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4.4 ON PIRCS MODELS' CONSISTENCY OF DYNAMICS WITH PRECIPITATION

Z. Pan[1 *], R.W. Arritt[1], W.J. Gutowski, Jr.[1,2], E.S. Takle[1,2], C.J. Anderson[1], F. Otieno[2], R. da Silva[1], D. Caya[10], S.-C. Chen[8], J.H. Christensen[5], D. Luthi[14], M. Fox-Rabinovitz[6], M.A. Gaertner[16], F. Giorgi[12], G. Grell[15], S.-Y. Hong[7], C. Jones[13], H.-M. H. Juang[7], J.J. Katzfey[4], W.M. Lapenta[9], R. Laprise[10], G. Liston[11], J.L. McGregor[4], R.A. Pielke, Sr.[11], J.O. Roads[8], J. Taylor[17]

[1]Department of Agronomy, Iowa State University, Ames, Iowa. [2]Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa. [4]Commonwealth Scientific and Industrial Research Organisation, Mordialloc, Australia. [5]Danish Meteorological Institute, Copenhagen, Denmark. [6]NASA Goddard Space Flight Center, Greenbelt, Maryland. [7]National Centers for Environmental Prediction, Camp Springs, Maryland. [8]Scripps Institution of Oceanography, La Jolla, California. [9]Marshall Space Flight Center, Huntsville, Alabama. [10]Universite du Quebec a Montreal, Canada. [11]Department of Atmospheric Science, Colorado State University, Ft. Collins, Colorado. [12]International Center for Theoretical Physics, Trieste, Italy.[13]Rossby Center at the Swedish Meteorological and Hydrological Institute, Norrköping, Sweden. [14]Swiss Federal Institute of Technology (ETH), Zurich, Switzerland. [15]Forecast Systems Laboratory, NOAA, Boulder, Colorado. [16]Department of Geophysics and Meteorology, University of Complutense, Madrid. [17]Mathematics and Computer Science Division, Argonne National Laboratory, Chicago, Illinois.

1. INTRODUCTION

The Project to Intercompare Regional Climate Simulations (PIRCS) is a volunteer effort that provides a common test bed for the regional climate modeling community (http://www.pircs.iastate.edu). PIRCS experiment 1 consists of two 60-day simulations: 1a - 1988 central U.S. drought (Takle et al. 1999), and 1b - 1993 Midwest flood (Arritt et al. 2000). Fifteen regional climate models (RCMs) have completed experiment 1b. The output allows us to perform a number of process intercomparisons among the models and with observations.

Previous studies on PIRCS 1b have largely concentrated on precipitation (e.g., Arritt et al. 2000). Although models were found to simulate realistic precipitation features, good rainfall simulations do not guarantee correct model dynamics/physics producing rainfall. For example, the PIRCS 1a experiment indicated that two models can produce similar precipitation features from different dynamic forcing (Takle et al. 1999). This paper explores consistency between precipitation and dynamic forcing as simulated by PIRCS models.

2. BRIEF DESCRIPTION OF EXPERIMENT

The simulation domain for PIRCS experiment 1 covers the continental U.S. with a focus on the central region. The period of simulation for PIRCS 1b is 1 June – 31 July 1993 which includes peak precipitation episodes of the 1993 flood. The most intense precipitation during the flood occurred from about 28 June through 10 July.

Atmospheric initial and boundary conditions were derived from the reanalysis produced by the National Centers for Environmental Prediction (NCEP) (Kalnay et al. 1996). One exception is the Swedish Rossby Centre model (RCAERA), which used the reanalysis from the European Center for Medium-Range Weather Forecasts (ECMWF) as initial and boundary conditions. Horizontal grid spacing for the regional models is about 50 km, though there is some variation from model to model because the models use a variety of map projections (see Takle et al. 1999). Boundary conditions were updated every 6 hours.

Sea-surface temperatures (SSTs) were derived from the reanalysis SST data, supplemented by direct observations of surface temperature in the Great Lakes and satellite observations of SST in the Gulf of California which the reanalysis grid cannot resolve. Soil moisture is not observed regularly over most of the PIRCS domain, so we derived initial soil moisture content from the reanalysis data that was simulated based on the surface water budget in the NCEP reanalysis model. To date, 15 modeling groups from Europe, Australia and Americas have completed experiment 1b. For this abstract, results are discussed from 11 models that have enough data to perform the analysis (Table 1).

Participating models used a range of cumulus parameterization schemes along with varying explicit stratiform precipitation schemes. Readers are advised to see details of each model’s scheme in other PIRCS publications (e.g., Anderson et al. 2001; 1999 Takle et al. 1999).

3. RESULTS

3.1 *Precipitation*

The large-scale, low frequency synoptic setting during the flood in the western Pacific and U.S. was dominated by strong zonal flows that served as a “duct” to bring cyclones from western Pacific to the U.S. In contrasting to June circulation, July large-scale synoptic situation was dominated by a persistent trough and a quasi-stationary front (Pan et al. 2000). These favorable conditions produced a series of intense mesoscale convective systems (MCS). The 1993 flood was most severe in the upper Mississippi River Basin (UMRB). We choose the UMRB as our analysis area, defined by a rectangular region bounded by 37-47°N and 89-99°W. All results presented in this report are areal averages over UMRB.

All models captured the five cyclone-induced rainfall episodes in June although the magnitudes differed (Fig. 1). The models did not capture timing of rainfall events in July, although most of them produced rainfall amounts that resemble the observation. The mismatch of the rainfall timing in July is not surprising given the relatively weak synoptic forcing (fewer major cyclones).

3.2 *Dynamic Fields*

Summer mesoscale precipitation in this region is mainly associated with local MCSs. It is not easy to define a single representative dynamic forcing for mesoscale events because of the feedback from precipitation on dynamic circulation. So, we examine several variables as dynamic fields which include relative vorticity, large-scale and mesoscale kinetic energy, and moisture divergence. All these variables are computed at 850 hPa averaged over UMRB.

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* *Corresponding author address:* Dr. Zaitao Pan, 3010 Agronomy Hall, Department of Agronomy, Iowa State University, Ames, IA 50011.
E-mail: panz@iastate.edu

We computed mesoscale kinetic energy by subtracting a locally derived spatial average of simulated wind from total wind (Giorgi et al. 1993) and squaring the results. The time series of mesoscale kinetic energy averaged over UMRB showed five well-defined peaks associated with passing cyclones in June while magnitudes differed considerably (Fig. 2). The mesoscale forcing evolution in July is much less consistent among models because of relatively weaker synoptic forcing compared with June. The overall moisture divergence time series are noisier than the kinetic energy (not shown). This is not surprising since the divergence operator amplifies small differences.

3.3 Correlation of Precipitation with Dynamic Fields

Relating dynamic forcing and rainfall response is difficult because of precipitation feedback and interaction between synoptic and mesoscale circulations. Regardless which is forcing (cause) or response (effect) for mesoscale events, dynamic/physics and precipitation should be consistent within mesoscale systems, at least in a statistical sense. For example, sustained mesoscale precipitation should be supported by moisture convergence (mostly in the lower troposphere) and upward motion. Without knowing the cause-effect relation between precipitation and dynamics, we use linear correlation to explore the consistency between dynamics and precipitation. The precipitation correlation to large-scale kinetic energy is low (all-model average of 0.28), suggesting that model precipitation is not closely related to this measure of large-scale circulation. On the other hand, the correlation to mesoscale kinetic energy is higher (0.58). It is expected that the mesoscale circulation is typically convergent (and ageostrophic) and often correlated with mesoscale precipitation.

The 850 hPa relative vorticity averaged over the UMRB also has high correlation (0.56) with precipitation (Fig. 3). For most models, correlation for vorticity is larger than for moisture divergence, except for MM5BTS and REGCM2 which share similar model dynamics. It should be pointed out that RCAERA using the ECMWF reanalysis has high correlations for both variables.

3.4 *Model Precipitation Production*

First we evaluate the inter-model spreads in dynamic forcing and precipitation. We use mesoscale kinetic energy (MKE) which has highest correlation with rainfall to represent dynamics. MKE also facilitates normalization because of its positive definition. The inter-model spread, defined as the ratio of individual model rainfall and MKE to corresponding all-model means, is larger for MKE than precipitation (Fig. 4). The spreads vary among models from 0.6 to 1.8 for forcing (R_f) as compared to 0.8-1.2 for precipitation (R_p), meaning that the models produced similar precipitation even though their dynamic fields were somewhat different as shown by scattered square dots in Fig. 4.

A number of models' MKE and rainfall are disproportionate, either R_p >1 while R_f <1, or vice versa. One would expect that if a model's MKE is stronger than the average of the models, then its precipitation should be proportionally larger than the average of models assuming reasonable model precipitation scheme functioning. But this expectation does not hold for a few models. The mismatch between the MKE and precipitation ratios reflects unequal sensitivity of model parameterization scheme in producing precipitation. For example, the models PROMES and ETHZEM had stronger forcing relative to other models, but produced about average rainfall. On the other hand, the models DARLAM and HIRHAM had weaker forcing, yet they produced above or near mean precipitation.

To quantify the forcing-precipitation relation, we define a ratio,

$$E = \frac{R_p}{R_f} = \frac{p\overline{K}}{\overline{P}K} , \qquad (1)$$

where $\overline{P}$ and $\overline{K}$ are the all-model means of precipitation and MKE, respectively. Figure 5 shows that (1) the two regional spectral models (ECPCRS and NCPRSM) gave similar ratios that are also close to 1.0; (2) all MM4/MM5 family models (MM5ANL, MM5BTS, and RegCM2) gave consistent ratios that are slightly less than 1.0; and (3) RCANCP and RCAERA, which are the same model but with the latter driven by ECMWF reanalysis, gave similar ratios. The values of *E* range from 0.7 to 2.3, a more than factor of three variability among models.

4. SUMMARY AND DISCUSSION

All RCMs reproduced the main large-scale dynamic features of the period when synoptic forcing was strong (June), but the models showed significant inter-model spread in mesoscale disturbance intensity and temporal variation when synoptic forcing was relatively weak (July). Model simulated precipitation has high correlation with mesoscale kinetic energy (0.58), relative vorticity (0.56), and moisture divergence (-0.54), but low correlation (0.28) with large-scale kinetic energy. The inter-model spread in rainfall is somewhat smaller than forcing, which implies that similar model-simulated precipitation may result from different internal model physics/dynamics. This signals the need for detailed analysis of model internal dynamics in addition to rainfall on the ground. Finally, it should be cautioned that mesoscale precipitation depends on many other factors than discussed in this preliminary analysis, and this abstract is meant as an initial step to explore the complicated interrelations between dynamics/physics and precipitation as seen in the models.

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Tab. 1. Model names and institutes included in this study

Model Names	Home Institute
DARLAM	CSIRO, Australia
ECPCRS	Scripps Institution of Oceanography
ETHZEM	Swiss Meteorological Institute
HIRHAM	Danish Meteorological Institute
MM5ANL	Argonne National Laboratory
MM5BTS	NASA Goddard Space Flight Center
NCPRSM	National Centers for Environmental Prediction
PROMES	University of Complutense, Madrid
RCANCP	Rossby Center, Swedish Meteor. & Hydro. Inst.
RCAERA	Rossby Center, Swedish Meteor. & Hydro. Inst.
REGCM2	Iowa State University

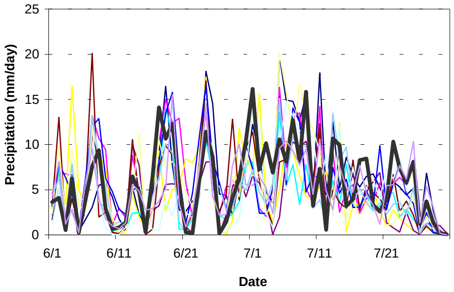

Fig.1. Time series of daily precipitation averaged over the upper Mississippi River Basin (UMRB) simulated by 11 PIRCS models. Thick line is the observation extracted from Higgins et al. (1996).

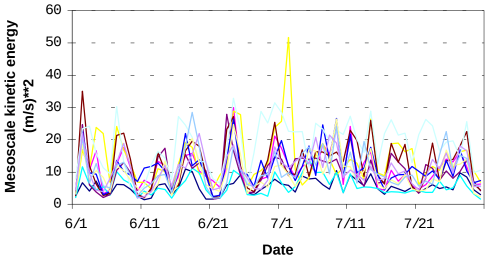

Fig. 2. Time series of 850 hPa mesoscale kinetic energy in UMRB simulated by 11 PIRCS models.

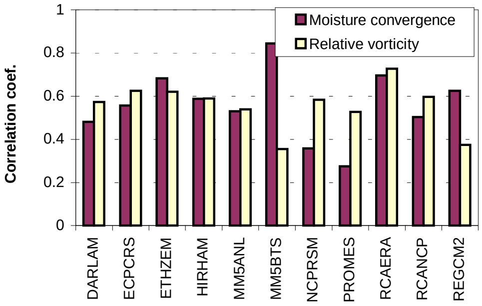

Fig. 3. Linear correlation coefficient between daily rainfall and dynamic fields in UMRB: rainfall versus moisture convergence and relative vorticity.

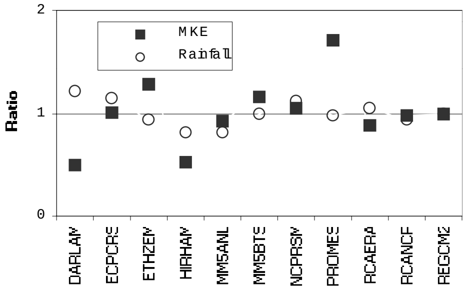

Fig. 4. Ratios of individual model precipitation and forcing to corresponding all-model means.

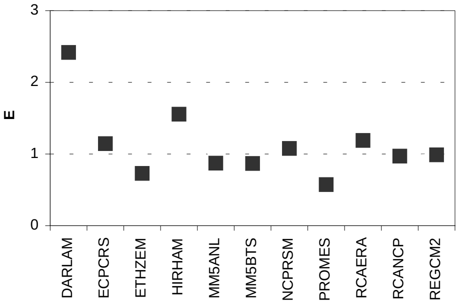

Fig. 5. Precipitation producing sensitivity of individual models (see text for details).