UNDERSTANDING ERROR IN THE LONG-TERM SIMULATION OF WARM SEASON RAINFALL USING THE WRF MODEL

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

1 INTRODUCTION

Owing to higher resolution, Regional Climate Models (RCMs) include a more precise description of regional topographic forcings due to orography and land surface heterogeneity than current global climate models. Higher resolution also allows for a better representation of smaller scale atmospheric phenomena such as mesoscale convection.

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. The predictability of regional climate is weakest during the warm-season over continental regions (Vidale *et al*., 2003). Lüthi *et al.* (1996) showed a RCM was less able to capture warm-season interannual variability than for the cold-season. Difficulty arises due to warm-season precipitation distribution being more substantially affected bye small-scale moist convection and surface hydrological processes, and warm-season interannual variability being associated with weaker effects in the dynamical fields than for the cold-season.

Many studies have looked at the sensitivity of the model warm-season climate to physical parameterizations, often with contrasting results. A second major source of error in RCM simulations arises from artifical constraints due to the model setup. Domain size appears to be a key factor for regional climate simulation (Vannitsem and Chromé, 2005). Seth and Rojas (2003) found that not only the simulated regional climate but also the climate sensitivity are a function of domain size.

In this study, the Weather Research and Forecasting (WRF) model is used in regional climate mode to identify and understand errors in the long-term simulation of warm season rainfall. The relative importance of physics versus model set-up constraints is investigated in a series of sensitivity studies. This study also aims to establish the WRF model as a valid tool for regional climate research.

2 MODEL SET-UP AND DATASETS

The WRF model is driven by initial, lateral and lower boundary conditions derived from the NCEP-NCAR reanalyses at 2.5° grid-spacing. Code modifications[1] to aid long-term integration include: updated sea surface temperature (SST), vegetation fraction and surface albedo; a combined linear-exponential functional form for the lateral boundary buffer zone (detailed in Liang *et al.* (2001)) and a wider buffer zone of 10 grid-points, following Giorgi *et al.* (1993).

Physics parameterizations are selected to be appropriate for long-term integrations and no attempt has been made to tune physics schemes to the grid spacing. Boundary and surface-layer processes are represented by a Monin-Obukhov surface scheme, the Noah land surface model and the YSU boundary layer scheme. Convection is parameterized by the Eta Kain-Fritsch scheme, based on Kain and Fritsch (1993). Explicit precipitation processes are parameterized by the WRF Single Moment 6-class microphysics. The long-wave and short-wave radiation scheme from the NCAR Community Atmosphere Model (http://www.ccsm.ucar.edu/models/atm-cam/) has been implemented into WRF and includes aerosol effects and updated ozone.

The observational dataset consists of daily rainfall amount and daily maximum and minimum 2m temperature 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[2].

3 MODEL SIMULATIONS

The model is run continuously for 6 years from 1st January 1988. This period includes the 1988 summer drought and the 1993 summer flood over the central U.S. The domain is large such that any contamination of sensitivity studies by lateral boundary forcing is minimized. Specifically, rainfall and large-scale dynamics are compared between climate simulations, NNRP analyses and observations for the warm-season, defined as the period June-July-August (JJA).

A number of 2-month simulations are performed to study the sensitivity of the model climate to aspects of the model including the choice of convection scheme, the choice radiation scheme, the cloud fraction parameterization and the magnitude of SSTs in the Gulf of Mexico. All other model details are the same as for the 6-year continuous simulation. The sensitivity simulations are made using restart files from the continuous 6-year simulation at 1st June 1993. This ensures the soil conditions have

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

[1] The regional climate capability of the WRF model has been implemented as an option to the standard WRF model, following a single source approach.

[2] This dataset is available at http://www.ocs.orst.edu/prism/docs/meta/

spun up and are in balance with the model climate. This period was chosen to include the 1993 summer flood over the MidWest: a subject of active RCM research (e.g. Anderson and Coauthors (2003)). A follow-on experiment to examine the importance of domain size is described in section 4.

4 RESULTS

Warm-Season Rainfall

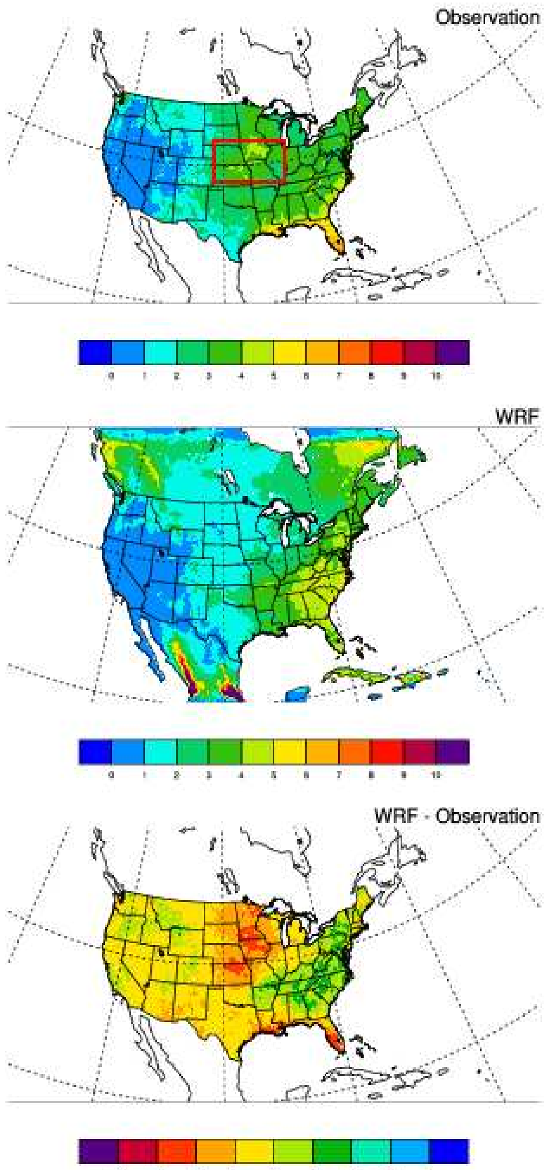

Figure 1: 6-Year warm-season average daily rainfall (mm) for (top) 1/24° gridded observations, (middle) WRF model and (bottom) the difference (model - observation). The red-box in (top) indicates the flood region over which area average rainfall values are taken.

A comparison of the 6-year mean warm-season daily rainfall between the RCM and the observations, shown in Fig. 1, shows a lack warm-season precipitation over the MidWest and the Gulf of Mexico coastal regions and an excess of rainfall over the Eastern U.S. This underprediction over the MidWest is consistent with many previous regional climate studies in the literature, and is a robust error in long-term simulations. The RCM simulation produces a general increase in rainfall across the U.S. from west to east and fails to reproduce the local rainfall maxima over the MidWest.

Warm-season rainfall over the Midwest is associated with mechanisms at both synoptic and local scales. Firstly, the large-scale dynamics of the model climate are less favorable for organized convection than in the analyses; the Upper-Level Jet (ULJ) has less meridional variability and reduced magnitude (not shown), and the northern extent of the Low-Level Jet (LLJ) over the central U.S. is reduced and the LLJ is too weak (not shown). Secondly, the soil conditions are too dry compared to the analyses (not shown). The relative importance of the soil conditions versus the large-scale dynamics have yet to be determined.

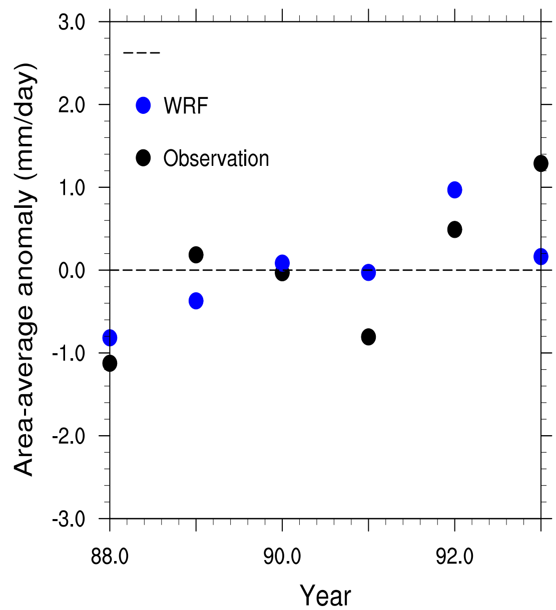

Figure 2: Departure of warm-season daily rainfall from the 6-year average, area-averaged over the MidWest for observations (black) and model (blue).

Fig. 2 shows the model and observed departure of warm-season rainfall from the 6-year mean for the region of the MidWest. The model is able to broadly capture the observed interannual variability in rainfall, and the 1993 minus 1988 precipitation signal is quite well simulated by the model.

Model Climate Sensitivity

Sensitivity simulations provide some insight into the lack of model warm-season rainfall over the MidWest. Simulations differ in one aspect of the model as outlined in Table 1. All simulations underpredict rainfall totals, but do capture a local maxima in rainfall over the MidWest, although not necessarily the precise location observed (not shown). The flood-region average daily rainfall totals for July 1993, given in Table 1, show generally low sensitivity to the changes in model physics and Gulf SSTs. The simulation using Grell Devenyi convection produces an even balance between parameterized and explicit convection, and produces the highest rainfall of all experiments at 72% of the observed. Rainfall from all other simulations falls in the range 38% - 52% of the observed.

There is current debate in the literature concerning the importance of land-surface conditions on the 1993 flood (e.g. Paegle *et al.* (1996)). As mentioned earlier, model soil conditions are too dry over the MidWest. Future work aims to assess sensitivity to soil moisture and to assess the strength of the land-surface atmosphere interaction.

Domain size

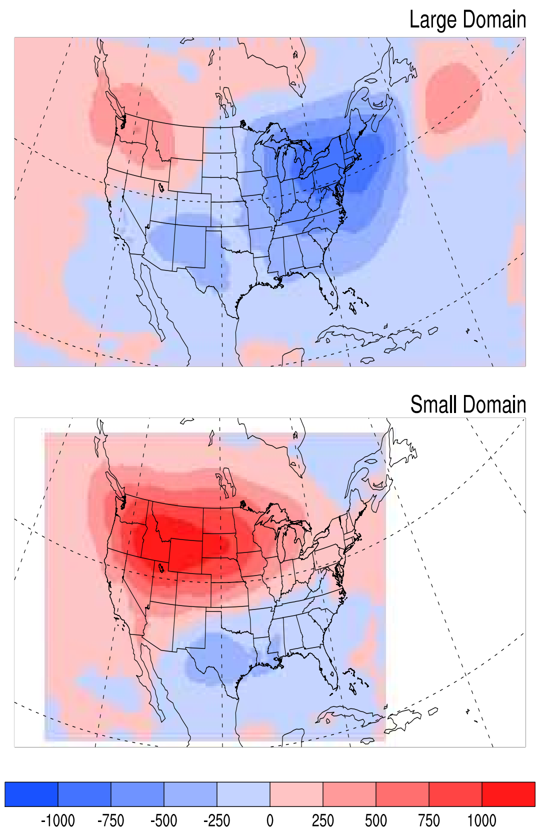

Figure 3: Difference in geopotential height (m) (model - analysis) for July 1993, for (top) large domain and (bottom) small domain.

The impact of domain size on warm-season rainfall is investigated by comparing rainfall between the 6-year continuous simulation with a simulation using a smaller domain. The domain sizes are shown in Fig. 3. The small domain is initialized on 1st June 1993 using an NCEP-NCAR analysis, but the soil conditions are derived from the 6-year large-domain continuous simulation[3]. Previous work has shown the model atmosphere takes approximately 12-15 days to reach a balance between the internal model dynamics and the boundary forcing data. It is therefore valid to compare the small domain and 6-year large-domain simulations for the period of July 1993.

As for other sensitivity studies, the simulation using the small domain reproduces a local maxima in rainfall in approximately the location observed (not shown). However, flood-region rainfall is only 23% of the observed: the lowest of all sensitivty studies.

The model large-scale flow appears to be highly sensitive to domain size. Figure 3 shows the difference in 300mb geopotential height between the model and the analyses for July 1993. The tri-pole spatial pattern in height bias for the simulation using a large domain (top panel, Fig. 3) is the same for all physics sensitivity simulations (not shown) but the magnitudes vary slightly. However, the height bias pattern for the simulation using a small domain (bottom panel, Fig. 3) is very different. It is likely that this difference in upper-level forcing for convection will have impacts not only for regional climate simulation but also on regional climate sensitivity and interannual variability.

[3]Soil conditions can take months to years to spin up with the model atmosphere

5 DISCUSSION

Consistent with previous RCM studies, the WRF model shows a dry bias in warm-season rainfall over the MidWest. The model shows some skill in capturing the interannual variability in warm-season rainfall, and the 1993 minus 1988 rainfall signal over the MidWest is quite well simulated. Generally, the lack of warm-season rainfall over the MidWest has low sensitivity to the range of physics representations examined here. Experimentation with domain size shows high sensitivity of the upper-level flow to domain size. This will possibly have impact on not only the climate simulation, but also on climate sensitivity and interannual variability.

6 FUTURE WORK

To determine in what sense 1988 and 1993 are anomalies, an analysis of anomalies in rainfall characteristics (e.g. frequency, intensity and diurnal timing) will be carried out. Futher analysis will determine how well the model captures different aspects that lead to reasonable simulation of the anomalies, including the ULJ, LLJ, moisture convergence and propagation of storms from the Rocky Mountains.

The impact of domain size on interannual variability is an important issue and may be investigated by comparing a 6-year simulation using the small domain with the existing 6-year simulation using the large domain.

ACKNOWLEDGEMENTS. We thank Wei Wang and Jimy Dudhia for assistance with the WRF model. This work is supported by the NCAR FY06 opportunity fund.

REFERENCES

Anderson, C. and Coauthors (2003). Hydrological processes in regional climate model simulations of

Data	*Change*	*Flood-Region Average Rainfall (mm/day)*	*Percent Parameterized Convection*
WRF	Default Model Set-up	3.19	75
WRF	Betts-Miller Convection	3.66	16
WRF	Grell-Devenyi Convection	5.33	48
WRF	RRTM/Goddard Radiation	3.91	77
WRF	0/1 Cloud-Fraction	2.81	72
WRF	Increased Gulf SSTs by 1.5K	3.70	73
Observation (1/24°)		7.43	

Table 1: Sensitivity of flood-region average rainfall for July 1993 to changes in model physics and Gulf SSTs

the central United States flood of June-July 1993. *J. Hydrometeor.*, **4**, 584–598.

Giorgi, F., Marinucci, M., and Bates, G. (1993). Development of a second-generation Regional Climate Model (RegCM2. Part II: Convective processes and assimmilation of lateral boundary conditions. *J. Climate*, **121**, 2814–2832.

Kain, J. and Fritsch, J. (1993). Convective parameterization for mesoscale models: The kain-fritsch scheme. In *Meteorological Monographs*, volume 24, pages 165–170. Amer. Meteor. Soc.

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

Lüthi, D., Cress, A., Davies, H., Frei, C., and Schär, C. (1996). Interannual variability and regional climate simulations. *Theor. Appl. Climatol.*, **53**, 185–209.

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.

Seth, A. and Rojas, M. (2003). Simulation and sensitivity in a nested modeling system for South America. Part I: Reanlayses boundary forcing. *J. Climate*, **16**, 2437–2453.

Vannitsem, S. and Chromé, F. (2005). One-Way nested regional climate simulations and domain size. *J. Climate*, **18**, 229–233.

Vidale, P., Lüthi, D., Frei, C., Seneviratne, S., and Schär, C. (2003). Predictability and uncertainty in a regional climate model. *J. Geophys. Res.*, **108**, 4586.