17.5 SOIL MOISTURE, LAND-ATMOSPHERE INTERACTION, AND THE 6-7 MAY 2000 MISSOURI FLASH FLOOD EVENT

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1. INTRODUCTION

On 6-7 May 2000, thunderstorms produced heavy rainfall and historic flash flooding in east-central Missouri with up to 14 inches of rain in some areas (Glass 2001; Market et al. 2001). The mesoscale convective system responsible for this heavy precipitation lacked the defined surface boundary of typical flash flood events (Maddox et al. 1979; Glass 2001). Rather, substantial moisture advected by a strong low-level jet (LLJ) contributed to the high rainfall rates (Market et al. 2001).

A number of studies on the 1993 Midwest Flood have indicated that the land surface can have a major impact on the development of the LLJ and subsequent precipitation (e.g., Paegle et al. 1996; Bosilovich and Sun 1999). For example, gradients in soil moisture can lead to strong differential heating and secondary circulations that enhance the LLJ, while uniform distributions of soil moisture reduce these effects (Bosilovich and Sun 1999). These results suggest that high quality observations of soil moisture are required to accurately predict the timing and location of heavy precipitation.

The ultimate goal of this research is to investigate the role of the land surface on LLJ intensity and heavy rainfall during the 6-7 May 2000 Missouri flash flood. Initially, we examine the necessity of a sophisticated land-surface model (PLACE) coupled to a mesoscale atmospheric model (MM5) to capture the rainfall event. Results from MM5-PLACE numerical simulations suggest that land- atmosphere interaction can dramatically enhance precipitation amounts during a flood event.

2. MODEL

The atmospheric component of the model is the Penn State/NCAR Mesoscale Model (MM5) Version 2.7. Two surface models are considered: 1) the SLAB model provided by MM5, and 2) the Goddard Parameterization for Land-Atmosphere-Cloud Exchange (PLACE; Wetzel and Boone 1995). The SLAB model calculates the surface energy budget of a single soil layer using the force-restore method, but soil moisture remains fixed. By contrast, PLACE considers five soil moisture layers and seven soil temperature layers. Momentum, sensible, and latent heat fluxes are calculated using similarity relationships. Soil moisture varies throughout the simulation in the PLACE model.

Two nested domains with grid spacing of 15-km and 5-km are used in these simulations. The 15-km grid uses the Kain-Fritsch cumulus parameterization while the 5-km grid uses the Goddard explicit cloud microphysics scheme (Tao and Simpson 1993). Atmospheric boundary conditions (updated every 12 hours) for the outermost domain are provided by NCEP reanalysis. Simulations are integrated for 36 hours from 0000 UTC 6 May 2000 through 1200 UTC 7 May 2000. Atmospheric initial conditions are provided by NCEP reanalysis. Initial soil moisture and soil temperature from MM5-supplied climatological data are used.

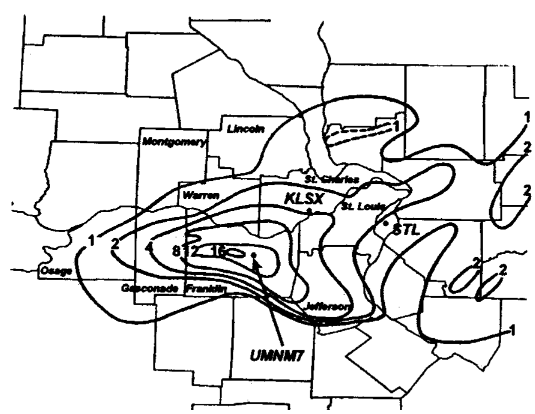

Figure 1. Precipitation analysis (inches) for the 24 hr period ending 1200 UTC 7 May 2000 (from Glass 2001). This map covers latitudes 38N to 40N and longitudes 92W to 89.5W.

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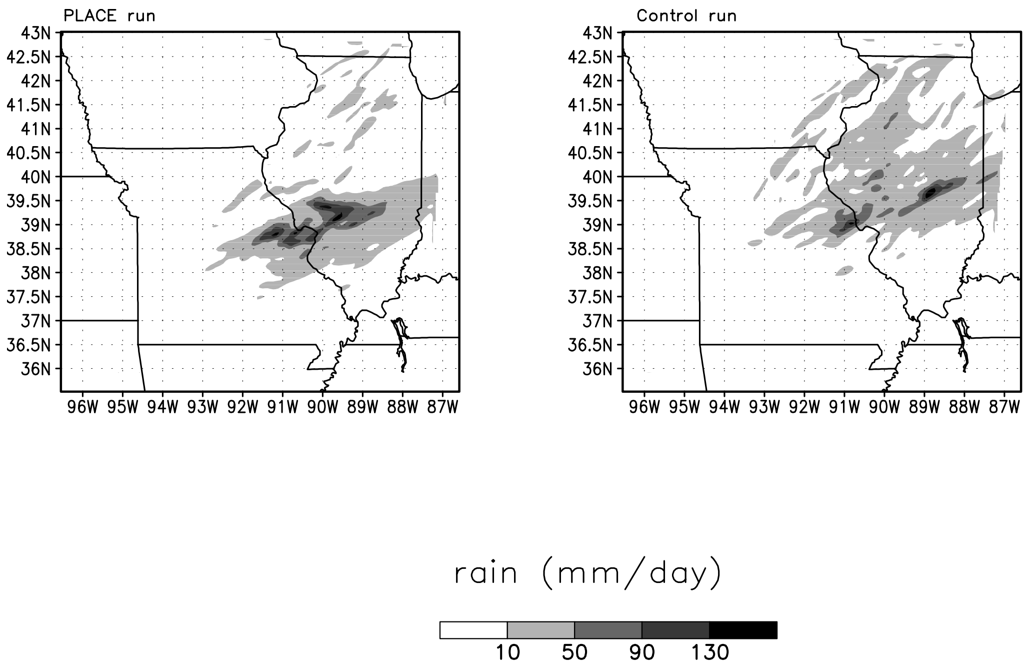

Figure 2. 24-hr accumulated rainfall (mm) ending 1200 UTC 7 May 2000 for the PLACE simulation (left) and the SLAB simulation (right).

3. RESULTS

Figure 1 shows the 24-hr precipitation analysis from Glass (2001) over east-central Missouri. This extreme rainfall event was localized with heavy rainfall amounts in Franklin County. The UMNM7 location marks the Union rain gauge that recorded the highest rainfall amount (13.5 inches or 344 mm).

Two simulations were conducted, one with the PLACE land surface model and one with the default SLAB model. Figure 2 shows the 24-hr accumulated rainfall for both the PLACE and SLAB simulations. The MM5-PLACE simulation captures the location of heavy precipitation well in east-central Missouri, while the SLAB simulation experiences the heaviest rainfall further east in Illinois.

Furthermore, the timing of heavy precipitation agrees well with observations. Figure 3 plots the accumulated rainfall over time at the Union site for both the PLACE and SLAB simulations. The PLACE run exhibits heavy rainfall beginning at roughly 0500 UTC and ending at roughly 1000 UTC, consistent with observations from the Union rain gauge (Glass 2001). In contrast, the SLAB simulation exhibits little rainfall at the Union site.

However, total rainfall in both simulations is severely underestimated. At the Union site, total accumulated rainfall amounts are only 18% and 3% of the observed amount for the PLACE and SLAB runs, respectively. The peak simulated 24-hr rainfall amount in the PLACE run at any location in the domain is roughly 140 mm, or 41% of the observed maximum.

4. DISCUSSION AND FUTURE WORK

The MM5-SLAB simulation (a case without an interactive land surface and without time-varying soil moisture) does not capture the heavy rainfall event of 6-7 May 2000 in terms of timing, intensity, or location of precipitation. Significant improvement in model

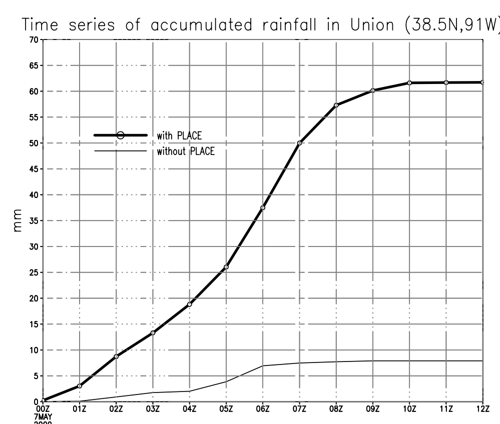

Figure 3. Time series of accumulated rainfall at the Union site for the PLACE simulation (thick line) and the SLAB simulation (thin line).

prediction occurs when an interactive land surface component (PLACE) is utilized. The MM5-PLACE simulation captures the timing and location of heavy precipitation. Although total precipitation is still underestimated, the MM5-PLACE simulation produces heavier rainfall than the MM5-SLAB case. These results suggest that land-atmosphere interaction plays a key role in the evolution of mesoscale convective systems and heavy precipitation in the Midwest.

Underestimation of extreme precipitation in numerical models remains a major issue. Two possible reasons for this discrepancy are relatively coarse grid resolution (5-km grid spacing in our model simulations) and coarse atmospheric boundary conditions. A preliminary high-resolution MM5-SLAB simulation with 3 nested grids (1.7-km grid spacing on the innermost grid) indicates significantly higher values of peak precipitation (roughly 350 mm over 24 hr) than for the 5-km simulations. Timing and location of heavy precipitation for the high-resolution simulation disagree considerably with observations, but the close agreement in precipitation intensity with observations highlights a need for higher resolution simulations. In addition, NCEP reanalysis provides boundary conditions of 2-degree resolution. Such coarse boundary conditions may not adequately represent important mesoscale processes at the boundaries. Future research will consider higher resolution (40-km) boundary conditions supplied by Eta model reanalysis.

The precise role of soil moisture on LLJ intensity for the 6-7 May 2000 Missouri flood will be examined in future investigations. Current simulations use MM5-supplied climatological soil moisture that may or may not adequately represent soil moisture conditions on that day. Soil moisture estimates from Eta model reanalysis on 6 May 2000 will be used to test this sensitivity. In addition, extreme values of soil moisture (wet vs. dry) and various distributions of soil moisture will be considered to assess the effect of soil moisture on mesoscale convective system evolution.

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