GLOBAL MODEL INVESTIGATION OF WARM-SEASON PRECIPITATION FOR THE NORTH AMERICAN MONSOON EXPERIMENT (NAME)

GUANG J. ZHANG & J. CRAIG COLLIER
SCRIPPS INSTITUTION OF OCEANOGRAPHY

CLIMATE PREDICTION PROGRAM FOR THE AMERICAS

I. INTRODUCTION

The North American Monsoon (NAM) system is an important warm-season climate regime in the southwestern U.S. and northwestern Mexico. Between its onset in June-July and its decay in September, locations over the arid terrain of NW Mexico and the SW U.S. experience a dramatic increase in rainfall (see Figure 1). Historically, state-of-the-art climate models have not done well in simulating the spatial distribution and temporal variability of the warm-season precipitation associated with the monsoon system. Thus it is difficult to place the simulation of the NAM circulation in a global climate perspective and thereby to assess how regions like the southwestern U.S. might respond to a changed climate scenario. Unsatisfactory simulation of warm-season precipitation may be the result of deficiencies in horizontal resolution [1], simulated moisture transport [4] and convection (e.g., [5], [2], [3]).

MONTHLY-MEAN ZONAL-MEAN PRECIPITATION RATE

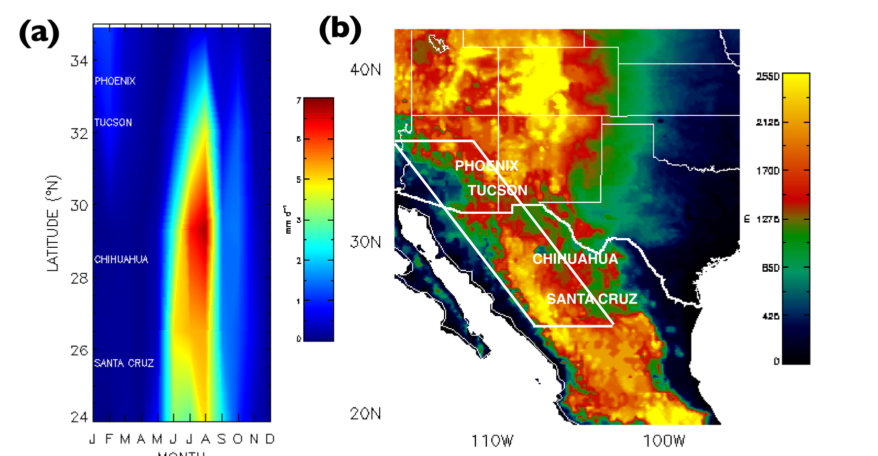

Figure 1. Monthly-mean zonal mean precipitation (mm d^{-1}) (a) as averaged over the parallelogram in the elevation map (b). Observations are derived from gauges over the U.S. and from TRMM over Mexico.

A modified Zhang & McFarlane [7] convection parameterization has shown much-improved simulations of precipitation over the U.S. Great Plains [6] and of tropical climate [8], [9] in the National Center for Atmospheric Research (NCAR) climate model. In this study, we use the NCAR Community Atmosphere Model (CAM3) and its predecessor, the Community Climate Model (CCM3) forced with observed sea surface temperatures to compose ensembles of independent simulations of the NAM. In this poster, we examine the following issues:

1. Simulation of the onset, evolution, and decay of the monsoon as well as the associated diurnal cycle of precipitation.
2. Possible improvements in the simulation of these features, as realized by increasing horizontal resolution and by use of an improved parameterization for convection.

II. DATA

To facilitate the model evaluation, we use a variety of data, whose records concur with the simulation period. These include gridded hourly U.S. precipitation data (HPD) from the National Weather Service (NWS) - Techniques Development Lab, complemented with rainfall measurements from the Tropical Rainfall Measuring Mission (TRMM) satellite as well as high-density observations from the NAME Enhanced Raingauge Network (NERN) over northwestern Mexico. We derive values of observed CAPE from the temperature and specific humidity fields of the NCEP-NCAR reanalysis.

III. RESULTS

During June & July, CAM3 is biased dry over NW MX and SW U.S. and biased wet over the U.S. Southern Plains and NE MX.

Onset & Maturation

Observations show a high-intensity rainfall belt over the Sierra Madre Occidental (SMO) mountains, not represented by CAM3.

By August, the model's wet bias over the U.S. S. Plains has decreased, but simulated precipitation is too low over NW MX and the SW U.S. It is too high over the Gulf of California.

Mature Phase

In September, observations show decreasing precipitation over the SMO and SW U.S., consistent with monsoon decay.

Decay

By contrast, CAM3 shows increased precipitation over the SW U.S. and NW MX and an enhanced wet bias over the Gulf of California.

MONTHLY-MEAN PRECIPITATION RATE

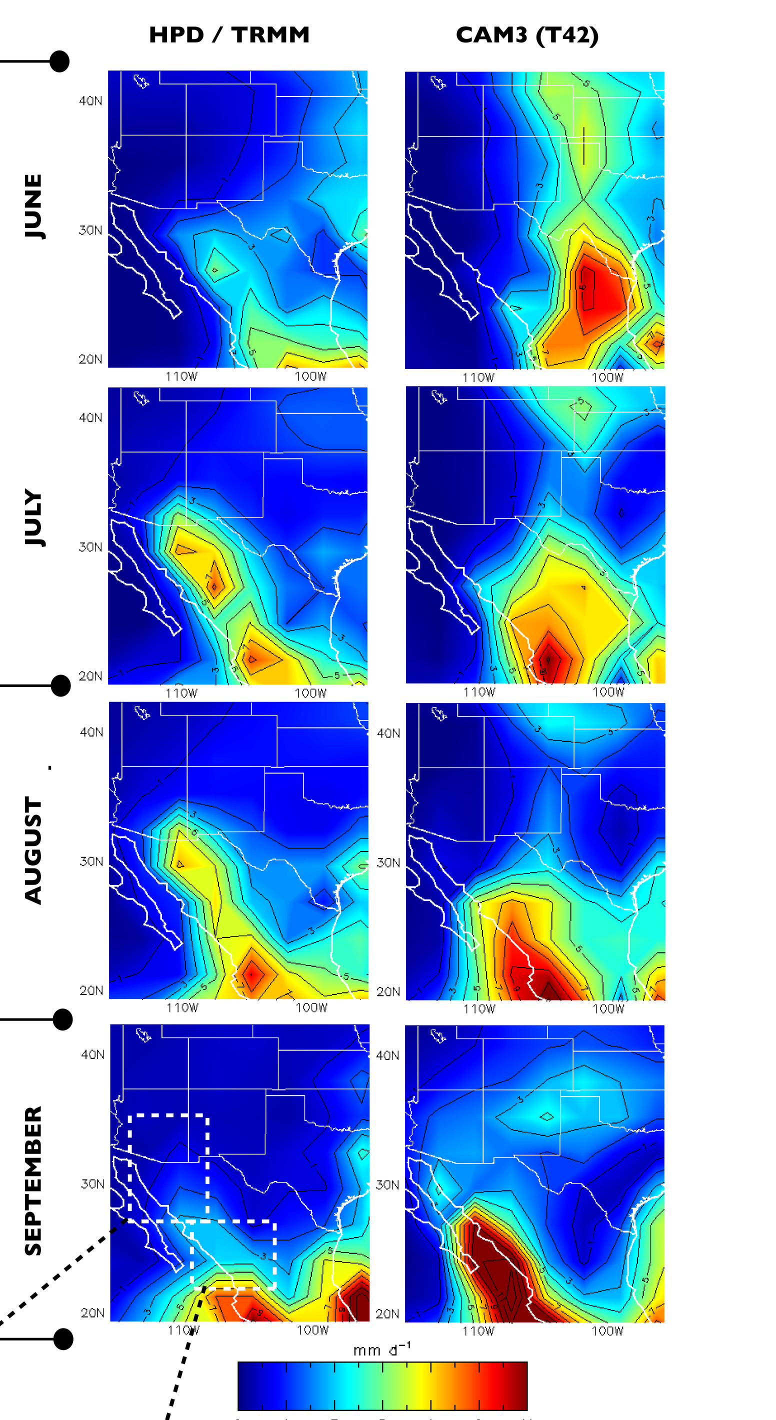

Figure 2. Monthly-mean precipitation rate (mm d^{-1}) as averaged over 1998-2002 for HPD (N of 30°N) and TRMM (S of 30°N) (left) and for an ensemble of CAM3 simulations at T42 resolution (right).

RAINFALL DIURNAL CYCLE: JAS MEAN

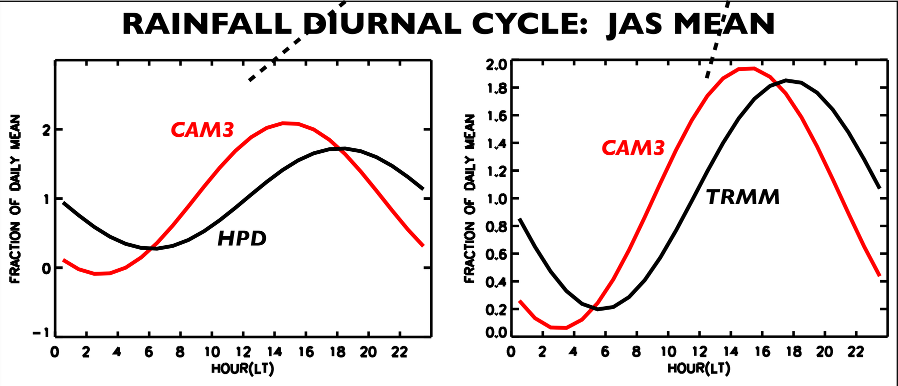

Figure 3. Semi-diurnal + diurnal harmonic of hourly-mean precipitation as a fraction of the daily mean, as averaged over JAS, 1998-2002 and for the regions outlined in Figure 2. CAM3 is shown in blue while the observations are shown in black.

Monsoon convection undergoes a significant diurnal cycle. Over these two regions of the NAM domain, rainfall is observed to peak around 1800 LT.

CAM3 is biased early, showing a peak around 1500 LT. Diurnal cycle biases such as these affect the surface energy budget on diurnal and seasonal timescales.

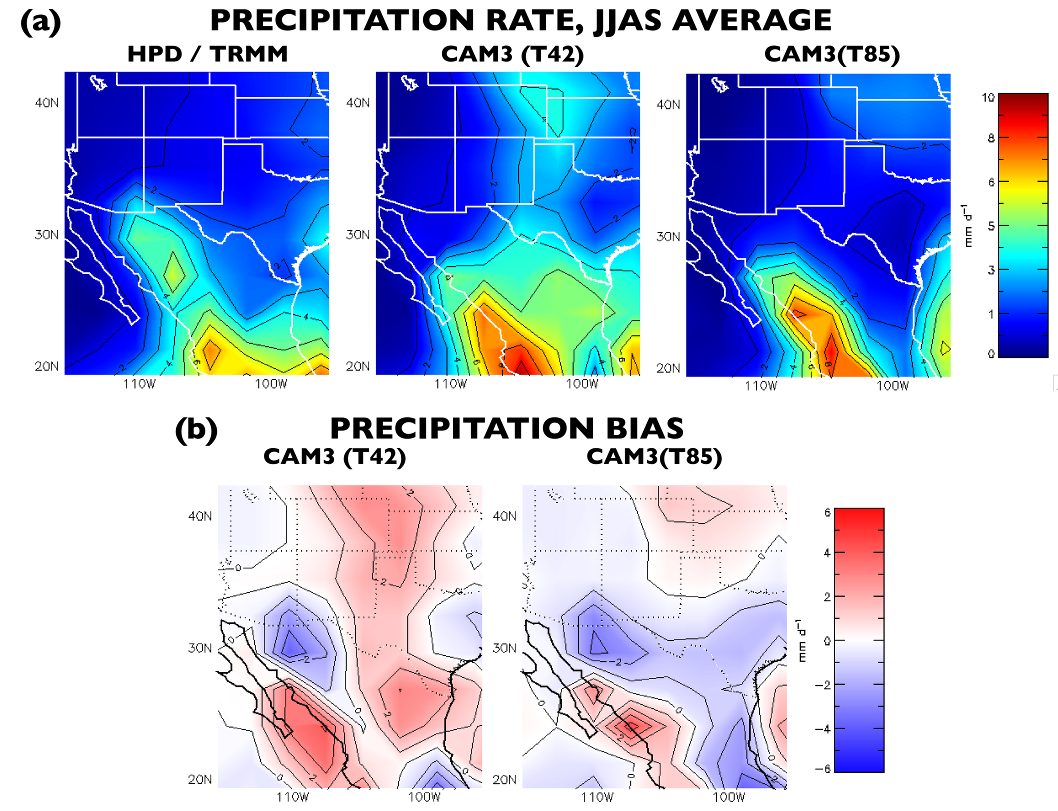

Figure 4. JJAS-mean precipitation rate (mm d^{-1}) as averaged over 1998-2002 for HPD/TRMM (left), CAM3(T42) (middle), and CAM3(T85) (right) (a). Precipitation biases are shown in (b).

Finer horizontal resolution allows for more realistic representation of such features as the SMO and the Gulf of California moisture source.

At T85, CAM3 simulates a better spatial distribution of rainfall over W MX, relative to its simulation at T42.

However, in the warm-season average, the dry bias over NW MX and SW U.S. is not reduced. In addition, a wet bias over TX & NE MX at T42 is replaced with a dry bias at T85.

MONTHLY-MEAN ZONAL-MEAN PRECIPITATION RATE

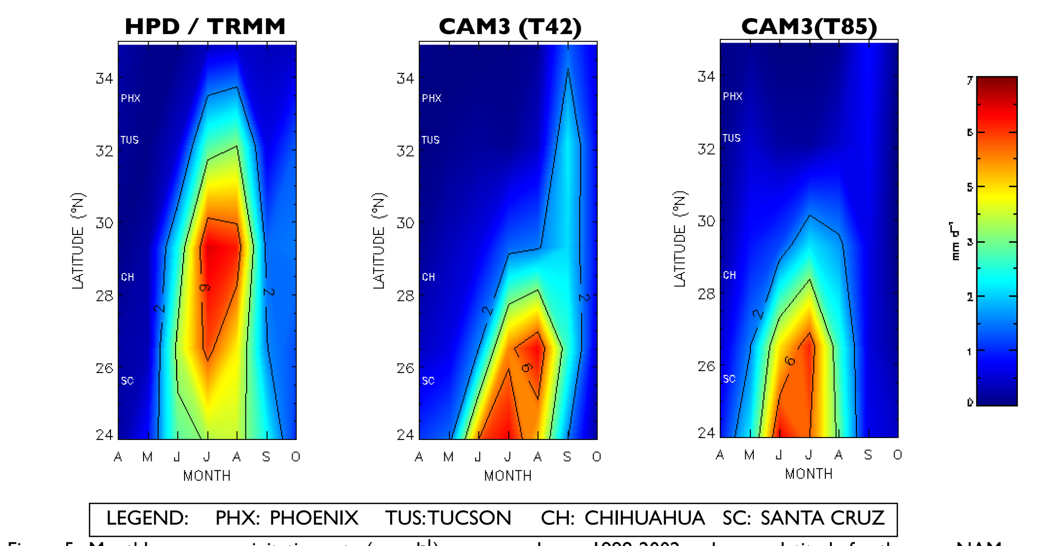

Figure 5. Monthly-mean precipitation rate (mm d^{-1}) as averaged over 1998-2002 and across latitude for the core NAM region depicted in Figure 1b.

Latitude - time plots show that, in the core NAM region, the monsoon is too weak north of 26°N and too strong south of this line at both T42 and T85 resolutions. The only noticeable improvement at T85 is the elimination of a late-season wet bias north of 30°N.

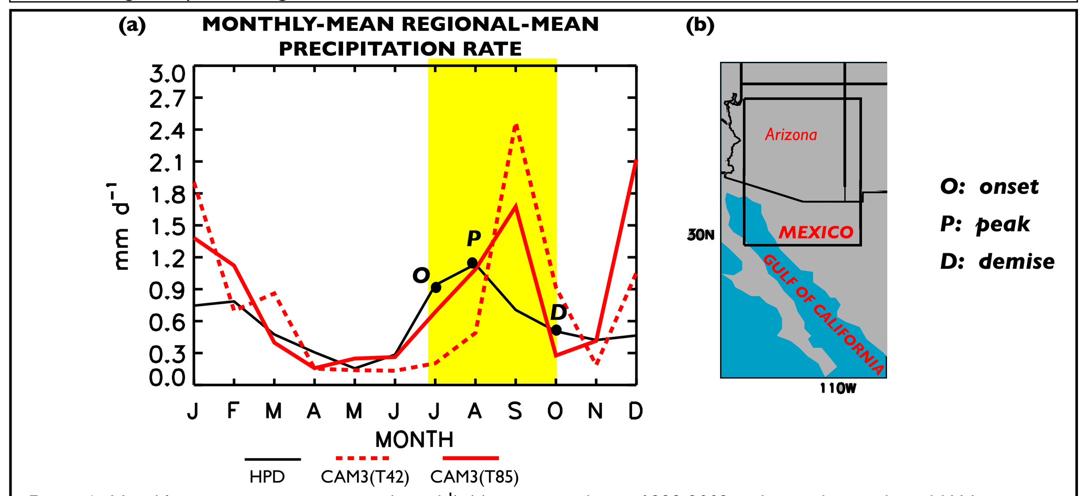

Figure 6. Monthly-mean precipitation rate (mm d^{-1}) (a) as averaged over 1998-2002 and over the northern NAM region depicted in (b). Observed "onset" ("demise") is defined by when the monthly-mean rainfall first rises above (falls to/below) the annual mean.

This improvement is evident in the monthly-mean precipitation rates, as averaged over the northern NAM domain. However, in terms of timing, the simulated monsoon lags that of the observations by at least 1 month.

At T85, the 1-month lag in demise is eliminated.

In the central Sierra Madre Occidental (SMO) region, the model's monsoon is evaluated with NAME rain gauge data (NERN) and with TRMM. While the observational estimates differ in overall rainfall amount, they both support that the CAM3 monsoon is too weak. Increasing the resolution of the model from T42 to T85 delays the onset of the monsoon and thus shortens its duration, since at both resolutions, its peak occurs in August, or 1 month later than in the observations.

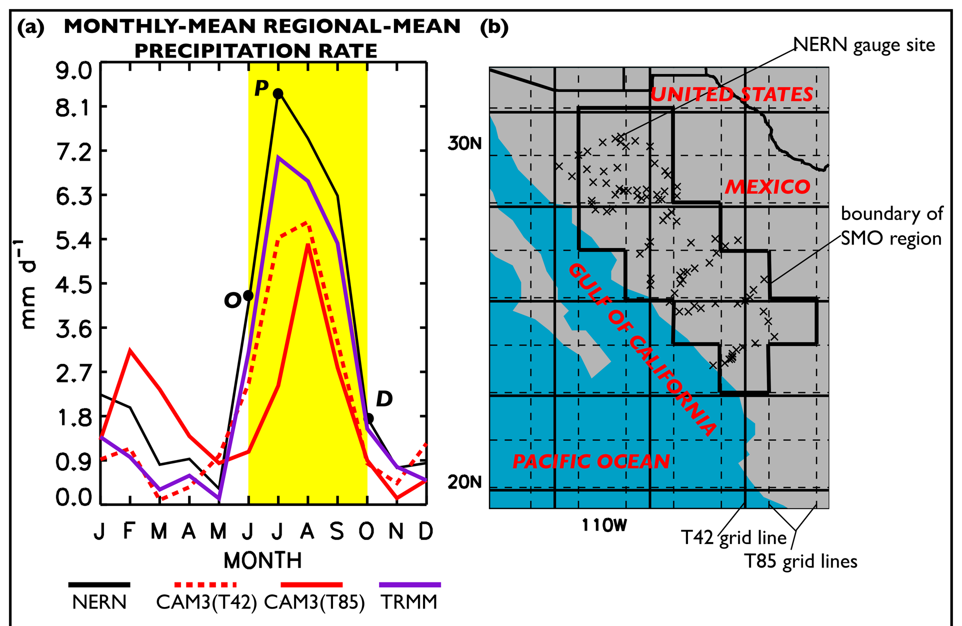

Figure 7. Monthly-mean precipitation rate (mm d^{-1}) (a) as averaged over 2002-2004 and over the SMO region depicted in (b). NERN refers to the average over the NERN gauges within the region.

When interpolated to T42, the T85 grid box diurnal cycles of precipitation are nearly indistinguishable from those at T42. In general, over the northern half of the NAM domain, the model leads the observations in the peak of daily rainfall by at least 2 hours. Thus, the diurnal cycle of rainfall over the NAM region is relatively insensitive to increasing the horizontal resolution.

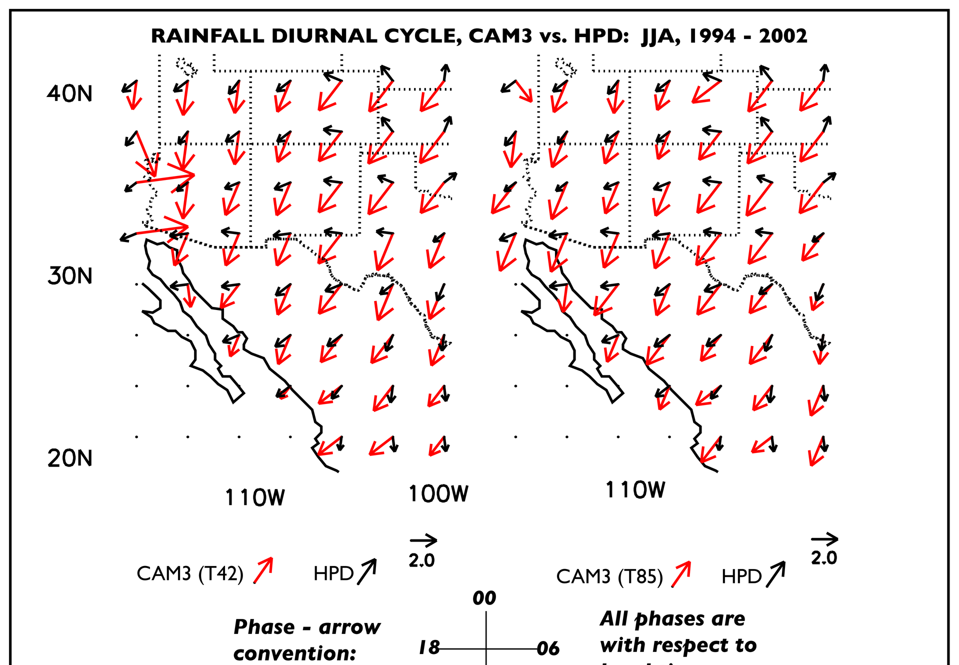

Figure 8. Diurnal + semidiurnal harmonics of JJA rainfall as simulated by CAM3 at T42 resolution (left) and at T85 resolution (right) vs. HPD data. Only harmonics significant at the 95% level are plotted. Note that a vector's length represents the amplitude of the harmonic as a fraction of the daily mean.

In the Zhang-McFarlane parameterization of deep convection, updrafts and downdrafts carry water and heat vertically through a convective cloud. Just as in the real atmosphere, updrafts and downdrafts are diluted by entrainment of environmental air. In the NCAR model, the scheme is activated when the atmosphere becomes conditionally unstable. The scheme is closed with specification of the cloud-base mass flux. In the original scheme, this flux is proportional to the amount of CAPE in the atmosphere. Zhang [6] found that the physical assumptions on which this closure is based are not valid for midlatitude continental convection and proposed an alternate closure based on the large-scale forcing of environmental virtual temperature. The new closure has been tested in CCM3 for simulation of the NAM.

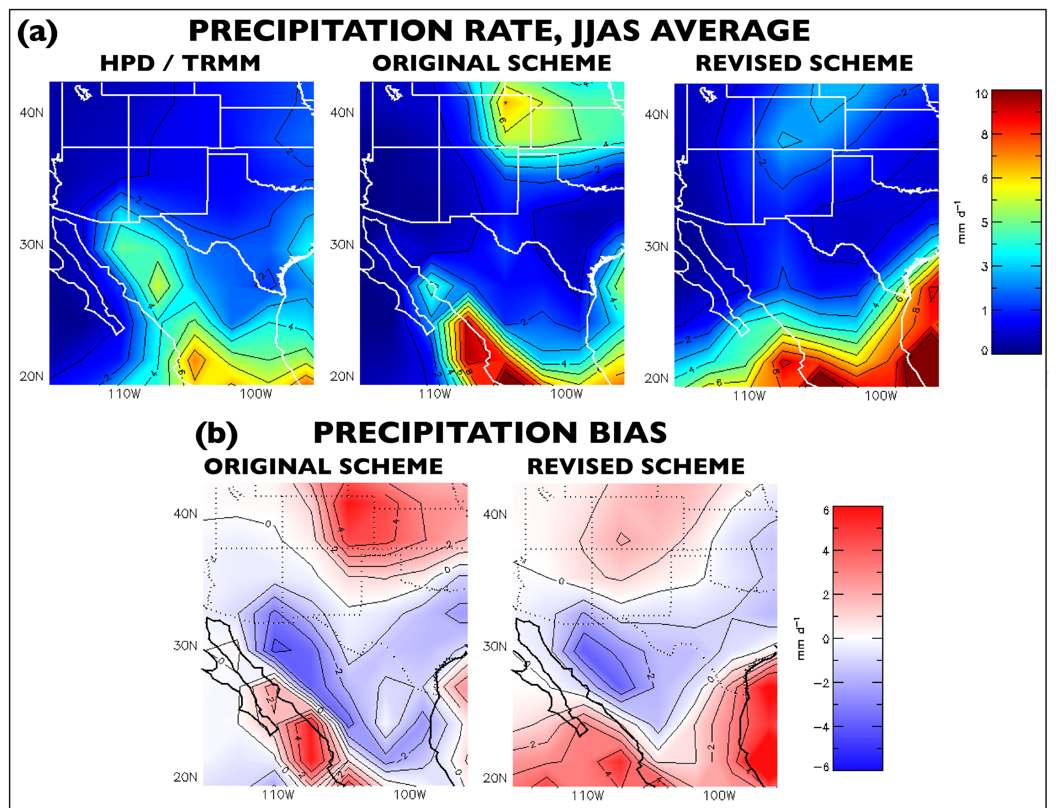

Figure 10. JJAS-mean precipitation rate (mm d^{-1}) as averaged over 1998-2002 for HPD/TRMM (left), CCM3 (ORIG) (middle), and CCM3 (REV) (right) (a). Precipitation biases are shown in (b).

In the seasonal mean, the CCM3 monsoon rainfall is quite similar to that of CAM3 (Fig. 4a). The model shows a wet bias over the U.S. Central Plains and along the west coast of MX, extending into the Gulf of California. Simulated precipitation is too scant over NW MX.

Use of the revised convection scheme reduces the wet bias over the Plains. In addition, a dipole wet/dry bias over the S. Gulf of California / W. MX south of 25°N also is reduced.

REGIONAL-MEAN MONTHLY-MEAN PRECIPITATION

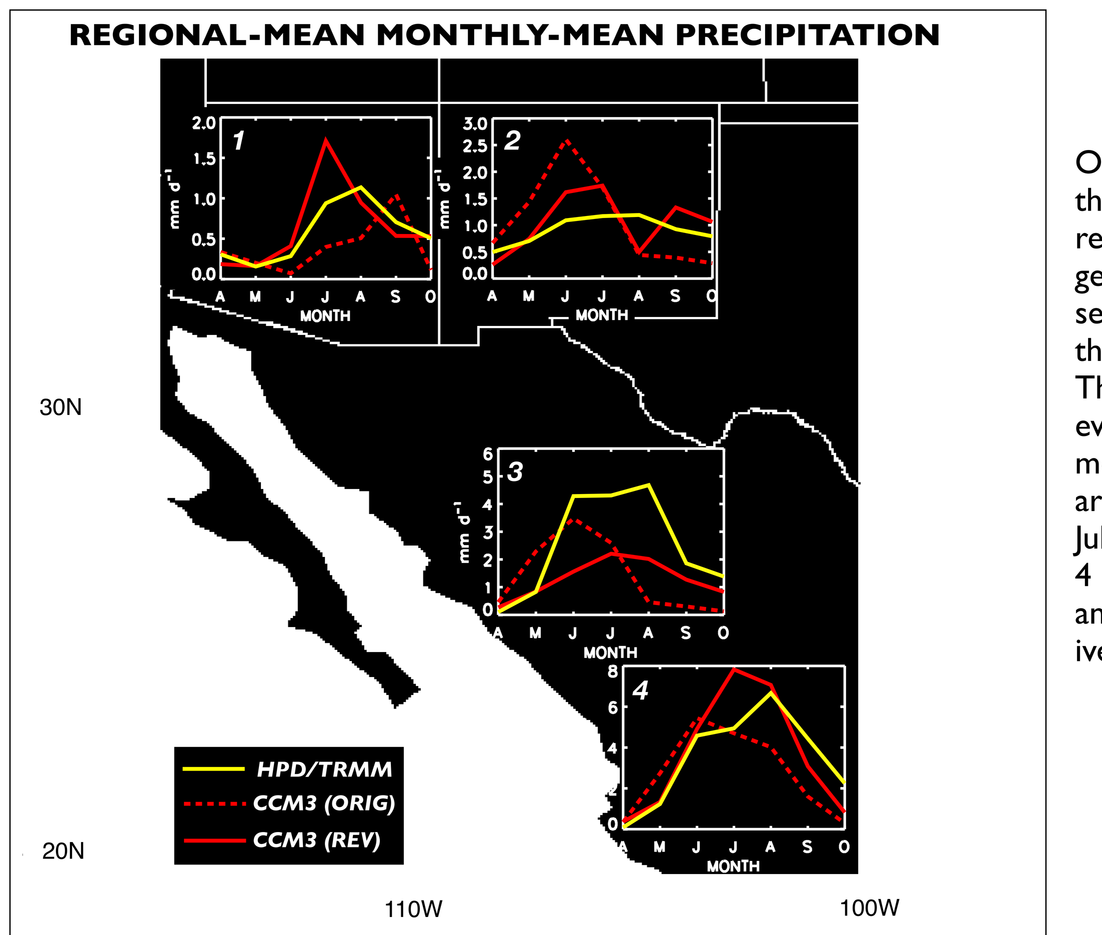

Figure 11. Regional-mean monthly-mean precipitation rate (mm d^{-1}) as averaged over 1994-2001 for regions 1 and 2 and over 1998-2001 for regions 3 and 4.

Over individual regions of the NAM domain, the revised convection scheme generates a more realistic seasonal cycle, relative to the observational data. The improvements are evident in the regional monsoonal peaks, which are shifted from June to July for regions 2, 3, and 4 (New Mexico, northern and central SMO respectively).

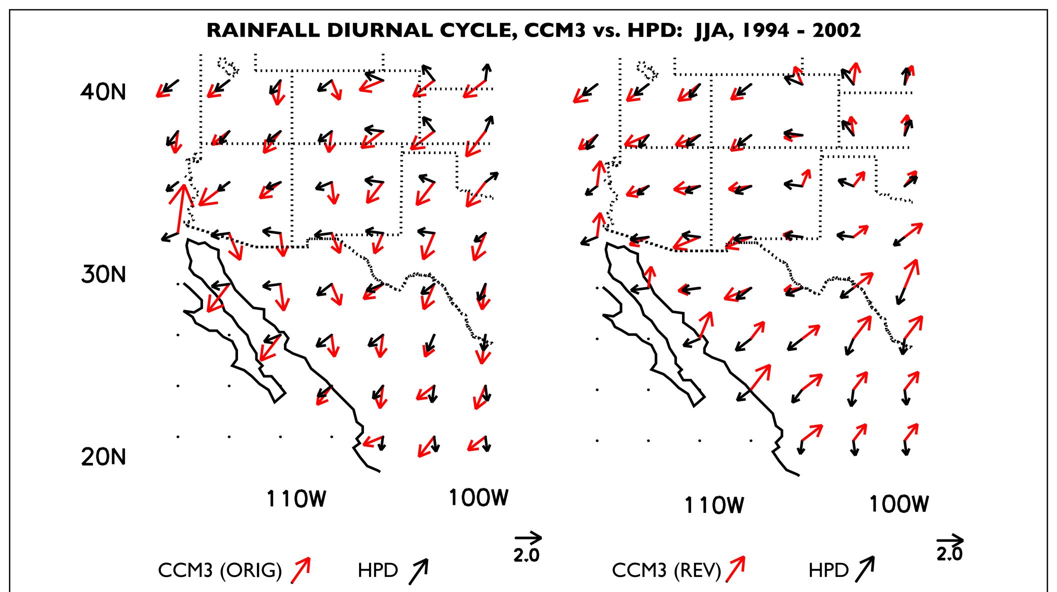

Figure 12. Diurnal + semidiurnal harmonics of JJA rainfall as simulated by CCM3 with the original convection scheme (left) and with the revised convection scheme (right) vs. HPD data. Arrow convention is the same as in Figure 8.

Using the revised convection scheme, the model's diurnal cycle phase biases over the SW U.S. and NW MX are eliminated.

On the other hand, phase biases *increase* south of 28°N and east of 105°W.

In general, phase biases decrease in regions where the diurnal cycle of precipitation is observed to *lag* that of CAPE. This includes the northern portion of the NAM domain. The revised scheme increases phase biases in regions where CAPE and precipitation are approximately in phase with each other. This finding suggests that the success of the improved parameterization is itself sensitive to the local convective regime.

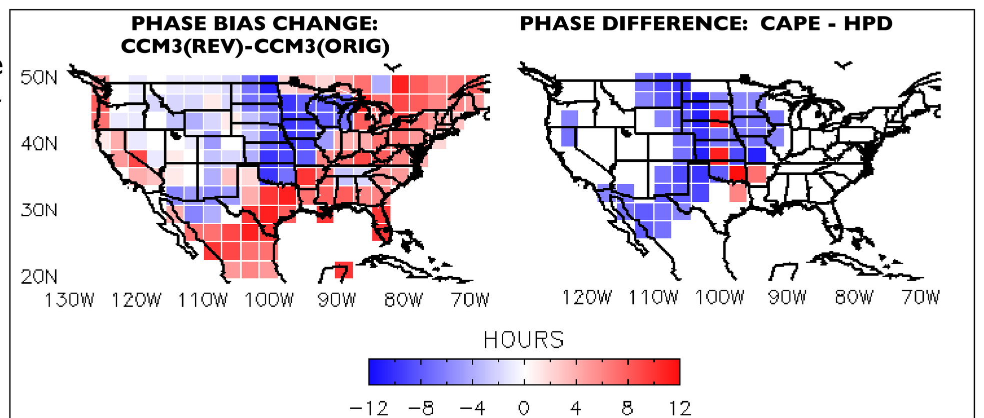

Figure 13. Change in the phase bias of the diurnal cycle of simulated precipitation due to the revised convection scheme (left) and the difference between the phase of the diurnal cycle of observed CAPE (calculated from the NCEP-NCAR reanalysis) and that of observed precipitation (right). Both maps represent averages for the JJA, 1994 - 2002 period.

IV. CONCLUSIONS

1. In the NCAR model, simulation of the North American monsoon suffers an unrealistic monsoonal evolution, a significant dry bias over the SW U.S., and convection which peaks at least 2 hours too early.
2. Except for an improved spatial distribution of rainfall over the SMO, most deficiencies are relatively insensitive to increasing horizontal resolution from T42 to T85.
3. Use of a revised convection parameterization, based on the large-scale forcing of environmental virtual temperature, results in a reduction in regional wet/dry biases, improved monsoonal evolution over specific regions, and elimination of diurnal cycle phase biases over the northern NAM domain. Reduction in diurnal cycle phase biases due to the new scheme occurs for a regime in which observed CAPE lags observed precipitation.

[1] Berbery, E.H., and M.S. Fox-Rabinovitz, 2003: Multiscale diagnosis of the North American monsoon system using a variable resolution GCM. J. Climate., **16**, 1929-1947.
[2] Gochis, D.W., W. J. Shuttleworth, and Z.-L. Yang, 2002: Sensitivity of the modeled North American monsoon regional climate to convective parameterization. J. Hydrometeor., **4**, 235-250.
[3] ---, 2003: Hydrometeorological response of the modeled North American monsoon to convective parameterization. J. Hydrometeor., **4**, 235-250.
[4] Mo, K.C., J.-K. Schemm, H. Juang, and R.W. Higgins, 2005: Impact of model resolution on the prediction of summer precipitation over the United States and Mexico, J. Climate, **18**, 3910-3927.
[5] Xu, J. and E.E. Small, 2002: Simulating summertime rainfall variability in the North American monsoon region: the influence of convection and radiation parameterizations. J. Geophys. Res., **107**, doi: 10.1029/2001JD002047.
[6] Zhang, G.J., 2002: Convective quasi-equilibrium in midlatitude continental environment and its effect on convective parameterization., J. Geophys. Res., **107**, doi: 10.1029/2001JD001005.
[7] Zhang, G. and N.A. McFarlane, 1995: Sensitivity of climate simulations to the parameterization of cumulus convection in the Canadian Climate Centre general circulation model. Atmos.-Ocean, **33**, 407-446.
[8] Zhang, G. J. and M. Mu, 2005a: Effects of modifications to the Zhang-McFarlane convection parameterization on the simulation of the tropical precipitation in the National Center for Atmospheric Research Community Climate Model, version 3. J. Geophys. Res., **110**, doi: 10.1029/2004JD005617.
[9] Zhang, G. J. and M. Mu, 2005b: Simulation of the Madden-Julian oscillation in the NCAR CCM3 using a revised Zhang-McFarlane convection parameterization scheme. J. Climate, **18**, 4049--4067.