Final Report for the NOAA CPO MAPP Project GC11-589

Title: Implementation of the Noah land surface model upgrades in the NCEP Climate Forecast System (CFSv2)

Principal Investigators: Michael Ek(EMC/NCEP/NOAA)
Co-Investigators: Rongqian Yang (EMC/NCEP/NOAA)
Jesse Meng (EMC/NCEP/NOAA)

Report Year: Final report

The objective of this MAPP-funded project is to transition and infuse the recent developments of the Noah land surface model (Noah LSM) into NCEP operation to improve the skill and reliability of NCEP seasonal climate predictions of precipitation, temperature, and land-surface hydrological variables, such as soil moisture, runoff, and snowpack. The improvement in prediction skill is to be accomplished by means of improved representation of land surface processes and land-atmosphere interactions in the NCEP operational global and regional climate prediction systems, including their companion land data assimilation systems. This project involves a number of important steps including physics upgrades in the Noah LSM and enhanced land initial conditions through the CFS Global Land Data Assimilation System (GLDAS), which is very important to CFS seasonal predictions.

Results and Accomplishments:

Project work has closely followed the deliverables schedule included in the proposal in two fronts. The first is to evaluate the land surface product from the NCEP operational coupled GLDAS (which runs an earlier version of the Noah LSM) and to implement the more recent Noah LSM upgrades in the experimental uncoupled GLDAS. The second is the testing of land physics changes in the NCEP operational CFSv2, in particular the Noah LSM with Multiple-Parameterization (Noah-MP) options.

Summary of Accomplishments:

1. The NCEP GLDAS

The NCEP GLDAS is implemented in the NCEP CFS Reanalysis (1979-2010) and the NCEP operational CFSv2 (2011-present). The NASA Land Information System (LIS) is employed as the NCEP GLDAS infrastructure. Due to the discontinuity of soil moisture (e.g., 1999, 2005 spin up related issues) between the six streams, a continuous single-stream simulation with land surface physics upgrades, including an adjusted surface thermal roughness parameterization for improved land surface skin temperature simulations, was proposed to solve this problem. The retrospective single-stream GLDAS-replay (GLDAS2) is able to preclude the known discontinuity of the multi-stream CFSR. Figure 1 shows the temporal anomaly correlation between GLDAS2 and higher-resolution North American Land Data Assimilation System (NLDAS) (0.82) is also improved from that between CFSR and NLDAS (0.79) across the CONUS domain. This retrospective GLDAS2 provides an enhanced global land surface

climatology reference and enhanced land surface initial conditions for the coupled CFS/GLDAS seasonal prediction experiments to assess the historical, current, and predicted global hydroclimate anomalies and drought information and to support the MAPP Drought Task Force research activities.

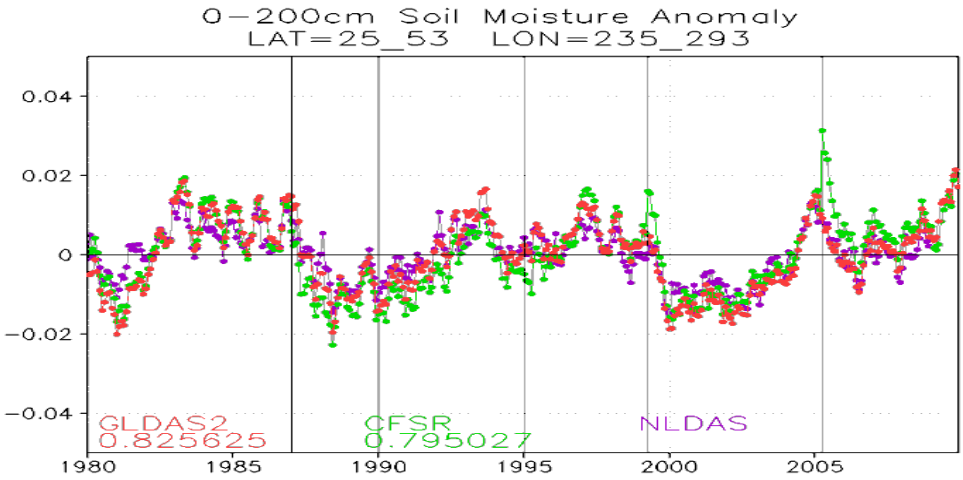

Figure 1. Monthly mean 2-meter column volumetric soil moisture temporal anomaly time series averaged over CONUS for GLDAS2 (red), CFSR (green), and NLDAS (purple). Numbers indicate the anomaly correlation between reanalysis products and NLDAS. Vertical lines indicate the beginning of each CFSR stream (units are $m^3\ m^{-3}$).

2. CFS experiments

2.1 CFS with changes in surface roughness length parameterization in Noah 2.7.1

The computation of skin temperature in land models depends on the treatment of the ratio of the roughness length for momentum over the roughness length for heat, the characterization of vegetation, and other model details. The Noah LSM uses seasonally variable green vegetation fraction (GVF) along with a constant LAI where bare soil and vegetated area are treated together.

An important physically-based constraint is the convergence of the turbulent fluxes and skin temperature to bare soil values when the above-ground biomass approaches zero in a grid cell - GVF becomes zero. This treatment has been included in the GLDAS2 re-play. The impact on the coupled CFS prediction is yet to be tested.

To examine the impact from using the new parameterizations on CFSv2 prediction sills, T126 CFSv2 reforecast experiments are carried out for selected nine years (1982, 1987, 1996, 1988, 2000, 2007, 1986, 1991,1999) with four ensemble members (4 cycles of May 1). The nine years are composed of three ENSO-cold, warm and neutral years. Using anomaly correlation as a measure, Figure 2 shows that the 2-meter temperature prediction skill with the new formulation shows a general improvement over the U.S. for the first month. This study indicates a promising result – improving seasonal prediction via infusion of the latest development in land physics.

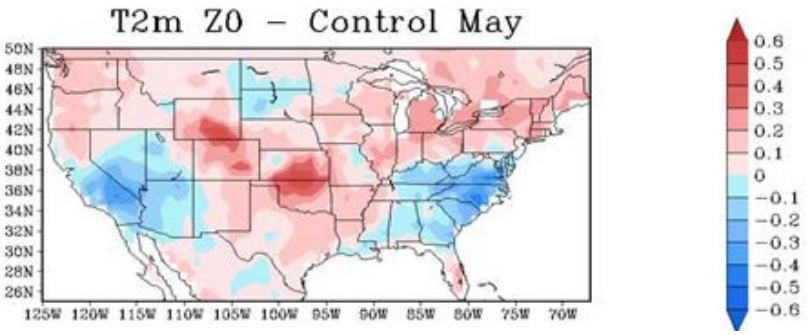

Figure 2. Differences in 2-meter temperature prediction skill between control and experimental runs for May.

2.2 CFS with the latest Noah LSM 3.4.1

The land model performance is also impacted by the surface (grid cell) on which the model is run. In addition to the near-surface atmospheric forcing, the Noah LSM needs one of the nine soil categories, which impacts the soil hydraulic conductivity, one of the thirteen vegetation types, which modifies the canopy resistance, the evapo-transpirative energy, and the transfer coefficient between the atmosphere and the ground, and a value of ground slope, which impacts runoff processes. An accurate specification of land surface vegetation and soil types, representative of recent land-use changes, is important to model near-surface fluxes since the physical processes run using these parameters. In addition, the Noah LSM version 2.7.1 is currently used in the operational NCEP CFS, and is the version of Noah that was implemented in the operational GFS in May 2005. Since then, the Noah LSM has had a lot of enhancement. Compared to the earlier version, the latest version Noah 3.4.1 (released in August 2012) now has many physical improvements, such as treatments for saturation slope, background emissivity, snow albedo, among others. To utilize these developments in the CFS, the new vegetation (MODIS/IGBP) classification and soil type (STATGO) datasets are required/introduced.

To examine the impact from using the new Noah3.4.1 LSM on CFS prediction sills, T126 CFS reforecast experiments were repeated using the same initial conditions and years specified in the above section 2.1. Figure 3 shows that the experimental CFS/Noah 3.4.1 performs better in predicting 2-meter temperature anomaly over the western CONUS.

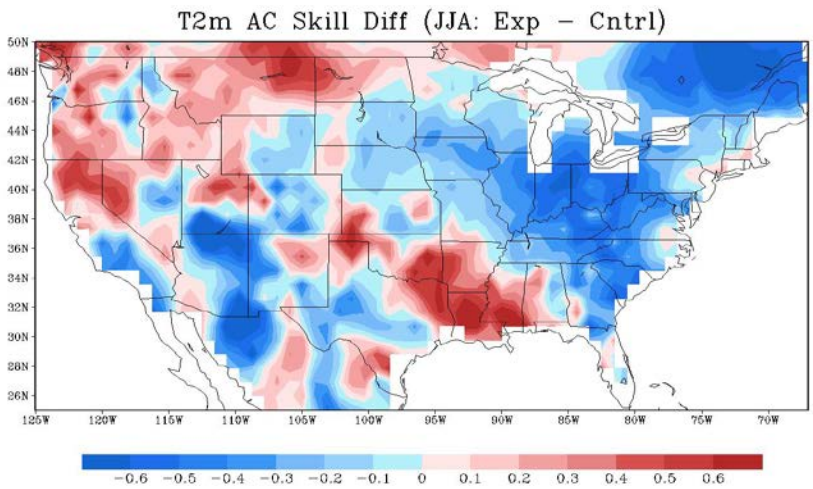

Figure 3. Difference in 2-meter Temperature (T2m; Averaged June-July-August: JJA) Anomaly Correlation (AC) Skill over CONUS between the Experimental (Exp) CFS and the Control (Cntrl) CFS.

2.3 CFS with Noah LSM with Multiple Parameterization (Noah-MP) options

The Noah LSM has several limitations in its overall structure, such as the combined surface layer of vegetation and ground, a bulk layer of snow and soil, shallow soil column, among others. In addition, only one option for the parameterizations is provided. To overcome these shortcomings, a new paradigm is proposed by the Noah community, where the Noah LSM is equipped with enhanced model physics and allows for Multiple Parameterization (Noah-MP) options.

The community Noah-MP LSM uses multiple options for key land-atmosphere interaction processes. It was developed to improve some limitations of the Noah LSM. Specifically, Noah-MP contains a separate vegetation canopy defined by a canopy top and bottom, crown radius, and leaves with prescribed dimensions, orientation, density, and radiometric properties. The canopy employs a two-stream radiation transfer approach along with shading effects necessary to achieve proper surface energy and water transfer processes including under-canopy snow processes. Noah-MP contains a multi-layer snow pack with liquid water storage and melt/refreeze capability and a snow-interception model describing loading/unloading, melt/refreeze capability, and sublimation of canopy-intercepted. Multiple options are available for surface water infiltration and runoff and groundwater transfer and storage including water table depth to an unconfined aquifer.

The Noah-MP model can be executed by prescribing both the horizontal and vertical density of vegetation using either ground- or satellite-based observations. Another available option is for prognostic vegetation growth that combines Ball-Berry photosynthesis-based stomatal conductance with a dynamic vegetation model that allocates carbon to various parts of the vegetation (leaf, stem, wood and root) and soil carbon pools (fast and slow). This CO_2-

assimilation-based photosynthesis model is capable of distinguishing between C_3 and C_4 photosynthesis pathways and defines vegetation-specific parameters for plant photosynthesis and respiration.

To examine the impact from using the new Noah-MP LSM on CFS prediction skills, T126 CFS reforecast experiments are carried out using the same specifications as those in the above two sections. Figure 4 shows the precipitation anomaly correlation scores from the two CFS runs. This figure indicates that compared with the control CFS, the experimental CFS with Noah-MP LSM, to some degree, has a positive impact on the prediction skill over the Pacific Northwest states and the Gulf states, where the soil moisture memory (with new ground water option, where the soil layer can access ground water) has a great impact on seasonal precipitation prediction.

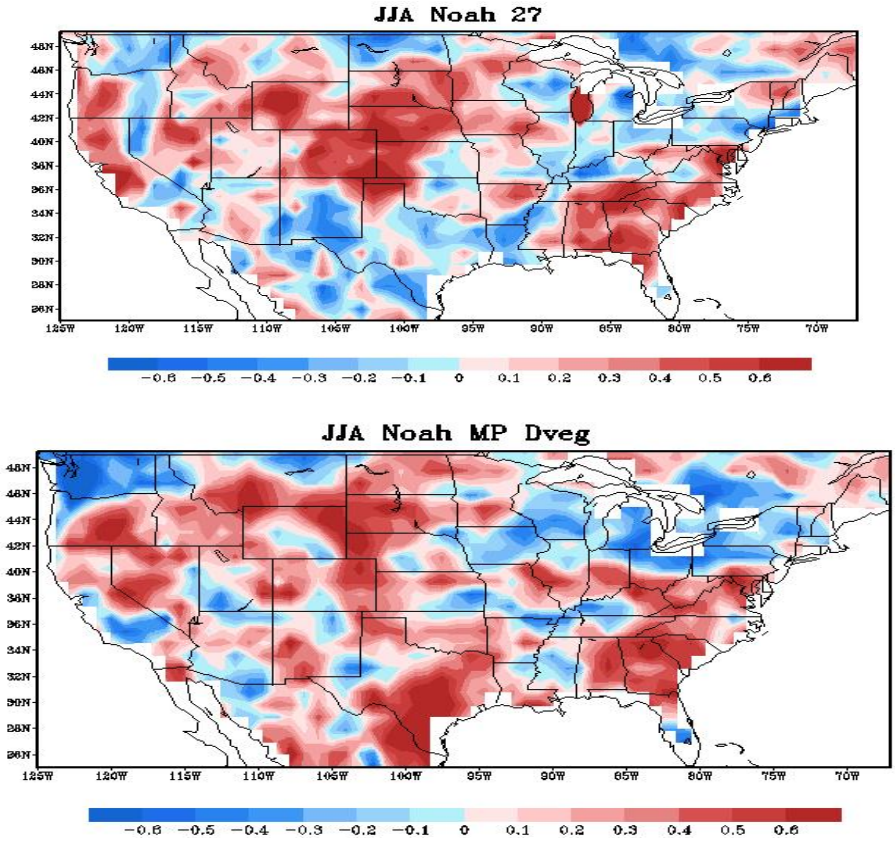

Figure 4. Anomaly correlation skill of precipitation over CONUS from the two CFS runs.

Future Related Work (for two CPO/ MAPP CTB funded proposals):

1) Fei Chen (PI): Improving the NCEP Climate Forecast System (CFS) through Enhancing the Representation of Soil-Hydrology-Vegetation Interactions

This funded proposal will leverage on the accomplishment from this project regarding the implementation of recent developments in Noah LSM in CFSv2 and further evaluate and improve the newly released community Noah-MP v2. The Noah-MP v2 enhancements include: 1) an additional option to treat horizontal transport of aquifer water and its upward transport to model soil layers; 2) a new soil moisture stress function option to improve soil moisture access for vegetation in summer; 3) new options for canopy radiation and under-canopy turbulence; and 4) fixes to the existing vegetation cover to improve performance in sparsely-vegetated areas. In the end, the project will address the question: To what degree can a more accurate representation of soil- hydrology-vegetation interactions improve CFS seasonal predictions?

2) Eric Wood (PI): Understanding the Role of Land-atmospheric coupling in Drought Forecast Skill for the 2011 and 2012 Droughts

The overall goal of this funded project is to understand land-atmospheric coupling processes in CFSv2 and their role in the predictability of drought development, intensification and termination and to perform attribution and modeling studies for the improvement of drought predictions.

To address the questions, CFSv2 forecasts with prescribed vegetation fraction will be used to analyze (and compare with CFSR) the local feedback mechanism, the large-scale circulation and their interactions in the development, intensification and termination of the 2011 and 2012 droughts in North America. In addition, the CFSv2 experiments will be conducted using both the observed GVF in the original Noah LSM and the new developed Noah-MP based CFS with dynamic vegetation (growth) option.

Publications from the Project:

Meng, J., R. Yang, H. Wei, M. Ek, G. Gayno, P. Xie, and K. Mitchell, 2012: The Land Surface Analysis in the NCEP Climate Forecast System Reanalysis. *J. Hydrometeorol*., **13**, 1621–1630., doi: http://dx.doi.org/10.1175/JHM-D-11-090.1.

Yang, R., M. Ek, and J. Meng, 2014: Surface Water and Energy Budgets for the Mississippi River Basin in Three NCEP Reanalyses, *J. Hydrometeorol.* (Accepted).

PI Contact Information:

Michael Ek
Environmental Modeling Center (EMC)
National Centers for Environmental Prediction (NCEP)
NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, MD 20740
Phone: 301-683-3957
Fax: 301-683-3703
Email: Michael.Ek@noaa.gov

Rongqian Yang
National Centers for Environmental Prediction (NCEP)
NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, MD 20740
Phone: 301-683-3699
Fax: 301-683-3703
Email: Rongqian.Yang@noaa.gov

Jesse Meng
National Centers for Environmental Prediction (NCEP)
NOAA Center for Weather and Climate Prediction
5830 University Research Court
College Park, MD 20740
Phone: 301-683-3950
Fax: 301-683-3703
Email: Jesse.Meng@noaa.gov