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WARM-SEASON LAND-ATMOSPHERE INTERACTIONS IN THE NEBRASKA SAND HILLS

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1. INTRODUCTION

The Nebraska Sand Hills are one of the largest grass-stabilized dune areas in the world. Even though the Sand Hills are generally perceived as a dry environment, they play an important role in the regional hydrology as a significant source of both groundwater recharge for the High Plains aquifer and surface flow in the Missouri Basin. With a climate varying from subhumid in the east to semiarid in its western portion, the Sand Hills support a unique mix of vegetation that changes across its breadth. Furthermore, the sandy soils of the Sand Hills, with their high infiltration rates, form a clear contrast to the soils in the cropland areas to the south. In these regions, clay soils with low hydraulic conductivity and slow infiltration rate predominate. The resulting spatial heterogeneity, both within the Sand Hills and with its surroundings, presents a challenge to understanding the role of land-atmosphere interactions and their seasonal variations on the region's weather and its hydrological cycle.

Preliminary investigations at the Omaha/Valley WFO have shown that the Sand Hills act as an orographic uplift area to initiate afternoon convection in the summer (S. Byrd, pers. comm., 1999). This was determined by analyzing surface wind fields just before, during and after convective events. However, a physical mechanism for this phenomenon was not determined. Contrasts between the Sand Hills and the surrounding plains may initiate a regional circulation in this part of the Great Plains. In the warm season, higher daily temperatures over the Sand Hills could cause rising motion and create a mesoscale pressure gradient towards the Sand Hills.

In order to allow analysis of the full range of the hydrologic cycle, representative wet, dry and average May, June and July (MJJ) periods were identified and three individual precipitation events were selected from each period. These events were chosen to represent 1) a synoptic event, 2) a convective event, and 3) a null event for the Sand Hills. This latter category is best described as a situation for which there was extensive precipitation in the region around the Sand Hills, but there was little or no precipitation over most of the Sand Hills.

The most recent version of MM5 includes a detailed land-surface model that represents a significant improvement in how MM5 computes surface fluxes and allows more realistic investigations of the effects of spatial variations or temporal changes of land surface characteristics on the atmosphere. Specifically, soil hydrology is now included explicitly, which vastly improves the utility of MM5 for hydrologic modeling. Land-surface characteristics (e.g., topography, vegetation cover, soil type) are varied individually during successive simulations. Modeled surface fluxes and near surface temperature and moisture fields are compared between control runs and runs with altered surface properties. These sensitivity runs yield estimates of the influence of the Sand Hills' surface characteristics on the atmosphere. Results for the response of the convective case in the normal year to a change in soil type throughout the Sand Hills are briefly discussed here.

2. MODEL CONFIGURATION

Simulations were performed using the latest release (version 3.40) of MM5 (Grell et al. 1994) to investigate the influence of the Nebraska Sand Hills on summer convection. Three two-way nested domains were defined (Figure 1) with grid spacing of 36, 12 and 4 km, respectively, and with the inner grid centered on the Sand Hills. Model physics for all three domains include the MRF PBL scheme, explicit moisture with the Reisner ice physics. The 36 km grid used the Grell cumulus parameterization, while the Kain-Fritsch parameterization was used for the 12 km grid. No cumulus parameterization was used for the 4 km grid, so that cumulus processes are explicitly resolved at this scale. The OSU/Eta land surface model (Chen and Dudhia 2001a,b) was used to predict surface energy fluxes and soil temperature and moisture fields.

The model was initialized at 0000 UTC 31 July 1986 using initial and boundary conditions derived from NCEP/NCAR Reanalysis data obtained from

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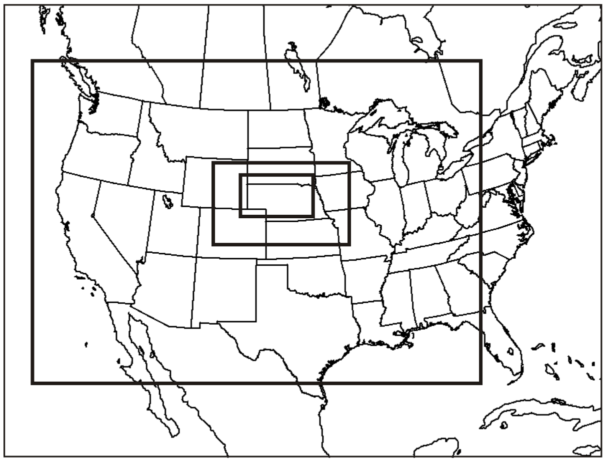

Figure 1: MM5 domains

CDC. The model was run for 48 hours with new lateral boundary conditions supplied every six hours.

Two simulations were performed using the configuration outlined above. The only difference between the runs was that for the second (experimental) run all grid points with sand soils were changed to a silt loam soil. This replacement was done for all three model domains, but only for those grid points located within the region defined by the innermost domain. Since soil moisture is specified as a fraction in the NCAR/NCEP Reanalysis, this change not only changes the thermal and moisture properties of the soil, but also changes the initial amount of moisture in the soil, as the field capacity and wilting points of these soils are specified differently in the MM5-LSM.

3. RESULTS

The general synoptic pattern is of northwesterly flow across the Sand Hills, with successive thunderstorm cells moving across the region throughout the 48 hour period. Both simulations reproduce the general conditions, although the timing of precipitation in both is incorrect. Nonetheless, significant differences between the control and experiment runs arise due to the change in soil type over the Sand Hills.

In both simulations, convection is initiated in the western Sand Hills at approximately 1900 UTC on 31 July 1986. The cells move east-southeastward across the region and, in the experimental simulation, the cells merge to form a larger, more vigorous cell. Furthermore, the cells are displaced to the south of their position in the control run. The experimental run produces more precipitation from these storms than does the control run and the band

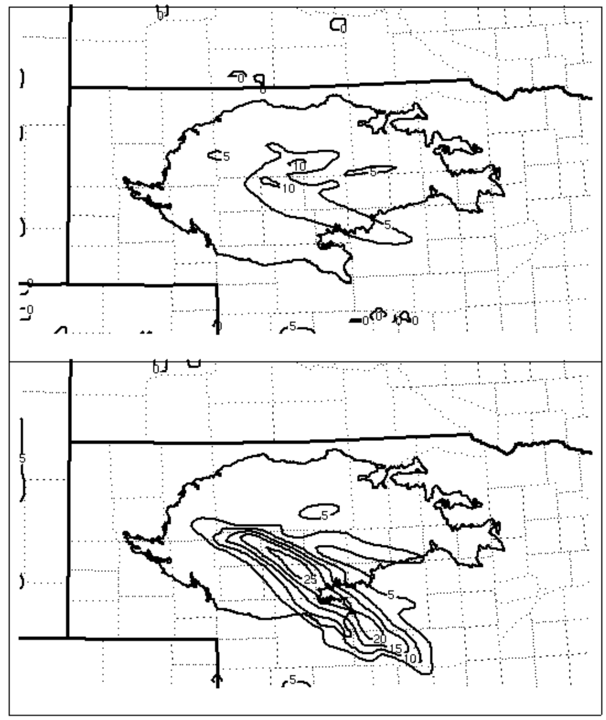

Figure 2: Total precipiation (mm) in MM5 domain 3 from 1800 UTC 31 July to 0000 UTC 01 August 1986 for the control run (top) and the experimental run (bottom). The approximate boundary of the Sand Hills is shown.

of precipitation is shifted southward (Figure 2). Just prior to the onset of convection in the southern Sand Hills, the surface layer (lowest 100 hPa) in the experimental run becomes slightly warmer (about 1.0-1.5 K) than in the control run (Figure 3a) and the simulated mixed layer deepens by 200 or more meters. This is due to a much larger sensible heat flux (50-100 W m^{-2} greater) in the southern Sand Hills in the experiment simulation as compared to the control run.

Two later rounds of storms are present in both runs and appear to be influenced by the location and extent of this first round. A second set of thunderstorm cells develops at about 0300 UTC on 01 August 1986 north of the region of earlier extensive precipitation in the experimental run. At this time, the control run has more extensive precipitation than the experimental run. It appears that the surface cooling (Figure 3b) that occurs as a result of the more extensive precipitation that occurred 6 hours earlier in the experimental run has increased the stability of the lower atmosphere. At approximately 1200 UTC 01 August 1986, a final round of storms develops in both simulations. In this case, the storms in the control run are again weaker and less extensive, as they are developing in the

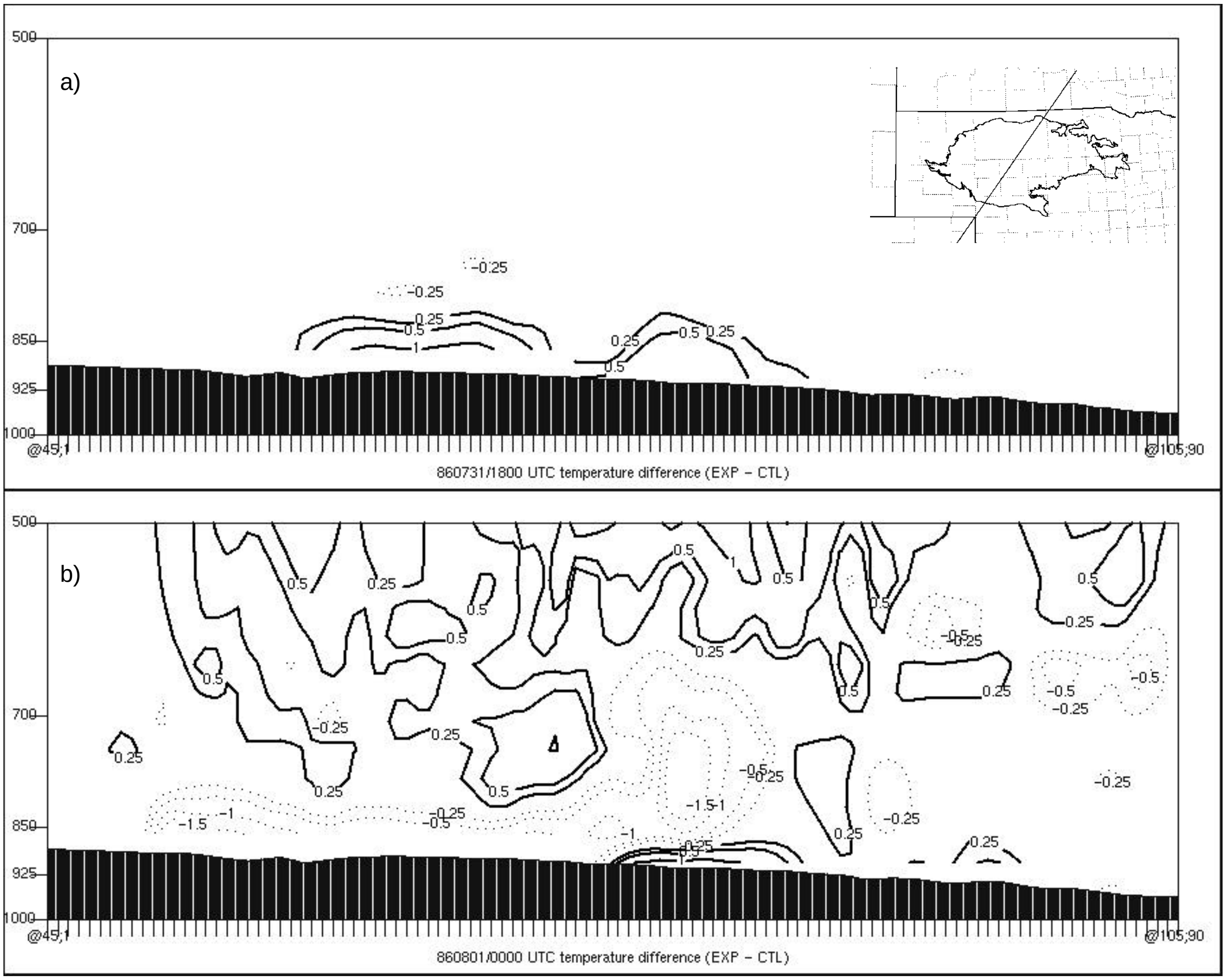

Figure 3: Cross section along a line (inset) perpendicular to the upper-level flow showing the temperature difference between model runs, before (top) and after (bottom) the first set of storms. Negative differences (experiment cooler than control) are dashed.

region stabilized by the second round of precipitation.

4. DISCUSSION

Changing the soil of the Nebraska Sand Hills from sand to a silt loam resulted in significant differences in the simulation of a convective storm system over the region using MM5 with the OSU/Eta land surface model. Given the default soil physical properties of these soils used in the model, evaporation from bare soil and transpiration from vegetation will be greater from the sand soil than from the silt loam at any given volumetric soil moisture content. As the two runs were initialized with the same volumetric soil moisture content, evapotranspiration and latent heat flux are greater in the control run than in the experiment run, at least until simulated precipitation over the region creates substantial differences in volumetric soil moisture content between the control and experimental runs. The greater sensible heat flux in the experimental run warms the lower atmosphere over the Sand Hills and results in a deeper mixed layer, leading to increased convection and greater precipitation amounts.

As part of an ongoing project, simulations of additional convective, synoptic and null events will be conducted for wet, dry and normal years in order to help determine the range of interactions between the Nebraska Sand Hills and the atmosphere.

5. ACKNOWLEDGEMENTS

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