9.2 SIMULATION OF WARM SEASON RAINFALL USING WRF REGIONAL CLIMATE MODEL

James M. Done* L. Ruby Leung[2], Christopher A. Davis[1] and Bill Kuo[1]
1. National Center for Atmospheric Research, Boulder, CO
2. Pacific Northwest National Laboratory, Richland, WA

1 INTRODUCTION

Regional Climate Models (RCMs) derive benefits over global climate models through a more accurate representation of regional climate forcings, achieved through higher resolution orography, land-water contrasts and land surface characteristics. Regional forcings can produce statistically significant climate signals, particularly for processes forced directly by topography including orographic rainfall and monsoon circulations. Such high resolution climate scenarios are important for resource management and impact assessment. Better resolved small-scale processes can have improved large-scale impacts and, in addition to downscaling climate information, RCMs can be used to study the upscale impact of regional forcings on the large-scale climate.

The high order numerical accuracy of the Weather Research and Forecasting (WRF) model and the extensive physics options have motivated the development of WRF as a regional climate model. Previous regional climate research using WRF RCM (Done *et al.*, 2004) has focused on the region of the Western United States where topographic forcings play an important role in defining the regional climate. The work presented herein represents the next step in assessing the capability of WRF RCM by evaluating the modeled warm season regional climate of the central US. Warm season rainfall over the central US has been identified with physical mechanisms at both planetary and local scales, and is therefore ideal for evaluating the performance of a RCM. In addition to evaluating WRF RCM, our goal is to identify and understand recurrent errors in the long-term simulation of warm season rainfall.

2 METHOD

Model Setup and Datasets

The record flooding over the Mississippi River Basin during June and July 1993 has been the subject of active RCM research (e.g. Liang and Kunkel (2001)), and is chosen as a case study for evaluating warm season regional climate simulations using WRF RCM. The floods coincided with an anomalous southward displacement of the Upper Level Jet (ULJ), a sustained Low-Level Jet (LLJ) and enhanced moisture convergence into the Basin resulting in frequent mesoscale convective activity (Mo *et al.*, 1995).

**Corresponding author address:* James M. Done, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307, USA ; e-mail: done@ucar.edu

The domain of 200×140 grid points (see for example Fig. 1a) covers the majority of the North American continent. The domain extends far enough west to include the ULJ upstream of the continent, and extends far enough south to include the Gulf of Mexico; the source region for the LLJ. Simulations are performed using a horizontal grid spacing of 30km and 31 vertical sigma levels. Initial condition and lateral and lower boundary conditions are derived from the NCEP-NCAR reanalyses at 2.5° interpolated onto the WRF RCM grid. Climate simulations are initialized on 1st October 1992 and run to 1st August 1993 with boundary conditions updated every 6 hours. Boundary relaxation has a combined linear/exponential functional form over 10 grid points. The orography includes terrain features on the smallest resolvable scales of the model. To aid long-term integrations Sea Surface Temperatures (SSTs), vegetation fraction and albedo are updated every 6 hours.

Surface and boundary-layer processes are represented by the Monin-Obukhov (Janjic Eta) surface scheme, the Noah land surface model and the Mellor-Yamada-Janjic (Eta) TKE scheme. Convection is parameterized by the Grell-Devenyi ensemble scheme, explicit precipitation processes are parameterized by the Ferrier scheme, and radiation is represented by the rapid radiative transfer model and the Dudhia short-wave scheme.

The dataset used to analyse warm-season rainfall over the United States consists of daily rain accumulations gridded at 1/24° (approximately 4.4km), developed by C. Daly and W. Gibson of the Spatial Climate Analysis Service at Oregon State University and G. Taylor of the Oregon Climate Service at Oregon State University. This dataset is available at $http://www.ocs.orst.edu/prism/docs/meta/$. A statistical topographic-precipitation relationship, developed by Daly *et al.* (1994), is used to spatially interpolate the station observations to capture the mesoscale details of precipitation distribution in regions of complex terrain.

As a first step towards understanding the model regional climate, simple experiments are performed to test the sensitivity of flood-region average rainfall to the choice of convection scheme, land-surface initialization, the choice of land surface model and errors in Gulf SSTs. To provide deeper insight into the mechanisms leading to errors in climate simulations, comparisons are made with series of concatenated weather forecasts using WRF RCM. Weather forecasts are initialized at 12 UTC daily, and the 12-36 hour periods are concatenated. All other

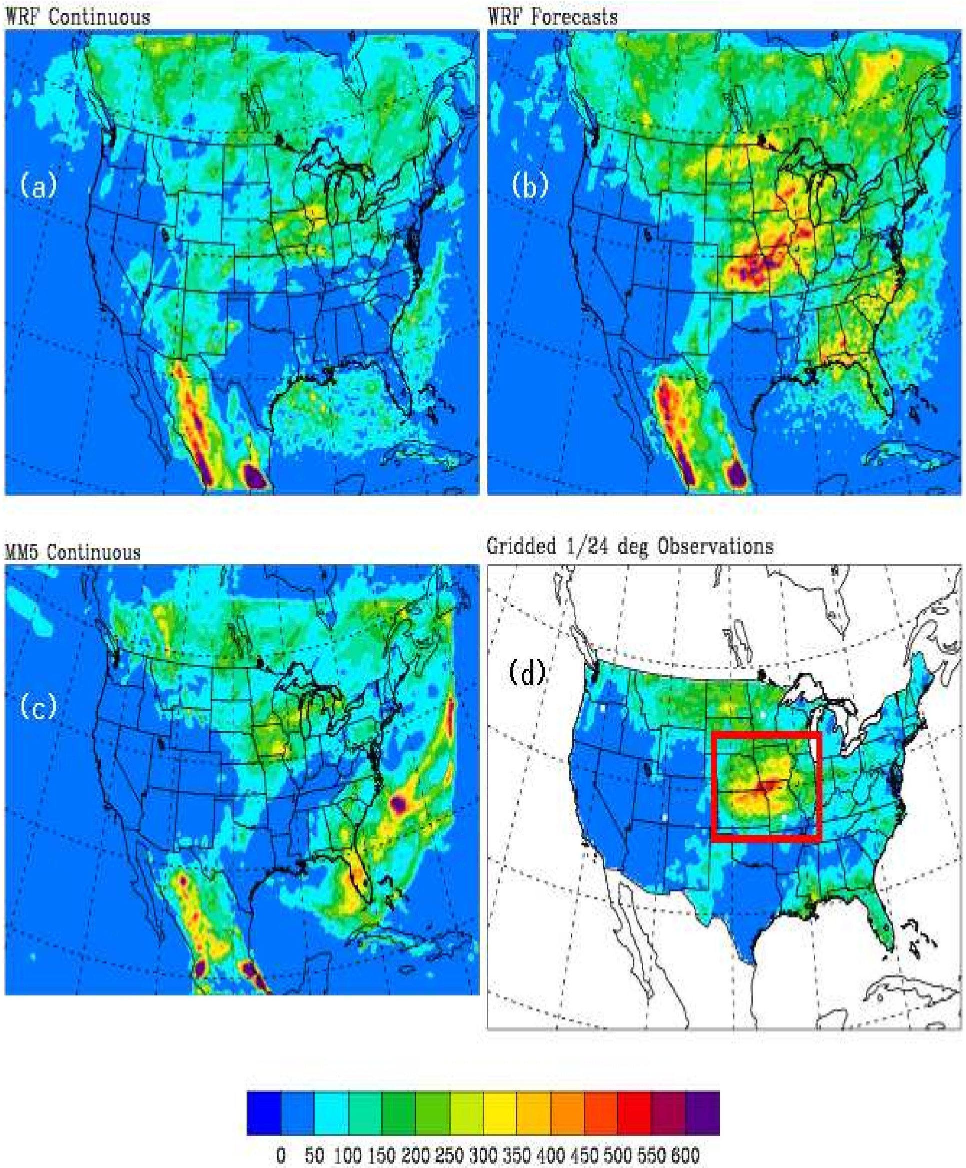

Figure 1: Rainfall (mm) for July 1993 for (a) the climate simulation using WRF RCM, (b) the weather forecasts using WRF RCM, (c) a climate simultaion using MM5 and (d) 1/24° gridded observations. The red-box in (d) indicates the flood region over which area average rainfall values are taken.

model details are the same as for the climate simulations. It is anticipated that the large scale circulation in the weather forecasts will not deviate too much from the large scale analysis (because of the short simulation time) so that a comparison between the forecasts and climate simulation may reveal the impacts of large scale biases within the WRF domain on the climate simulation. Specifically, rainfall, large-scale dynamics and boundary-layer structure are compared between climate simulations, series of weather forecasts and NNRP analyses and observations.

3 RESULTS

Rainfall

The simulation of the 1993 flood using WRF RCM underpredicts rainfall amount within the flood region (as defined by the red box in Fig. 1d), as shown by a comparison of Figs. 1a and 1d, producing 57% of the observed rainfall amount. A simulation using the fifth-generation Pennsylvania State University-NCAR mesoscale model (MM5) with similar model set-up also underpredicts flood-region rainfall by a similar amount (also shown in Fig. 1). This underprediction of warm-season rainfall in climate simulations appears to be a recurrent problem for RCMs (Ruby Leung, personal communication).

Results from the series of sensitivity experiments are

Data	*Convection Scheme*	*Land Surface Model*	*Flood-Region Average Rainfall (mm)*
WRF Climate	GD	Noah LSM	97
WRF Climate	BM	Noah LSM	97
WRF Climate	KF	Noah LSM	80
WRF Climate	GD	RUC LSM	91
WRF Climate	GD	Noah LSM*	107
WRF Climate	GD	Noah LSM**	104
MM5 Climate	KF	OSU LSM	95
WRF Forecasts	GD	Noah LSM	233
Obs (1/24°)			165

Table 1: Sensitivity of flood-region average rainfall for July 1993. Highlighted in red is the component of the model that has changed between experiments. *Gulf SSTs increased by 1.5K. **Soil moisture multiplied by 1.3 on 1st June 1993.

presented in Table 1. Experiments differ in one aspect of either the model initialization or physics parameterization in order to assess the sensitivity of flood-region rainfall to different components of the model, and to understand which mechanisms contribute to the lack of rainfall in the climate simulation. The flood-region average rainfall for July 1993 shows low sensitivity to the choice of convection scheme and land surface model. Some studies have shown a large impact of the land-surface conditions on the 1993 flood (e.g. Paegle *et al.* (1996)). However, experimentation with soil moisture initialization shows that errors in soil moisture are unimportant for long-term rainfall simulation. In addition, a simulation with modified SSTs over the Gulf of Mexico (a moisture source region) shows low sensitivity of flood-region rainfall to errors in Gulf SSTs.

The series of weather forecasts using WRF RCM overpredicts rainfall within the flood region (as shown by a comparison of Figs. 1b and 1d), producing 135% of the observed rainfall amount. The series of short-term rainfall forecasts shows that WRF RCM is clearly able to produce the approximate magnitude of the observed rainfall, even in excess. Differences in the large-scale flow between the climate simulations and the weather forecasts (not shown) are thought to contribute to the differences in flood-region rainfall amounts. This suggests that longer-timescale feedback mechanisms are not being represented accurately in climate simulations.

Diurnal Cycle

A strong climate signal over the Midwest is the diurnal cycle in warm-season rainfall (e.g. Carbone *et al.* (2002)), and the associated diurnal cycle in the Great Plains LLJ and boundary-layer thermal structure. Both the climate simulation and the weather forecasts capture a diurnal cycle of model rainfall closely in phase with the observed diurnal cycle, as shown in Fig. 2. Rainfall amounts are overpredicted by the weather forecasts and underpredicted by the climate simulation throughout the diurnal cycle.

The climate simulation and weather forecasts also

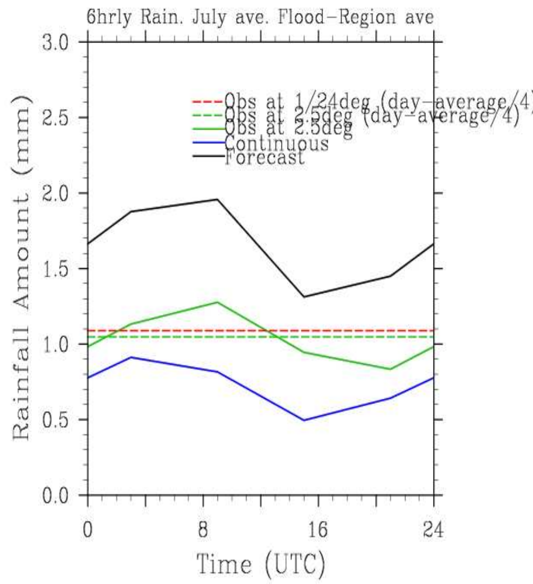

Figure 2: July-average diurnal cycle of rainfall averaged over the flood region for the weather forecasts (black), the climate simulation (blue), and observations at 2.5°×2.0° (green). Sub-daily observations at 1/24° are not easily available so the 24hr mean for the two observational datasets are included for comparison (dashed).

show a diurnal cycle in the strength of the LLJ (see Fig. 3). However, the LLJ in the climate simulation is too shallow compared to the LLJ in the NNRP analyses. An analysis of the July-average boundary-layer structure shows reasonable prediction of boundary layer temperature in the weather forecasts whereas the boundary layer is persistently too cool in the climate simulation (see Fig. 3). A shallower LLJ and a cooler boundary layer contribute to a less favorable profile for the convection initiation and subsequent mesoscale organization.

4 DISCUSSION

Climate simulations using WRF RCM underpredict rainfall amounts during the 1993 flood, and show low sensitivity to the choice of convection scheme, the choice of land surface model, the initial land surface state and errors in Gulf SSTs. The overprediction of flood-region rainfall by a series of weather forecasts suggests the lack of rainfall in climate simulations is due to either poor representation of longer timescale feeback mechanisms or the presence of unphysical feedbacks due to the model setup. Errors in the large-scale flow, such as the shallow LLJ, may be a result of such feedback mechanisms that indirectly affect long-term rainfall simulation. Candidate mechanisms thought to be important for long-term rainfall simulations include the convective cloud-radiation feedback and the interactions and reflection of the internal domain dynamics with the lateral boundaries (as evidenced in Miguez-Macho *et al.* (2005)).

A more detailed comparison of the climate simulations and the series of weather forecasts is needed to

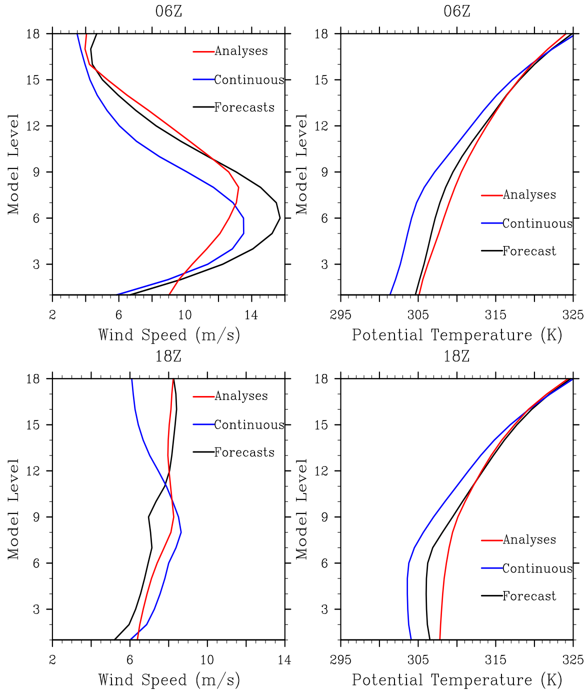

Figure 3: July-average vertical profile of wind speed (left) and potential temperature (right) averaged over the flood region at 06UTC (local midnight, top) and 18UTC (local noon, bottom) for the weather forecasts (black), the climate simulation (blue) and NNRP analyses (red).

identify the mechanisms responsible for the lack of rainfall in climate simulations. In particular, a detailed comparison of the tendency terms for the large-scale flow and thermal structure is proposed.

ACKNOWLEDGEMENTS. We thank Wei Wang and Jimy Dudhia for assistance with the WRF model. This work is supported by the NCAR FY05 opportunity fund.

REFERENCES

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

Daly, C., Neilson, R., and Phillips, D. (1994). A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *J. Appl. Meteor.*, **33**, 140–158.

Done, J., Leung, L., Davis, C., and Kuo, B. (2004). Regional climate simulation using the WRF model. In *Preprints from the 5th WRF/14th MM5 Users' Conference, Boulder, 22-25 June*.

Liang, X.-Z. and Kunkel, K. (2001). Development of a regional climate model for U.S. Midwest applications. Part I: Sensitivity to buffer zone treatment. *J. Climate*, **14**, 4363–4378.

Miguez-Macho, G., Stenchikov, G., and Robock, A. (2005). Regional climate simultaions over North America: Intercation of local processes with improved large-scale flow. *J. Climate*, **18**, 1227–1246.

Mo, K., Nogues-Paegle, J., and Paegle, J. (1995). Physical mechanisms of the 1993 summer floods. *J. Atmos. Sci.*, **52**, 879–895.

Paegle, J., Mo, K., and Nogues-Paegle, J. (1996). Dependence of simulated precipitation on surface evaporation during the 1993 United States summer floods. *Mon. Wea. Rev.*, **124**, 345–361.