Representing Great Plains Prairie Wetland Feedbacks in WRF

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1 INTRODUCTION

The prairie wetland region of the Northern Great Plains of North America (identified as the blue region within the black outline of Figure 1b) is a mixture of cropland, pasture and sporadic woodland. However, its defining characteristic is a complex matrix of wetland systems of varying sizes and durations of inundation. This wetland region was created upon the retreat of glaciers at the end of the last ice age, approximately 11,000 years ago. As the glaciers retreated, the exposed rolling surface of the glacial till and depression created by stagnant ice bodies produced numerous closed basins that are ideal settings for permanent and seasonal lakes and wetlands [*LaBaugh et al.*, 1998; *Rahn*, 1998].

The spatial and temporal variability of these wetlands plays an important role in the regional hydrology, ecology, biogeochemistry, and climate [*W.C. Johnson et al.*, 2003; *W. C. Johnson et al.*, 2010; *LaBaugh et al.*, 1996; *Poiani and Johnson*, 2003; *Poiani et al.*, 1995; *Poiani et al.*, 1996]. For example, in the 1980s the prairie wetland systems were in a drought cycle, with many of the smaller and even larger wetland units completely dry. Then, in the 1990s and through this decade, the wetland coverage is at historical maxima with significant impacts on farmland, property, and wildlife populations. The impact of these lake-level and lake-area increases can be seen in Landsat Thematic Mapper (TM) imagery shown in Figure 2 which contrasts the surface water coverage in 1984 to 2011 over the Waubay Chain of Lakes in

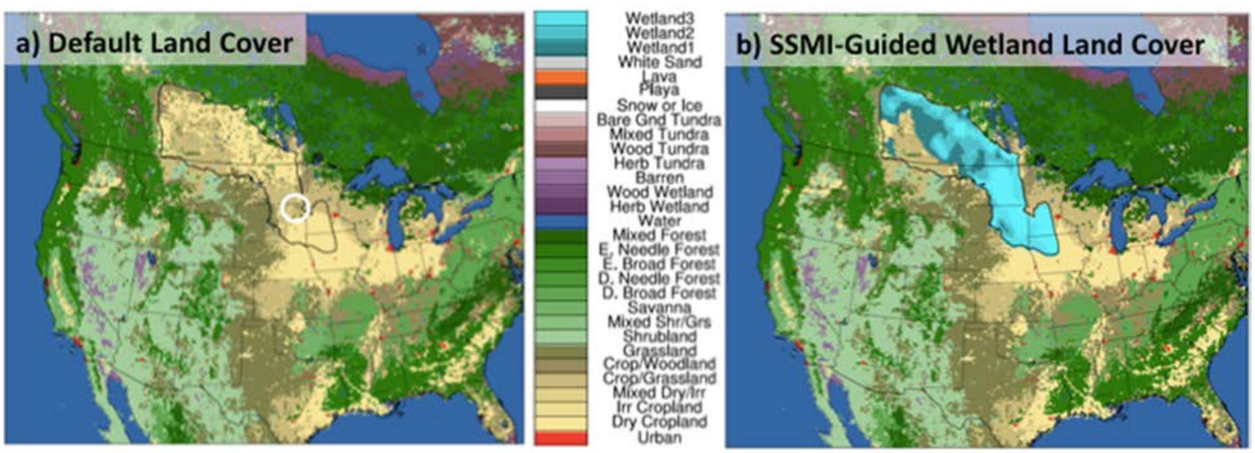

Figure 2: USGS/NOAH Land Cover and WRF Simulation Domain for a) the default wetland-free simulation, and b) the wetland simulations. The black outline denotes the prairie wetland region. The white outline highlights the Waubay Chain of Lakes region shown in Figure 2.

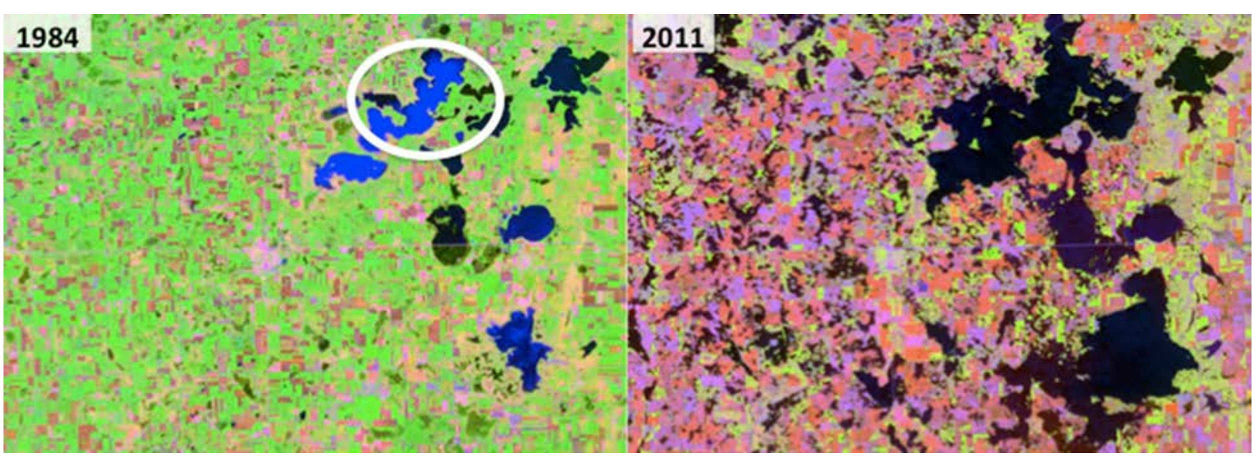

Figure 1: 40-x28-km Landsat TM Images of the Waybay Chain of Lakes Region for a) 03 July 1984 and b) 11 May 2011. Band combinations are R=TM Band 6, G=Normalized Difference Vegetation Index, and B=TM Band 1. Water bodies are shown as dark features. The Waubay Lake as it appeared in 1984 is circled in white.

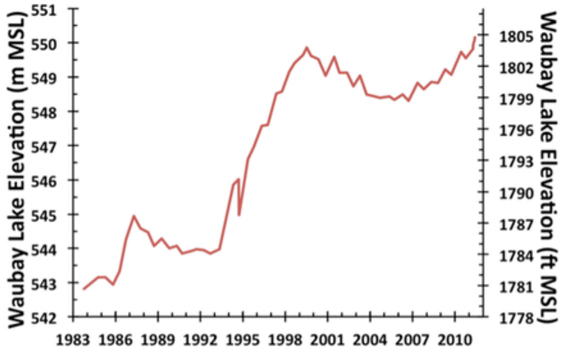

Figure 3: Waubay Lake Elevations from 1983-2011.

northeastern South Dakota. Also shown in Figure 3 is the surface elevation level for Waubay Lake over the period between the images. As can be seen in comparing the Landsat imagery to the lake elevation, *a small change in lake elevation over the flat terrain of the prairie wetland region results in a major change in surface area coverage of the water bodies*. We also believe that these wetlands have a significant role in climate. It is this relationship between prairie wetlands and regional climate that we wish to examine.

Models of the surface hydrology commonly detach surface hydrologic processes from meteorological and climate processes, relying on external coupling or one-way imposition of meteorological forcings. However, wetlands are not simply passive responders to climate but can, in turn, influence aspects of regional climate. Studies by *Findell and Eltahir* [2003a; b] noted that the eastern periphery of the Northern Great Plains is a region where both surface and atmospheric conditions control convective precipitation but, additionally, the high surface moisture can have both a positive and negative feedback on convection and convective precipitation. This influence by the land surface was further confirmed by *Capehart et al.* [2004], and *Capehart and Taylor* [2005] using storm- and climate-scale simulations with the Penn State/NCAR Mesoscale Model and NOAH land-surface model (MM5-LSM) [*Chen and Dudhia*, 2001; *Grell et al.*, 1994]. *Capehart and Taylor* [2006] expanded on these findings by generating seasonal and multi-year MM5 simulations using varying wetland densities. Their results indicated non-linear interactions between progressively increasing wetland influence and rainfall in the eastern regions of the prairie wetland region, specifically the North Dakota and South Dakota prairie coteaus. As wetlands begin to increase from the control scenario, simulations begin to exhibit a higher likelihood for more rainfall in the affected area. *However, as the wetland extent increased to a hypothetical maximum extent, precipitation likelihood was shown to slightly decrease*.

These previous simulations were limited by both computational restrictions that required domains that covered only the Northern Great Plains (and were thus strongly controlled by the nearby lateral boundary conditions) and also a simplistic and quasi-static representation of prairie wetlands using soil moisture as a proxy to open surface water cover illustrated as happening in Figure 2. As such, our long-term goals are to represent prairie wetlands in a more dynamic framework using areal water percentages that can be updated over time, including coupling with a wetland ecology model. However, in this pilot study, our goal is to recreate our earlier work with MM5 using WRF-ARW [*Skamarock et al.*, 2008] for a region with a larger spatial extent for the most recent increase in wetland area coverage.

2 MODEL CONFIGURATION AND MODIFICATIONS

Similar to our earlier work [*Capehart and Taylor*, 2005; 2006], we are adapting the NOAH land scheme to incorporate three new "prairie wetland" classes following the current "Dry Cropland and Pasture." As wetlands at most Numerical Weather Prediction and Regional Climate Modeling resolutions are subgrid-scale features (though potentially occupying a large percentage, albeit not a majority, of a grid cell), we use the grid cell soil moisture as a proxy for the wetlands. Here we limit the *minimum* possible soil water content in the grid cell in proportion to a wetland category ("Minimum Wetland," "Moderate Wetland," and Maximum Wetland").

These wetland regions are determined by SSM/I (Special Sensor Microwave/Imager) surface water products developed by *Basist et al.,* [1998]. Here, wetlands from 1988-2003 for the months of March through September were averaged over the Prairie Wetland region (Figure 4). Three wetland regions were defined as those areas whose mean SSM/I warm-season wetland coverages over the prairie wetland region fall into the top four quintiles. The highest two quintiles (60-80%, and 80-100%) were defined as the "Maximum Wetland" category; the "Moderate Wetland" category is the third quintile (40-60%); and the "Minimum Wetland Category" is assigned the second quintile (20-40%). The lowest first quintile (0-20%) is assigned the default NOAH/USGS land cover category.

For this paper, we are using two wetland scenarios, and a default scenario with no modifica-

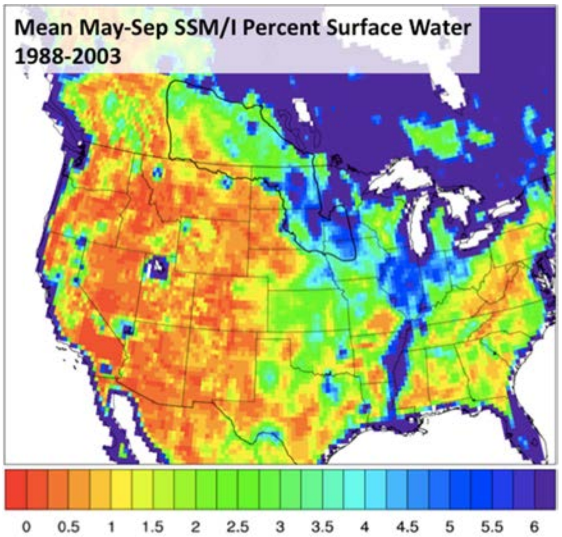

Figure 4: SSMI/I Surface Water Product for averaged between May-Sep for 1988-2003.

tions to the native WRF NOAH submodel. The first scenario represents a hypothetical maximum potential prairie wetland coverage in which the soil water coverages for the three classes were restricted to a minimum soil water content of 50%, 60% and 70% of saturation for Minimum, Moderate, and Maximum Wetland categories, respectively. The second scenario limits the minimum soil water content to 10%, 25% and 50% saturation to these categories. These modifications to the soil moisture were imposed over the entire soil column.

Our simulation covers the warm season of 2008, March through September. Calendar year 2007 was characterized as a period where wetlands, still at high coverages from their 1990s expansion, began a renewed expansion phase. This state of elevated wetland coverage continues into this current year. The single 4500-km x 3750-km domain, Figure 1, has a grid spacing of 15 km, and 35 vertical levels. For this scenario, in addition to the NOAH land surface scheme, we used the Kain-Fritsch 2 cumulus scheme [*Kain*, 2004], the YSU Boundary Layer scheme [*Hong et al.*, 2006] with Monin–Obukhov similarity for the Surface Layer, CAM Radiation Scheme [*Collins et al.*, 2004], and WSM6 Microphysics [*Hong and Lim*, 2006].

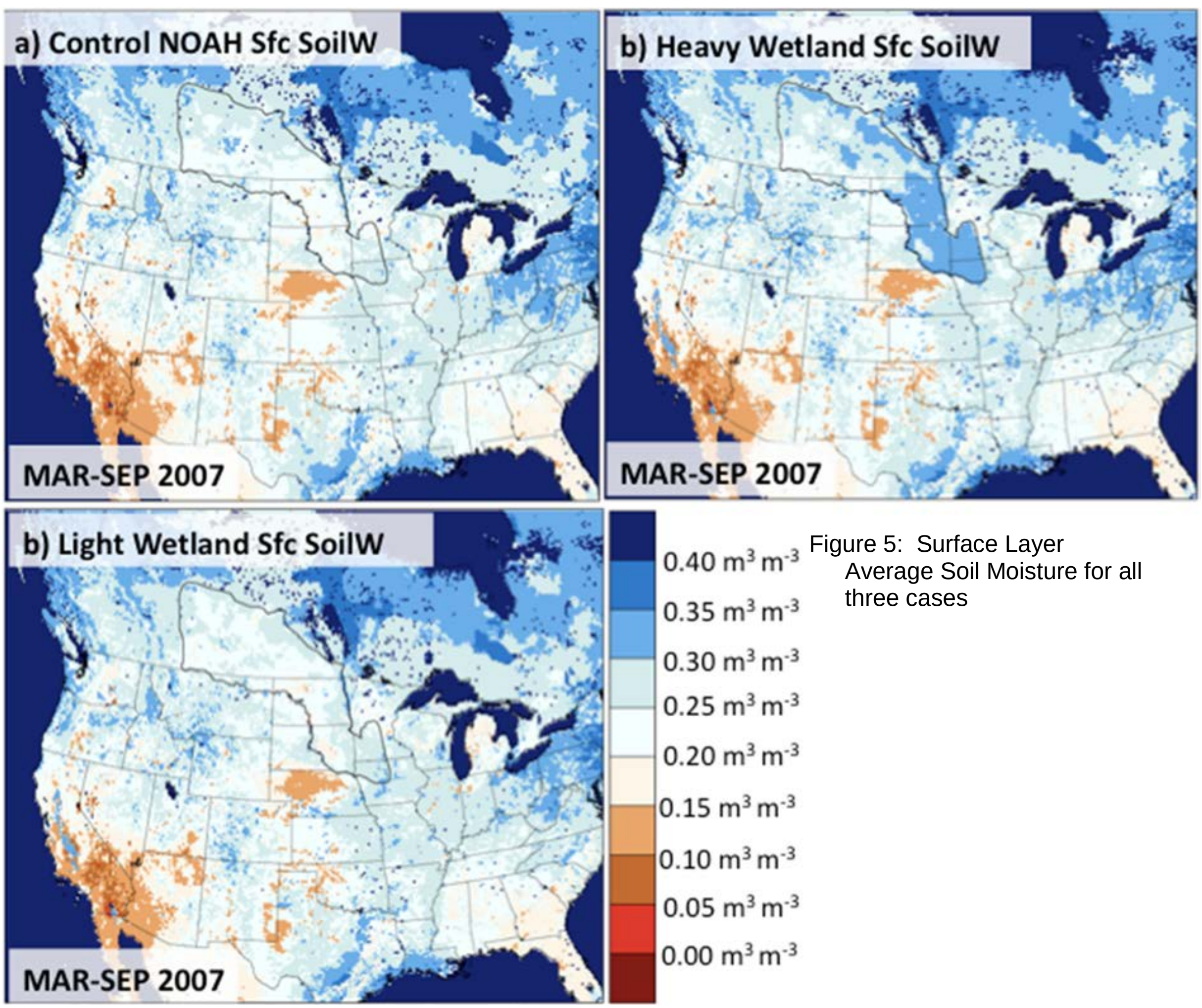

Figure 5: Surface Layer Average Soil Moisture for all three cases

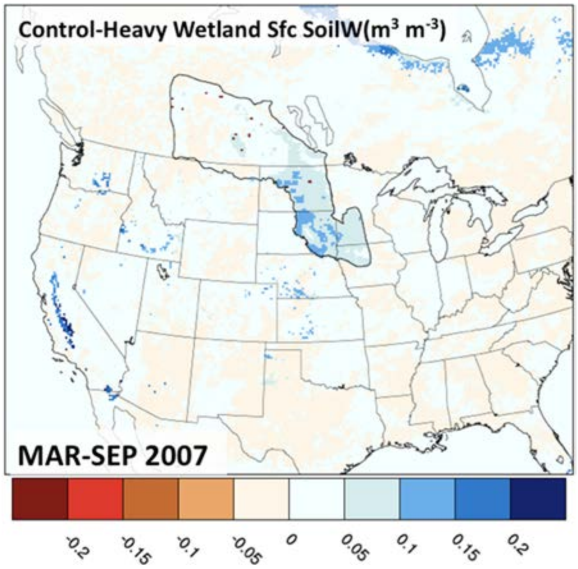

Figure 6: Surface Average Soil Moisture Difference between the Control and Heavy Wetland Scenarios

3 RESULTS

Preliminary results are presented here for precipitation and soil moisture over the region.

The soil moisture over the prairie wetland region (Figure 5) shows the imposed elevated averaged soil water patterns through the simulation. These "wetland" anomalies are clearly seen in the heavy wetland scenario with smaller anomalies seen over the prairie wetland region in the light wetland scenario. It should be noted that calendar year 2007 was characterized by high surface moisture over the prairie wetland region. Additionally, irrigated zones outside of the prairie wetland region can be seen as high average soil moisture differences between the control and high-wetland scenario in Figure 6.

The soil moisture anomalies' most immediate feedback is seen in the portioning of net radiation between sensible and latent heat fluxes. This is shown in Figure 7 using Bowen Ratios averaged over the period. Here, high evaporation is realized over the prairie wetland region for the heavy wetland scenario. While the light wetland scenario appears to have soil water contents over the prairie wetland region that are proximate to the default case, the evaporation in the light wetland scenario shows broadly higher evaporation amounts over the prairie wetland region than the non-wetland scenario.

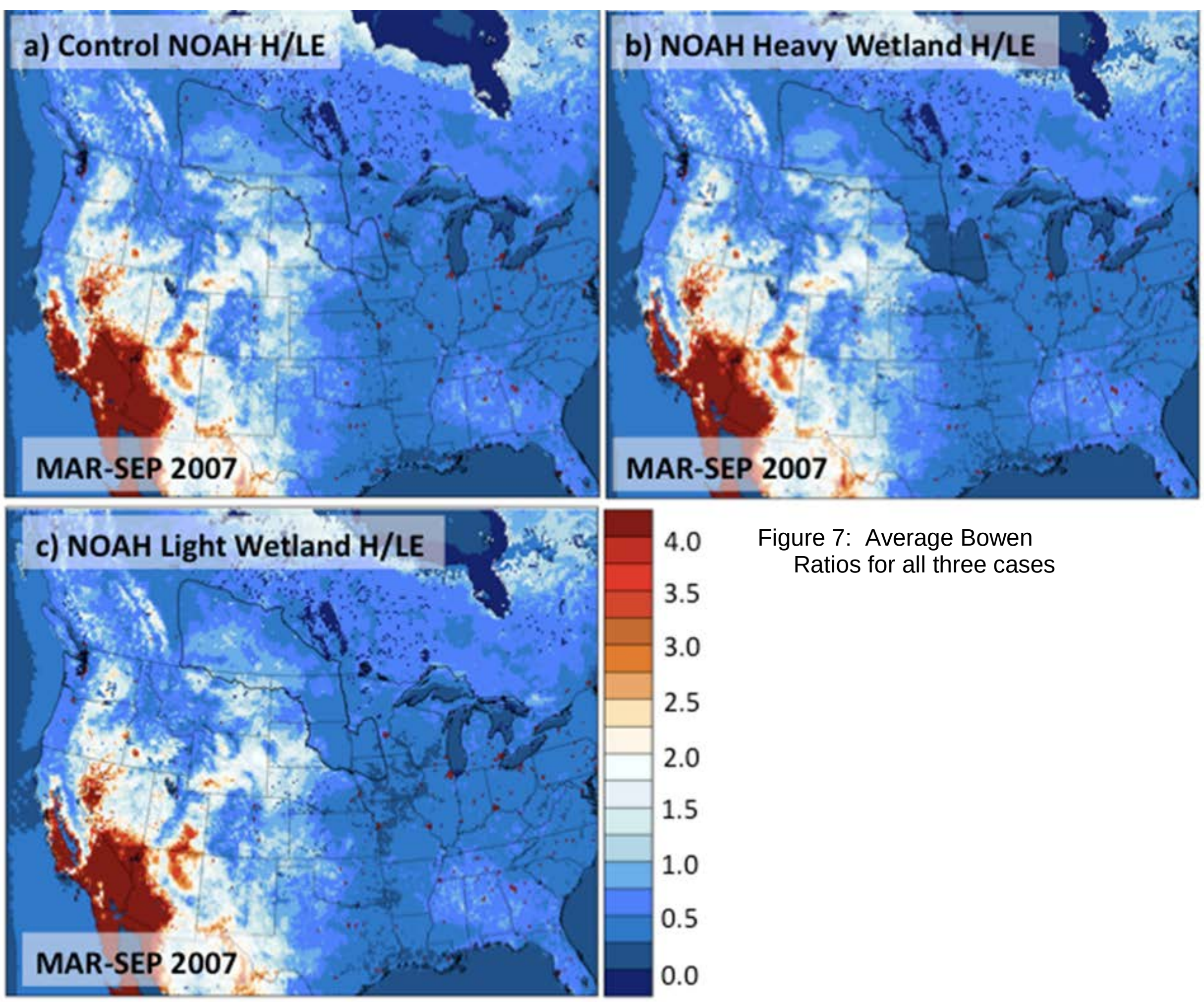

Figure 7: Average Bowen Ratios for all three cases

Precipitation results are shown in Figure 8. Overall, the general pattern of precipitation over the prairie wetland region and adjacent regions agreed fairly well with the NCEP Climate Prediction Center (CPC) and German Meteorological Service Global Precipitation Climatology Centre (GPCC) precipitation analyses with a moist bias over the prairie wetland region, but managed to capture the general precipitation patterns over the central US. The primary divergence between model and observed precipitation is along the southeast boundary.

In comparing the three scenarios against each other (Figures 8 and 9), even when discounting the major precipitation bias in the southeast region of the domain, one can see the impacts of altering the surface soil moisture over the wetland (and irrigated regions, mostly in the isolated areas in the western part of the domain). When focusing attention over the prairie wetland region and vicinity, both the heavy and light wetland scenarios show elevated precipitation over much of the prairie wetland region. Additionally, in comparing the heavy and light wetland scenarios we see sporadic wet and dry anomalies over this already initially wet region. The notable reduction in precipitation seen in earlier studies [*Capehart and Taylor, 2006*] is not seen but may be explained by noting that the region's soil-moisture, in contrast to the early 1990s, is already significantly elevated in all three scenarios without the incorporation of wetlands.

4 FUTURE WORK

The results shown here are encouraging and demonstrate that prairie wetlands indeed modulate the local climate. Future work entails long-term simulations of the early-to-mid 1990's initial deluge

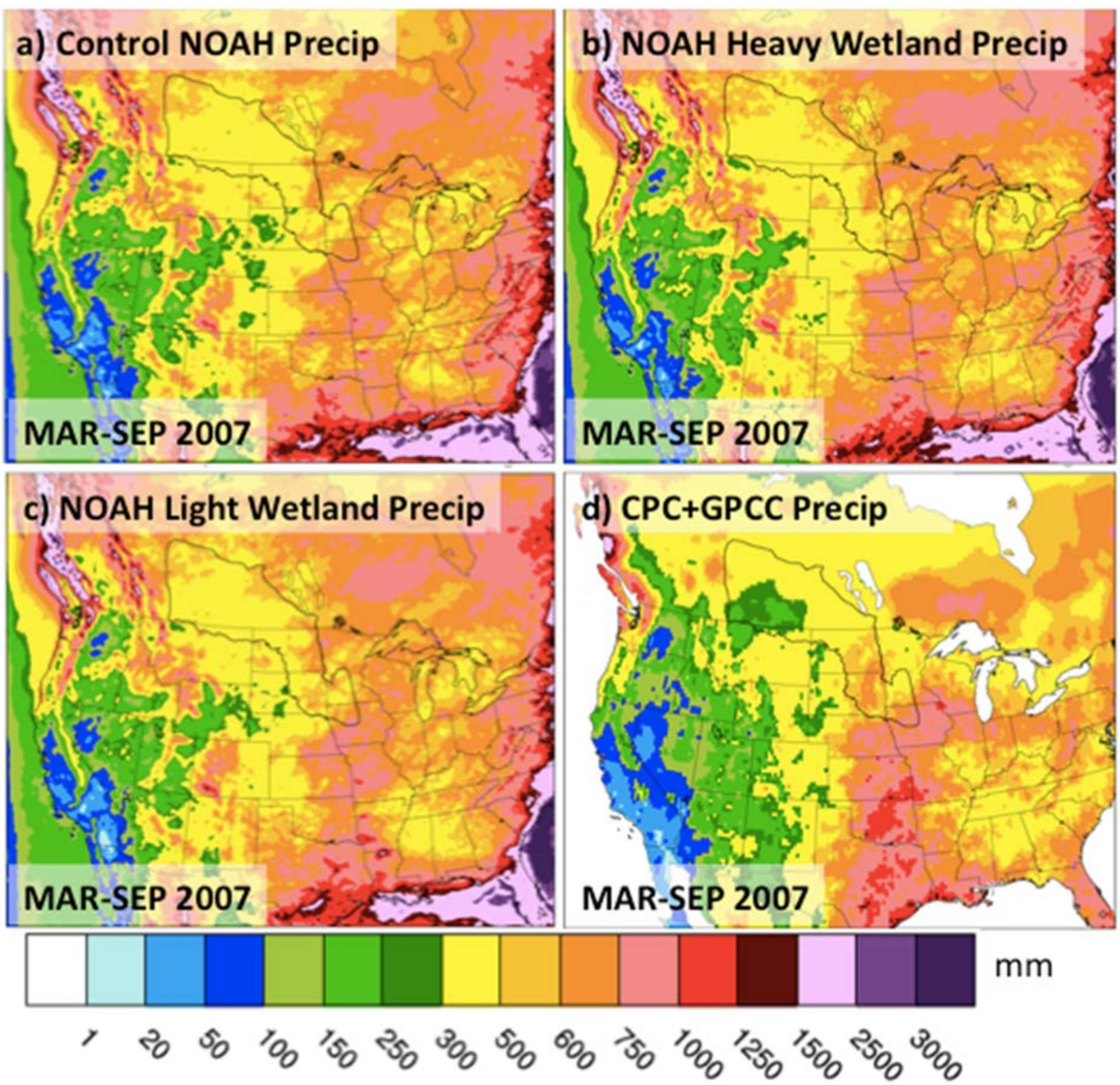

Figure 8: Total Precipitation for all three scenarios and merged land-based ¼° CPC (US only) and ½° GPCC precipitation.

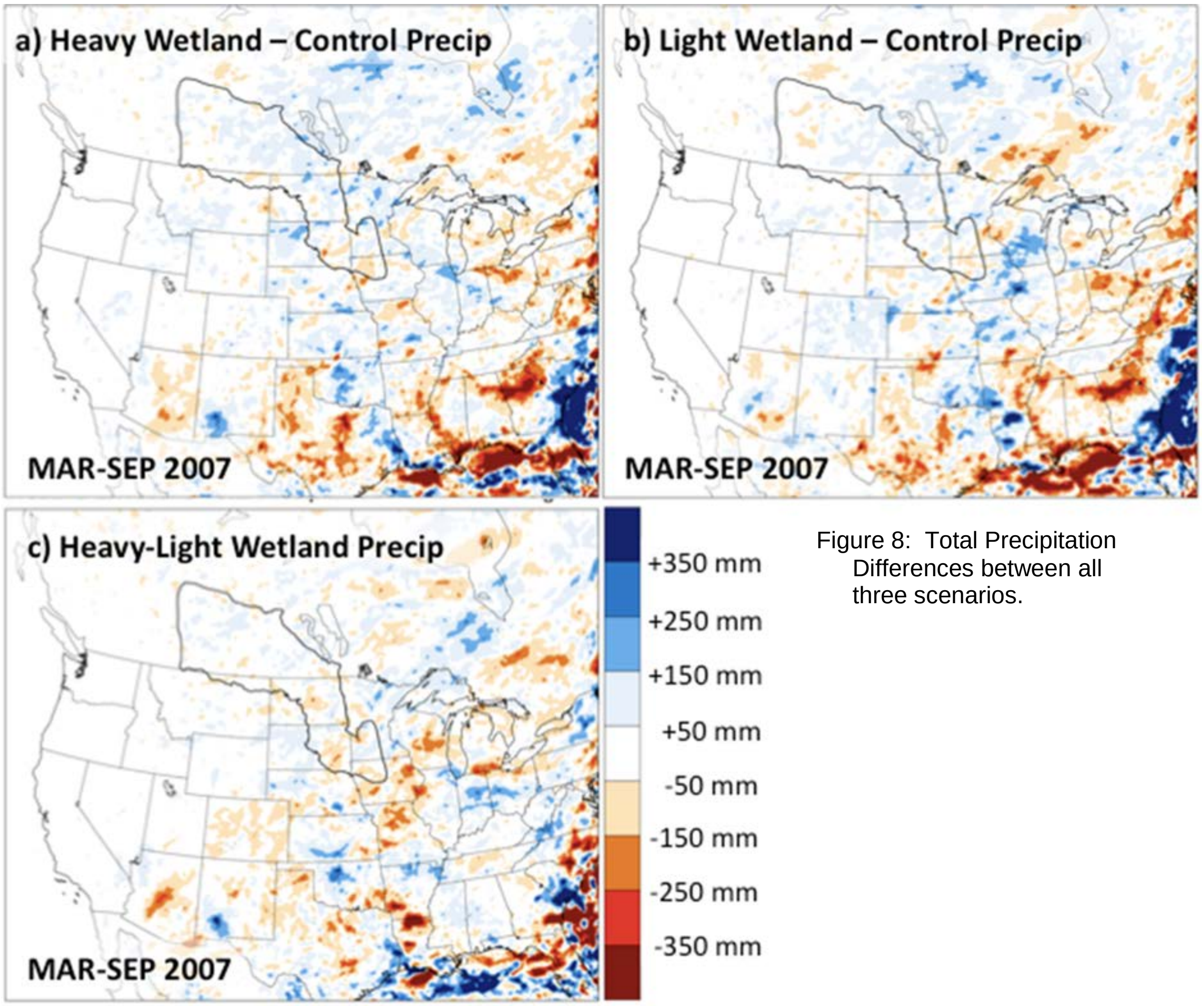

Figure 8: Total Precipitation Differences between all three scenarios.

period from the drier ambient state that existed in the late 1980s and early 1990s into their more contemporary wet phase. In these scenarios, the contrast between "default" (wetland-free) simulations and even light wetland scenarios should be more noticeable.

Additionally, it can be seen in the current configuration used in these studies, that the wetlands are simulated not as explicit open water bodies but as soil moisture anomalies across the larger grid cell "landscape." We further propose to adapt WRF to include a subgrid-scale surface water category that can be updated through lower boundary conditions so that WRF water can be coupled to an external wetland ecology model. This would permit WRF to function with a true active prairie wetland system operating within its framework.

5 ACKNOWLEDGEMENTS

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