A Comparative CWRF Study of the 1993 and 2008 Summer U.S. Midwest Floods

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1. Introduction

The heavy rainfall events over the U.S. Midwest, a critical agricultural area of the world, often have considerable socioeconomic consequences due to their devastating damages to the agricultural growth, public properties, and infrastructures. One of the most devastating floods over Midwest occurred in the 1993 June/July, which caused severe impacts across nearly nine states with the total economic damage around $18 billion (Changnon 1996). After fifteen years the 2008 late spring to early summer floods again affected the vast areas of the Midwest with large damages at least of $15 billion (Coleman et al. 2009). The comparative severity of these two floods has drawn a great public attention and the study of these two cases would be conductive to better understand the responsible physical processes and the underlying mechanisms.

There have been a great number of observational and numerical studies that investigated the record 1993 floods, with their focuses primarily on the typical large-scale atmospheric circulation pattern and the associated mesoscale convective systems (Junker et al. 1999; Bell and Janowiak 1995; Mo et al. 1995; Kunkel et al. 1994), the moisture transport associated with the GPLLJ (Coleman et al. 2009), the model simulations of the heavy rainfall features, especially the nocturnal precipitation maxima over the Great Plains (Liang et al. 2001, 2004), and the effect of soil moisture (Paegle et al. 1996; Bosilovich and Sun 1999). It was found that the large-scale atmospheric circulation anomalies, including a stronger upper-level westerly jet stream and enhanced lower-level moisture transport, which combined to be favorable for the formation and propagation of mesoscale convective systems. Particularly, the eastward propagating mesoscale convective systems have proven to be critical features for faithful simulations of nocturnal precipitation maximum in the Great Plains and Midwest by regional climate models. In addition, the soil moisture has also been considered to have impact in 1993 floods, but the actual role was not clear because of the conflicting results from the existing studies.

A few studies compared the 2008 and 1993 Midwest floods in terms of their differences in the timing and duration of flooding, as well as their affected areas by the observational analysis (Hilberg 2008; Coleman et al. 2009). The 2008 flood took place from May, approximately 1 month earlier than the 1993 case that started in June. Compared to the 1993 flood that persisted toward to the end of July, the 2008 case lasted over a much shorter period. The geographic area affected by the 2008 flood extended eastwards into Indiana and the Wabash River Basins, rather than limited to the Upper Mississippi River Basin in 1993 case. Coleman et al. (2009) also examined the potential relationship between North Atlantic oscillation (NAO) and the Midwest flooding and found a positive NAO phase two months before the onset of flooding and it remains negative for the duration of the floods. The numerical studies for the most recent 2008 floods have rarely been performed and the objective of this study is to focus on comparing the two floods, from both observational analysis and numerical model simulation, to evaluate the capability of regional climate model (CWRF) in capturing the primary features of extreme rainfall events, regarding to the rainfall spatial distribution, daily and diurnal variations over the concentrated flooding areas.

2. Model Experiments and Data

The newest version of CWRF (Liang et al. 2010) is employed to simulate the 1993 and 2008 floods over the Midwest. The lateral boundary conditions driving the CWRF were constructed from the NCEP-DOE AMIP II Reanalysis (R-2). The grid spacing of CWRF uses a 30 km, with the vertical resolution of 36 levels. The integration period is from May 1st to July 31st. The Grell and Dveneyi (2002; G3) ensemble scheme and Emanuel and Zivkovic-Rothman (1999; MIT) scheme are used to depict the result sensitivity to the convective parameterizations.

The G3 scheme includes a large ensemble of convective closures and parameters that are taken from cumulus parameterizations which are currently used in various weather forecast and climate prediction models. It provides an opportunity to evaluate the effect of different convective closures and trigger functions and to derive the statistically optimal mixture of subensembles compared to the observations. The MIT scheme uses the buoyancy-sorting hypothesis (Emanuel 1991) to determine the net mass flux, with a primary concern of precipitation efficiency (PE) in formulating the microphysics. Another unique feature of MIT scheme is its incorporation of the convective downdraft effect on the surface fluxes. Therefore, the use of G3 and MIT can help to examine the model sensitivity on three aspects associated with the closure effects, PE effects and the downdraft effects on surface fluxes, which will be implemented in the future work.

Daily precipitation data over U.S. for 1993 is constructed from daily measurements at the 7235 cooperative stations over the U.S. following Liang et al. (2004) and adjusted by using monthly mean precipitation data from PRISM

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(Parameter-elevation Regression on Independent Slopes Model, Daly et al. 1997). The data over the adjacent ocean for 1993 is derived from the CPC pentad mean precipitation global analysis merging gauge observations with satellite estimates (Liang et al. 2005). For the 2008, the TRMM (Tropical Rainfall Measuring Mission) merged high quality (HQ)/infrared (IR) precipitation data is implemented for the U.S. land and its surrounding ocean.

The high temporal 3-hourly rainfall data is from the North American Regional Reanalysis (NARR) for 1993 and from the TRMM for 2008. In addition, R-2 product of 3-hourly precipitation is also compared to demonstrate the CWRF downscaling skill in the simulated rainfall diurnal cycle.

3. Results

a. Geographic distribution

Figure 1 and 2 compare with observations monthly mean precipitation geographical distributions simulated by the CWRF using G3 and MIT scheme for 1993 and 2008 May-July. Both CWRF simulations well capture the evolution of heavy rainfall locations and also realistically reproduce the different timing and duration of these two events, in which the 1993 floods concentrated in June and July, and the 2008 case was more prominent in May and June. However, both G3 and MIT schemes tend to underestimate the relatively light precipitation over the west Illinois in 2008 July, implying the difference of large-scale circulation changes in July for both years (Coleman et al. 2009), or the deficiency of PE parameterizations in these two schemes.

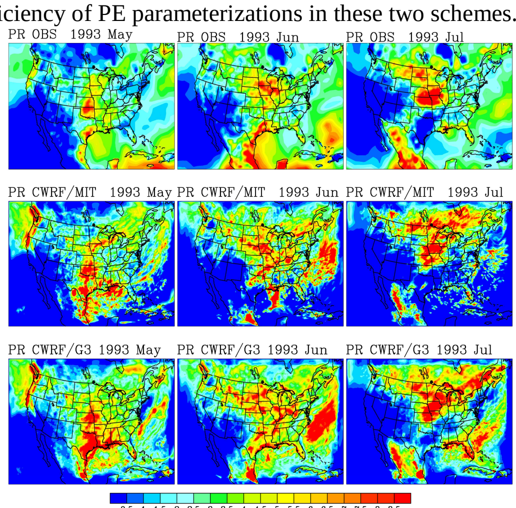

Figure 1. Geographic distributions of 1993 May-July monthly mean precipitation (mm/day) as observed (OBS), and downscaled by the CWRF using the G3 (CWRF/G3) and MIT (CWRF/MIT) scheme.

Table 1 shows the 2008 July atmospheric water cycle indices (PE and Recycling ratio β) and their associated water balance components (Qin is the atmospheric moisture influx; Qout is the atmospheric moisture outflux; ET is the evapotranspiration) averaged over the Midwest U.S. to describe the sensitivity of water cycle to convective schemes, attempting to explore the relationship of PE to the underestimate of rainfall in 2008 July. Based on the areal coverage of floods for both cases, the Midwest U.S. region in this study is specified by (35°N-45°N, 100°W-87°W). The PE is defined as the fraction of water that actually rained out from the atmospheric moisture originally enters the domain (evapotranspiration and moisture influx). The Recycling ratio (β) is defined as the fraction of precipitation that originates from the evapotranspiration within the specific domain (Yuan et al. 2008).

The observed PE (19.65%) is smaller than the recycling ratio (26.17%), indicating that the precipitation in 2008 July is most likely from the local evaporation, rather than the atmospheric transport. However, the G3 scheme in both simulations uses moisture convergence closure over the U.S. land and it could be a potential cause of the reduced rainfall in this case.

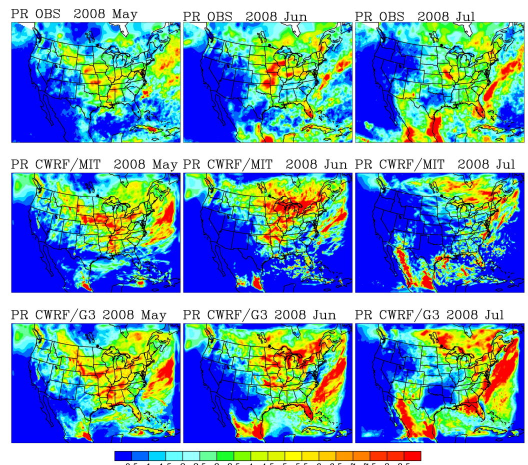

Figure 2. Geographic distributions of 2008 May-July monthly mean precipitation (mm/day) as observed (OBS), and downscaled by the CWRF using the G3 (CWRF/G3) and MIT (CWRF/MIT) scheme.

Table 1. The atmospheric water cycle indices and their associated components averaged over the Midwest U.S. in 2008 July.

	2008 July		
	OBS	**CWRF/G3**	**CWRF/MIT**
PE (%)	19.56	9.07	3.76
β(%)	26.17	20.90	15.08
PR (mm d-1)	3.87	1.56	0.77
Qin (mm d-1)	14.63	13.60	17.48
Qout (mm d-1)	0.59	15.40	19.03
ET (mm d-1)	5.19	3.59	3.10

The G3 and MIT both have relatively too small PE than the observations, primarily caused by the large moisture flux out of the Midwest U.S. The misinterpretation of moisture flux is greatly associated with the large-scale circulation simulation, which requires to be more carefully investigated.

b. Daily Precipitation variation

Figure 3 shows the daily precipitation variation averaged over the specified Midwest U.S. for 1993 and 2008 May-July. It clearly presents that the 1993 floods are composed by two typical periods, featured by the nearly periodic rainfall from May through early June due to the regular passages of cyclones, and followed by two heavy rainfall events in the middle of June and July as a result of strong mesoscale convections. However, the 2008 case started from early May and exhibited no periodic feature, but had three major heavy rainfall events during May-June. The CWRF simulations well produces the phase of daily rainfall variation for both floods, but tends to overestimate the peak amounts of heavy rains and underestimate the observed rainfall intensity in 2008 July.

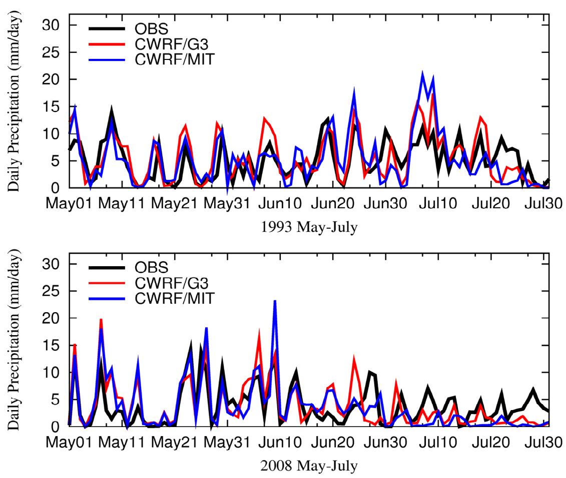

Figure 3. The daily mean precipitation variations (mm/day) averaged over the Midwest U.S for 1993 and 2008 May-July as observed (OBS), and simulated by the CWRF using G3 (CWRF/G3) and MIT (CWRF/MIT) scheme.

Figure 4 shows that G3 scheme is more capable of capturing the daily rainfall variation over the Midwest U.S. in 1993, having a generally higher frequency of larger correlation and smaller RMS error with observations than MIT scheme. But two schemes show a comparative ability for 2008 case in the daily precipitation simulation.

c. Precipitation diurnal cycle

Figure 5 compares the 1993 and 2008 May-July mean normalized precipitation diurnal cycle averaged over the Midwest U.S. as observed, simulated by R-2 and CWRF with the G3 and MIT schemes. R-2 produces a daytime maximum and a nighttime minimum, failing in captures the nocturnal peaks over the Midwest U.S. just as most GCMs (Liang et al. 2004, 2006). The CWRF using G3 scheme also does not show notable improvement, indicating the ensemble closures in the G3 scheme require careful adjustments and/or weight optimizations. Fortunately, MIT scheme reproduces this prominent nocturnal rainfall feature in both floods. Liang et al (2004) found that the Grell

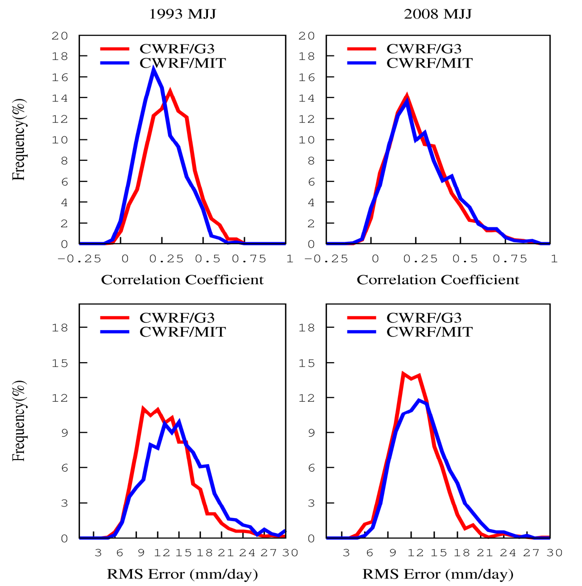

Figure 4. The Frequency of correlation coefficient and RMS error for 1993 (Left panel) and 2008 (Right panel) May-July daily precipitation between the observation and CWRF simulations using G3 (CWRF/G3) and MIT (CWRF/MIT) scheme.

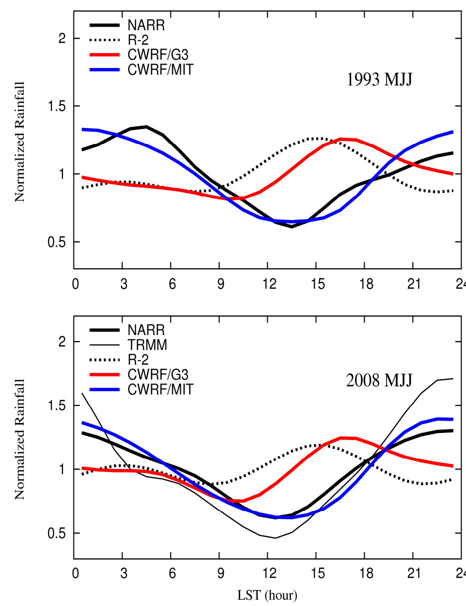

Figure 5. The 1993 (upper) and 2008 (bottom) May-July mean diurnal cycles (relative to LST) of the normalized rainfall averaged over the Midwest region, by the observational analysis (NARR for 1993, NARR and TRMM for 2008), and simulated by the NCEP-DOE reanalysis 2 data (R-2), as well as by the CWRF using the G3 (CWRF/G3) and MIT (CWRF/MIT) scheme.

scheme could realistically simulate the nocturnal rainfall maxim a and their associated eastward propagation of convective systems over the Great Plains. It will be our next step to incorporate the Grell scheme into the CWRF model, exploring the influential factors for generating the nocturnal rainfall over the Midwest using both Grell and MIT schemes.

4. Concluding Remarks

The CWRF simulations driven by R-2 data have been conducted to study the two outstanding floods that occurred in the 1993 and 2008 summer over the Midwest U.S. The model sensitivity to the cumulus parameterization is examined by using the G3 and MIT scheme for both cases, in order to evaluate the capability of CWRF in capturing the primary features of extreme rainfall events, regarding to the rainfall spatial distribution, daily and diurnal variations over the key flooding areas.

Both CWRF simulations well capture the major heavy rainfall locations and the different timing and duration of two floods, in which the 1993 flood concentrated in June and July, and the 2008 case was more prominent in May and June. The problem is that both G3 and MIT schemes underestimate the precipitation over the west Illinois in 2008 July, partially due to the deficiency in convective closure in G3 or MIT scheme given the analysis of monthly mean PE and recycling ratio.

The CWRF simulations realistically reproduce the phase of daily rainfall variation during the flooding period. The G3 scheme is more capable of capturing the daily rainfall variation over the Midwest U.S. in 1993 than the MIT scheme. However, the MIT scheme shows a remarkable ability of reproducing the prominent nocturnal rainfall peaks for both floods, while R-2 and the G3 both fail to capture this typical rainfall diurnal cycle feature.

Therefore, the future study will focus on the improvement in the closure algorithm in G3 or MIT scheme in order to solve the insufficient amount of rainfall in 2008 July, and work on the convective triggering functions in G3 scheme to better capture the rainfall diurnal cycle. Furthermore, together with MIT scheme, the Grell scheme in CMM5 (Liang et al. 2004) would be incorporated into the current CWRF, attempting to explore the major factors in producing the typical nocturnal rainfall maxima over the Midwest U.S.

5. Acknowledgement

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