

## **Improving the NCEP Climate Forecast System (CFS) through Enhancing the Representation of Soil-Hydrology-Vegetation Interactions**

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### **1. Background:**

The overarching goal of this collaborative effort is to improve the NCEP Climate Forecast System (CFS) forecast skill by enhancing the representation of soil-hydrology-vegetation interactions through the use of the new community Noah-MP (Multiple-Parameterization) land surface model (LSM). Numerous studies have illustrated the substantial influence of land-atmosphere interactions on seasonal-to interannual prediction. Soil moisture memory has been identified as a key in determining seasonal predictability in climate forecast systems. Improving soil-moisture related processes (e.g., evaporation, runoff, and groundwater) is important for potentially enhancing seasonal predictability of temperature and precipitation, which has direct benefit to the other MAPP call for “Research to Advance Understanding, Monitoring, and Prediction of Droughts”. This proposal leverages on the ongoing work of the NCEP/EMC land team regarding the testing of Noah-MP v1 in CFS v2 and further evaluate and improve the newly released community Noah-MP v2, and address the overall scientific and operational questions: To what degree can a more accurate representation of soil-hydrology-vegetation interactions improve CFS seasonal predictions?

## **1 Results and Accomplishments:**

### **1.1 Enhancements to the community Noah-MP land model**

We have implemented the following enhancements in Noah-MP v2 and released it in HRLDAS V3.8 (April 2016):

- code structure was modified to include a new capability of specifying spatially-varying soil properties;
- two crop-growth-model (corn and soybean) modules were added;
- added new vegetation options: LAI – read, specified, predicted; fveg – read, maximum, empirical;
- added glacier option added (consistent with the Noah method);
- added a new surface resistance option (treating soil/snow evap/sub resistance);
- fixed patchy-snow surface temperature option.

### **1.2 Implementation of Noah-MP v2.0 in CFS v2+**

The enhanced Noah-MP v2 mentioned in Section 1.2 has been successfully implemented in the NCEP CFS described below. The CFS used in this study is based on the operational CFSv2, but equipped with many physics enhancements. The atmospheric component of the CFS is the operational GFS model (operational GFS as of May 2012). The GFS is a spectral triangular model with hybrid MPI-OpenMP parallel implementation and has 64 levels in the vertical direction. The GFS physics includes SAS shallow, SAS deep convections, and Zhao cloud physics. The oceanic component of the CFS is the MoM4p0, which is a finite difference version of the ocean primitive equations configured under the Boussinesq and hydrostatic approximations. Interoperability is achieved with the ocean, atmosphere, sea- ice and the land-surface components being coupled with the Earth System Modeling Framework (ESMF) coupler and runs on the Multiple Program Multiple Data (MPMD) paradigm.

### **1.3 Implementation of new land-cover and land-use (LULC) and soil-type data, and Noah LSM 3.4 in CFS**

To perform CFS land simulation benchmarking, we have implemented the new global IGBP vegetation-classification data (derived from MODIS) and global soil type (STATGO) datasets in CFS, together with Noah 3.4.1. Compared to the legacy Noah LSM version 2.7.1 (released in early 2000s), the latest version Noah 3.4 (released in August 2012) now has a number of bug fix and improved physical treatments such as treatments for saturation slope, background emissivity, snow albedo, etc.

### **1.4 Noah-MP offline physics ensemble simulations**

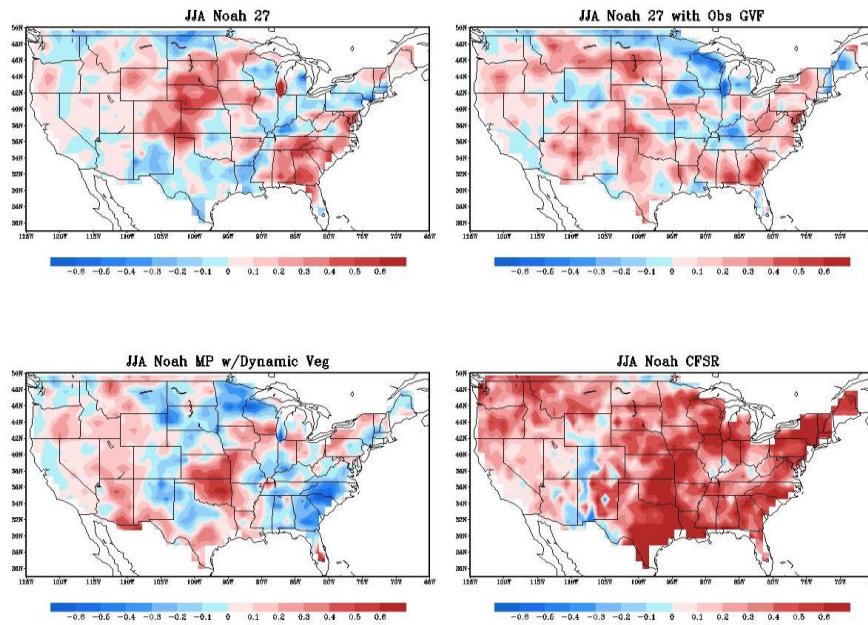
Because the computational cost of running the uncoupled LSM is much cheaper than running the coupled model, we first performed a sensitivity assessment of the Noah-MP model options to obtain an initial reduction in the total number of coupled simulations. We used the offline system called the High Resolution Land Data

Assimilation System (HRLDAS) to conduct Noah-MP ensemble simulations. We choose the grid to be exactly the same as the CFS T382 grid. To do these offline tests, we created atmospheric forcing conditions on the CFS grid. Our NCEP collaborators have provided CFSR output to drive the offline model, and we have developed the software to convert the GRIB CFSR output to HRLDAS NetCDF forcing. We conducted 12 Noah-MP ensemble simulations for 1979-2009, which consists of various combinations of Noah-MP physics options in runoff (2 options), dynamic vegetation (2 options), canopy resistance (2 options), and soil moisture threshold functions (2 options). The span-up soil state variables from those Noah-MP ensemble simulations are being transferred to NCEP computers, which will be used as initial soil conditions for the coupled CFS/Noah-MP hindcasts experiments.

### **1.5 Assessment of the CFS performance with different vegetation treatment in Noah and in Noah MP v2**

Land surface models serves as the lower boundary to provide fluxes to its parental atmospheric model. The Noah LSM used in the current operational CFS model has several limitations in its overall structure, such as the combined surface layer of vegetation and ground, a bulk layer of snow and soil, and shallow soil column. The CFS performance is not only impacted by these limitations, but also by the surface characteristics (e.g., soil and vegetation types and parameters associated with these characteristics). In particular, the specification of the Greenness Vegetation Fraction (GVF) impacts the canopy resistance and surface latent heat fluxes. As such, an accurate representation of the GVF is essential to improve CFS performance.

Currently, the operational CFS/Noah uses a monthly GVF climatology along with a constant Leaf Area Index (LAI), which does not reflect inter-annual variability. Various CFS sensitivity experiments are conducted with the climatology GVF replaced by near realtime satellite observations, and with Noah-MP dynamic vegetation model to generate inter-annual GVF and LAI variability. To examine these effects on CFS prediction skills, T126 CFS reforecast experiments are carried out for selected eleven years (1982, 1987, 1996, 1988, 2000, 2007, 1986, 1991, 1999, 2011, 2012) with four ensemble members (00z of May 1 to May 4). The eleven years are composed of three ENSO-cold, three ENSO-warm and five neutral years. Figure 1 shows the summer-season (June-July-August: JJA) precipitation anomaly correlation scores from the two CFS runs, compared to the control CFS (top left). The experimental CFS with Noah-MP (bottom left) improves prediction skills over the western states (mainly west of the Rockies) with sparse vegetation and over the central Great Plains where the soil moisture memory and atmospheric coupling strength has a great impact on seasonal precipitation prediction. The CFS with observed satellite observation (top right) shows improvement over most of the U.S., indicating the important role of GVF in Noah. Note that the CFS precipitation prediction skill over the western U.S. in the two CFS runs is comparable to that in the CFSR (bottom right).



*Figure 1. Anomaly correlation skill of averaged JJA precipitation over CONUS from the two CFS experiments and Comparison with Control CFS and CFSRR*

Figure 2 shows the comparison of CFS JJA precipitation skills in hindcast using Noah v2.7 (current CFS operational setting), Noah v3.4, and Noah-MP with and without dynamic vegetation. The hindcast with Noah-MP has significantly improved the precipitation prediction skill over the Pacific Northwest and the Gulf states, and the CFS with Noah-MP dynamic has the best performance over the central Great Plains. Similarly, Figure 3 compares the AC score of JJA averaged 2-m temperature between those CFS hindcast, and indicates that the CFS coupled to Noah-MP performs better in predicting 2-m temperature anomalies. In general, the CFS/Noah-MP without dynamic vegetation has the largest area of positive AC despite its relatively lower precipitation skill.

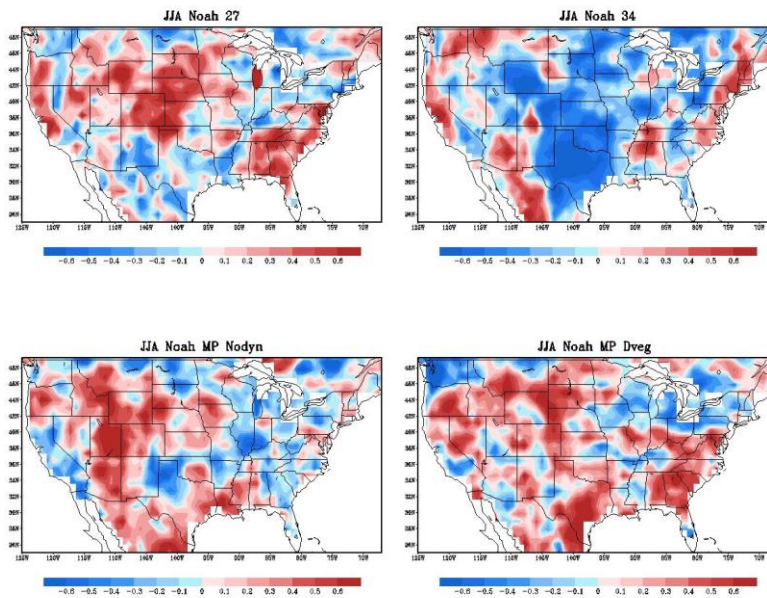


Figure 2: Anomaly Correlation (AC) skill of averaged JJA precipitation over CONUS from the four CFS experiments: top left is CFS coupled with Noah 2.7; top right: CFS coupled with Noah 3.4; bottom left: CFS coupled with Noah-MP 1.0 without dynamic vegetation; bottom right: CFS coupled with Noah-MP v1.0 with dynamic vegetation.

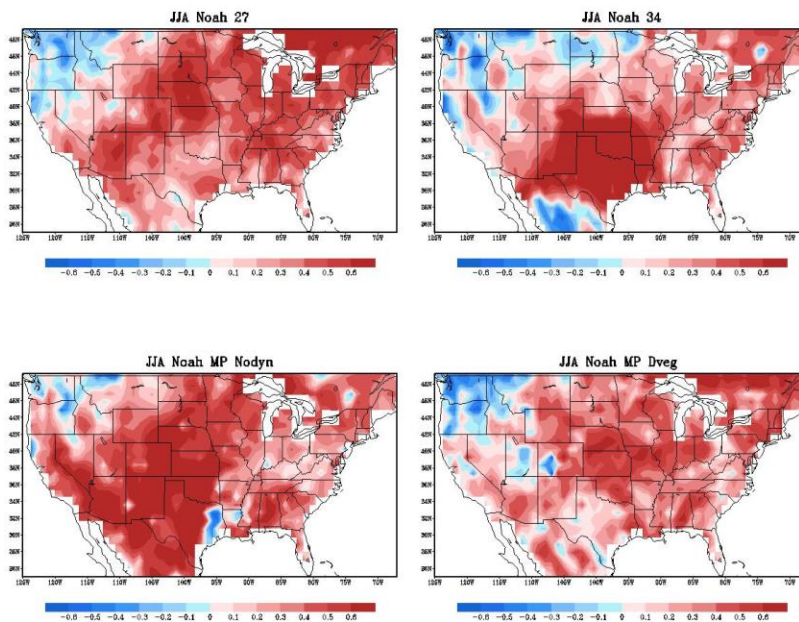


Figure 3: Same as Figure 2, but for Anomaly Correlation skill of averaged JJA 2-m temperature over CONUS.

## 2 Highlights of Accomplishments:

- CFS land-surface modeling system is enhanced with new global land-cover and land-use (LULC) and soil texture data, which is consistent with recent community efforts to improve the specification of surface characteristics.
- Preliminary CFS reforecast results show positive impacts of using Noah-MP with ground-water and dynamic vegetation parameterizations in CFS seasonal prediction skills in precipitation and surface temperature.

## 3 Publications from the Project:

- Peer-reviewed paper
  - Chen, L., Y. Li, F. Chen, A. Barr, M. Barlage, and B. Wan, 2016: The incorporation of an organic soil layer in the Noah-MP Land Surface Model and its evaluation over a Boreal Aspen Forest. *Atmospheric Chemistry and Physics*, 16, 8375-8387, doi:10.5194/acp-16-8375-2016.
  - Liu, X., F. Chen, M. Barlage, G. Zhou, D. Niyogi, 2015: Noah-MP-Crop: Introducing Dynamic Crop Growth in the Noah-MP Land-Surface Model. *J. Geophys. Res.*, under review.
- Conference/Workshop
  - “Improving Climate Forecast System (CFS) through Enhancing the Representation of Soil-Hydrology-Vegetation Interactions”, NOAA Climate Test Bed meeting, 9-10 November 2015, NCWCP, College Park, MD.
  - “Coupling Noah-MP to the NCEP Climate Forecast System to Improve Land-Atmosphere Interactions at Seasonal Forecast Timescales”, AMS Annual Meeting, January 13, 2016, New Orleans, LA.

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