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THE ROLE OF PRAIRIE WETLAND EXTENT ON THE PRE-STORM ENVIRONMENT OF THE NORTHERN GREAT PLAINS

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1 INTRODUCTION

The role of the land surface on the pre-storm environment has been well established (Lanicci et al., 1987). Given this, numerical weather prediction (NWP) frameworks have adapted to accommodate the role of vegetation and soil moisture on the surface energy budget and, likewise, have characterized these often rapidly varying parameters for operational and research applications. However, many land surface features may be omitted due to their small individual sizes in relation to the larger ecosystem (and land cover dataset resolutions), yet may play an important role in the land surface energy budget of the region.

One such feature is the prairie wetland complexes of the Northern Great Plains. These wetlands exist at a number of spatial and temporal scales. As individual landscape elements, they are often smaller than the 1-km resolution that often serves as the reference for most NWP land cover regimes. But their number and extent often places them on parity in area coverage with the surrounding agricultural-grassland upland matrix that describes the overall Northern Great Plains east of the Missouri River (the land west of which is characterized as semi-arid rangeland thus creating a sharp surface moisture gradient over the larger basin). Moreover, the prairie wetland region's influence at larger scales can be seen in global-scale satellite imagery (Figure 1). Over the past decade, beginning in the early 1990's, these wetlands have undergone extensive expansion and are now at their maximum recorded extent. Consequently, it has been hypothesized that this new land-surface state may be modifying the regional pre-storm environment, altering the potential for precipitation. This is further complicated in that positive and negative feedbacks of surface moisture on convective potential – the dominance of boundary layer instability and convective available potential energy (CAPE) vs. reduced surface heating from wet surfaces – have yet to be determined in this geographic region in comparison to other regions (Findell and Eltahir, 2003a, b).

To examine the role of surface moisture on the Northern Great Plains storm environment in more detail, both in the context of "resolvable" properties such as soil moisture and presently irresolvable properties such as wetland coverage, we are conducting a series of sensitivity experiments for warm-season storm events of varying levels of synoptic forcing.

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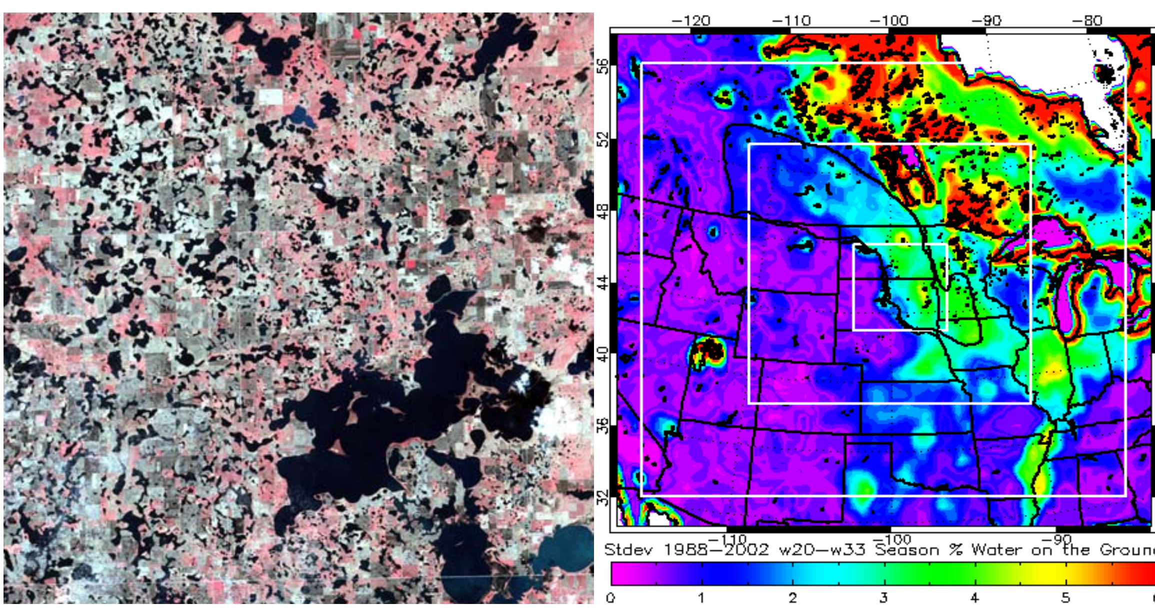

Figure 1: [Left] 30×30-km False-Color Landsat Thematic Mapper image of the Waubay Lake area, South Dakota, for 21 April 1998, and [Right] NOAA-NCDC SSM/I Surface Wetness (Basist et al., 1998) warm season 1988-2003 standard deviations. The prairie wetland region is outlined in black. (The SSM/I data underestimates available water magnitudes in the Northern Great Plains but accurately shows the region's boundaries and relative large-scale wetland distributions.) MM5-LSM domains are outlined in white.

2 SIMULATION ENVIRONMENT

In these scenarios we are using the NCAR/PSU Mesoscale Model using the NOAH land surface parameterization (MM5-LSM) (Grell et al., 1994; Chen and Dudhia, 2001a, b) for a nested 36-, 12- and 4-km resolution domain centered on eastern North and South Dakota. The scenarios' base land surface is derived using MM5-LSM's default 1-km land cover/land use characterization after Loveland et al. (2000). Both the overall first-guess initialization fields, and initial soil moisture and temperature fields, are taken from the NCEP/EDAS analyses. As the wetlands are not resolved at the 1-km resolution of the derivative land cover datasets, the 40-km NCEP soil moisture analyses, or the 4-km resolution of this study's finest domain, soil moisture is used as surrogate. This is done by creating a mask of the prairie wetland region (delineated in Figure 1) and progressively changing the affected soil moisture.

Our goal is to perform a series of simulations over the eastern Dakotas for scenarios of strong, moderate and weak synoptic forcings. Presented here are the results using two synoptically-forced convective events as scenario templates. Given the structure of the domains and overall extent of the events, it is currently not our intention to accurately forecast these events, per se. Rather our goal is to demonstrate the role of the land surface in modifying the storm environment of a convective event that is strongly influenced by larger synoptic forcings.

3 29 JULY 2003 SENSITIVITY BATTERY

The first scenario presented here is based on a tornado-producing frontal event that passed through South Dakota on 29-30 July 2003. For this scenario, a 24-hr simulation battery beginning 12 UTC 29 July 2003 was executed using the NCEP/EDAS-estimated values of soil moisture as a control case, and a range of soil moistures from 0.15 to 0.50 over the prairie wetland region. These soil moistures, when translated into effective overall surface wetness (both wetland and upland), permit the representation of surface conditions ranging from drought to deluge.

Figure 2 shows the resulting CAPE 9 hrs into the simulation (beginning 12 UTC 29 July 2003). Shown are the control run using NCEP/EDAS soil moisture, and two perturbed scenarios using elevated soil water contents of 0.33 and 0.50 over the prairie wetland region to represent moderate and high-end wetland extents. The results show a notable increase in the already elevated CAPE fields in the center of the domain caused by an increase in the boundary layer humidity and shallower boundary layer depths in the elevated moisture simulations. In the other simulations in this battery, CAPE continued to increase with progressively higher soil moistures. These higher instabilities are also reflected in the total event precipitation where a westward shift in the heavier precipitation cells is seen in the modified cases (Figure 3). This is consistent with, and can be explained through, idealized 2-D simulations using the Advanced Regional Prediction System (ARPS) (Xue et al., 2000) with an east-west wetland gradient (Figure 4) in which convection along the surface moisture gradients are seen. This is also consistent with other studies (Segal et al., 1988) where boundaries of vegetation and moisture have been shown to create sufficient circulations and instability to generate convective precipitation along the surface boundaries.

4 02 AUGUST 1997 SENSITIVITY BATTERY

The second case presented here represents a more moderately-forced event on 02 August 1997 in which convection was supported by upper-level divergence. As with the previous battery, the MM5-LSM was run for a set of 24-hr long simulations (beginning at 12 UTC 02 August 1997) with NCEP/EDAS and adjusted soil moisture fields to represent the control surface moisture state and different degrees of wetland inundation.

The resulting fields of 5-hr CAPE are shown in Figure 5 for the control surface moisture, 0.33 and 0.50 surface moisture cases. In contrast to the previous 2003 case, the maximum values of CAPE are lower in

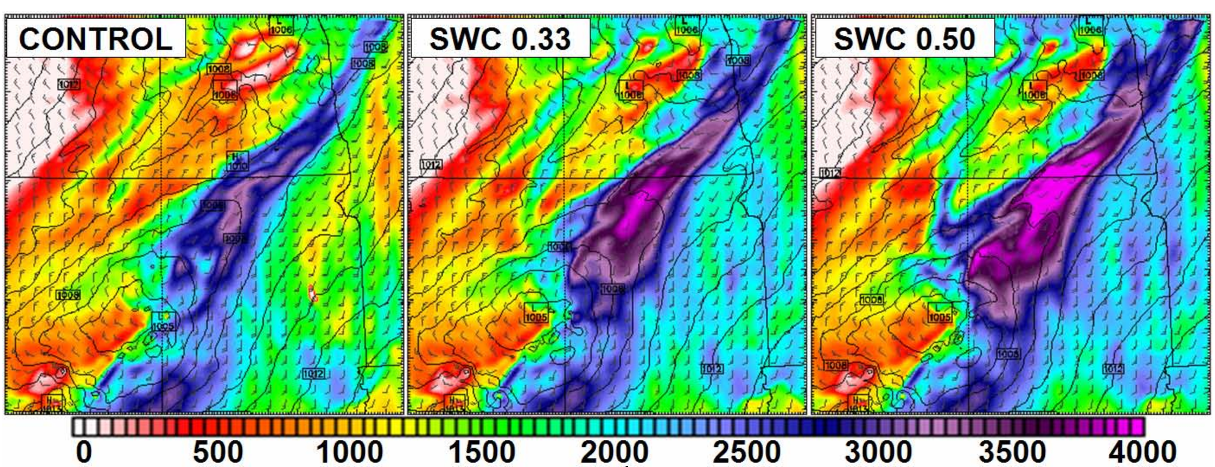

Figure 2: Comparisons of forecasted 9-hr CAPE (J kg^{-1}) for the 12 UTC 29 July 2003 sensitivity runs' 4-km innermost domain for the control case [Left], and the 0.33 [Center] and 0.50 [Right] soil moisture cases. Shown also are isobars of mean sea level pressure and surface wind barbs.

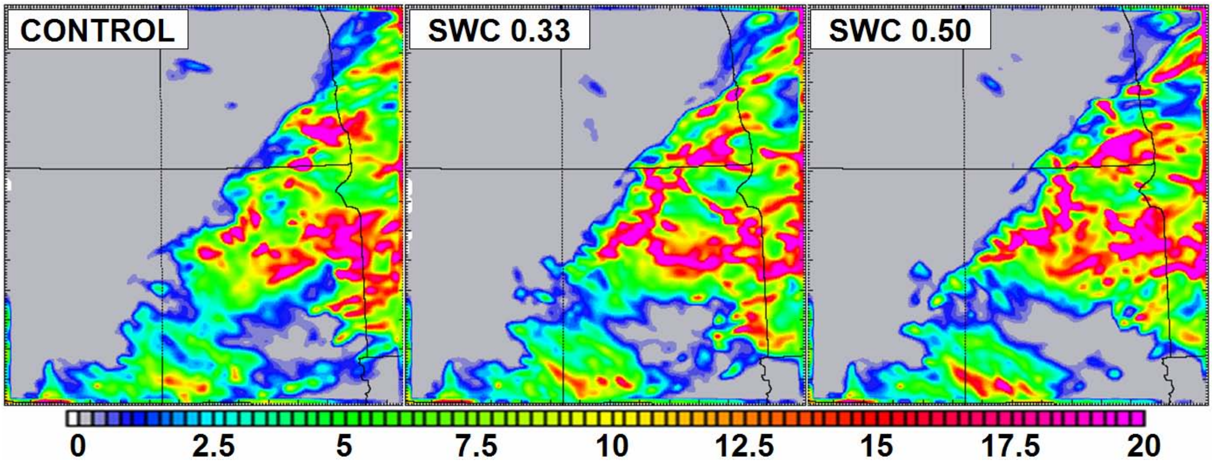

Figure 3: Comparisons of forecasted 24-hr total precipitation (mm) for the 12 UTC 29 July 2003 sensitivity runs' 4-km innermost domain for the control case [Left], and the 0.33 [Center] and 0.50 [Right] soil moisture cases.

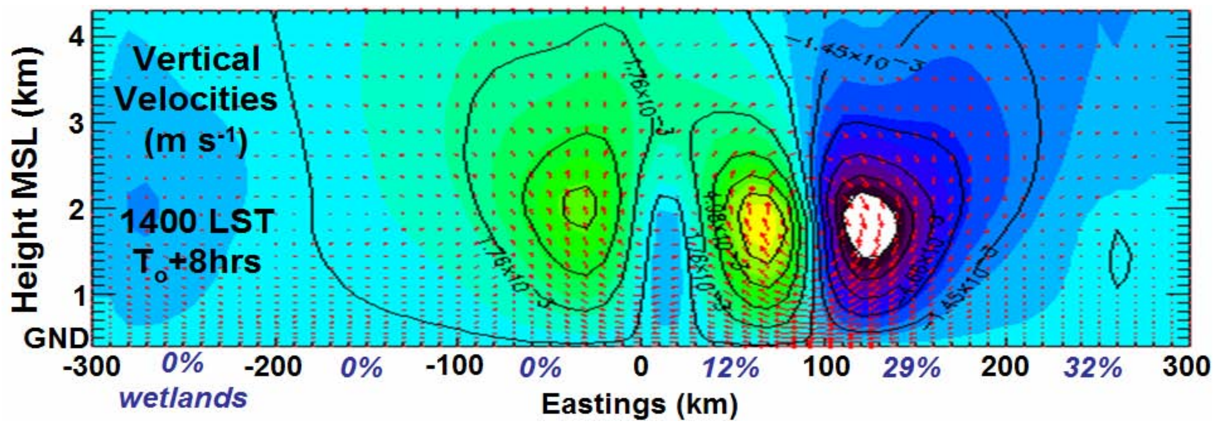

Figure 4: Simulated vertical velocities and wind vectors derived from an idealized 2-D ARPS simulation using the NCAR-Land Surface Model (Bonan, 1996) to represent wetlands of varying area coverage placed in 100-km-wide strips from west to east.

the enhanced surface wetness runs, but the 0.33 soil wetness run shows a larger area coverage of high CAPE values. Additionally over time, the increase in CAPE leading up to the onset of precipitation is progressively slower in the enhanced surface moisture cases. Though the overall boundary layer humidity is higher in the perturbed cases, the surface temperature increase remains slower as with the 2003 case. The differences in the CAPE fields are also reflected in the resulting precipitation fields (Figure 6) in which the control and 0.33 soil moisture cases exhibit large areas of high total precipitation while the extreme wetness case (0.50 soil water content) has the strongest cells focused near the edge of the wetland region, at the west edge of the precipitation field. This suppression of large scale convective precipitation in the extreme wetness case differs from the strongly-forced 2003 case in that the 2003 case did not show a major change in the precipitation distribution or intensity as the initial soil water contents were raised to anomalously high values.

5 CONTINUING WORK

The results of these two numerical experiments demonstrate a sometimes subtle, albeit recognizable, influence by surface wetness anomalies (which in this region would be primarily manifested as variations in wetland area coverage) on synoptically-forced precipitation. The analyses of these two scenarios continues, and we are preparing further simulation batteries using scenarios more representative of air-mass convective events as well as more moderate synoptic forcings. Additionally, rather than applying a single soil water content by which to proxy wetland coverage, a more realistic distribution is being prepared.

6 ACKNOWLEDGMENTS

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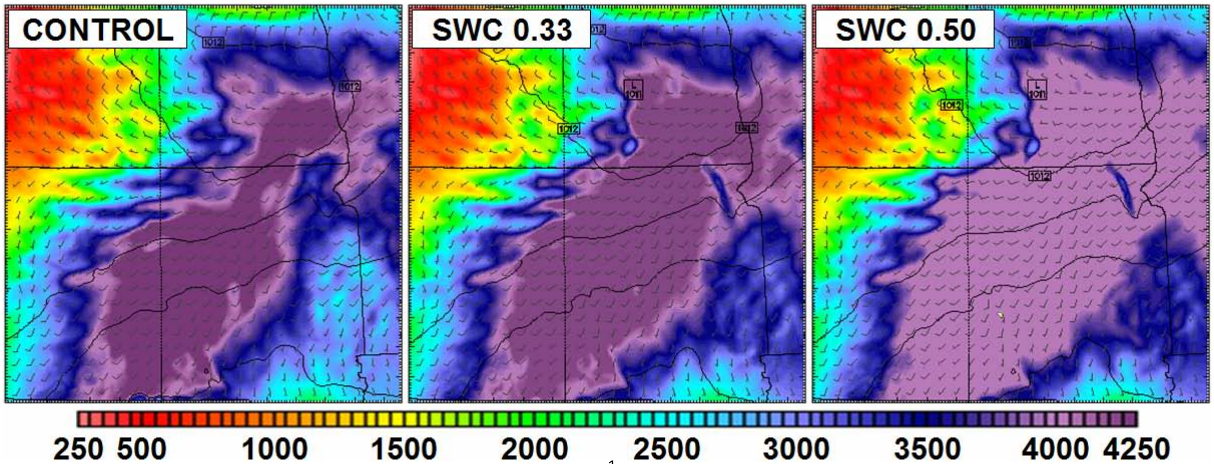

Figure 5: Comparisons of forecasted 5-hr CAPE (J kg^{-1}) for the 12 UTC 02 August 1997 sensitivity runs' 4-km innermost domain for the control case [Left], and the 0.33 [Center] and 0.50 [Right] soil moisture cases. Shown also are isobars of mean sea level pressure and surface wind barbs.

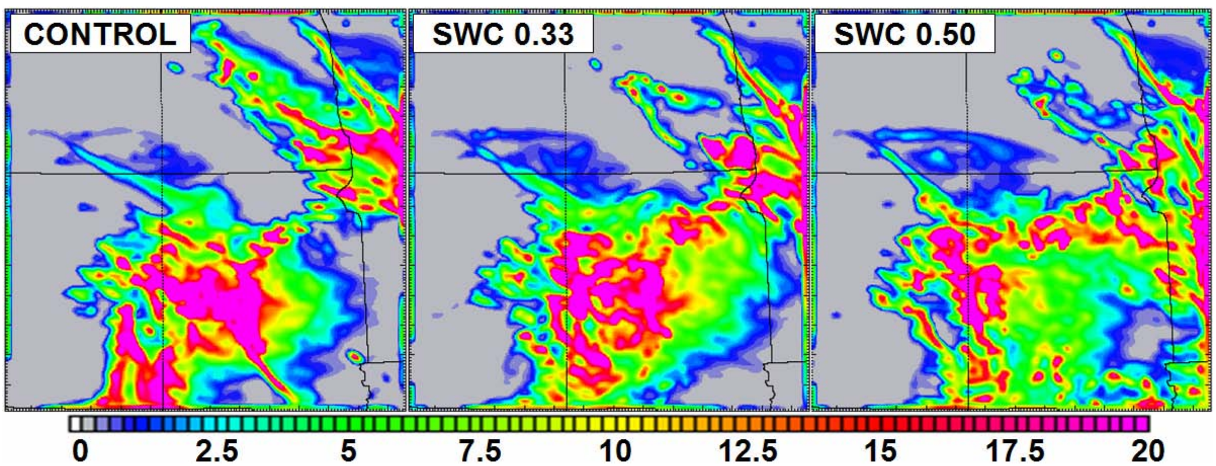

Figure 6: Comparisons of forecasted 24-hr precipitation (mm) for the 12 UTC 02 August 1997 sensitivity runs' 4-km innermost domain for the control case [Left], and the 0.33 [Center] and 0.50 [Right] soil moisture cases.

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