The Relative Impact of Initial Land States on Warm Season Precipitation over North America with the Eta Regional Climate Model

Rongqian Yang and Kenneth Mitchell
5200 Auth Road
NOAA Science Center Environmental Modeling Center
NOAA/NWS/NCEP, Camp Springs, MD 20746
Email: Rongqian.Yang@noaa.gov

1. ABSTRACT

To examine seasonal climate predictability using regional models, in this study we developed and tested a high resolution Regional Climate Model (RCM). The model was based on the NCEP operational Eta model (as of 24 July, 2001, namely, the Eta model version in the National Centers for Environmental Prediction (NCEP) 25-year Regional Reanalysis), with changes made to make the model run over a longer time period and to update the sea surface temperature (SST), sea ice, greenness fraction, and albedo fields on a daily basis. The model was run on the same large domain as does the operational Eta model and Regional Reanalysis (RR), with a resolution of 32 km and 45 levels, as used in the Regional Reanalysis. Presently, the model can be executed off of analyzed lateral boundary conditions of the NCEP Global Reanalysis I and II or predicted lateral boundary conditions from the NCEP global Seasonal Forecast Model (SFM).

To examine the impact of initial land states and to test the skill of the Eta RCM in warm season precipitation simulations, two summertime cases (1990 and 1991) were chosen, where 1990 is the choice of North American Monsoon Assessment Project (NAMAP). Most previous studies of RCM seasonal simulation driven by analysis lateral boundary conditions and observed SST were initialized from one single date. In contrast, we executed 6 members whose starting dates vary by one and a half day. The study period is from May to September and the executions were started from late April and continued to early October. To test the relative importance of initial soil moisture and soil temperatures on seasonal precipitation simulations, two sources of land states were used. First was from the NCEP Global Reanalysis II (GR2), and the second was from the NCEP Regional Reanalysis. Results obtained from the two years are compared and our focus is the role of initial land states and interannual variability in precipitation.

We examine the resulting ensemble mean to demonstrate a) the role of initial soil moisture and soil temperature on seasonal precipitation simulation, b) whether the Eta RCM successfully captures both wet and dry interannual anomalies in total precipitation over the NAMAP core area and Arizona and New Mexico (AZNM) of U.S. between the two years, and c) there are substantial member-to-member variabilities in both total monthly precipitation. The results show that the use of RR soil moisture/land states in the Eta RCM improves the simulation of interannual variability between two years,

suggesting that the Eta RCM is sensitive to the choice of initial land states, and the model can capture the dry bias of precipitation over the core monsoon region in 1991. Also the wide spread among ensemble members suggests that previous RCM studies that employed only "one member" and initialized from one single date may be misleading by failing to represent the inherent internal variability, indicating that a choice of ensemble strategy embracing different initial conditions is important to warm season precipitation simulations.

2. INTRODUCTION

It is well established that seasonal climate anomalies over continental regions are forced in part by slowly varying boundary conditions of sea surface temperature and land surface conditions. It is also well realized that the SST anomalies, especially in the tropical oceans, can be predicted by the coupled ocean-atmosphere model. One would expect that accurate prediction of boundary conditions would allow prediction of regional climate for a lead time beyond the limit of a deterministic predictability. Land surface potentially provides additional sources of extended predictability for climate. The intrinsic time scales for land surface is much longer than those of atmosphere-only processes. The land surface variability is fundamentally less dynamic than atmosphere or ocean. However, compared to oceans, much less research has focused on the impacts of land-atmosphere interactions, particularly impact of the initial land states on the seasonal precipitation simulations.

The North American Monsoon (NAM) has particular importance to southwestern U.S. and Northwestern Mexico regions. The timing of its onset and duration have important implications for many climate studies and water resources management applications as it involves land/sea and atmosphere interactions, especially at the presence of land/sea contrasts and complex terrain. Land surface conditions, soil moisture, in particular, have been shown to have a large impact on warm season climate prediction in many observational and numerical studies and to be responsible for modulating the surface atmosphere interactions at a continental scale, at time scales ranging from the diurnal to the seasonal. For example, in the NCEP Global Forecast System (GFS) the prediction skill of surface temperature increases considerably over the core monsoon region with initialized soil moisture. Hong and Pan (2000) showed that there is a strong positive feedback between the initial soil moisture anomalies and simulated seasonal precipitation in their 3-month integration with the NCEP Regional Spectral Model (RSM). They found that the response of precipitation to soil moisture anomalies is region dependent and the processes involved are not well understood. A better understanding of the processes in the atmosphere and the physics behind these processes should advance the accuracy of hydroclimate forecasts.

To investigate how initial soil moisture and its associated land states (including soil moisture, soil temperature, and skin temperature among others) influence summertime precipitation simulations, particularly over the NAM regions, in this study we use the Eta Regional Climate Model (Eta RCM) developed at NCEP and evaluate the differences in precipitation caused by using two different sources of land states, focusing on the seasonal variation of area averaged monthly mean precipitation over the core monsoon area and Arizona New Mexico region and interannual variability.

3. MODEL, DATA AND CASES CHOSEN

To assess if regional climate modeling can add values to existing climate modeling using downscaling technology, we developed and tested a high-resolution Regional Climate Model. The regional climate model used in this study is a slightly modified version of the NCEP Eta model that became operational in November of 2001. The Eta model is a state-of-the-art mesoscale weather forecast model, with an accurate treatment of complex topography using the eta vertical coordinate and step-like mountain (Mesinger, 1984; Black, 1994), which eliminates errors in the pressure gradient force over steeply sloped terrain present in the sigma coordinates. The model employs semi-staggered Arakawa E-grid in which wind points are adjacent to mass points, configured in a rotated spherical coordinates. The model physics has been described by Janjic (1990, 1994), and includes a modified Betts-Miller scheme (Betts and Miller, 1986) for deep and shallow convection, and predicted cloud water. The GFDL scheme is used for radiation. Free atmospheric turbulent exchange above the lowest model layer is via Mellor-Yamada level 2.0, and the surface layer similarity functions are derived from Mellor-Yamada level 2.0 (Mellor and Yamada, 1982). A viscous sublayer is used over water surfaces. The land surface is a version of the Oregon State University scheme modified by Chen et al (1997) and Ek (2003).

To test how the model performs in the simulation of warm season precipitation, the Eta Regional Climate Model developed was used. The model was based on the operational Eta model as of July 24, 2001 and as implemented in the Regional Reanalysis. Currently, the model has a horizontal resolution of 32 km with 45 levels. The time step is 90 seconds. To make the model run over a longer period of time, we update sea surface temperature on a daily basis. We also update monthly greenness fraction based on satellite NDVI based products, and seasonal 1 degree snow free albedo climatology.

Two sources of initial land states were used. The first is from the NCEP Global Reanalysis II, and the other is from the just completed NCEP Regional Reanalysis. The initial snow depth data were from the US Air Force 47 km daily snow depth analysis. In contrast to traditional "one member" method, we use 6 ensemble members, whose starting dates vary by 1 and a half day. They are 12Z of 23, 27, 31 of April and 00Z of 25, 29 of April, and 1 of May respectively. The integration is about 5 months long, starting from late April to the end of September.

The results shown here are ensemble means using different land states for both years. Our focus is two-fold. One is the total precipitation. The other is interannual variability.

4. RESULTS

To iterate, the goal of this study is to study the differences in precipitation simulation, particularly over NAM core and AZNM areas arising from using two different sources of initial land states. To do this, we executed the Eta RCM using 6 ensemble members for both 1990 and 1991. We first present results for 1990 using GR2 land states. This is followed by results from the exact same configurations but with the RR land states. We repeat this exercise for 1991 (only ensemble means are shown). A comparison of interannual variability using different sources of initial land states and some preliminary conclusions are then presented.

Figure 1 shows the ensemble mean of total precipitation (in mm) for the summer of 1990 using GR2 land states. Figure 2, Figure 3, and Figure 4 are the same except for the months of July, August, and September. Inspection of these figures reveals buildup of the North American Monsoon in June, onset during July, as manifested by the amount of precipitation over the NAME core area (from 112 ° W to 106° W, 24° N to 30° N), continuation on August, and dying down on September, demonstrating that the Eta RCM can capture the life cycle of NAM evolution.

It should be pointed out that the wide spread in precipitation among ensemble members (shown on the three panels on Figures 1-4) suggests that the model is sensitive to initial conditions and more ensemble members might be needed. The top left panels are ensemble means, whereas the top right and the two bottom panels are individual members. They are from 00Z of May 1, 12Z of April 29, and 00Z of April 28 runs respectively.

Figure 5 shows the area-averaged precipitation over both NAM core and AZNM (Arizona and New Mexico) areas. Comparison with observations (solid black lines are model results, dash lines are observations) shows that the Eta RCM underestimates the area averaged precipitation over the core area. However, it does a much better job over the AZNM region, where the model results show closer to the observations. In general, the model can capture the seasonal variations of precipitation over the two regions (maximum precipitation on July). The bottom two panels show results from individual members over CORE and AZNM areas (where the AZNM area is from 112.5 ° W to 107.5 ° W, and 32 ° N to 35 ° N). The evolution of these curves indicates that not all the members have the July maximum precipitation, especially over the AZNM region, where 2 out of 6 members show a maximum precipitation on August.

Figures 6 - 9 are the exact same as Figures 1 - 4 except that the RR land states were used. Figure 10 is the same as Figure 5 except this plot was generated from the model runs using RR land states.

Comparison between Figures 5 and 10 indicates that the model generates more precipitation over the NAM core area, and slightly higher precipitation over the AZNM region when the GR2 land states were used. Also, the timing of simulated maximum precipitation (July or August) suggests that soil moisture plays an important role in determining the intensity and the timing of maximum precipitation.

Figure 11 is the differences in total soil moisture availability between the two sources of initial land states. Close inspection reveals that the total soil moisture availability is larger in the GR2 land states over the core monsoon area, whereas RR land states exhibit a drier soil instead. Note that the same land surface model was used in both RR data assimilation and the Eta RCM, indicating that a mismatch between the land surface scheme used in the data assimilation model and the regional climate model could have a large impact on seasonal precipitation simulations.

Figures 12 and 13 are the ensemble means of total precipitation from May to August for 1991 using both GR2 and RR land states, when a relatively dry year over the core monsoon region occurred.

Figures 14 and 15 show the differences in total precipitation between the two years using GR2 and RR land states.

Figure 16 shows observed differences in total precipitation between the two years. Compared to observations, the interannual variability using RR land states seems to be better, although a relatively less precipitation was simulated by the model. Especially, on July, the model results with the RR land states show much closer to observations over the eastern part of the country, demonstrating that the difference in initial soil moisture can make a difference not only in warm season precipitation simulations during the first couple of months. The interannual variation was significantly impacted as well.

5. CONCLUSIONS AND FUTURE WORK

This study presents the simulation results of the Eta RCM runs using two different sources of initial land states for both 1990 and 1991, focusing the differences in the total precipitation over the core monsoon and AZNM regions.

The model is able to capture the dry/wet anomalies between the two years, demonstrating that the lateral boundary conditions do play an important role in these two years. The impact of difference in initial prescribed land states is evident not only for the first couple of months, but also the interannual variability, indicating that the contribution of land surface to precipitation anomalies is only part of the story and something else also plays a bigger role and needs to be investigated further.

The response of precipitation to the difference in the initial land states is region dependent. These figures show that the strongest response is on the central and eastern part of the country in July. For the rest of the country, the response is relatively weak, suggesting that local processes might dominate the overall responses.

It should be pointed out that the model results are sensitive to many factors, including domain size, convection schemes, and the location of lateral boundary. The results are also model dependent. Studies such as Seth and Giorgi (1998) suggest that in order to study internal forcing, the domain size should be much larger than the area interested. As a consequence, cautions are advised when using and interpreting these results.

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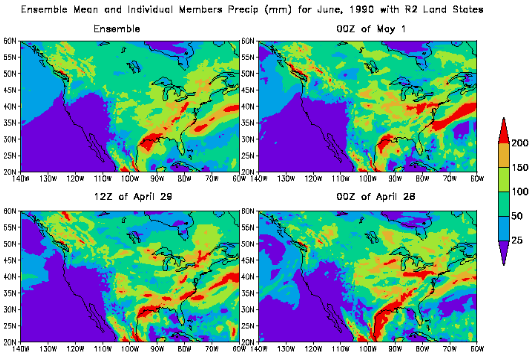

Figure 1. Ensemble Mean Precip and Individual Members for June, 1990 using GR2 land states

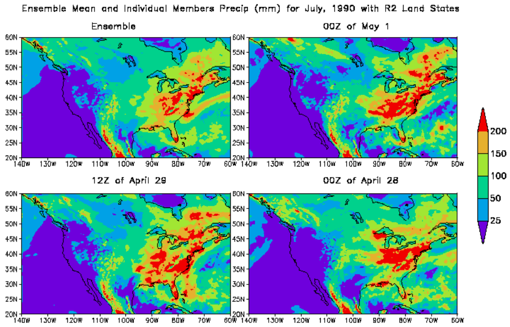

Figure 2. Ensemble Mean Precip and Individual Members for July, 1990 using GR2 land states

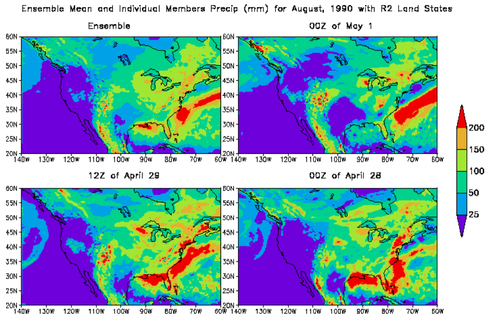

Figure 3. Ensemble Mean Precip and Individual Members for August, 1990 using GR2 land states.

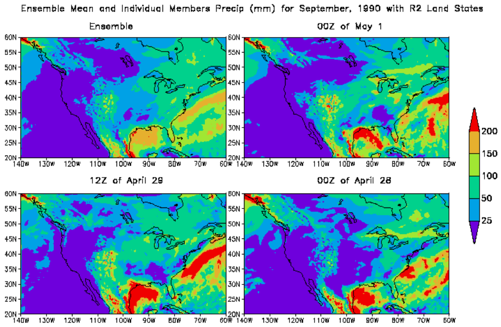

Figure 4. Ensemble Mean Precip and Individual Members for September, 1990 using GR2 land states.

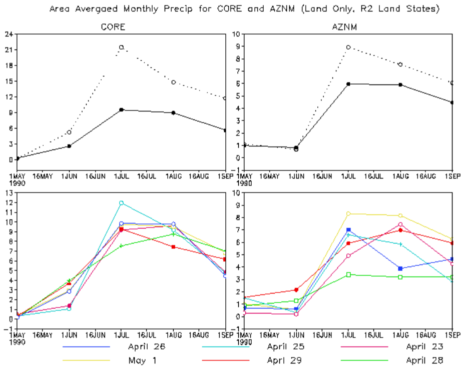

Figure 5. Area Averaged Ensemble and Individual Members Monthly Precip over the CORE and AZNM areas using GR2 land states.

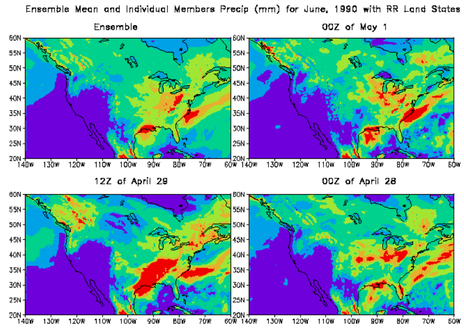

Figure 6. Ensemble Mean Precip and Individual Members for June, 1990 using RR land states.

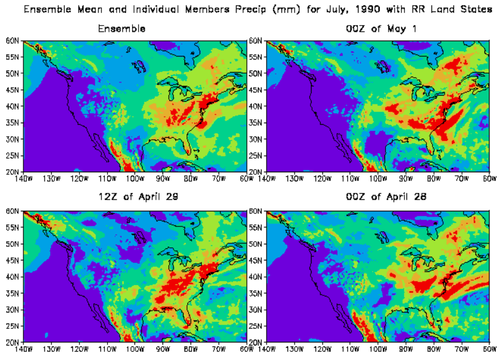

Figure 7. Ensemble Mean Precip and Individual Members for July, 1990 using RR land states.

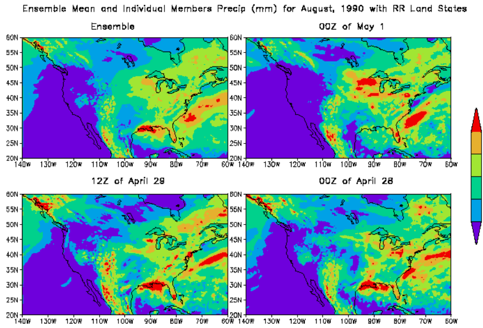

Figure 8. Ensemble Mean Precip and Individual Members for August, 1990 using RR land states

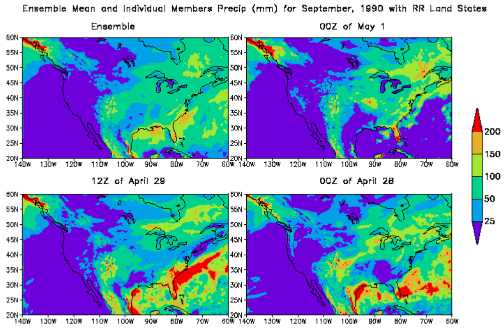

Figure 9. Ensemble Mean Precip and Individual Members for September, 1990 using RR land states

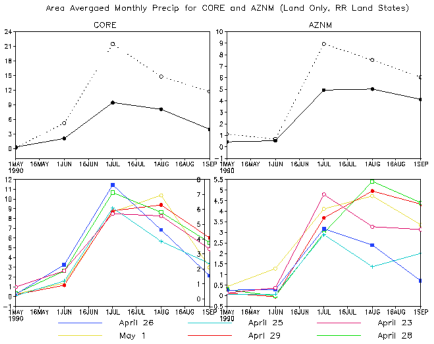

Figure 10. Area Averaged Ensemble and Individual Members Monthly Precip over CORE and AZNM areas using RR land states

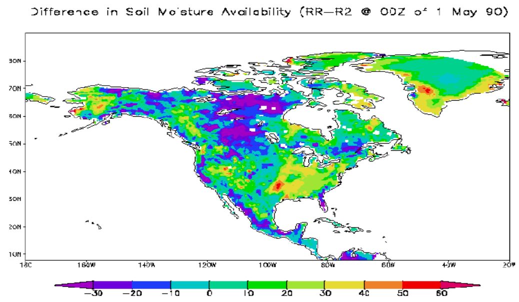

Figure 11. Differences in total soil moisture availability between the two sources of initial land states.

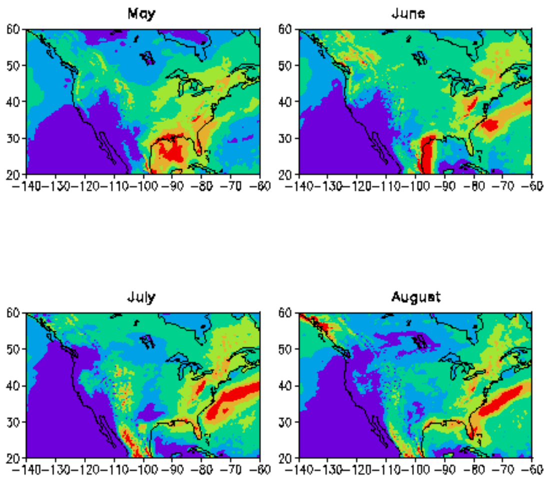

Figure 12. Ensemble Mean Precip and Individual Members for May, June, July, and August, 1991 using GR2 Land states

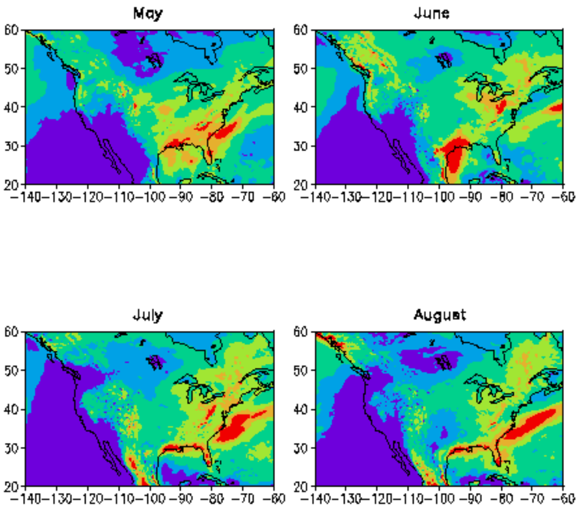

Figure 13. Ensemble Mean Precip for May, June, July, and August, 1991 using RR land states

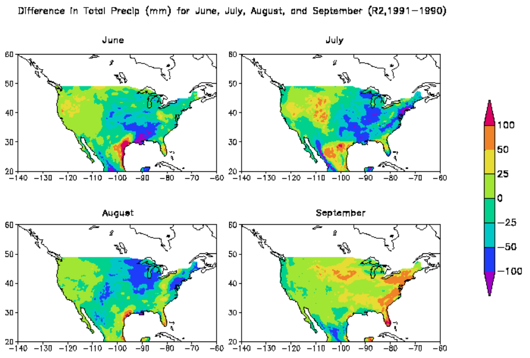

Figure 14. Differences in total precipitation between the two years using GR2 land states

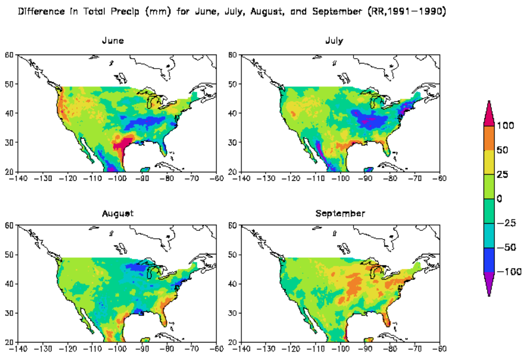

Figure 15. Differences in total precipitation between the two years using RR land states

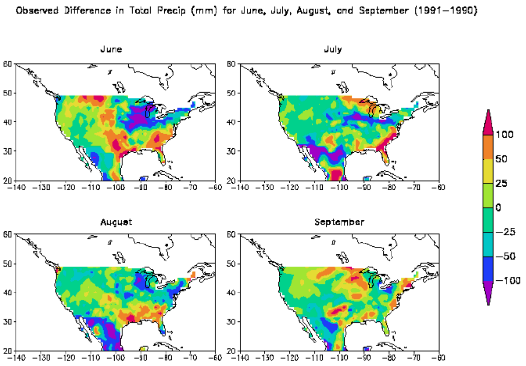

Figure 16. Observed differences in total precipitation between the two years (91-90).