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THE ROLE OF FINE-SCALE LANDSCAPE AND SOIL-MOISTURE VARIABILITY IN CONVECTION INITIATION

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1. INTRODUCTION

In arid and semi-arid regions, the distribution of surface latent and sensible heating may significantly influence humidity, near-surface winds, and precipitation. Understanding the feedback between land-surface variability and precipitation has been a central issue for various international water and energy study programs, because of its potential benefit in improving climate predictability.

In summer, mesoscale boundaries play a critical role in the initiation of heavy precipitation. The zones of enhanced convergence along these boundaries have been recognized as areas of deep-convection initiation. The origin of these mesoscale boundaries includes synoptic-scale fronts, outflows from previous storms, orographic features, and differential surface heating. The differential heating can be enhanced by heterogeneities in land-surface conditions. The land surface may have differing impacts, depending on atmospheric conditions. Small-scale ground features, such as vegetation, hillslopes, and urban or industrial areas can also have subtle impacts that can determine the exact boundary and intensity of storms.

Chen et al. (2001) examined the impact of the land surface and terrain on the 1996 flash flood that struck Colorado's Buffalo Creek watershed. Among their findings: the wildfire burn area received particularly heavy rainfall during the flood, possibly because the denuded site transferred more heat into the atmosphere than an area filled with living trees would. That extra heat would enhance a local storm by adding to the buoyancy of updrafts.

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We use here a numerical case-study of Trier et al. (2004) to demonstrate how soil heterogeneity at different scales influences the boundary layer development and precipitation for the semi-arid Southern Great Plains.

2. MODELING SYSTEMS USED

2.1. MM5 MODEL

The coupled Pennsylvania State University/NCAR MM5/Noah land surface modeling (LSM) system is used in this study. MM5 (Grell et al. 1994) is configured with up to 4 two-way interactive grids having horizontal grid spacing of 30, 10, 3.3, and 1.1 km, respectively. The locations of the nested domains, along with the terrain used in the 10km (outermost) nest D2, are shown in Fig. 1. The coarse domain D1 (not pictured) comprises the southwesternmost 2/3 of the continental United States and extends farther south into central Mexico, also covering the entire Gulf of California and much of the Gulf of Mexico.

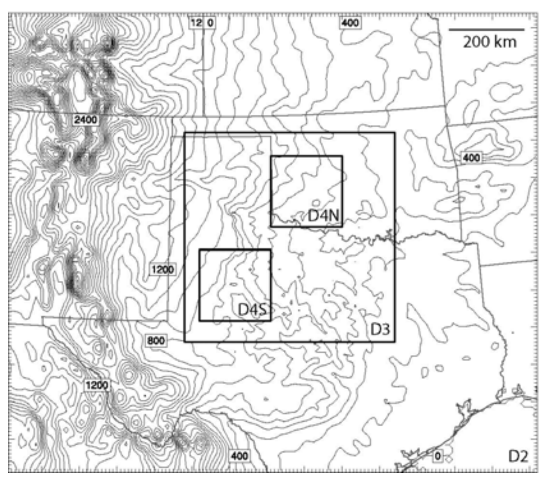

Figure 1. Nested domains for simulations. Terrain elevation for the first inner domain D2 is contoured in 100 m intervals.

2.2. NOAH LAND SURFACE MODEL

The Noah LSM provides surface sensible and latent heat fluxes, and surface skin temperature as lower boundary conditions (Chen and Dudhia, 2001; Ek et al, 2004). It has single vegetation canopy layer and the following prognostic variables: soil moisture and temperature in the soil layers, water stored on the canopy, and snow stored on the ground. The depth of the individual soil layers from top to bottom are 0.1, 0.3, 0.6 and 1.0 m. The root zone is contained in the upper 1 m (top three layers).

2.3 HIGH-RESOLUTION LAND DATA ASSIMILATION SYSTEM (HRLDAS)

To minimize the interpolation of soil moisture and temperature from HRLDAS to MM5/LSM coupled system, we designed the HRLDAS finest domain (the 4-km grid on Fig. 2) in a nested mode to approximately overlap the 3.3-km MM5 grid. The HRLDAS was run for the period from 1 January to August 1998 to determine the antecedent soil moisture/temperature conditions prior to our MM5 24-hour QPF simulation.

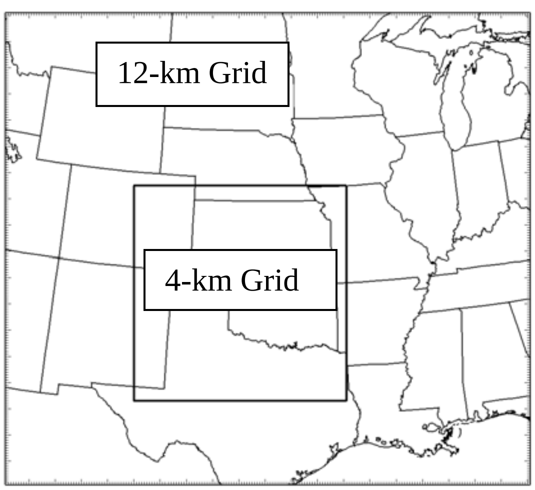

Figure 2: HRLDAS domains for the MM5 coupled simulations for selected 1998 dryline deep convection cases.

The HRLDAS characterizes soil moisture/temperature and vegetation variability at small scales (~4km) over large areas in order to provide improved initial land and vegetation conditions for the MM5/Noah LSM coupled model for our QPF simulations. As shown on Fig. 3, the HRLDAS soil moisture field captures not only the general west-east soil-moisture contrast, but also fine-scale heterogeneity caused by small-scale convective rain, landuse types, soil texture, and vegetation characteristics.

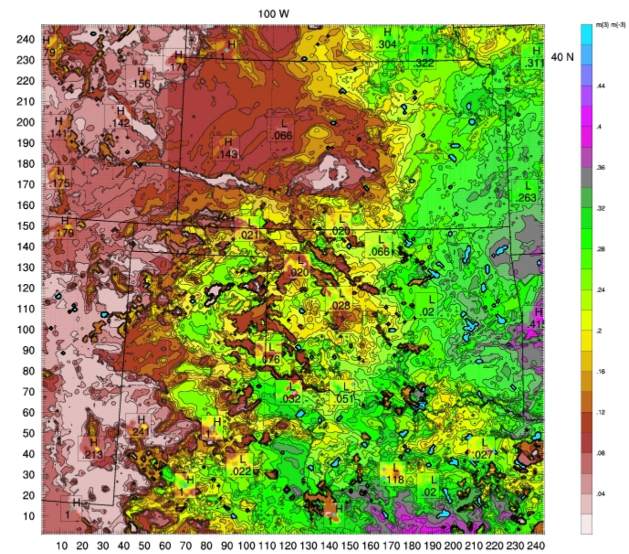

Figure 3: 4-km grid volumetric soil moisture at 5 cm below the ground surface simulated by HRLDAS for the IHOP area; valid at 1200 UTC 31 May 2002.

The HRLDAS soil moisture and temperature fields were used, as initial soil state conditions, in our high-resolution MM5 simulations

3. RESULTS AND DISCUSSIONS

In this study (for details, see Trier et al., 2004), we used high resolution MM5 simulations, initialized with soil moisture and temperature fields obtained from HRLDAS, to investigate how both surface processes and other aspects of mesoscale forcing influence the initiation of deep convection for a single diurnal cycle (0600 CST 19 June - 0600 CST 20 June 1998).

Our simulations were conducted over a regional scale domain with 30-km horizontal grid spacing that had additional domains with 10- and 3.3-km grid spacing nested within. Initial atmospheric fields were obtained from Rapid Update Cycle (RUC-II) analyses. Deep convection formed along or slightly ahead of the NE-SW oriented surface moisture gradient (dryline) from west Texas into central Oklahoma by mid to late afternoon on 19 June (Fig. 4).

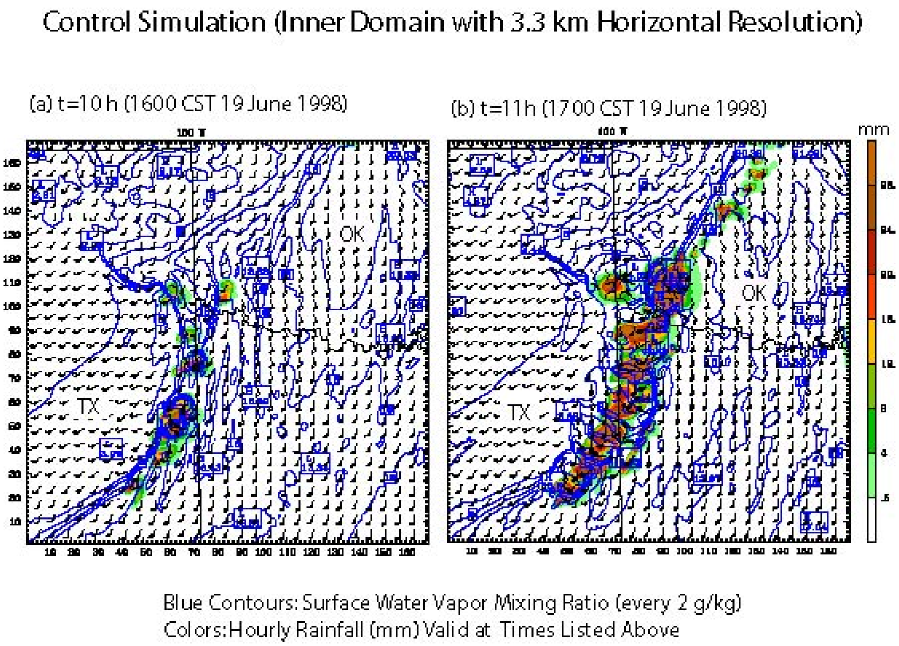

Figure 4: Surface winds (barbed symbols), water vapor mixing ratio (g/kg, contoured every 2 g/kg), and hourly accumulated precipitation (in mm, color scale at right) on domain 3 of the control simulation valid at (a) t=10h (1600 CST 19 June 1998), and (b) t=11h (1700 CST 19 June 1998). Tick marks on the border have a spacing of one horizontal grid length (3.3 km) within the 558 x 558 km2 innermost domain.

The dryline was particularly intense across west Texas (TX, Fig. 4a). By contrast, the dryline was slower to develop and somewhat weaker across Oklahoma (OK, Fig.4a), but did eventually intensify by late afternoon (Fig.4b). Comparison of infrared satellite data with radar-rain gauge (stage IV) precipitation estimates (not shown) revealed that the timing and location (with respect to the dryline) of the onset of deep convection was similar to these results from the control simulation.

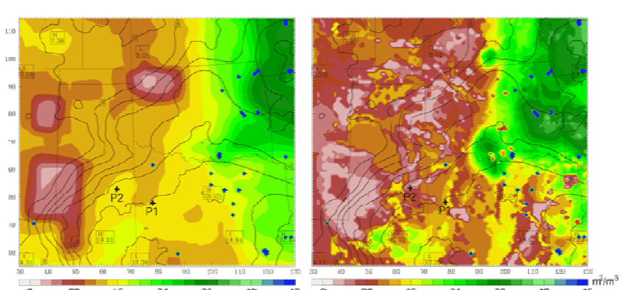

Figure 5: Initial conditions of surface water vapor mixing ratio and surface volumetric soil moisture in simulations (a) ETASM3 and (b) HRESM3 (control).

In one sensitivity test, we used the soil moisture and temperature from 40-km NCEP EDAS. A comparison of the 0.1m top layer at 0600 CST 19 June 1998 between EDAS (Fig. 5a) with that obtained from HRLDAS (Fig. 5b) shows much finerscale structure from HRLDAS. Large regional differences between EDAS and HRLDAS, in both absolute soil moisture values and their mesoscale gradients, are also evident. Also, the EDAS analysis is typically wetter.

Heavy convective rainfall initiates in HRESM3 (using HRLDAS soil conditions) both along and up to 50 km east of the leading edge of the dryline by mid-to-late afternoon (Fig. 6b). Convection first initiates directly along the strongest portion of the dryline in west Texas at 1500 CST, while subsequent convection develops ~1 h later from southwest to northeast near the dryline that extends from the southwest OklahomaTexas border region into northcentral Oklahoma.

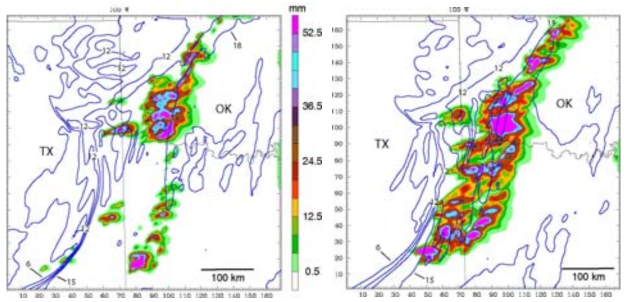

Figure 6. Simulated 3h precipitation from 1500 to 1800 CST 19 June 1998 in color scheme with 4mm intervals starting at 0.5 mm and 1500 CST 19 June (t = 9 h) surface water vapor mixing ratio in blue contours with 3 g kg -1 intervals starting at 6 g kg-1for domain 3 of simulations (a) ETASM3 and (b) HRESM3.

The simulated convective rainfall and its relationship to the dryline position depends on the soil moisture initialization. Despite strong similarities to HRESM3 over Oklahoma, in ETASM3, which uses coarser and generally wetter initial soil moisture conditions, the majority of the convection over Texas develops ~130 km east of the dryline (Fig. 6a). Convection initiation occurs farther west, either directly along or much closer to the dryline, in the observations. In contrast, only a few isolated storms occur along or adjacent to the dryline in ETASM3, despite an even stronger dryline in ETASM3 than in HRESM3. The timing, position, and SWNE orientation of the simulated heavy rainfall near the dryline in HRESM3 is quite similar to observations.

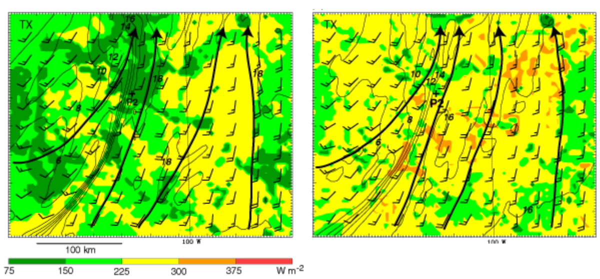

Figure 7. Time averaged 1000-1400 CST (t = 4-8 h) surface sensible heat flux (shaded) for the southern part of the dryline in Texas for (a) ETASM3 and (b) HRESM3.

One key reason that the convection did not initiate in Texas for ETASM3 simulation is its generally weak surface heating (Fig 7a). As a result, the smaller sensible heat flux in ETASM3 is insufficient to deepen the boundary layer and remove stability about it to trigger convection.

4. SUMMARY

This study reveals the importance of multiple scales of motion on convection initiation. A ~100km wide late morning to early afternoon zone of enhanced PBL depth, oriented along a surface moisture gradient of variable strength from southwest Texas into north-central Oklahoma, contained finescale (~10 km) PBL circulations that initiated deep convection.

The mesoscale zone of enhanced PBL depth was particularly crucial to the simulated convection initiation over Oklahoma, where an intense and localized surface dryline did not occur. In this region the mesoscale zone of preferential PBL deepening was initiated by differential sensible heating over sloped terrain of differing soil moisture. The differential sensible heating forced a mesoscale solenoidal circulation, which reinforced the differential PBL deepening and thermodynamic destabilization, and helped govern the horizontal scale within which more intense finescale circulations that directly initiated deep convection occurred.

The simulations showed significant sensitivity of the location and areal coverage of convection initiation to details of the soil moisture initialization. A control simulation that used a fine-scale initial soil moisture field obtained from HRLDAS accurately captured the timing and location of the observed convection initiation. In a sensitivity simulation that used a coarser initial soil moisture representation, typical of those currently in use in operational NWP models, the location of the forecast convection initiation was less accurate despite a forecast of dryline structure and evolution that was broadly similar to that of the control simulation. The differences in the two forecasts of convection initiation are attributed to subtle differences in the lower tropospheric thermodynamic structure that appear to have originated from localized differences in the partitioning between surface sensible and latent heat fluxes.

One interesting result from this study is that a dry soil seems to favor convection triggering for semi-arid region, because it provides the critical surface heating for deepening boundary layer and penetrating the inversion zone above the boundary layer.

5. REFERENCES

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