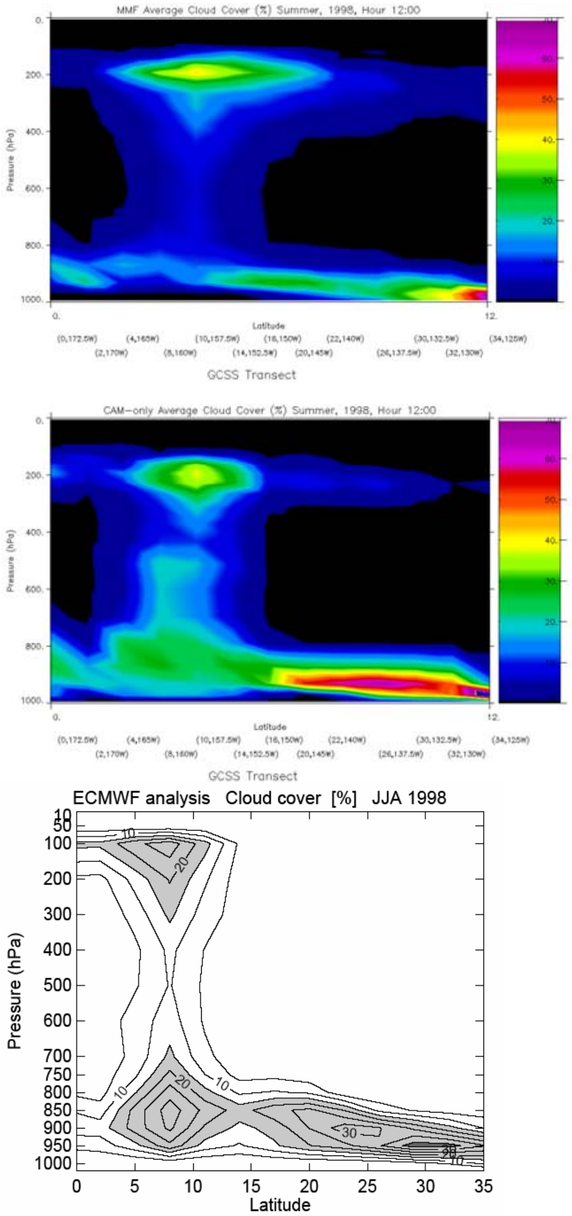

Figure 4. Same as Figure 2, but for fractional cloud cover. (ECMWF analysis plot courtesy of the EUROCS Project)

Focusing first on the stratocumulus regime, we see that the CAM produces the highest cloud fraction values. The ECMWF analysis and MMF produce similar amounts, but the MMF clouds are quite low in altitude, suggesting less boundary layer development. ISCCP values of total cloud cover for this period are about 80%, which is consistent with the CAM. Both the MMF and ECMWF values are considerably less at about 50 to 60%. In the current MMF, the CRM is run at 4 km resolution and has no explicit boundary layer cloud formulation. This most likely leads to an underprediction of these clouds. A preliminary comparison of liquid water amounts shows that the MMF has about a 50% larger average liquid water path compared to the CAM (about 60 g/m^2 compared to 40 g/m^2) in this region. Thus it seems that the MMF is producing fewer, but more optically thick stratocumulus clouds than the CAM. LWP estimates from SSM/I are about 90 to 100 g/m^2.

Turning now to the ITCZ area, we see quite notable differences. The MMF has the least amount of low cloud and is probably underpredicting actual cloud amount here. Both the MMF and CAM have considerably more high cloud than the ECMWF analysis, with the MMF producing a somewhat broader horizontal maximum than the CAM. It is very difficult to know exactly what the correct value is. After comparing results from 9 different models, Siebesma et al. (2004) conclude that “The differences in cloud cover between the models are especially large in the ITCZ near the tropopause where cloud cover values range between 0 and 50 %”.

4. CONCLUSIONS

The results shown here are quite preliminary and require considerably more analysis. We have plans to extend our analysis into other aspects of the circulation, including top-of-atmosphere radiation, surface energy balance, and precipitation. In addition, we are applying the ISCCP simulator as described by Klein and Jakob (1999) and Webb et al. (2001) to our results along the transect in order to improve our understanding of cloud properties.

Our intent in this analysis is to demonstrate whether or not the MMF provides a superior representation of cloud properties and of the climate state along this transect. The results thus far are inconclusive. The MMF seems to provide a somewhat better representation of deep convection. The best evidence of this is in the vertical velocity field. However, our analysis suggests the MMF produces too little low cloud in the ITCZ region. Not unexpectedly, the MMF fails to produce adequate cloud cover in the marine stratocumulus area, most probably because it has no boundary layer cloud parameterization. Our ongoing analysis of these clouds, including their effect on the TOA energy budget, should help us determine the extent to which the MMF is lacking in this area. While we have no plans to address this problem at the moment, it is something that will have to be dealt with if the MMF is to be used successfully to study cloud processes and feedbacks.

We think that the MMF represents a new and potentially very important method to study cloud processes on the global scale. We recognize that this current model is only the first step in the development of a MMF. While we can demonstrate model success in some respects, we can also see that future model development is required. We expect to continue our analysis and comparison of this model using a variety of data and diagnostic tools (see, for example, see McFarlane et al., 2005) and to participate in model developments based on the outcome of the analysis.

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