ARM Modeling Nugget 3

Advancement of cloud resolving models to address climate change problems via the Multi-scale Modeling Framework

Intercomparison studies of the ARM Cloud Parameterization and Modeling working group have established that cloud resolving models (CRMs) are superior to single-column models (SCMs), particularly for the simulation of deep convection, for which SCMs rely on convection parameterizations. CRMs should be superior since they explicitly simulate convection with their high resolution.

The superior quality of cloud-resolving models motivates the desire to use them to address climate directly. One possibility is to simulate the entire globe with the resolution of a CRM. Japanese scientists have done this on the Earth Simulator, but they are not able to do many climatologically significant simulations due to the computational expense *[Tomita et al. 2005]*. An alternative and less-computationally expensive approach is the incorporation of a cloud resolving model at each grid-point of today's low-resolution climate models. Essentially the parameterization of cumulus convection, and other physical processes such as large-scale condensation, radiation, and turbulence, are removed from the climate model and replaced with a low-resolution 2-dimensional cloud resolving model (Figure 1). This approach called "super-parameterization" or more recently "Multi-scale Modeling Framework" has been intensively developed by Dave Randall and Marat Khairoutdinov at Colorado State University with seed money from ARM following the original idea of Wojiech Grabowski of NCAR *[Randall et al. 2003, Khairoutdinov et al. 2005]*. The initial MMF simulations appear to yield an improved simulation of the Madden-Julian Oscillation and the diurnal cycle of precipitation over land, two features that are difficult for conventional climate models to simulate.

ARM data has been used in the development of the cloud resolving model used in the MMF *[Khairoutdinov and Randall 2003]* and in the evaluation of the MMF simulations *[Ovtchinnikov et al. 2006]*. As example, Figure 2 shows the height dependence to the histogram of cloud condensate as retrieved from the ARM instruments at the TWP sites Manus and Nauru and simulated by the MMF and the NCAR climate model "CAM" with the conventional parameterizations *[McFarlane et al. 2007]*. Because the retrievals of cloud condensate are restricted to times of no precipitation, the MMF data must be sampled for times of no precipitation and when this is done better agreement is found. The conventional NCAR CAM overestimates the occurrence of cirrus clouds, consistent with other studies.

An important goal of the ARM program is to narrow of the uncertainty of climate change predictions due to uncertain cloud feedbacks. A first investigation of the cloud feedbacks from the MMF shows a surprisingly low climate sensitivity. Intriguingly, the global CRM of the Japanese also appears to show a similarly low climate sensitivity *[Miura et al. 2005]*. However, the low sensitivity is mainly due to cloud types such as boundary layer stratocumulus and mid-latitude frontal cloud systems for which the MMF simulations are not necessarily superior to those of conventional climate models *[Wyant et al. 2006]*. A more significant result is that the MMF simulates a positive water vapor feedback similar to conventional models, thus providing increased confidence in the water vapor feedback, which is the largest of the known positive feedbacks in the climate system.

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Figure 1. Illustration of the Multi-scale Modeling Framework or "super-parameterization". The figure shows a single grid-box of a global climate model (GCM). In this case the grid box has sides with approximate length of 300 km. For each grid box, a cloud resolving model is used to simulate the cloud, convection, radiation, and turbulence processes. The figure shows a cloud-resolving model in the configuration that has been used most often; namely, the cloud resolving model is 2-dimensional and consists of 64 columns which have a horizontal spacing of 4 kilometers. (Figure courtesy of Tom Ackerman)

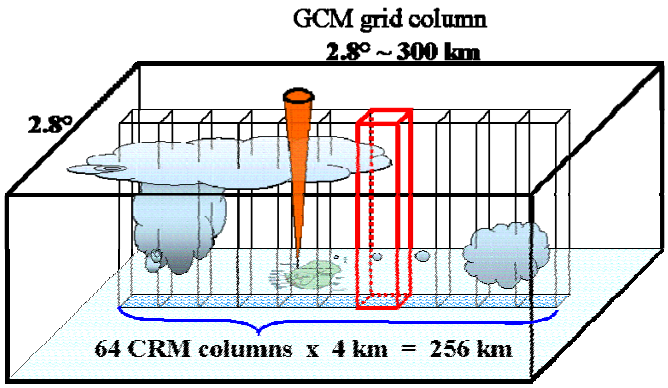
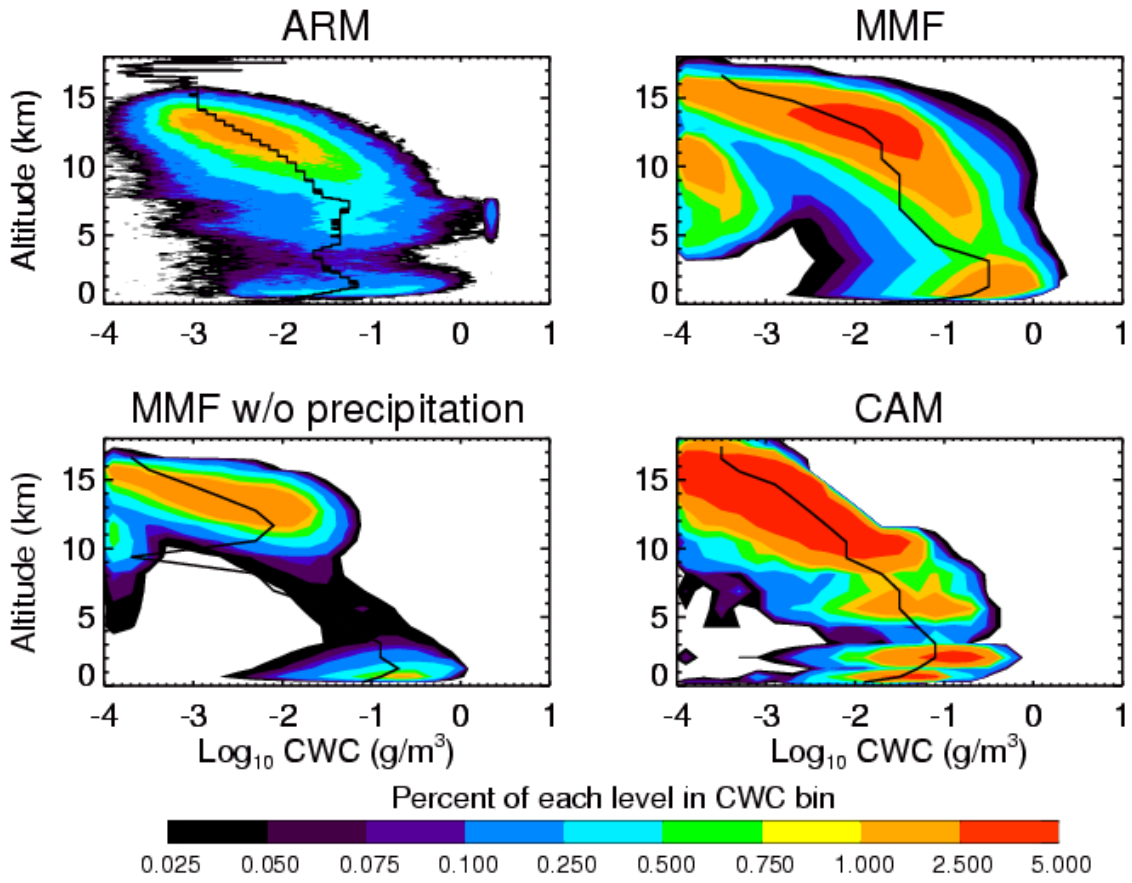
Figure 2. Comparison of the distributions of cloud condensate for the ARM TWP sites Manus and Nauru. Each panel consists of the histogram of cloud condensate which is computed separately for each altitude bin and then displayed as a function of height. The upper left panel ("ARM") consists of the retrievals of cloud condensate from the ARM remote sensors. The MMF panel is shown twice – once for all grid columns and once for grid columns that do not contain precipitation. Note that ARM retrievals are not performed in columns with precipitation. The results of the conventional NCAR CAM climate model are shown in the lower right. (Figure from *McFarlane et al. [2007]*)