4.4 EVALUATION OF AN IMPROVED CONVECTION TRIGGERING MECHANISM IN THE NCAR COMMUNITY ATMOSPHERE MODEL CAM2 UNDER CAPT FRAMEWORK

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1. INTRODUCTION

The problem that convection over land is overactive during warm-season daytime in the National Center for Atmospheric Research (NCAR) Community Atmosphere Model CAM2 and its previous version (CCM3) has been found both in its single-column model (SCM) simulations (Xie and Zhang 2000; Ghan et al. 2000; Xie et al. 2002) and in its full general circulation model (GCM) short-range weather forecasts (Phillips et al. 2003) and climate simulations (Dai and Trenberth 2003). These studies showed that this problem is closely related to the convection triggering mechanism used in its deep convection scheme (Zhang and McFarlane 1995), which assumes that convection is triggered whenever there is positive convective available potential energy (CAPE). The positive CAPE triggering mechanism initiates model convection too often during the day because of the strong diurnal variations in the surface isolation and the induced CAPE diurnal change over land in the warm season. To reduce the problem, Xie and Zhang (2000) introduced a dynamic constraint, i.e., a dynamic CAPE generation rate (DCAPE) determined by the large-scale advective tendencies of temperature and moisture, to control the onset of deep convection. They showed that positive DCAPE is closely associated with convection in observations and the dynamic constraint could largely reduce the effect of the strong diurnal variations in the surface fluxes on the initiation of convection. Using the SCM version of CCM3, which has the same deep convection scheme as CAM2, Xie and Zhang (2000) showed that considerable improvements can be obtained in the model simulation of precipitation and other thermodynamic fields when the dynamic constraint was applied to the model triggering function. However, the performance of the improved convection triggering mechanism in the full GCM has not been tested.

In this study, we will test the improved convection trigger mechanism in CAM2 under the U.S. Department of Energy's Climate Change Prediction Program (CCPP) - Atmospheric Radiation Measurement Program (ARM) Parameterization Testbed (CAPT) framework, which provides a flexible environment for running climate models in Numerical Weather Prediction (NWP) mode. In comparison with testing physical parameterizations in climate simulations, the CAPT strategy uses more available observations and high-frequency NWP analyses to evaluate model performance in short-range weather forecasts. This allows specific parameterization deficiencies to be identified before the compensation of multiple errors masks the deficiencies, as can occur in model climate simulation. Another advantage of the CAPT approach is its capability to link model deficiencies directly with atmospheric processes through case studies using data collected from major field programs (e.g., ARM).

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2. BRIEF DESCRIPTION OF THE MODEL AND THE IMPROVED TRIGGERING MECHANISM

The model used in this study is the NCAR Community Atmosphere Model (CAM2), which is a global spectral model with T42 truncation (2.8^0 x 2.8^0, which is around 300 km) in the horizontal and 26 levels in the vertical. Detailed information about CAM2 can be seen in Collins et al. (2003). The deep convection scheme used in CAM2 was proposed by Zhang and McFarlane (1995). It is based on the plume ensemble concept similar to Arakawa and Schubert (1974). This convection scheme assumes that convection occurs whenever there is a positive CAPE. Previous studies showed that this assumption could lead the model to produce excessive daytime precipitation over land during the warm season. To reduce this problem, Xie and Zhang (2000) introduced a dynamic CAPE generation rate (DCAPE) to control the onset of deep convection. DCAPE is defined as the change of CAPE solely due to the total large-scale advection over a time interval. They assumed that deep convection occurs only when the large-scale advection makes a positive contribution to the existing positive CAPE. This large-scale dynamic constraint allows CAPE to accumulate from surface process before convection occurs and links model deep convection closely to the large-scale dynamical processes, such as large-scale upward motion and low-level moisture convergence. It is well known that these large-scale dynamical processes play an important role in destabilizing the atmospheric structure, initiating and maintaining deep cumulus convection. Xie (1998) showed a strong in-phase correlation between positive DCAPE and convective activities using data collected over both midlatitude land and tropical ocean.

3. EXPERIMENTS AND RESULTS

As part of the CAPT framework, the CAM2 model is initialized with the European Center for Medium-range Weather Forecast (ECMWF) reanalysis (ERA-40). A series of 36-hour forecast runs is initiated every day at 00Z for 31 days starting from June 18, 1997 to July 18, 1997. This period is selected to cover the ARM summer 1997 Southern Great Plains (SGP) Intensive Operational Period (IOP), which is from 2330Z June 18, 1997, to 2330Z July 17, 1997. A composite of 12-36 hour forecasts from the series of 36-hour runs is analyzed. Selected important meteorological fields are discussed with a focus on the model-simulated precipitation field. Comparisons are made with available ARM and other observations, and with high-frequency NWP analyses at the ARM SGP site and other important climate regions. In this extended abstract, however, only the simulated precipitation, temperature, and moisture fields are summarized. More detailed discussions about the simulation of other fields, such as clouds, surface sensible and latent heat fluxes, and radiation fluxes, will be given in the upcoming American Meteorology Society (AMS) meeting and a separate research paper. For convenience, we use CAM2O to represent the original model and CAM2M to represent the model with the modified triggering mechanism, and OBS to represent observations in the following discussions.

3.1 Comparison at ARM SGP site

Figure 1 shows the time series of surface precipitation rates for CAM2O, CAM2M, and the corresponding observations averaged over a grid cell centered at the model grid point (37.67N, 98.44W). Similar results are seen at other neighbor grid cells. The observations show several strong convective events during this period. It is seen that convection is triggered too often in CAM2O, which produces precipitation almost

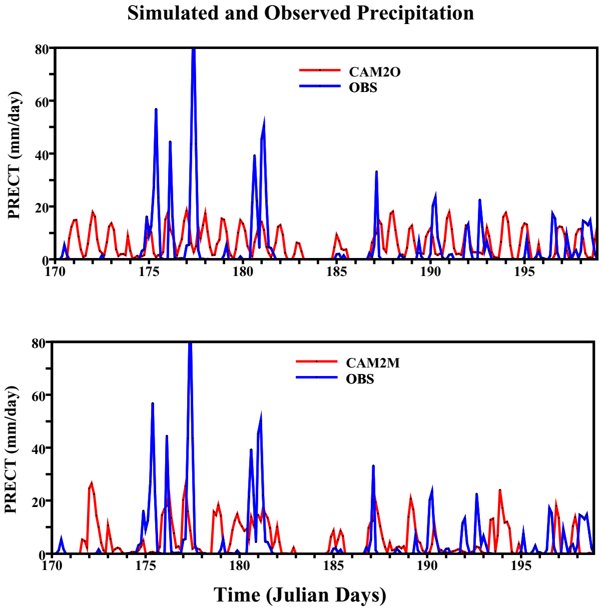


Figure 1. Time series of precipitation for CAM2O, CAM2M, and the observations at the ARM SGP site.

everyday during the daytime. This problem is noticeably reduced when the dynamic constraint is used to control the initiation of convection (CAM2M). Since CAPE can accumulate before convection occurs in CAM2M, relatively stronger precipitation events are produced by the improved scheme in comparison with CAM2O.

Even with the overall improvement, some spurious precipitation events, such as those on days 172-173 and day 194, are still seen in CAM2M. In addition, the magnitude of the observed precipitation is still underestimated in CAM2M during strong convective periods that occurred on days 174 – 178 and days 180-181. The underestimation is also seen in CAM2o. Note that the underestimation of the observed precipitation events, which are mainly dominated by subgrid-scale convective processes, is not uncommon in climate models, which typically use horizontal resolutions that are larger than 200 km. The problem could be improved with increasing the model resolutions (Duffy et al. 2003). In addition, the performance of model convection scheme is largely dependent on the accuracy of the initial data and the model-produced large-scale dynamic fields, such as large-scale vertical motion and advective tendencies of winds, temperature, and moisture. A comparison between the large-scale vertical motion derived from the ERA-40 reanalysis and the ARM objective variational analysis shows that the ERA-40 reanalysis-derived vertical motion is much weaker than that derived from the objective analysis during these strong precipitation periods (not shown). This may also cause the weaker precipitation produced by the model.

Differences between the simulated temperature and the ERA-40 reanalysis at the selected model grid point are shown in Fig. 2. The original model (CAM2O) shows a warm bias in almost the entire troposphere, especially in the levels between 665 mb and 215 mb, when compared to the ERA-40 reanalysis. The warm bias exhibits a diurnal variation, indicating that it may be related with the model-produced overactive convection that releases excessive convective heating in the mid- and upper troposphere. The warm bias is largely reduced in CAM2M. The improvement is mainly located between 665 mb and 215 mb. Below 665 mb, both CAM2O and CAM2M display a very similar error pattern with a similar magnitude of the model bias. This may suggest that the error in the lower troposphere is related to problems associated with the model boundary layer processes.

Figure 3 is the same as Fig. 2 except for the moisture simulation. Both CAM2O and CAM2M show dry bias in the lower troposphere over the whole period except for day 185, where both models produce significant moist bias due to the failure to capture the abrupt reduction of moisture shown in the ERA-40 reanalysis during that time. However, the magnitude of the dry bias in CAM2M is much smaller than that in CAM2O because convection is less active in CAM2M than the original model. This results in less moisture consumed by convection in CAM2M.

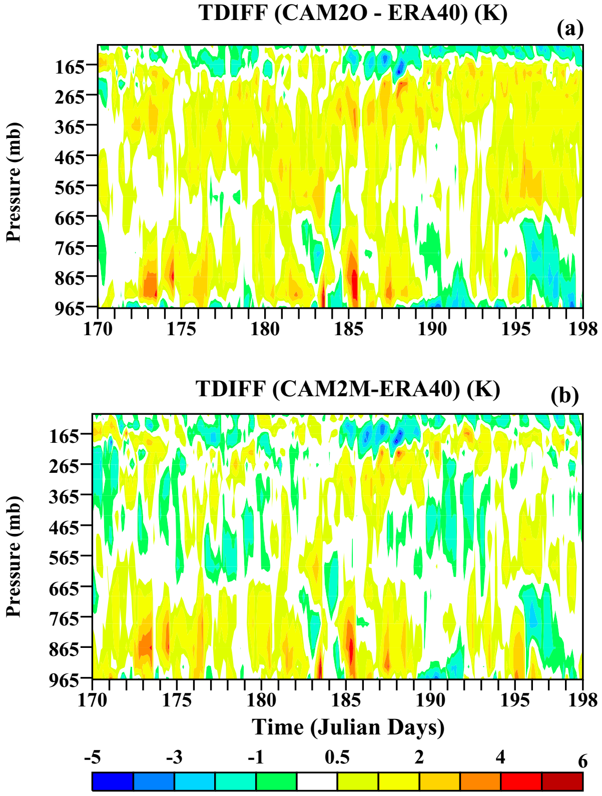


Figure 2. Differences between the simulated temperature and the ERA-40 reanalysis. (a) CAM2O; and (b) CAM2M.

In comparison with the ARM observations and the ERA-40 reanalysis at the ARM SGP site, overall improvements can be seen in other important atmospheric fields, such as clouds, surface sensible and latent heat fluxes, and radiation fluxes, when the new triggering mechanism is used (not shown in this abstract). These results are similar to those shown in the SCM tests (Xie and Zhang 2000; Ghan et al. 2000; Xie et al. 2002). Note that improvements made in SCM tests are not guaranteed to be transferable to its parent GCM due to the limitation of the SCM framework, such as the lack of the internal feedback between the model dynamical processes and physical processes. The encouraging results shown in this study indicate that the improved scheme proposed by Xie and Zhang (2000) based on the SCM framework has passed another important test, i.e., the test in a full GCM.

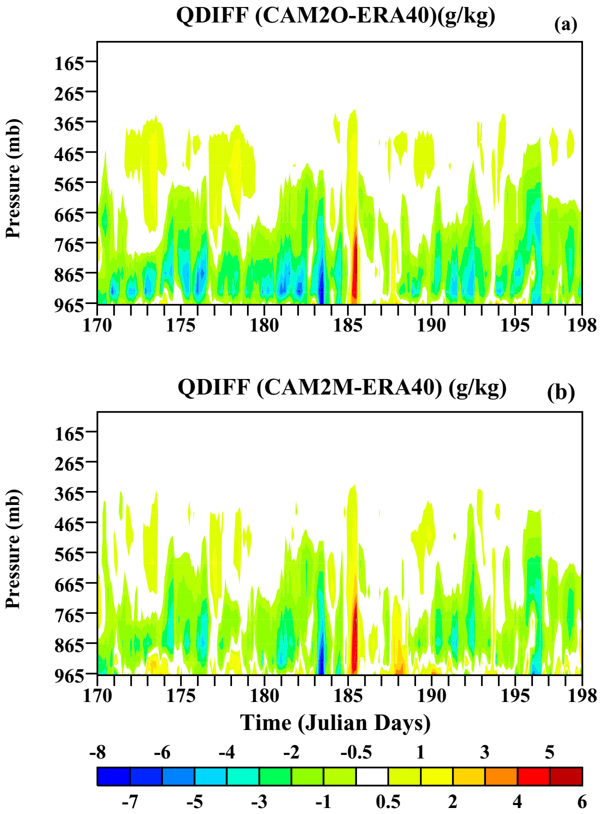


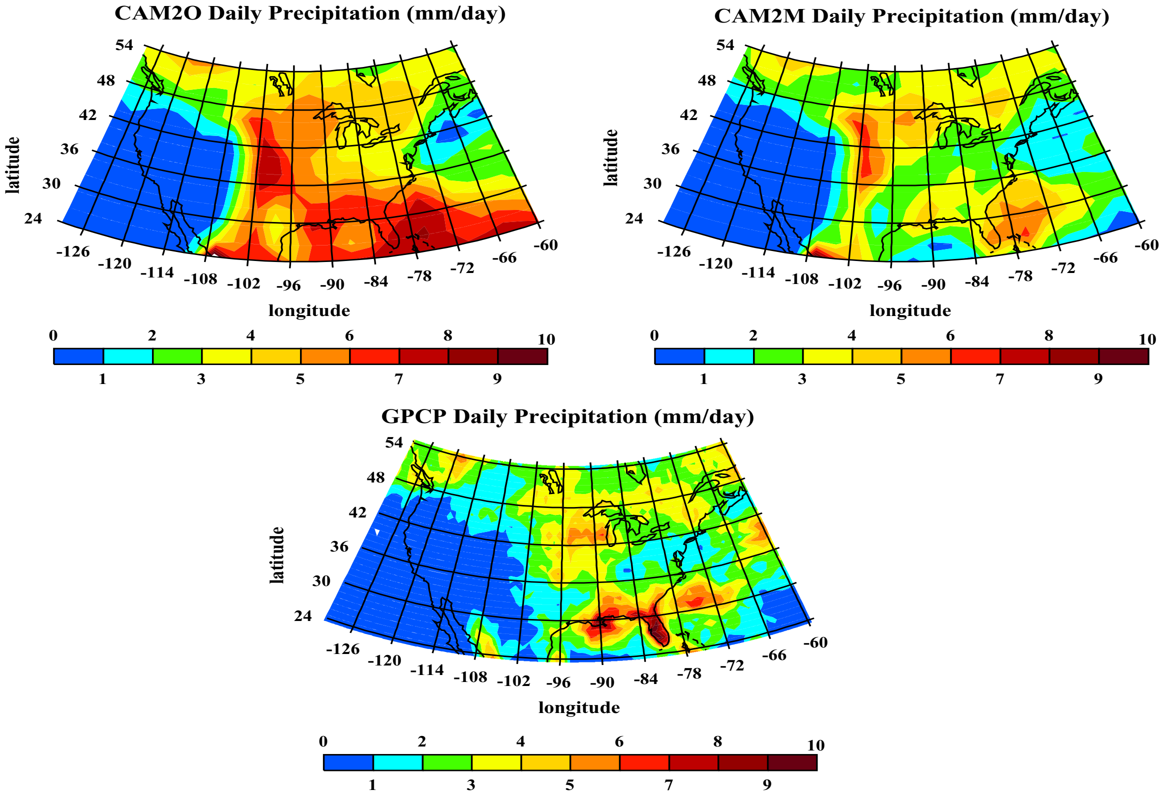
Figure 3. Differences between the simulated moisture and the ERA-40 reanalysis. (a) CAM2O; and (b) CAM2M.

3.2 Comparison beyond the ARM SGP site

To examine the impact of the improved convective trigger on simulations in regions beyond the ARM SGP site, Figure 4 displays the geographical distribution of precipitation over the region that covers the continental United States. The model data are the ensemble mean precipitation of 0-24h forecasts over the 31 days as described earlier. The observations are taken from Global Precipitation Climatology Project (GPCP) daily precipitation data (Huffman et al. 2001) and these data are averaged over the same period as that covered by the model data. The GPCP dataset has a spatial resolution of 1^0. During the summer period, the heaviest precipitation is seen in the southeast and along the Gulf Coast in the GPCP data. Another relatively large rainfall region in the observations is located southwest of the Great Lakes along the Mississippi-Wisconsin Rivers. Slight precipitation is seen between these two major precipitation areas from the southwestern U.S. stretching northeastward into the Northeast Coast. Overall, the observed spatial pattern of precipitation appears to be more realistically simulated in CAM2M, although it underestimates the southeast precipitation and shifts the center of the precipitation along the Mississippi-Wisconsin rivers slightly father north compared to the observations. The original model overestimates the observed precipitation in most parts of the country while the excessive precipitation is clearly reduced in CAM2M. It is interesting to note that both CAM2O and CAM2M show a precipitation maximum located in the east of the Rockies, which is not shown in the observations. This phenomenon is also present in the summer precipitation field for the mean of all CMIP (Coupled Model Intercomparison Project) models (Coquard et al. 2003). The physical reasons for the model systematic error are not well understood and are subject to additional study. However, results from this study indicate that this model systematic error can be detected in the early stage of model integration. This has very important implications for understanding what model deficiencies cause the systematic error since it allows us to perform a more in-depth analysis during a short time period where more observations are available and different model errors from various processes have not compensated for the systematic error.

In addition to these improvements over midlatitude lands, more encouraging improvements are also seen in other areas, including the tropical and subtropical regions. As shown in Fig. 5, which gives the global distribution of precipitation for CAM2O, CAM2M, and the observations, CMA2M reproduces dramatically well the principal features of the observed precipitation distribution, particularly in the Tropical Pacific and India Oceans and in north Africa. In contrast, CAM2O generally overestimates the observed precipitation globally in the short-range weather forecasts while it underestimates the magnitude of the observed precipitation maxima, such as those in the eastern

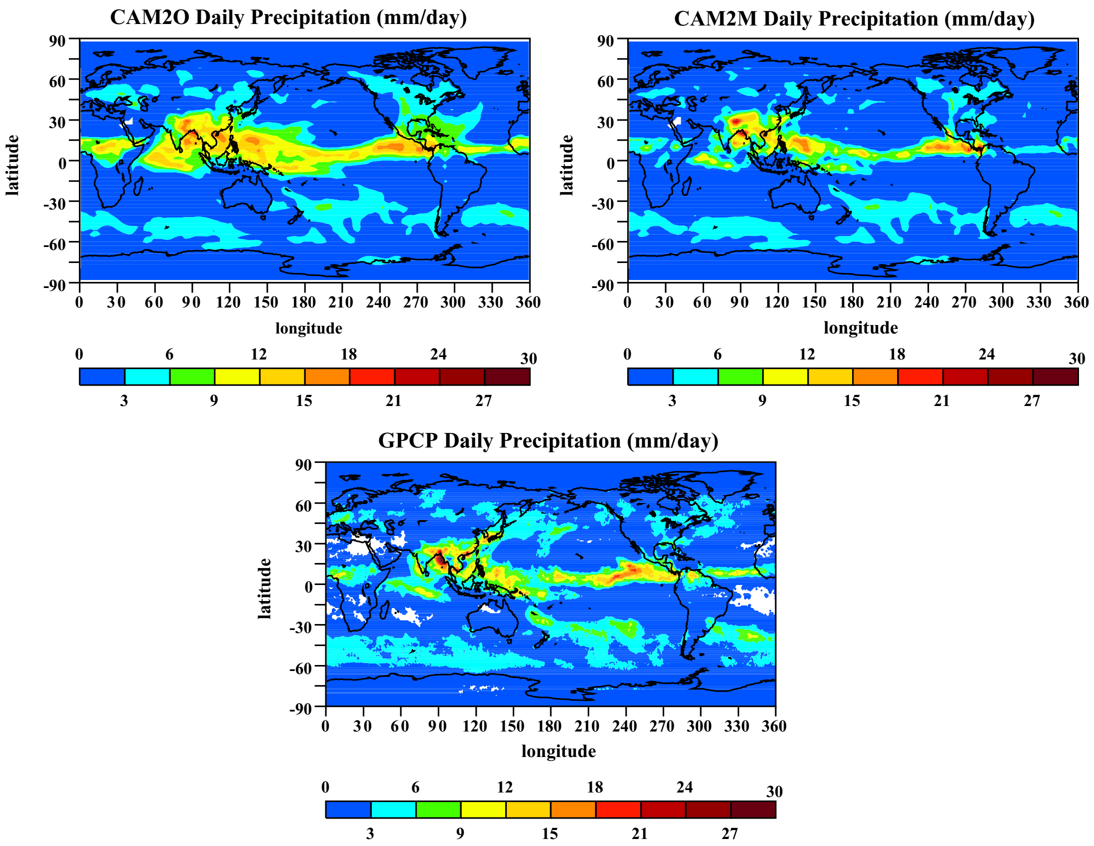
Pacific and in the northeastern boundary of the Bay of Bengal. These results indicate the improved triggering mechanism developed by Xie and Zhang (2000) based on the midlatitude observations is also suitable for use globally and, in fact, it makes even larger improvement over oceans than lands.


CAM2O Daily Precipitation (mm/day)

CAM2M Daily Precipitation (mm/day)

GPCP Daily Precipitation (mm/day)

Figure 4. Geographical distribution of 31-day ensemble mean precipitation over the continental United States for CAM2O, CAM2M, and the GPCP data.


CAM2O Daily Precipitation (mm/day)

CAM2M Daily Precipitation (mm/day)

GPCP Daily Precipitation (mm/day)

Figure 5. Global distribution of 31-day ensemble mean precipitation for CAM2O, CAM2M, and the GPCP data.

4. CONCLUSIONS

In this study, we have evaluated the improved convective triggering mechanism proposed by Xie and Zhang (2000) in CAM2 under the CAPT framework, in which the climate model is run in NWP mode. The new triggering mechanism introduces a dynamic constraint on the initiation of convection. It has been shown that the model with the new triggering mechanism can effectively reduce the problem associated with the overactive convection in the original model. This results in a more realistic precipitation field simulated by the model. Improved results are seen over both land and ocean when compared to the available observations at the ARM SGP site, in the continental United States, and around the global. Similar improvements are also present in other important meteorological fields, such as temperature, moisture, and clouds (not shown). This study represents an important and efficient step to transfer improved parameterizations made from SCM tests to 3-dimensional climate models before they can be used to improve climate simulations. Evaluation of the new triggering mechanism in climate simulation is being pursued in a separate study.

5. ACKNOWLEAGEMENT

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