Modeling Impacts of Land Surface Processes on Heavy Rain and Drought Over US

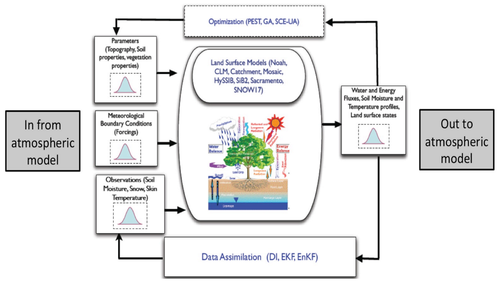
Y. P. Zhou (Morgan State U.), K.-M. Lau (GSFC), D. Wu (SSAI), W. Tao (GSFC)

Introduction

The spring of 2011 continent US (CONUS) was an excellent case study for climate extremes. During the March–May of 2011, the CONUS was hit by many episodes of heavy precipitation events in Midwest and Ohio Valley, which contributed to the worst flood in record history in the lower Mississippi River. Excessive rainfall was also found over northern States especially the Northwest. At the same time, record dry condition prevailed in the southern US. Texas and New Mexico were stricken by the worst drought in recorded history.

La Nino – like large-scale circulation persisted from the previous winter to the spring was likely the main factor for the extreme wet conditions in the north and the hot and dry conditions in the south. The study implores the Nu-WRF model simulations to investigate the interaction and feedback between the large-scale forcing and local processes, especially the land surface processes to the evolution of soil moisture and atmospheric boundary conditions. Spring 2010 was used as a quasi-normal year for comparison.

Nu-WRF Simulations



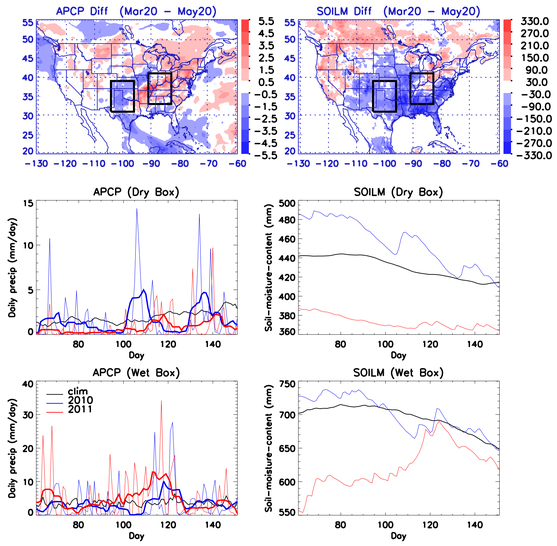
Schematics of Nu-WRF coupled with LIS (Land-Information System)

Two-tier nested domain for NU-WRF simulations of April and May 2011 extreme rain events in CONUS.

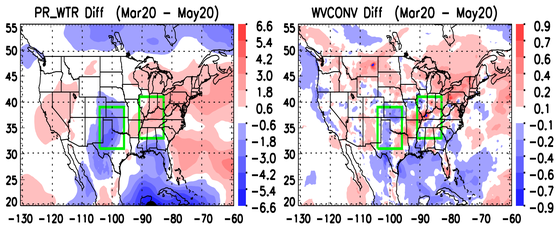
Four 2.5-month (Mar 20- June 13) swap simulations were conducted:

- 2010 forcing, 2010 soil moisture
- 2010 forcing, 2011 soil moisture
- 2011 forcing, 2011 soil moisture
- 2011 forcing, 2010 soil moisture

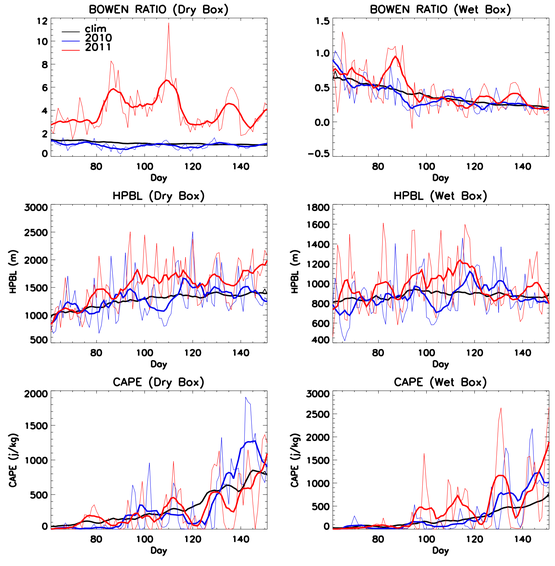
Large-Scale and Land Atmospheric Conditions in 2010 & 2011 from NARR



Top: Precipitation (APCP) and soil moisture (SOILM) difference (2011 – 2010).
Middle: Domain mean APCP and SOILM from 2010, 2011 and climatology for the dry box.
Bottom: Same as the middle panel but for the wet box.

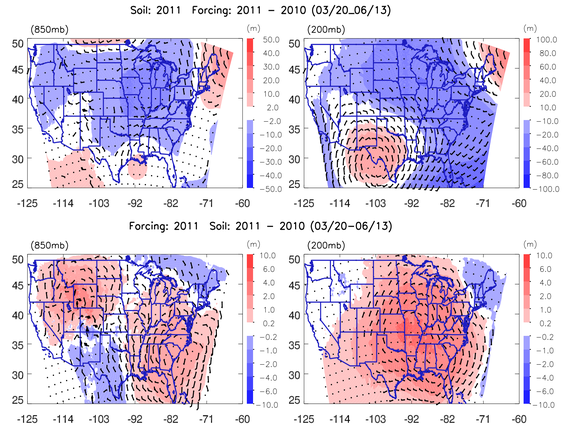


Daily mean total precipitable water (PR_WTR) and moisture convergence (WVCONV) difference (2011 – 2010) for the period Mar20 – May 20.

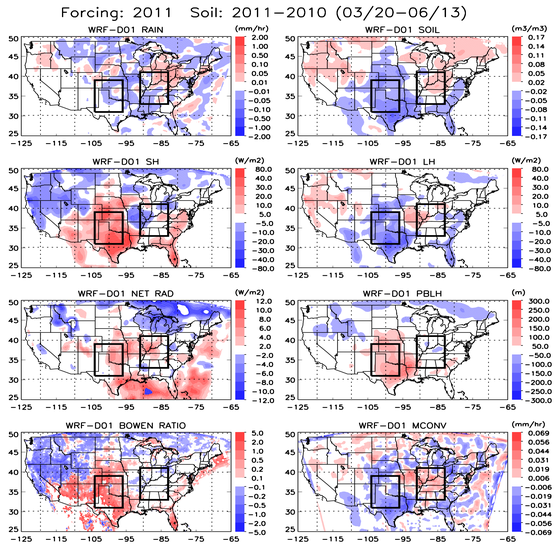


Domain mean Bowen ratio (top), PBL height (middle) and CAPE (bottom) in 2010 and 2011 compared with climatology for the dry (left) and wet (right) box.

2011-2010 Swap Runs: Sensitivity on Soil Moisture and Large-Scale Forcing

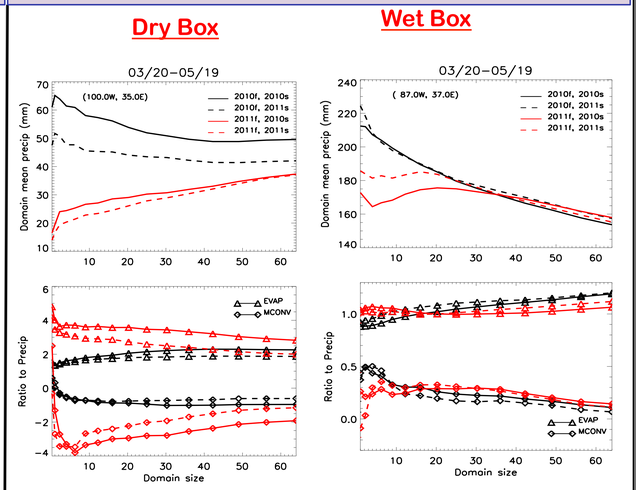


Difference in geopotential height and wind field for simulations generated with different large-scale forcing (upper panel) and soil moisture (lower panel).

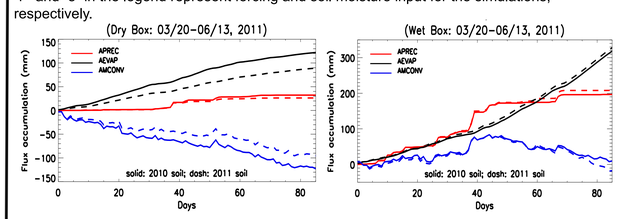


Systematic differences in surface and boundary conditions in response to different soil moisture.

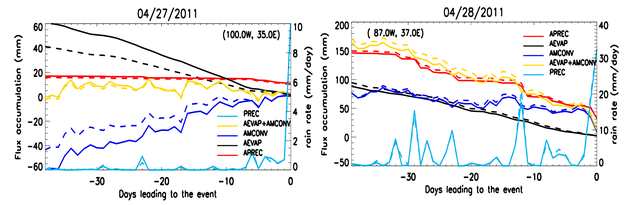
Scale Dependence of Moisture Budget



Comparison of domain mean precipitation (top) and the ratio of evaporation and moisture convergence to precipitation (bottom) from 4 model simulations for the dry (left) and wet (right) boxes for the period 3/20 – 5/19. The x-axis represents domain size from 1 to 64 square degrees. "f" and "s" in the legend represent forcing and soil moisture input for the simulations, respectively.



Moisture flux accumulations with time for the dry (left) and wet (right) regions using the same atmosphere forcing but different soil moistures.



Moisture budget for individual rain events occurred on day-0 with different starting points. Left : Rainfall on Aril 27 in dry region. Evaporation and moisture divergence nearly cancel out with a small positive net leading to the event. Right: Rainfall on April 28 in wet region. Evaporation and moisture convergence are both positive and equivalent in magnitude up to 20-day accumulations. Moisture convergence dominates the daily rainfall close to the event for the heavy events.

Summary

Nu-WRF simulations capture major rain events in spring 2011 in Central South US but underestimate the magnitude of extreme heavy rains. The study shows large-scale atmospheric forcing plays a major role in producing regional precipitation. Soil moisture has larger impact in the dry region where drier soil moisture tends to further reduce the precipitation, a positive feedback that could worsen drought conditions in the Southwest US. The impact of soil moisture is not as significant in wet region and heavy rain events as in the dry region and light rain events.

The sensitivity of precipitation to soil moisture can be analyzed with moisture budget in the atmosphere. The relative contributions of evaporation and moisture convergence depend on temporal and spatial scales. The relative contributions can vary in small domain and individual rain episodes. Evaporation plays increasingly larger roles in larger domain and longer period. Evaporation provides major moisture source in the dry region and light rain events, which leads to greater sensitivity to soil moisture in the dry region and light rain event. The feedback of land surface processes to large-scale forcing is also noticed through changes in large-scale circulation and moisture convergence.