J5.12 INFLUENCE OF VARIATIONS IN LOW-LEVEL MOISTURE AND SOIL MOISTURE ON THE ORGANIZATION OF SUMMER CONVECTIVE SYSTEMS IN THE U. S. MIDWEST

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1. INTRODUCTION

A primary focus of the operational forecasting community is the timing of convective initiation. Rapid changes in the structure of the planetary boundary layer (PBL) during the daytime can have a significant influence on the timing of convective initiation and on the development of summer storms. Numerous studies have focused on the sensitivity of moist convection to various thermodynamic properties of the PBL. For example, Crook (1996) showed that the initial stage of convective development was most sensitive to the temperature and moisture drop off at the surface (defined as the difference between the values measured at the surface and those in the boundary layer). Brooks et al. (1993) found that the structure of a simulated storm changed significantly when the low-level temperature was altered by 1.0^{o}C. Takemi and Satomura (2000) demonstrated strong dependencies between thunderstorm persistence, mixing depths and the vertical profile of moisture in the mixed layer.

A number of observational and mesoscale modeling studies have also shown that soil moisture strongly contributes to the variability of continental precipitation via the exchange of water and energy between the land surface and atmosphere (e.g., Koster et al. 2000; Anderson et al. 2004). There is also evidence that elevated dewpoint temperature and moisture fluxes within the PBL can increase the convective available potential energy, promote atmospheric instability, and enhance daytime cloud cover (Stohlgren et al., 1998). Localized extreme dewpoints, which do not appear to result from moisture advected from the Gulf of Mexico, are increasingly being observed in the central United States, especially during hot summer periods.

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These are most likely related to changing agricultural practices, including increased evaporation from irrigation (Sparks et al., 2002; Adegoke et al. 2005). Vegetation is probably also a factor in the initiation and organization of convection. For example, Lu and Shuttleworth (2002) show that incorporation of satellite-derived leaf area index (LAI) into the land surface scheme of a mesoscale model produced a wetter and cooler climate in the summer growing season in the central U.S.

These studies underscore the importance of accurate representation of surface characteristics via improved surface conditions. In this paper, initial results of an ongoing study on the connections between PBL thermodynamics, mixing depths, extreme dew points and soil moisture variability are presented, with particular emphasis on how these interactions impact the evolution and persistence of convective systems in the Midwest. The Regional Atmospheric Modeling System (RAMS), developed at Colorado State University, is employed. The focus here is to evaluate whether more realistic surface boundary conditions add value to the RAMS simulations. Specifically, the incorporation of heterogeneous soil moisture as an initial condition and the use of satellite-derived Leaf Area Index (LAI) on the simulation of convective systems over Midwest is examined.

The influence of changes in land surface variables such as soil moisture on the development of convective systems can be an important forcing factor during weak synoptic flow regimes. Prior observational analyses (Carleton, 2005) suggest that August 2000 would be a candidate period to examine these impacts. Surface meteorological variables (diurnally-averaged) from an atmospheric reanalysis suggest changes occur around August 5-6, 2000, which coincides with the aftermath of heavy convective precipitation events associated with a major change in the synoptic atmospheric circulation around that time. In the subsequent weeks as a high pressure ridge developed over the Midwest, the synoptic-scale environment was unfavorable for convection, yet convective precipitation across the southern parts of Illinois and Indiana occurred prominently. During this same time period, latent heat fluxes and potential evapotranspiration were relatively large and positive vertical motion was observed in this area. These analyses point towards the very real possibility that surface conditions, notably the increased soil moisture following the storm events of August 5-6, provided "memory" to force convection locally for the proceeding two weeks. The mesoscale modeling experiment is focused on this period to more fully evaluate this possibility and to provide insights into the physical mechanisms of convective initiation and organization.

2. METHODOLOGY AND EXPERIMENTAL DESIGN

A standard reanalysis dataset in wide use for initializing lateral boundary conditions in mesoscale models is the six hourly 2.5º latitude by 2.5º longitude NCEP/NCAR Global Reanalysis (GR) dataset (Kalnay et al., 1996). A new long-term, consistent, high-resolution reanalysis data for North American domain, the NCEP North American Regional Reanalysis (NARR), is now available (Mesinger et al., 2005). The NARR was developed as a major improvement upon the GR in both resolution and accuracy. The NARR model uses the NCEP Eta Model (32km/45 layers) together with the Regional Data Assimilation System (RDAS), which assimilates precipitation along with other variables. The NARR dataset substantially improves the accuracy of temperature, winds and precipitation compared to the NCEP-NCAR GR data (Mesinger et al., 2005). The NARR is currently available for January 1, 1979-December 31 2004 and includes atmospheric data for 29 vertical levels 8 times daily (every 3h). For this study, routines were developed to derive RAMS initial and lateral boundary conditions from the NARR dataset. Use of the NARR improved the RAMS model-generated precipitation compared to using the GR (not shown), so the NARR dataset was used for all the RAMS simulations.

RAMS (version 4.3) is a three dimensional atmospheric model (Pielke et al., 1992) constructed around a set of nonhydrostatic equations that address atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities such as water vapor and liquid mixing ratios. These equations are supplemented with a selection of parameterizations for turbulent diffusion, solar and terrestrial radiation, and moist processes including the formation of clouds. The Chen and Cotton radiation parameterization scheme (Chen and Cotton, 1983), which accounts for the radiative effects of cloud liquid water, is used here. The model setup downscales the NARR data to one grid covering the U.S. Midwest region with a 5km X 5km spacing. This scale is not appropriate for a convective scheme, so only the microphysics option is used to generate precipitation. Weak internal nudging at a half day timescale is used to maintain the large-scale atmospheric variability in the simulation (Castro et al. 2005). Each experiment was performed for the entire month of August 2000 on a PC-based Linux cluster of 24 nodes located at the Laboratory for Climate Analysis and Modeling (LCAM) at the University of Missouri-Kansas City (UMKC).

The land surface model in RAMS version 4.3 is the Land Ecosystem Atmospheric Feedback model, version 2 (LEAF2) (Walko et al. 2000). This submodel of RAMS represents the storage and vertical exchange of water and energy in multiple soil layers, including effects of temporary surface water, vegetation, and canopy air. Surface grid cells are divided into subgrid patches, each with different vegetation or land surface type, soil textural class, and/or wetness index to represent subgrid variability in surface characteristics. Each patch contains separate prognosed values of energy and moisture in soil, surface water, vegetation, and canopy air. The grid cell exchange with the overlying atmosphere is weighted according to the fractional area of each patch. A hydrology model, based on Darcy ' s law for lateral downslope transport, exchanges subsurface saturated soil moisture and surface runoff between subgrid patches. LEAF-2 inputs standard land use datasets in order to define patches and their areas, as well as to obtain biophysical parameters for different vegetation types. While different initial soil moisture values can be prescribed for each layer below the surface, soil moisture is homogeneous spatially across the model domain. Additionally, for each vegetation type in LEAF-2, LAI is prescribed according to climatology.

Two offline datasets are used to assess the impact of prescribing a more realistic surface boundary on the ability of the land surface sub model in RAMS to simulate land surface processes and their influence on the PBL. First, retrospective North American Land Data Assimilation System (NLDAS) soil moisture from the MOSAIC land surface model (Brian et al., 2003) is used to provide a spatially variable initial soil moisture condition. Second, satellite derived-LAI, based on the Global Inventory Modeling and Mapping Studies (GIMMS, NASA) Normalized Difference Vegetation Index (NDVI), is used to replace the RAMS default LAI in Leaf-2, similar to Lu and Shuttleworth (2002). The NLDAS soil moisture has a 0.125º spatial resolution over central North American domain. The GIMMS, NASA –NDVI data has a spatial resolution 8km X 8km. The following experiments were performed for the month of August 2000: (1) homogeneous soil moisture and Leaf-2 LAI (the default run); (2) NLDAS heterogeneous soil moisture and Leaf-2 LAI (NLDAS run); and (3) soil moisture and satellite- derived LAI (LAI run). A fourth simulation which uses both NLDAS heterogeneous soil moisture and satellite-derived LAI is in progress.

3. RESULTS AND DISCUSSION

a) Soil moisture and LAI spatial patterns

In order to evaluate the differences between simulations based on the default configuration of RAMS and model runs that incorporate either variable soil moisture or satellite-derived LAI, the spatial distributions of these two parameters after 15 days of simulation are presented in Figures 1 and 2, respectively. Compared to the homogeneous soil moisture experiment, more spatial detail and stronger horizontal gradients in soil moisture over the entire model domain are evident in the heterogeneous soil moisture run. Soil moisture is notably higher across a swath of the central Midwest extending from southern Minnesota through Iowa, Illinois, Indiana and western Ohio (Figure 1). This soil moisture pattern is remarkably similar to the LAI distribution in the model run with satellite-derived LAI (Figure 2). The RAMS default LAI values are much larger over most of the model domain compared to the satellite-derived LAI. The obvious question is to determine whether the incorporation of these enhanced surface datasets have any significant impact on PBL processes, namely the magnitude and organization of convection. This issue is examined next by comparing total precipitation fields of the three simulations for the month of August 2000 (and sub-periods) with observations.

b) Impact of initial variable soil moisture and satellite-derived LAI on precipitation

The observed rainfall dataset against which we compared the model results is the daily precipitation gauge data from the U.S. Climate Prediction Center (NCEP-CPC) real-time and retrospective dataset (Higgins et al., 1996), derived from the U.S. Cooperative observing network. These gridded (0.25 degree by 0.25 degree) data span the period 1950-present and encompass all of the contiguous U.S. The total precipitation for August 2000 from the CPC data and the three RAMS experiments is shown in Figure 3. The impact of incorporating more realistic representations of soil moisture and LAI into RAMS is clearly evident in Figures 3c (NLDAS run) and 3d (LAI run). Compared to the default run, both simulations tend to better capture the observed precipitation patterns by shifting the centers of maximum convective activity towards the south-central part of the model domain. The maximum precipitation in the LAI run is also notably similar to that of the NCEP-CPC observed data, though slightly shifted southwards.

To further examine the impact of initial variable soil moisture and satellite-derived LAI on precipitation for sub-periods within August 2000, difference fields of weekly total precipitation are plotted for the NLDAS run minus default (Figure 4) and the LAI run minus default (Figure 5). In both cases, there appears to be a distinct influence of land surface forcing on both the spatial organization and magnitude of convection in parts of central Midwest (Illinois and Indiana) and southern Missouri. These changes are also more pronounced during the second week of August in both cases. It is particularly noteworthy that these changes are more pronounced during the latter part of the simulation when the synoptic forcing is weaker. A close examination of both Figures 4 and 5 appear to show that the more realistic surface data is affecting the organization of convection on the scale of approximately 10-25 km, with week-to-week variations. Additional, and more quantitative, analysis into the physical mechanisms associated with these spatial patterns is currently in progress. In particular, the technique of Stein and Alpert (1993) will be used to identify the relative contributions of soil moisture and vegetation to convective rainfall. A two-dimensional spectral analysis of the moisture flux convergence, such as used in Castro et al. (2005), applied to these experiments should demonstrate how enhanced surface information affects how convection organizes beyond the scale which the NARR can resolve.

4. CONCLUSION

Preliminary results of dynamical downscaling experiments with a mesoscale model have been presented for a summertime case study of August 2000 in the Midwest. As there was little or synoptic forcing of vertical motion during this time, the convective rainfall, particularly in southern parts of Indiana and Illinois, was locally forced. The experiments use the new NARR as an initial and lateral boundary condition to drive the model and evaluate the value added by the use of heterogeneous initial soil moisture from a NLDAS model and satellite-derived LAI. Results show a more realistic representation of the surface boundary affects the amount and spatial distribution of precipitation and improves the model-generated precipitation as compared to NCEP observations. Both the NLDAS run and LAI run show a shift of precipitation to the south-central part of the model domain, coincident with the areas of locally forced convection. There also appear to be changes in the scale of organization of convection, and ongoing analysis of the simulations will explicitly quantify this.

5. ACKNOWLEDGEMENTS

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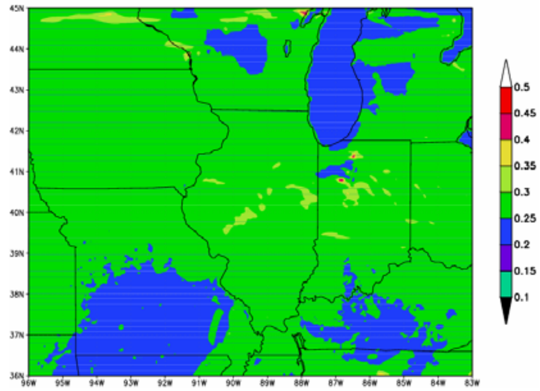
(a)



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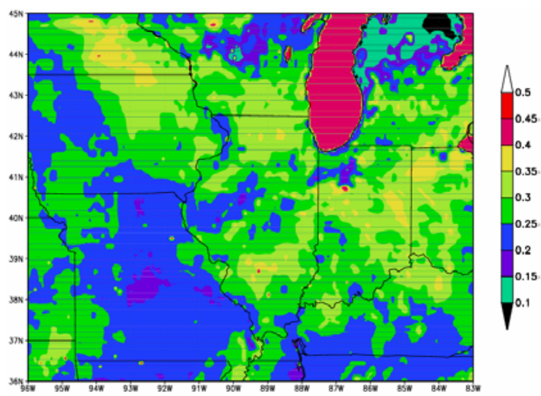
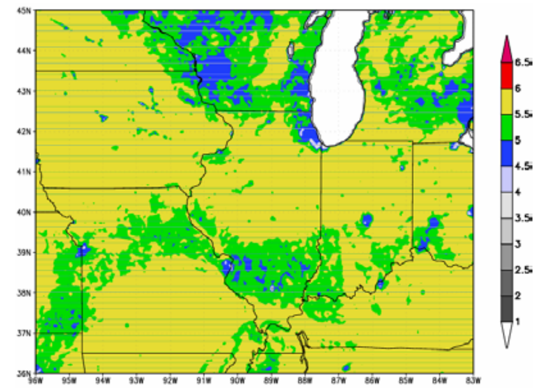


Figure 1: (a) Volumetric soil moisture (m3 m-3) after 15 days of simulation from Default run (b) NLDAS run

(a)



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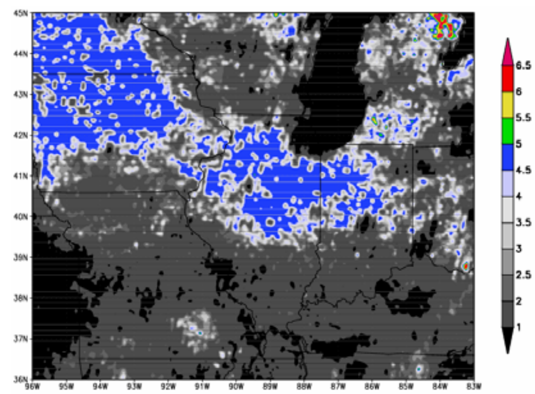


Figure 2: (a) Leaf Area Index (m2 m-2) after 15 days of simulation from Default run (b) LAI run

(a)

(b)

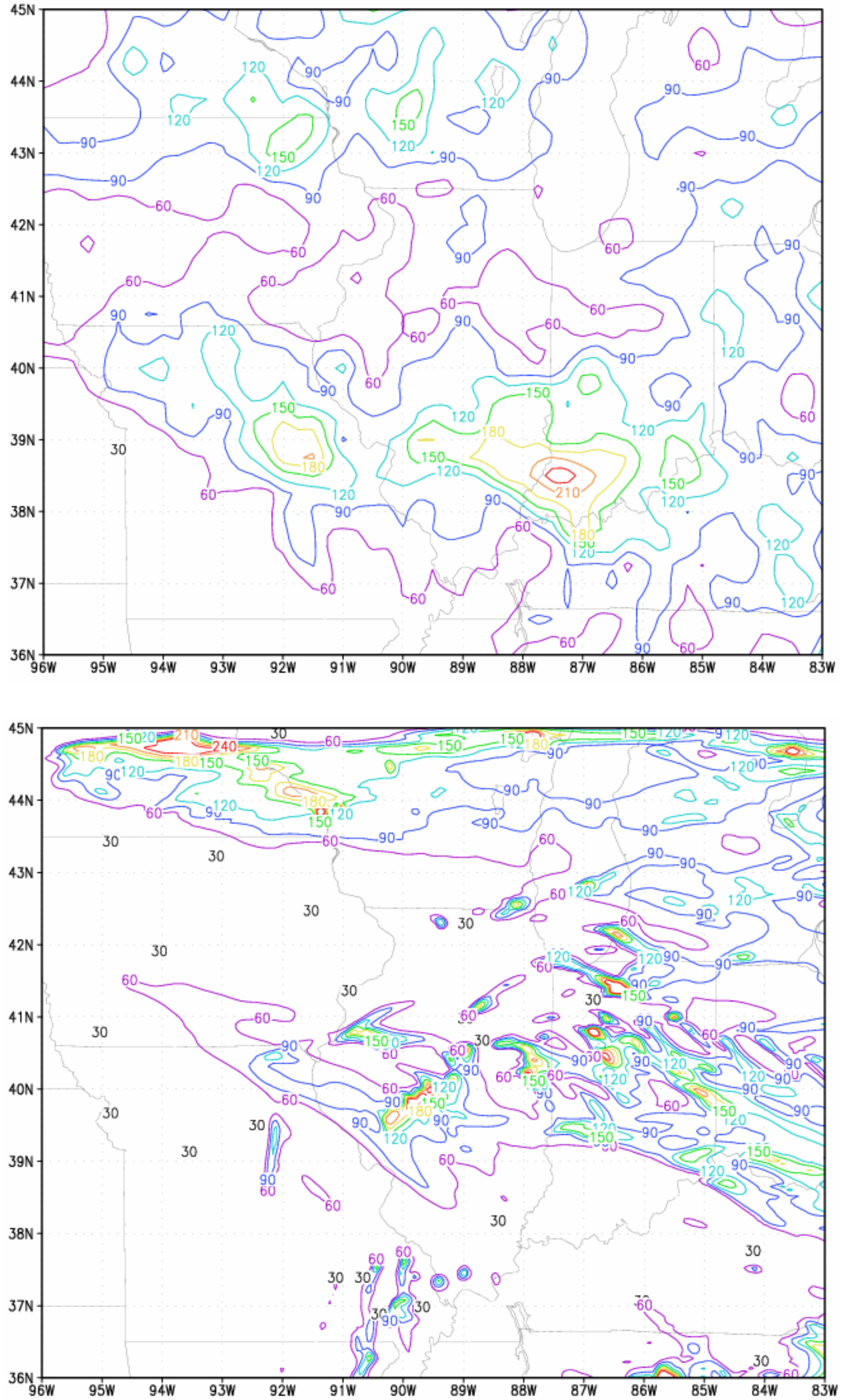
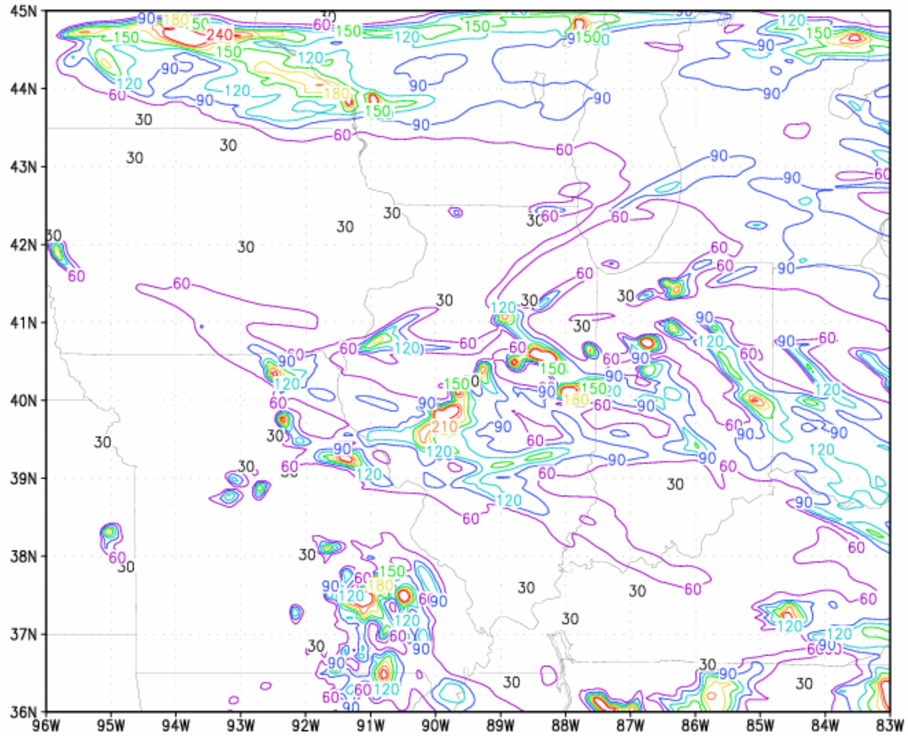


Figure 3: Total precipitation (mm) for August 2000 from (a) NCEP observations, (b) Default run

(c)



(d)

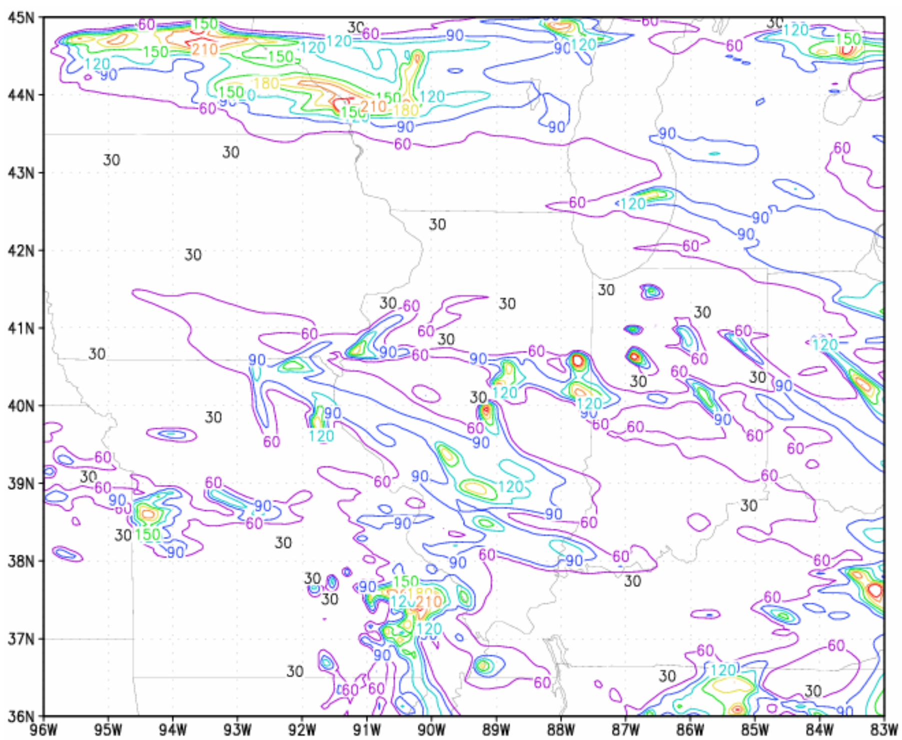


Figure 3 (continued): Total precipitation (mm) for August 2000 from (c) NLDAS run and (d) LAI run

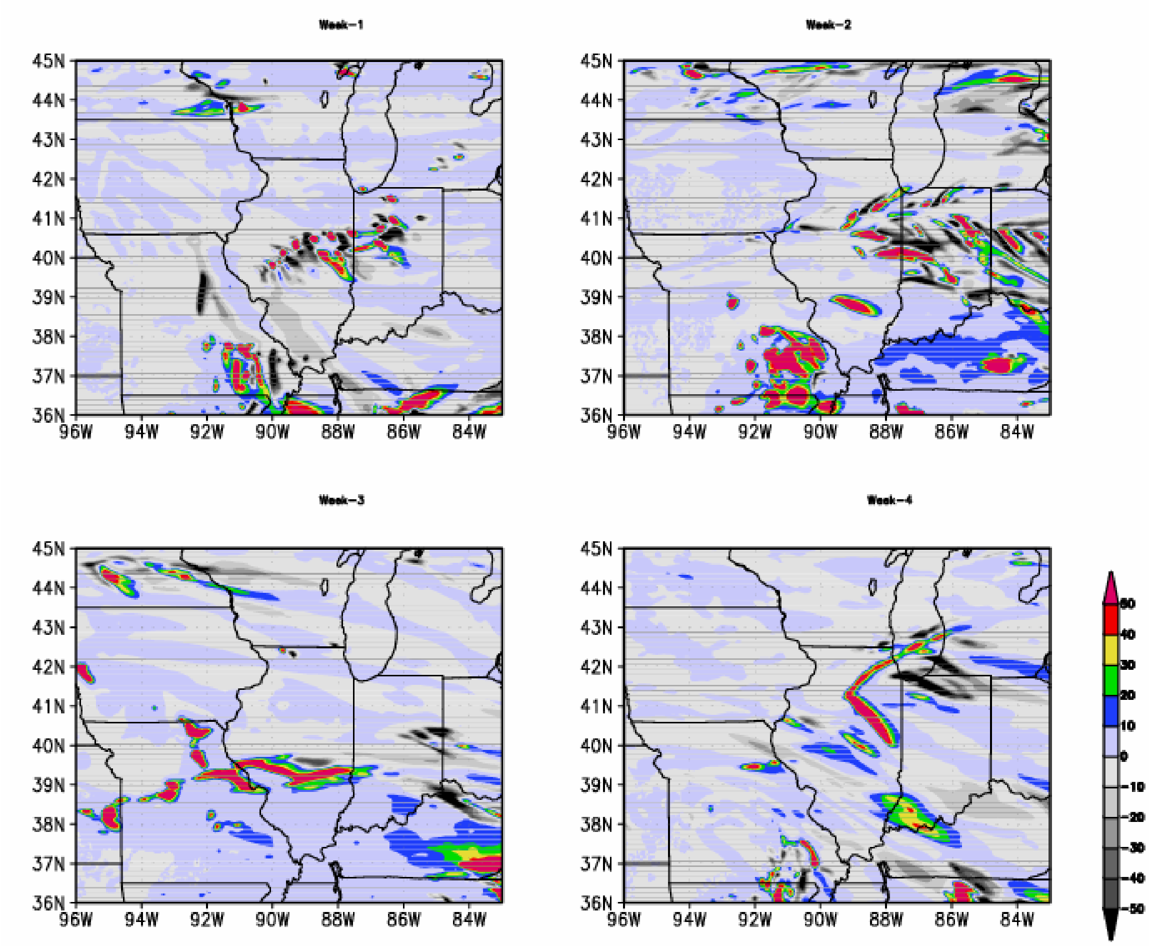


Figure 4: Difference of total precipitation; NLDAS run – Default run. Week 1 to 4 of August 2000.

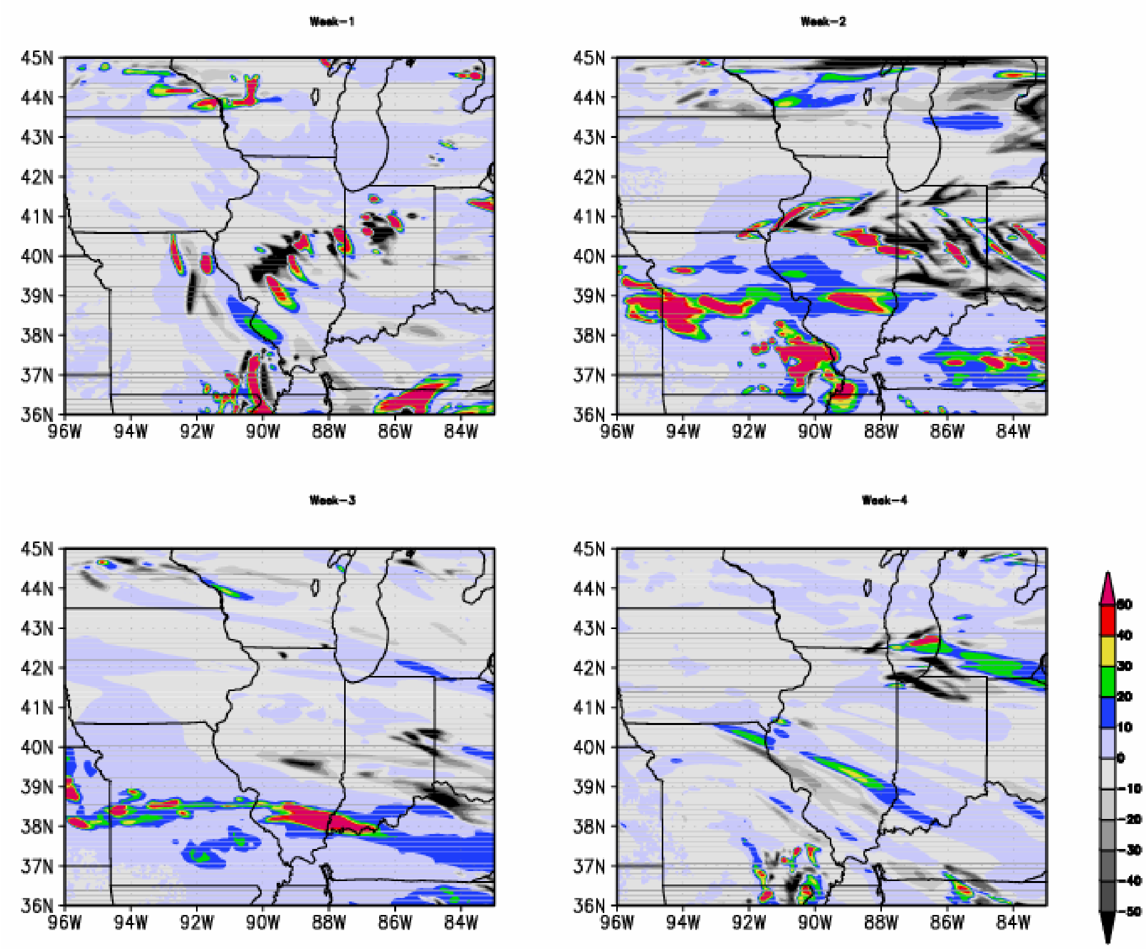


Figure 5: Difference of total precipitation; LAI run – Default run. Week 1 to 4 of August 2000.