P.24 Influence of Vegetation Cover Estimates on the Simulation of the Northern Great Plains Regional Climate

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1. INTRODUCTION

Over the years Land Surface Models (LSM) have been employed to parameterize the interactions between the Earth's surface and the atmosphere in Numerical Weather Prediction. A major component of the biogeophysical processes which govern the land-atmosphere interaction is the vegetation. The vegetation cover partitions the incoming solar radiation into the sensible and latent heat fluxes. Vegetation structure also affects the surface roughness, which can in turn alter heat and moisture transport. With gaining support of the land surface being a second order forcing on the climate system (Bonan 1997; Findell et al. 2007; Hoffmann and Jackson 2000; Pitman et al. 2004), accurate descriptions of vegetation are needed for simulation of the regional climate. LSMs have evolved over time with vegetation cover being prescribed, referenced from a surface variable, or more recently derived from satellite reflectance data. Typically vegetation fraction estimates used by the LSM, coupled to a numerical atmospheric model, for forecasting the regional climate often rely on multi-year climatologies. These vegetation fraction climatologies typically exhibit seasonal variation but do not change from year to year. Due to ongoing land cover change or other land forcings these climatologies may no longer be representative for regional climate simulations. The influence of vegetation anomalies (difference between a climatological and a more representative vegetation fraction estimate) on the regional climate may be more apparent in the Northern Great Plains (NGP). In this region the western and eastern halves are delineated by arid and more humid regimes.

Here we shall demonstrate the influence of altering the vegetation fraction data source for seasonal NGP regional climate simulations. Using the Advanced Research Weather Research and Forecasting Model (WRF-ARW) (Skamarock et al. 2008) two growing seasons, 2002 and 2007, were simulated. Using WRF's "Default" vegetation fraction and an ambient MODIS satellite derived vegetation fraction data set. Comparisons were made between the two vegetation schemes with attention focused on the impact on the surface energy and water budget.

2. METHOD

Simulations were completed for two growing seasons, 2002 with below normal precipitation ("dry") and 2007 with higher than normal precipitation ("wet"). The model domain was centered on the central U.S. to include the transport of moisture from the Gulf of Mexico, as well as the influence of the Rocky Mountains, and the stronger jet dynamics to the north. The domain used (200x200) has a grid spacing of 20 - km (Figure 1). The simulations began on 00 UTC 01 March and continued through to 00 UTC 01 November using WRF-ARW version 3.1.0. WRF was initialized by the North American Regional Reanalysis (NARR) with a grid spacing of 32.5 - km at six hour intervals (Mesinger et al. 2006). For the southern portion of the domain the NCEP Global Forecast System Final Analysis (FNL) was used above 100 - hPa, where NARR has a model top (NCEP 1999). WRF was run using the WRF Single-Moment 6-Class (WSM6) microphysics scheme (Hong et al. 2006), the NOAH land surface model (Chen and Dudhia 2001a, b), the YSU planetary boundary layer scheme (Hong et al. 2005), the New Grell (G3) cumulus scheme, and the CAM scheme (Collins et al. 2004). WRF was configured in regional climate mode to run for 24 hours and then restart using the previous day for initialization.

The ambient MODIS vegetation cover runs required WRF to be modified to run on a "36 - month" year, since MODIS data has a temporal interval of 16 days. The MODIS vegetation fraction was created from 1 - km MODIS reflectance data using the Scaled Difference Vegetation Index (SDVI)

$$SDVI = \frac{DVI - DVI_s}{DVI_v - DVI_s}$$

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Here DVI is the Difference Vegetation Index given by the difference in the near infrared and red reflectances (Jiang et al. 2006). SDVI is the difference between bare soil DVI (DVI_s) and dense vegetation DVI (DVI_v). Jian et al. (2006) showed SDVI is equivalent in value to the vegetation fraction. SDVI also has advantages over the Normalized Difference Vegetation Index (NDVI), namely the linearity of SDVI and the insensitivity of DVI to shadowed soil. Prior to running WRF with the satellite vegetation fraction the MODIS data was scaled up from 1 - km to the domain grid size. Once the initial run of WRF with the Default vegetation fraction was complete, WRF was run again using the MODIS data with the same parameterization schemes. Thus, the only difference between the two simulations is the source of the vegetation fraction cover data.

3. RESULTS

WRF output from both vegetation schemes were compared to NARR as well as NCEP Climate Prediction Center (CPC) precipitation as a bench mark for the representation of the NGP regional climate. Overall WRF produced reasonable temperature and precipitation patterns and distributions for both 2002 and 2007. Both of the WRF runs showed a slight warm bias on the order of 1 - 2 °C for the total season. The precipitation was overestimated by WRF, but there was some improvement of the wet bias with the MODIS vegetation fraction.

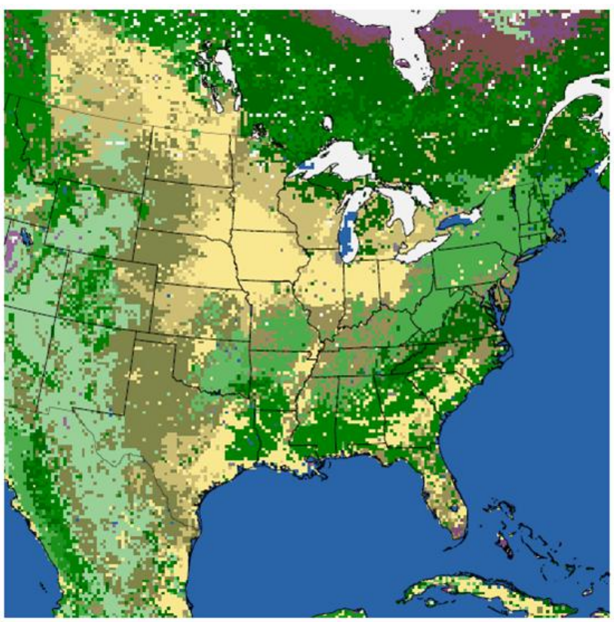

Figure 1 Central U.S. domain with land categories.

The Default and MODIS vegetation runs were also compared to each other to identify the influence of the vegetation cover on NGP regional climate. Figure 2 shows the difference field (MODIS minus Default) of the total season vegetation fraction for 2002 and 2007; also plotted are two first-order stations in South Dakota. The 2002 "dry" run shows a swath of positive vegetation anomalies (MODIS greater than Default) extending from the northwest to the southeast. These positive anomalies are bounded by negative vegetation anomalies (MODIS less than Default) to the southwest and northwest with some higher vegetation embedded. The 2007 "wet" run was much greener overall as compared to 2002.

The first-order stations KRAP (Rapid City) and KFSD (Sioux Falls) represent both the arid and more humid regimes of the NGP. Inspecting the difference of the vegetation for a 1° latitude and longitude box around KRAP (Figure 3a), the MODIS vegetation fraction was significantly different from the Default. The KRAP MODIS vegetation fraction was lower for 2002 and greater for 2007 initially, but peaked lower than the Default and remained less for the duration of the season. In the KFSD area (Figure 3b) the MODIS vegetation fraction peaked much higher and sooner than the Default. The vegetation also senesced at a faster rate than the Default towards the latter half of the growing season.

The influence of the vegetation schemes at both the KRAP and KFSD areas on the energy and water budgets (Figures 4 and 5) appear minor initially, while the MODIS vegetation follows closely to the Default vegetation fraction. However, when the differences in the vegetation fraction become larger a more appreciable difference is observed in the components of the energy and water budgets. Evaporation and ground flux at the KRAP site (Figure 4a, c) was lower with MODIS, as compared to the Default later in the growing season, while more energy was partitioned to the sensible heat (Figure 4b) with the MODIS for both years. In the more humid regime (Figure 5a, c), KFSD showed the opposite, where the evaporation and ground flux from the MODIS runs were higher than the Default. The sensible heat (Figure 5b) from MOIDS was lower for both the wet and dry years. Comparing 2002 to 2007, there was less evaporation and more sensible heat flux for the dry 2002 simulation as compared to the wet 2007 run.

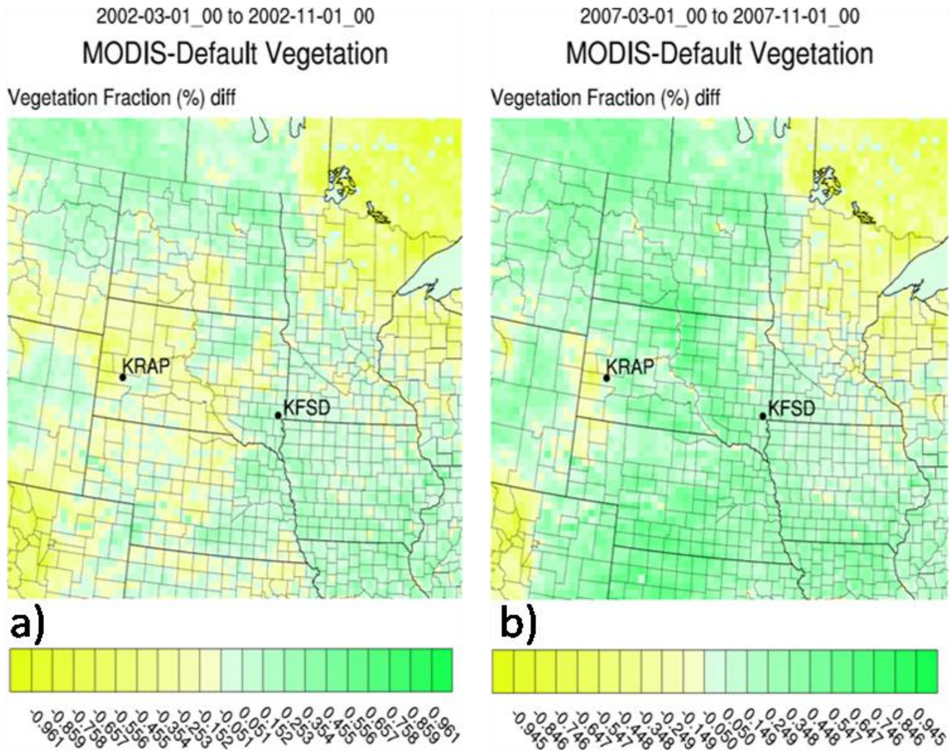

Figure 2 March to October average Vegetation Fraction difference for a) 2002 and b) 2007 with two first-order stations, Rapid City (KRAP) and Sioux Falls (KFSD).

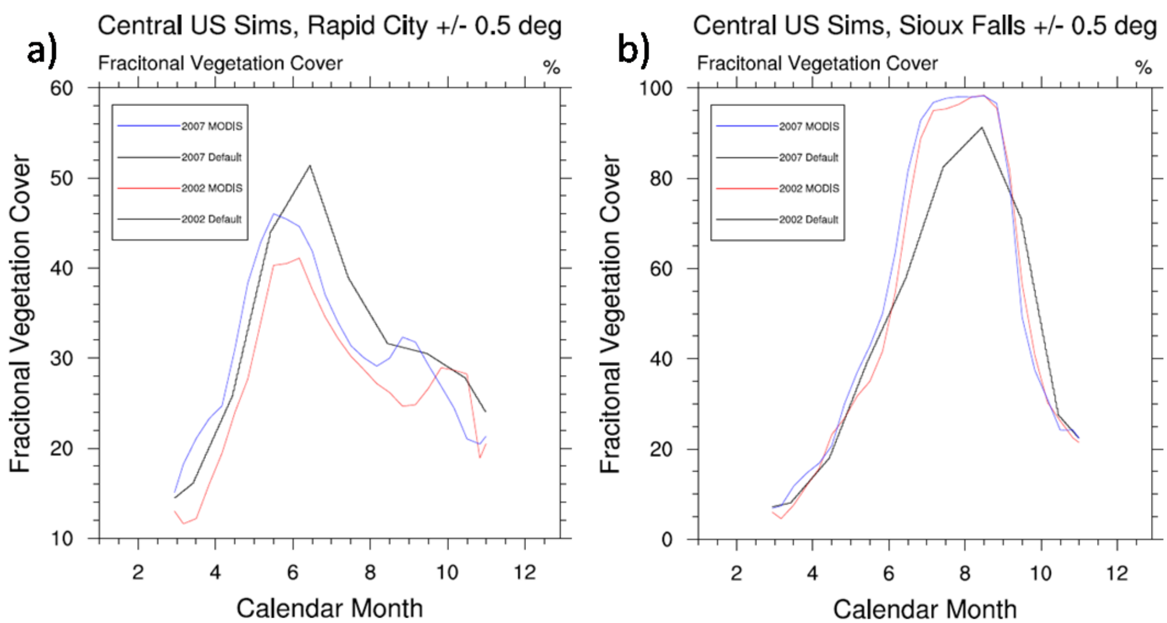

Figure 3 Time series of Vegetation Fraction for a) KRAP and b) KFSD for Default (black), 2002 MODIS (red), and 2007 MODIS (blue).

The water budget was also altered by the differences in the vegetation cover schemes. At KRAP, the precipitation from the MODIS simulations was generally less than the Default (Figure 4d). The surface runoff and soil moisture (Figure 4e, f) showed MODIS was greater than the Default, especially during the period June to September. The 2007 wet year indicated more of a difference in the soil moisture and surface runoff between MODIS and the Default than the 2002 simulation. KFSD precipitation (Figure 5d) displayed similar behavior as KRAP, except for the magnitude of the difference between MODIS and Default. The difference in 2007 was much more substantial, but less so for 2002. For the soil moisture, the 2007 runs were similar to KRAP. The 2002 runs were very similar until the end of July where the MODIS exhibited lower soil moisture (Figure 4f) through the start of September. Surface runoff at KFSD again showed a larger difference than KRAP (Figure 5e). A similar pattern to KRAP was noted where the MODIS soil moisture was larger than the Default for both years (Figure 5f).

Comparing the NGP regional subset of precipitation produced by WRF using both vegetation schemes (Figures 6 and 7), with each other and with the CPC precipitation analysis, indicated an overall wet bias for both 2002 and 2007 runs. While the MODIS and the Default total precipitation fields appear similar overall to the naked eye, the difference field indicated precipitation anomalies on the order of 15 mm. Thus, the ambient vegetation altered the distribution and overall precipitation patterns. Comparing the MODIS with the CPC, there was a slight reduction in the wet bias by MODIS over the Default simulation.

Since the ambient vegetation cover has altered the regional climate simulation, comparing grid point to grid point, the influence of the difference in vegetation over a distance was examined by employing spatial correlation. This was accomplished by taking the vegetation anomalies (MODIS – Default) and the differences between both vegetation schemes of a parameter, such as evaporation, holding the vegetation anomalies fixed and rotating the parameter anomalies while computing the spatial correlation. Figures 8 and 9 are the total spatial correlation of evaporation, 2-m temperature, precipitation, and precipitation minus evaporation (P-E) for 2002 and 2007, respectively. Both 2002 and 2007 evaporation and 2-m temperature have strong spatial correlation (positive and negative, respectively), particularly 2007, with the vegetation anomalies. The precipitation was uncorrelated spatially for both years. However, the P-E started to indicate a hint of negative spatial correlation moving in from the southwest. Overall the temperature and evaporation were strongly spatially correlated while the precipitation and P-E were essentially uncorrelated with the vegetation anomalies.

4. CONCLUSIONS

The temporally averaged vegetation climatologies have been shown to become unrepresentative over time due to land cover change for regional climate modeling. This was demonstrated for the NGP with dry (2002) and wet (2007) year WRF simulations. The influence of the ambient vegetation cover difference on the regional NGP climate had produced areas of warming (negative vegetation anomalies) and cooling (positive vegetation anomalies) on the order of 1 – 2 °C. The MODIS simulations produced a less cold and wet bias over the Default. The vegetation differences also changed the energy and water budgets, by altering the partitioning of energy into the sensible and latent heat fluxes as well as altering the distribution and patterns of the precipitation.

5. ACKNOWLEDGEMENTS

This work was supported through NASA grant NNX07AT61A.

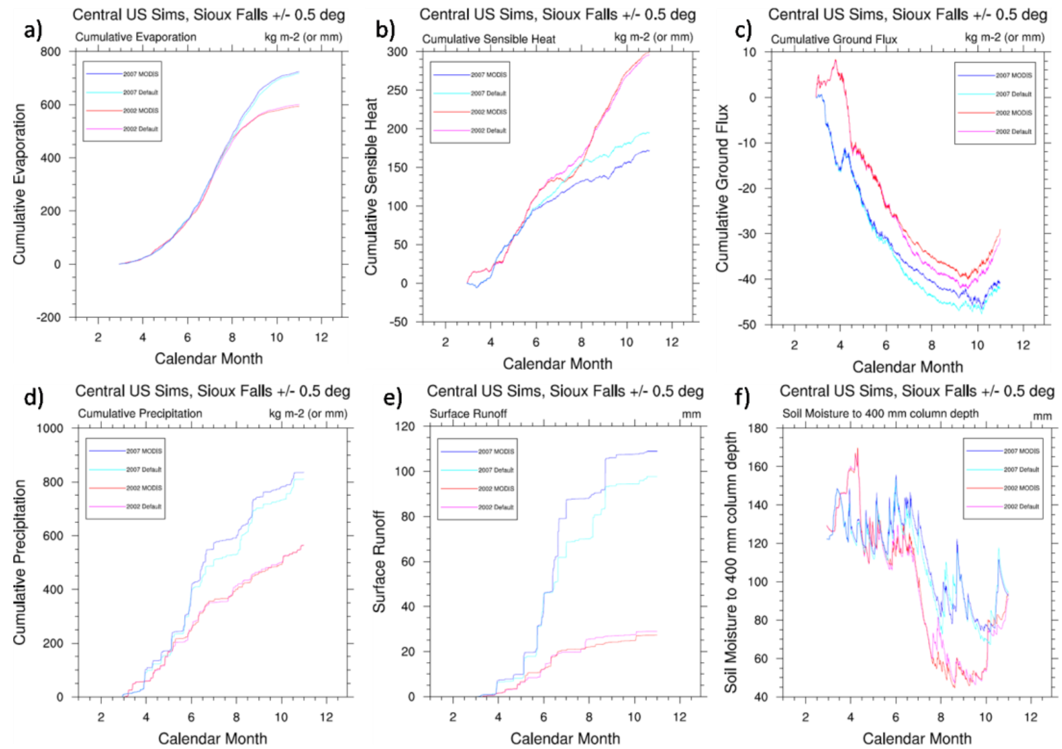

Figure 4 Rapid City 2002 (red curves) and 2007 (blue curves) average time series of a) evaporation, b) sensible heat, c) ground flux, d) precipitation, e) surface run off, and f) soil moisture for the Default and MODIS simulations.

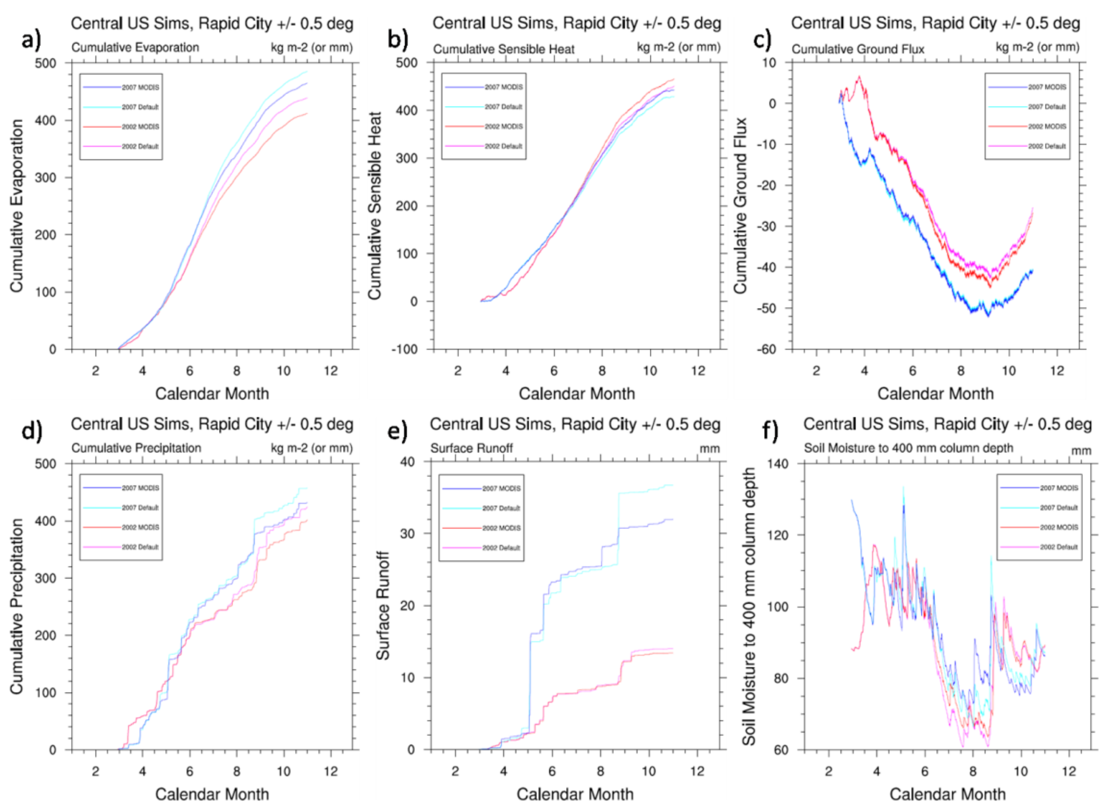

Figure 5 Same as Figure 4 except for the Sioux Falls area.

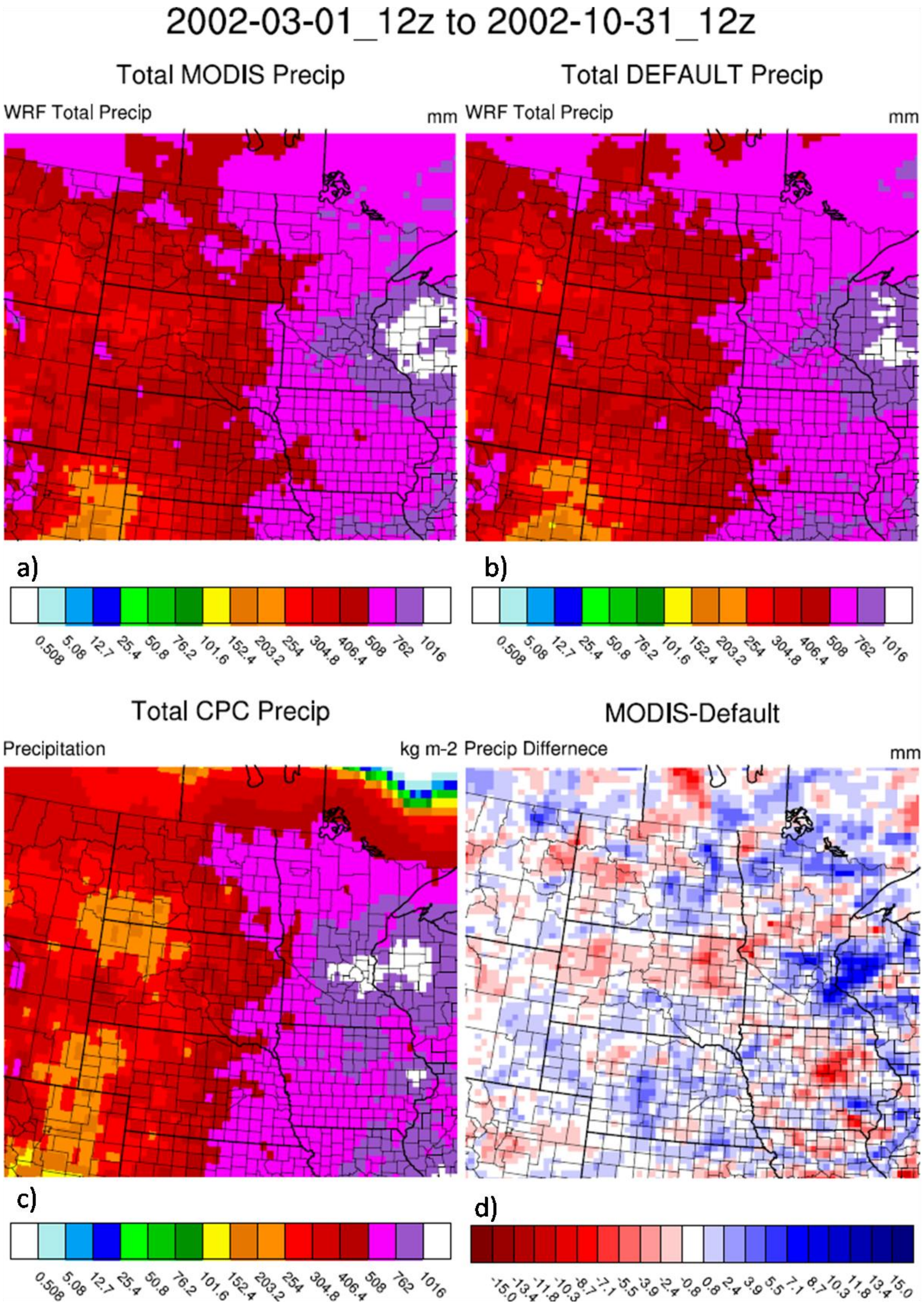

Figure 6 Total 2002 cumulative precipitation for a) MODIS, b) Default, c) Climate Prediction Center precipitation analysis, and d) difference between MODIS and Default.

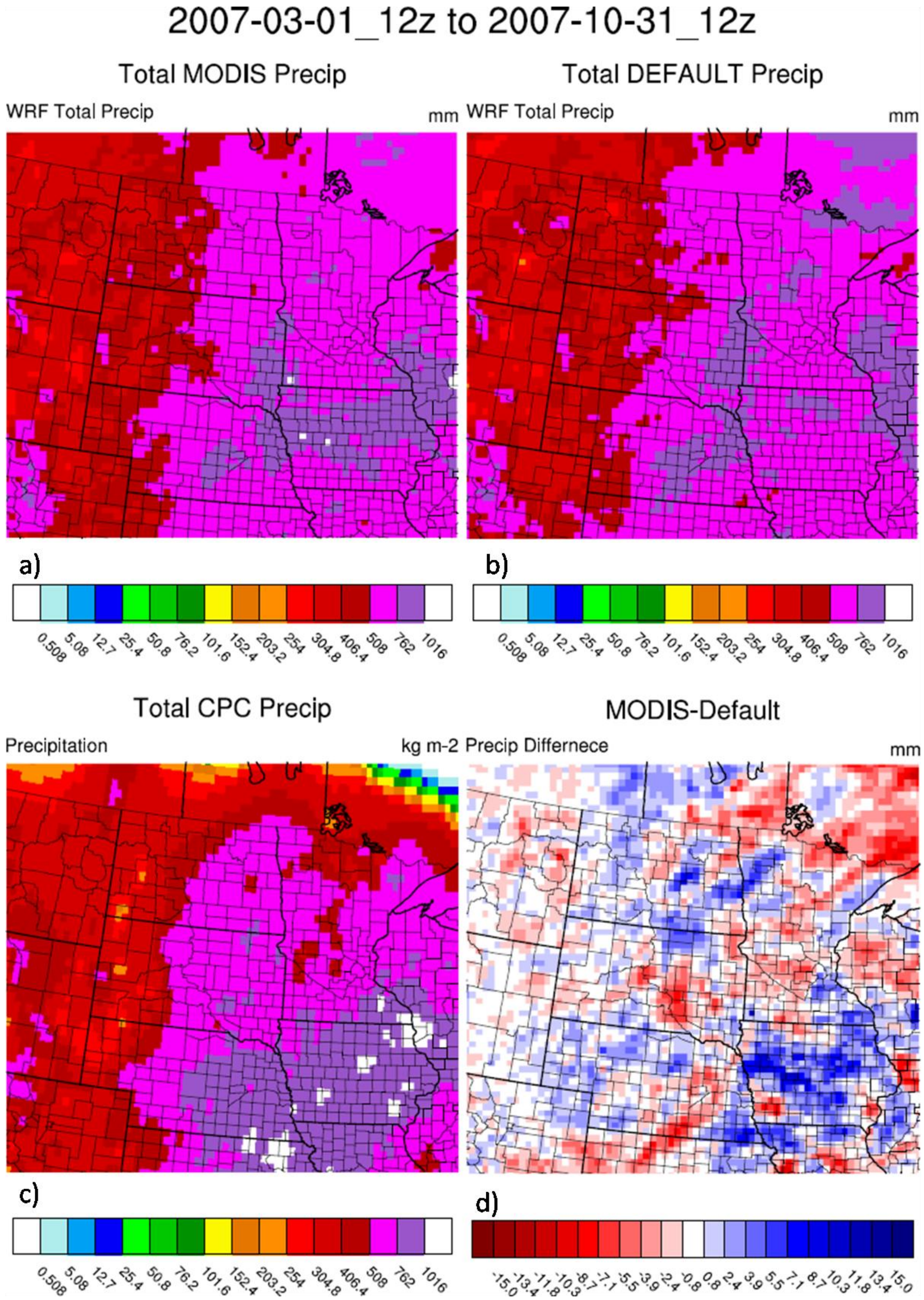

Figure 7 Same as Figure 6 except for the 2007 growing season.

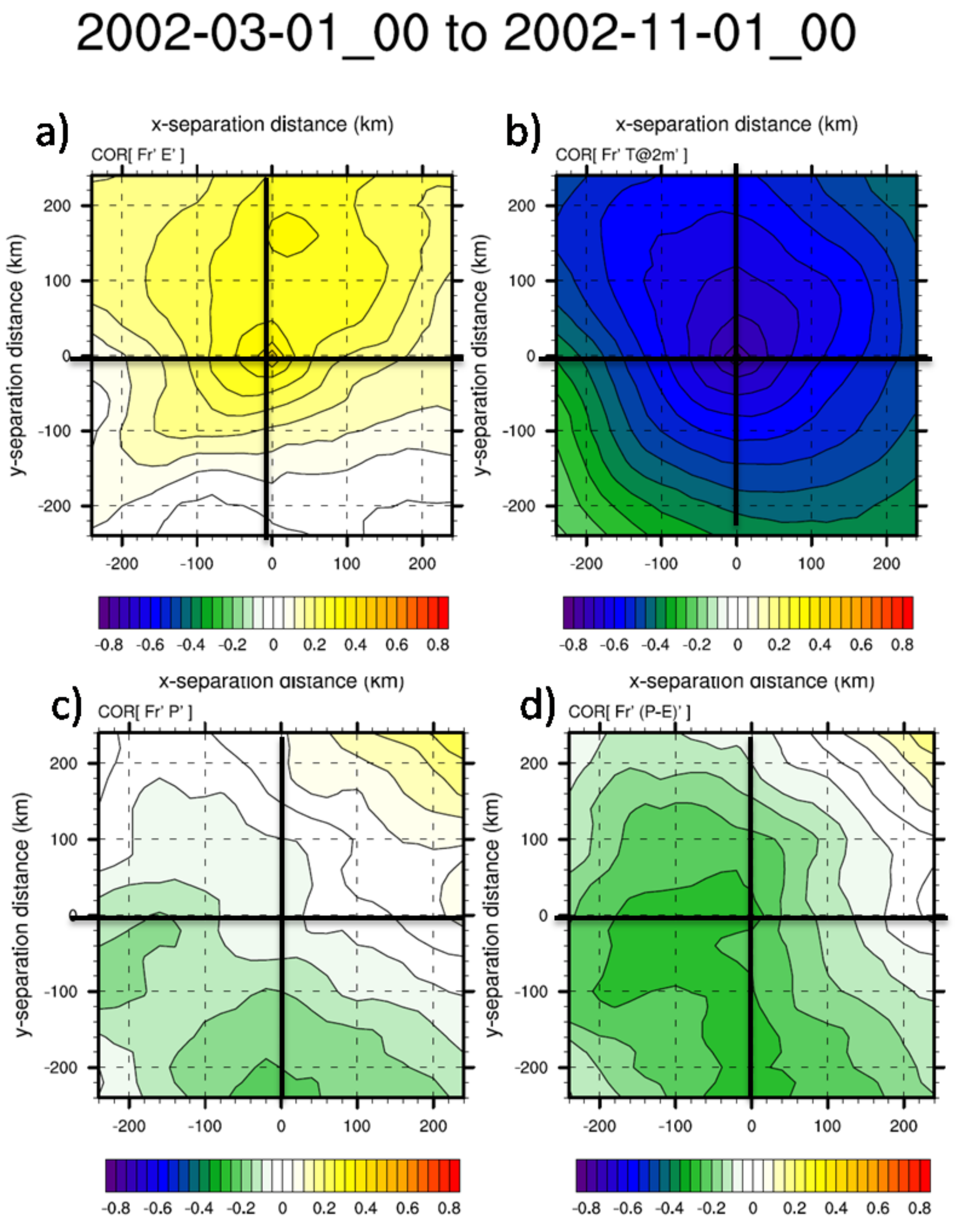

Figure 8 Total 2002 Spatial Correlation for a) evaporation, b) 2-m temperature, c) precipitation, and d) precipitation minus evaporation (P-E).

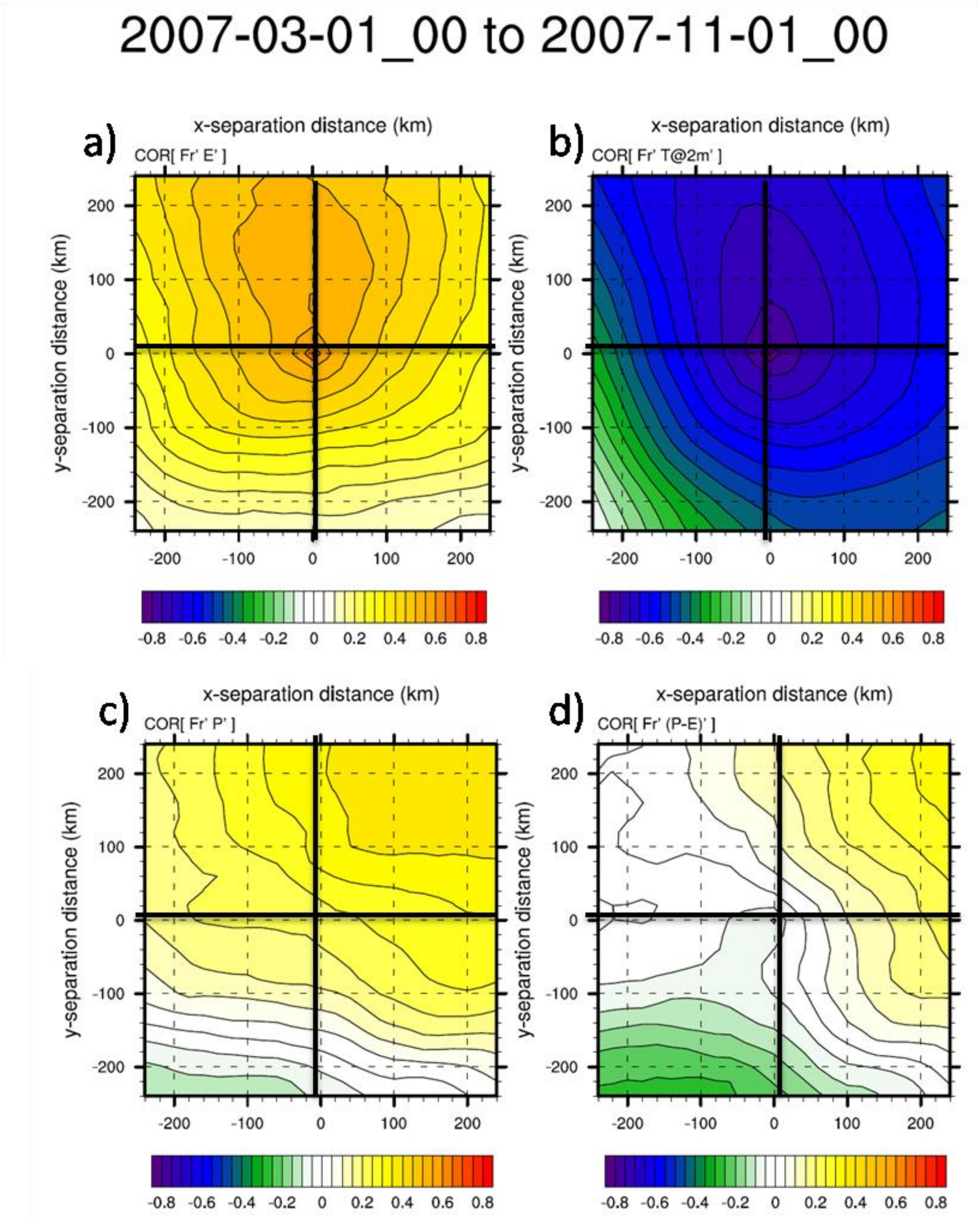

Figure 9 Same as Figure 8 except for 2007.

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