Evaluating and Improving GCM Simulation of Convection Using ARM Observations at the SGP Site

G. J. Zhang
Center for Atmospheric Sciences
Scripps Institution of Oceanography
La Jolla, California

Introduction

Atmospheric convection undergoes strong diurnal variation over both land and oceans (Gray and Jacobson 1977; Dai 2001). This diurnal variation has a large impact on the atmospheric radiation budget. Convection also affects the surface energy budget by modulating the surface sensible and latent heat fluxes, in addition to solar radiation flux. Global Climate Models (GCMs) have not been very successful in simulating convection well at the SGP site and elsewhere over the U.S. continent (Dai et al. 1999; Betts et al. 1999). For example, over the U.S. Southern Great Plains (SGP) and the Mississippi River basin, convection simulated by the National Center for Atmospheric Research (NCAR) Community Climate Model, Version 3 (CCM3) peaks in early afternoon (Dai et al. 1999), whereas observations indicate that convection reaches maximum at night. Similar errors in the diurnal phase of convection are found in the European Centre for Medium-Range Weather Forecasts (ECMWF) global forecast model (Betts et al. 1999).

In our previous study supported by the ARM Program, we developed an improved closure for convection parameterization (Zhang 2002) based on the analysis of the ARM SGP observations. In this study, we apply the new closure to the NCAR CCM3 global climate model, and examine the GCM simulation of convection and the associated top of the atmosphere (TOA) energy and radiation budgets over the SGP site, focusing mainly on the diurnal variation of convection.

Data and Model

The data used in this study are from the SGP site of the ARM Program for the July intensive operational period (IOP) of 1995, June/July IOP of 1997, and the April/May IOP of 1998. The observations include surface precipitation, surface, and TOA radiation, and cloud amount, available at 3-hourly resolution. The cloud radiative forcing for the 1997 IOP is obtained from the collocated Minnis cloud product. The global model simulations are from NCAR CCM3, with and without the new convection closure. Two model simulations are conducted, using the standard CCM3 with and without the new convection closure. The simulations are for 3 years, from 1996 to 1998 for analysis of the diurnal cycle of convection, with data saved hourly.

Results

Figure 1 shows the diurnal variations of precipitation, total cloud amount, and TOA cloud shortwave and longwave radiative forcing from the observations and the model simulations. On diurnal timescale, the observed precipitation reaches maximum at night and a minimum near local noon during the 1997 summer IOP. The CCM3 simulation without the new closure has maximum precipitation in late afternoon and a minimum near sunrise. The amplitude of the diurnal variation is much too strong. The simulation with the new closure reaches the maximum in the early morning, but with smaller amplitude. The simulated cloud amount is in good agreement with the observations. Both reach a maximum during the day and a minimum at night. In contrast, the cloud amount in the standard simulation reaches a maximum in early evening and a minimum in midmorning. The shortwave cloud radiative forcing is also in much better agreement with the observation with the new convection closure. The amplitude of the diurnal variation of the longwave cloud radiative forcing in the simulation with the new closure is comparable to that of the observations. However, the phase of the variation is not well simulated.

Figure 2 shows the observed diurnal variation of precipitation from the three IOPs and the simulation with the new closure for the months of May to August. Both the 1995 and 1997 IOPs were conducted in the summer, thus precipitation was of convective in nature and reaches maximum at night. On the other hand, the 1998 IOP was conducted in late April to early May before the active convection season began. The diurnal variation of precipitation shows a broad maximum during the day. The model simulation shows the diurnal variation of precipitation for each month from May to August. In all 4 months, precipitation reaches maximum near midnight to early morning and minimum near local noon. This is in good agreement with the ARM observations as well as other surface observations (Dai et al. 1999). From June to July and August, there is a significant decrease in precipitation in the model. This reflects the development of the North American monsoon in Arizona and New Mexico. Studies on North American monsoon (Higgins et al. 1997) found that precipitation in the Great Plains decreases from June to July when the monsoon onset begins south of it.

To demonstrate the improvement of the diurnal cycle of precipitation in other regions of the continental United States in general, Figure 3 shows the phase dial vector of diurnal cycle of convection following Dai et al. (1999). In the figure, the direction of a vector gives the local time at which the maximum precipitation occurs using the harmonic analysis of Dai et al. (1999), and the vector length gives the amplitude of the diurnal harmonic of convective precipitation, normalized by the seasonal average precipitation amount at each grid point. A vector pointing southward means maximum precipitation at 0000 LST, pointing westward means maximum precipitation at 0600 LST, etc. In the CCM3 simulation, maximum convective precipitation occurs in early to mid afternoon across the country, with large amplitude. This is similar to the results from other studies (Dai et al. 1999). In the simulation with the new closure, there is a significant change in the diurnal cycle of convection. West of the Rockies, maximum precipitation occurs near 1800 LST, with fairly large amplitude. East of the Rockies across the Great Plains and further eastward, maximum convection occurs from early evening to night. The diurnal amplitude of convective precipitation is much weaker than in the standard CCM3 simulation. All these features are in good agreement with the observations (Dai et al. 1999, Trenberth et al. 2003). In the southeast of the United States, the amplitude of the diurnal variation is somewhat too weak, while the phase is in good agreement with the observations.

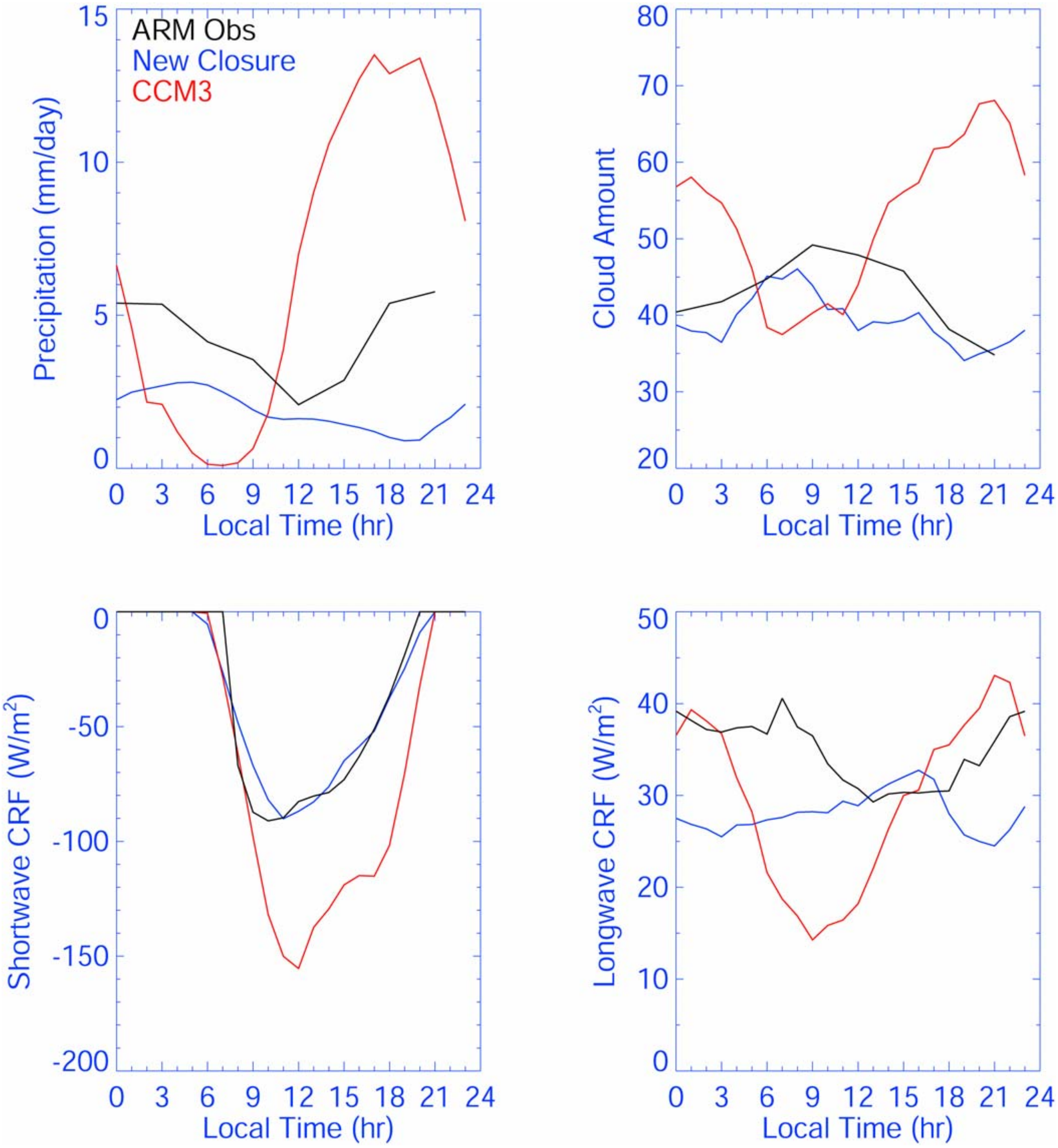

Figure 1. Diurnal variation of precipitation, cloud amount, and TOA shortwave and longwave cloud radiative forcing from observations and CCM3 model simulations with and without the new convection closure for the summer 1997 IOP. The cloud radiative forcing data is obtained from Minnis cloud product.

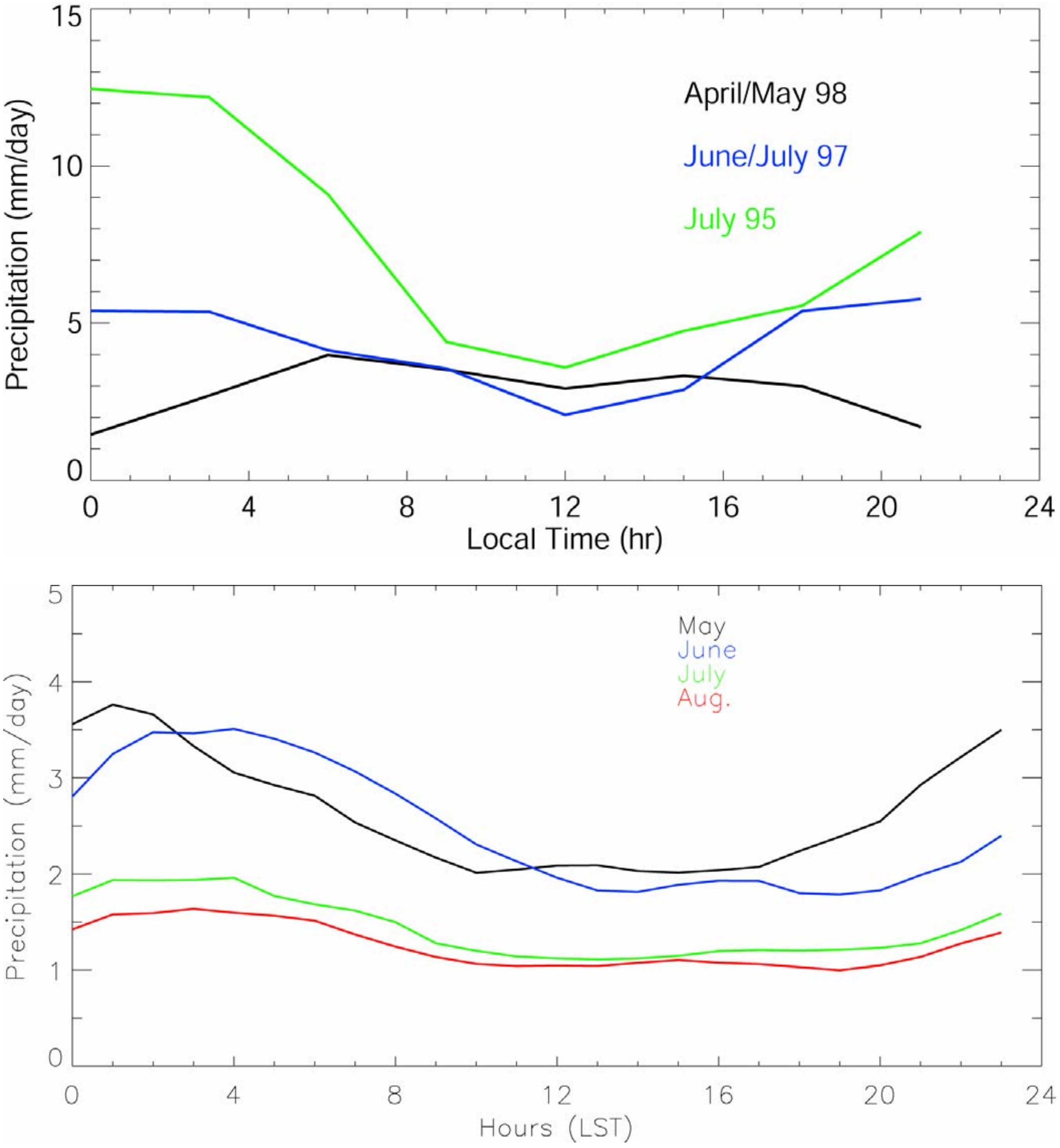

Figure 2. Diurnal variation of precipitation from three ARM IOPs (top) and a 3-year CCM3 simulation for the summer months using the new convection closure (bottom).

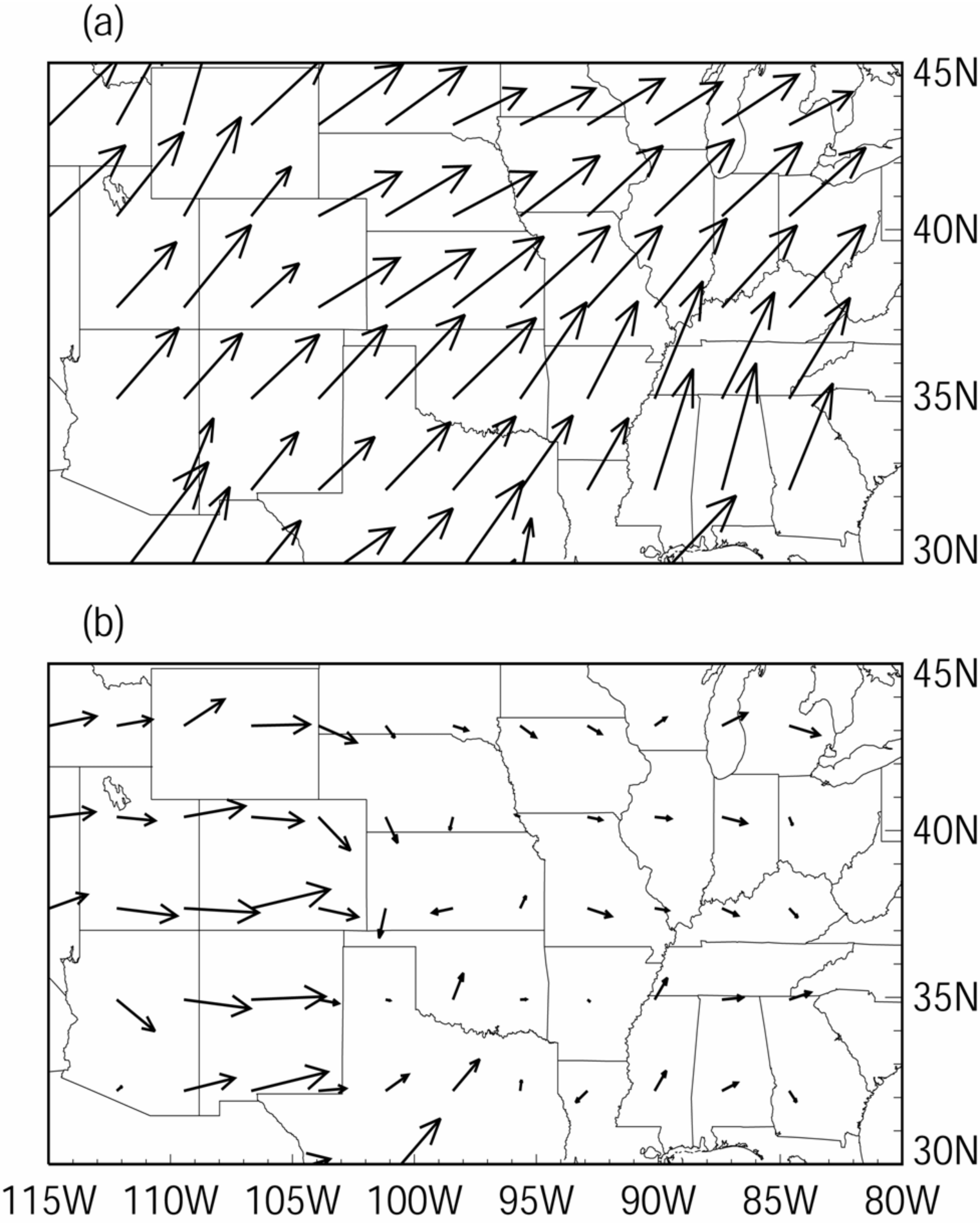

Figure 3. Diurnal phase and normalized amplitude of convection as simulated from (a) standard CCM3 and (b) CCM3 with new convection closure.

Observations of the convective systems in the Oklahoma/Kansas area often show that convection develops in the Rockies and propagates eastward into the Great Plains. Our model simulation is able to reproduce this characteristic very well when the new convection closure is used. Figure 4 shows the Hovmöller diagram of precipitation averaged along the latitude belt 37°N-40°N. In the standard CCM3 simulation, convection develops more or less simultaneously in the afternoon from east of the Rockies to the east seaboard. There is no sign of eastward propagation of the systems. On the other hand, in the simulation with the new closure, convection develops in the Rockies in mid- to late afternoon and propagates eastward into the Great Plains. This is very similar to the radar observations of the storms by Carbone et al. (2002).

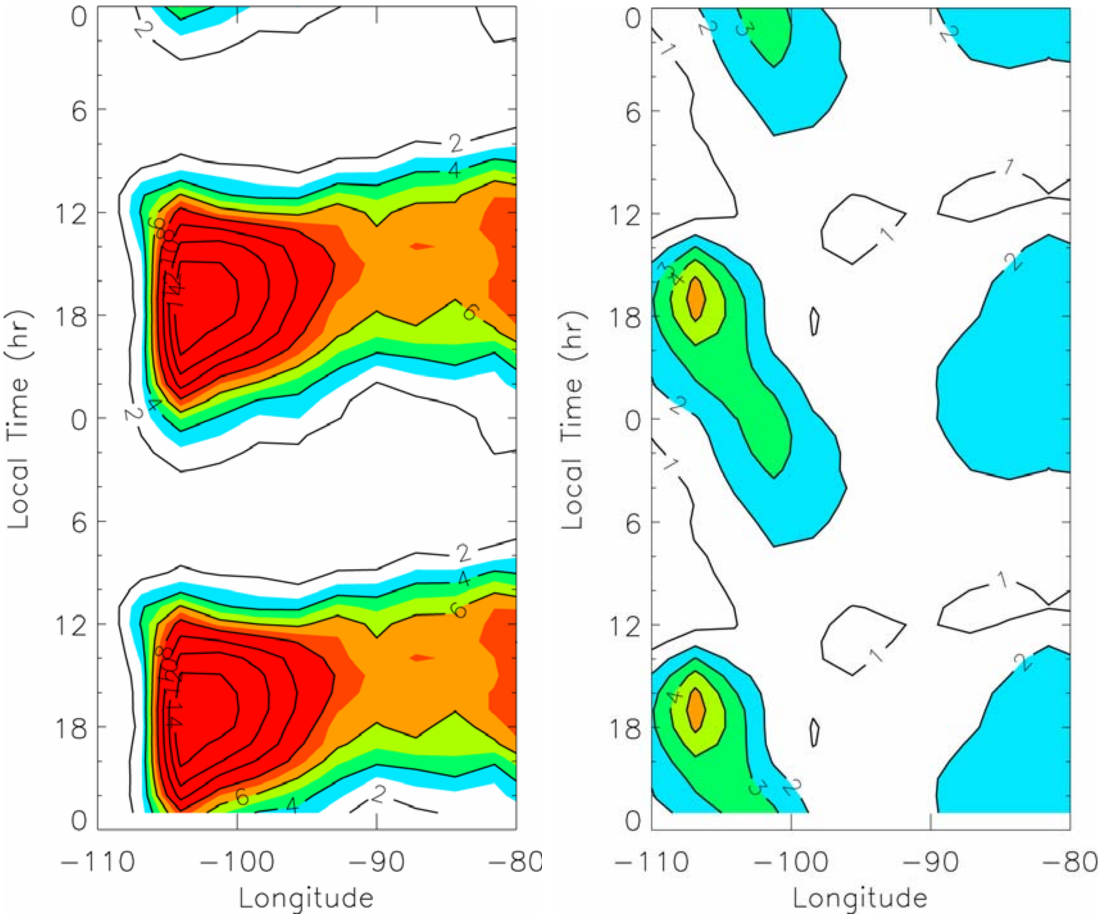

Figure 4. Hovmöller diagram showing two diurnal cycles of precipitation (mm/day) along 37°N-40°N from CCM3 with (right) and without (left) the new closure.

Summary

In this study, the NCAR CCM3 was used to investigate the improvement in the simulation of the diurnal cycle of convection with a new convection closure developed using the ARM data. The simulation results are compared with the ARM observations from several IOPs at the SGP site. We found that the diurnal phase of convection is significantly improved. Maximum convection in the new closure simulation occurs at night at the SGP site, in agreement with the observations. The diurnal variations of the total cloud amount and shortwave radiative forcing are also in good agreement with the ARM observations. However, the simulated longwave cloud radiative forcing has larger errors in its diurnal variation.

The improvement of the diurnal cycle of convection occurs not only at the SGP site, but also in other regions of the continental United States. In particular, the simulated convection develops in late afternoon over the Rockies, and propagates eastward into the Great Plains at night.

Acknowledgement

This research was support by the Atmospheric Radiation Measurement Program of the Environmental Science Division of U.S. Department of Energy under Grant DE-FG02-03ER63532.

Corresponding Author

Guang J. Zhang, gzhang@ucsd.edu, (858) 5347535

References

Betts, A. K., J. H. Ball, and P. Viterbo, 1999: Basin-scale surface water and energy budgets for the Mississippi from the ECMWF analysis. *J. Geophys. Res*., **104**, 19,293–19,306.

Carbone**,** R. E., J. D. Tuttle, D. A. Ahijevych, and S. B. Trier**,** 2002: Inferences of predictability associated with warm season precipitation episodes**.** *J. Atmos. Sci.* **59,** 2033–2056.

Dai, A., F. Giorgi, and K. E. Trenberth, 1999: Observed and model simulated diurnal cycles of precipitation over the contiguous United States. *J. Geophys. Res*., **104**, 6377–6402.

Gray, W. M., and R. W. Jocobson, Jr., 1977: Diurnal variation of deep cumulus convection. *Mon. Wea. Rev*., **105**, 1171–1188.

Higgins, R. W., Y. Yao, and X. L. Wang, 1997: Influence of the North American Monsoon System on the U.S. summer precipitation regime. *J. Climate*, **10**, 2600–2622.

Trenberth, K., E., A. Dai, R. M. Rasmussen, and D. B. Parsons, 2003: The changing character of precipitation. *Bull. Amer. Meteor. Soc*., **84**, 1205–1217.

Zhang, G. J., and N. A. McFarlane, 1995: Sensitivity of climate simulations to the parameterization of cumulus convection in the Canadian Climate Centre general circulation model. *Atmosphere-Ocean*, **33**, 407–446.

Zhang, G. J., 2002: Convective quasi-equilibrium in midlatitude continental environment and its effect on convective parameterization. *J. Geophys. Res*., **107,** 4220, doi:10.1029/2001JD001005.