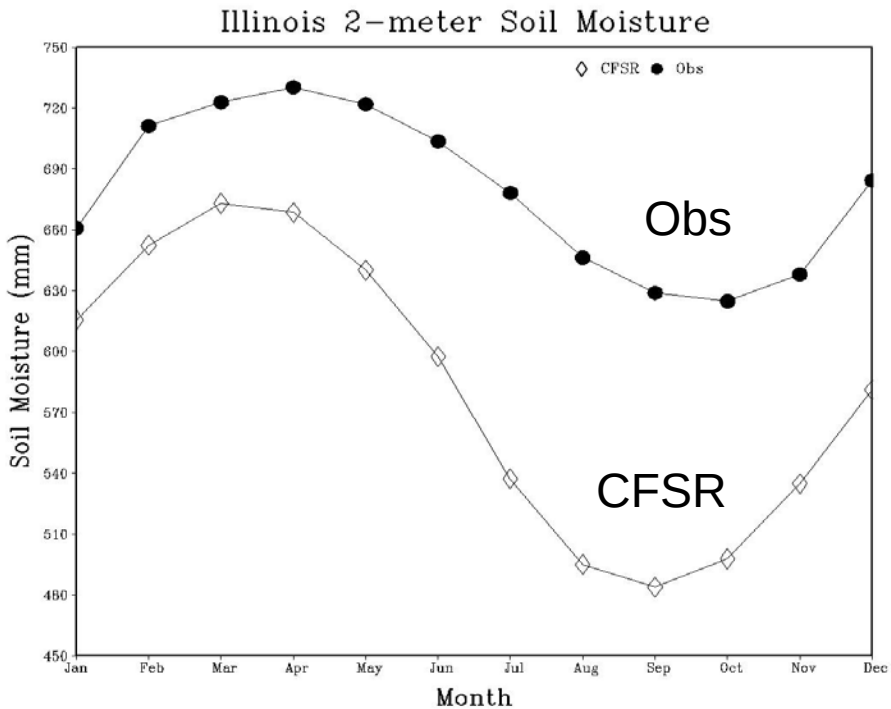
Improving Climate Forecast System (CFS) through Enhancing the Representation of Soil-Hydrology-Vegetation Interactions

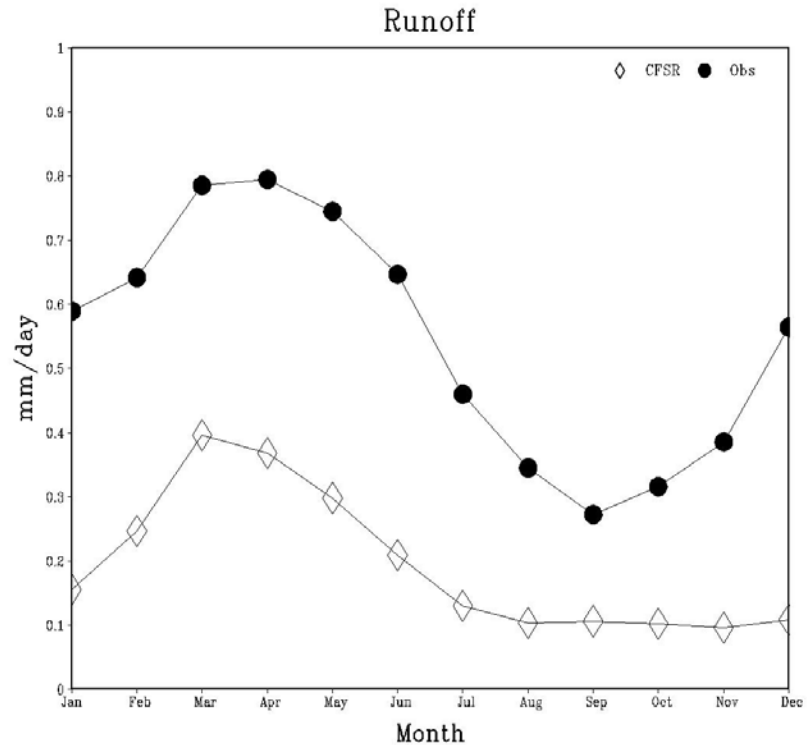
- PI: Fei Chen, NCAR
- Co-PI:
  - NCAR: Michael Barlage
  - University of Texas at Austin: Zong-Liang Yang
  - NCEP/EMC: Michael Ek, Rongqian Yang, Jesse Meng

1. Motivations
2. Progress so far
3. R2O schedule; leverage community Noah-MP development efforts

Problem in NCEP CFS land/hydrology modeling

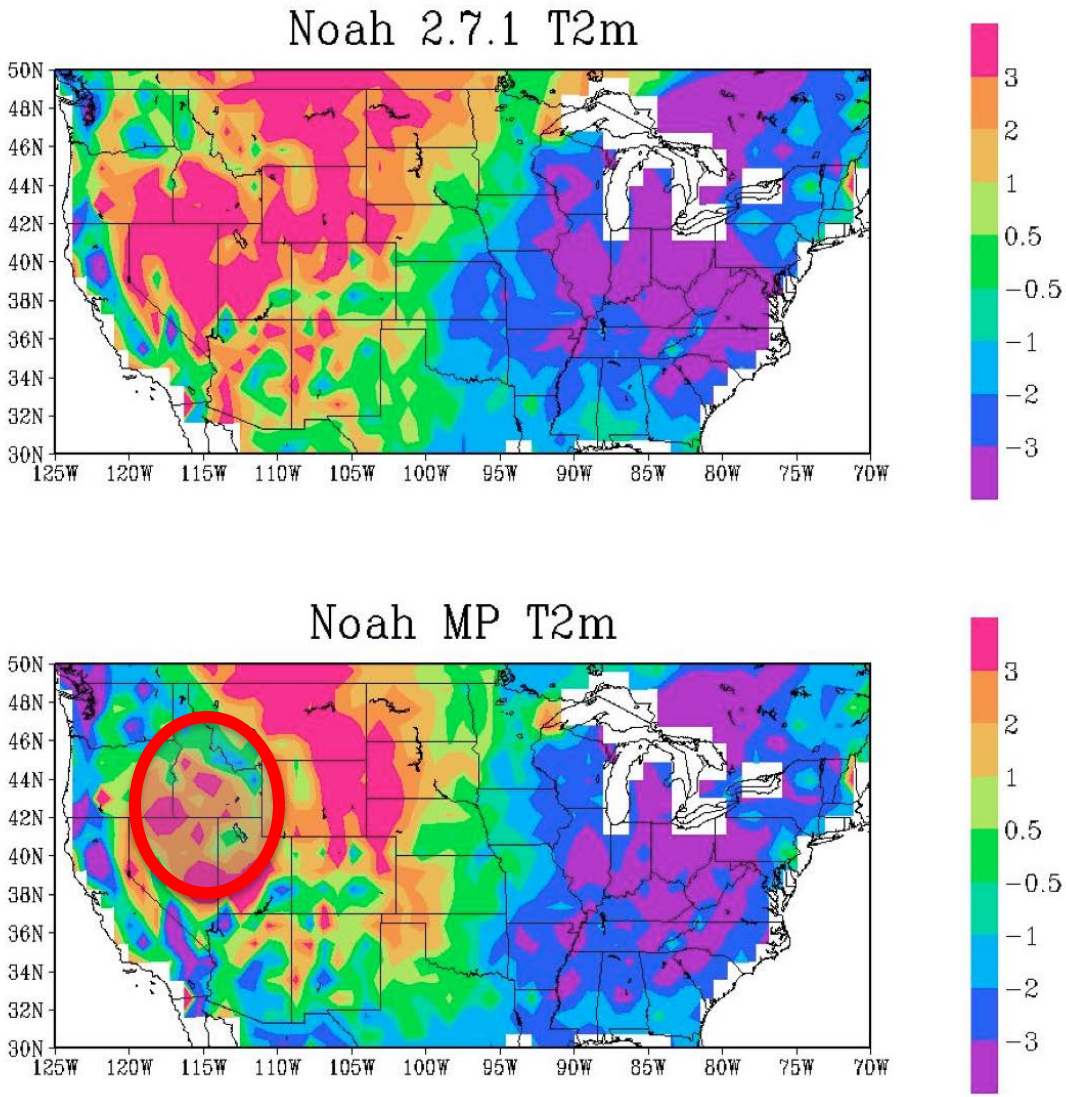


Seasonal cycle of soil moisture (mm) averaged over the state of Illinois from the CFSR (◊), and observation (●) for the period from Jan 1981 to Dec 2004.



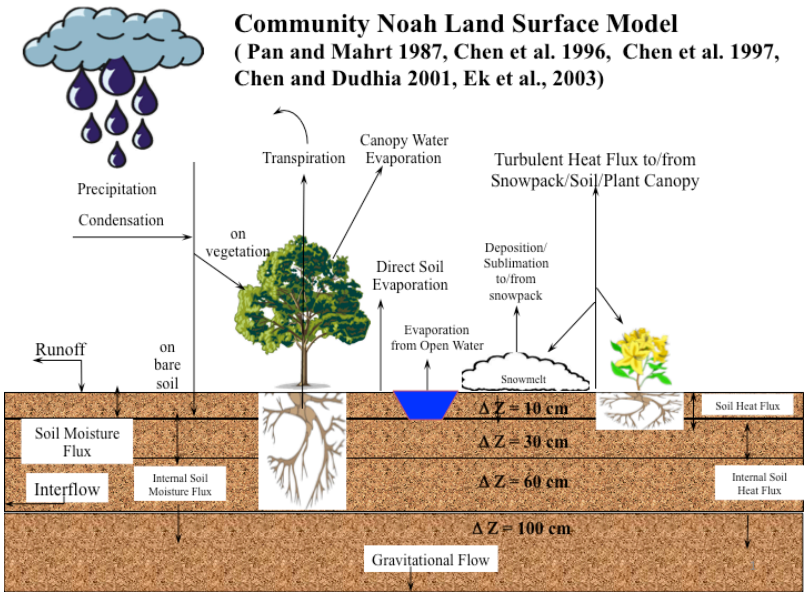
Seasonal cycle of surface runoff (mm/day) averaged over the Mississippi River basin from the CFSR and observations. Observed runoff climatology based on the stream flow at Vicksburg, Mississippi. from Oct 1979 to Sep 1999.

Impacts of land/hydrology modeling on CFS



Monthly mean 2-meter temperature bias for May 1982 (unit: K) produced by the CFS v2 coupled with Noah v2.7.1 (top panel) and coupled with Noah-MP v1 (bottom panel).

New Generation Noah-MP (Multi-parameterization)



Limiting ability for seasonal prediction

New Generation Noah-MP (Multi-parameterization)

- Multi-parameterization=Multi-physics ≡ Multi-hypothesis
- Multiple parameterizations to treat key hydrology-snow-vegetation processes paradigm in a single land modeling framework:
  - Canopy turbulence (2 schemes)
  - Canopy radiation (3 schemes)
  - Canopy resistance (2 schemes)
  - Frozen ground physics (2 schemes)
  - Snow physics (2 schemes)
  - runoff/water table (4 schemes)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D12109, doi:10.1029/2010JD015139, 2011

The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements

Guo-Yue Niu,[1,2] Zong-Liang Yang,[1] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Anil Kumar,[5] Kevin Manning,[4] Dev Niyogi,[6] Enrique Rosero,[1,7] Mukul Tewari,[4] and Youlong Xia[3]

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Noah-MP a powerful tool for assessing land physics uncertainties and for physics ensemble prediction!

Received 4 October 2010; revised 3 February 2011; accepted 27 March 2011; published 24 June 2011.

Noah-MP Official Release Site at NCAR/RAL

https://www.ral.ucar.edu/solutions/products/noah-multiparameterization-land-surface-model-noah-mp-lsm

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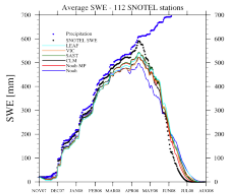
NOAH-MULTIPARAMETERIZATION LAND SURFACE MODEL (NOAH-MP LSM)



Noah-MP is a land surface model (LSM) using multiple options for key land-atmosphere interaction processes (Niu et al., 2011). 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 (Dickinson, 1983; Niu and Yang, 2004). 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 snow (Yang and Niu 2003; Niu and Yang 2004). Multiple options are available for surface water infiltration and runoff and groundwater transfer and storage including water table depth to an unconfined aquifer (Niu et al., 2007).

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 a Ball-Berry photosynthesis-based stomatal resistance (Ball et al., 1987) with a dynamic vegetation model (Dickinson et al. 1998) that allocates carbon to various parts of vegetation (leaf, stem, wood and root) and soil carbon pools (fast and slow). The model is capable of distinguishing between C3 and C4 photosynthesis pathways and defines vegetation-specific parameters for plant photosynthesis and respiration.

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NOAH-MP VERSION 1.6 (AS IMPLEMENTED IN WRFV3.6)

- Offline 2D driver code: High-Resolution Land Data Assimilation System (HRLDAS)
  - Readme: README
  - Gzipped tar file: HRLDAS-v3.6.tar.gz
  - For more general HRLDAS user info, see: HRLDAS_USERS_GUIDE

NOAH-MP VERSION 1.1 (AS IMPLEMENTED IN WRFV3.4.1)

- Noah-MP LSM Version 1.1 code -- August 2012
  - Readme: README
  - Changes to Noah-MP v1.1 since Noah-MP v1.0: CHANGES
  - Source code directory: noahmp-v1.1
  - Gzipped tar file: noahmp-v1.1.tgz
- Offline 1D Noah-MP LSM v1.1 driver program (with sample dataset) -- 02 Oct 2012
  - Readme: README
  - Source code directory: Simple-Driver-NoahMP-v1.1
  - Gzipped tar file: Simple-Driver-NoahMP-v1.1.tgz

NOAH-MP VERSION 1.0 (AS IMPLEMENTED IN WRFV3.4)

- Noah-MP LSM Version 1.0 code -- April 2012
  - Readme: README
  - Source code directory: noahmp-v1.0
  - Gzipped tar file: noahmp-v1.0.tgz
- Offline 1D Noah-MP LSM v1.0 driver program (with sample dataset) -- April 2012
  - Readme: README
  - Source code directory: Simple-Driver-NoahMP-v1.0
  - Gzipped tar file: Simple-Driver-NoahMP-v1.0.tgz

NOAH-MP (AND NOAH) RUN-TIME TABLES FOR VEGETATION AND SOIL PARAMETERS

General parameters	-- GENPARM.TBL	-- (documentation)
Soil Parameters	-- SOILPARM.TBL	-- (documentation)
Vegetation Parameters	-- VEGPARM.TBL	-- (documentation)
Noah-MP Parameters	-- MPTABLE.TBL	-- (documentation)

BACKGROUND SURFACE FIELDS

- USGS 30-second global 24-category vegetation (land-use) data

Noah-MP Official Release Site at NCAR/RAL

https://www.ral.ucar.edu/solutions/products/noah-multiparameterization-land-surface-model-noah-mp-lsm

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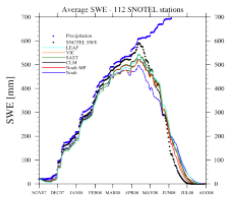

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Noah-MP implemented and used in:

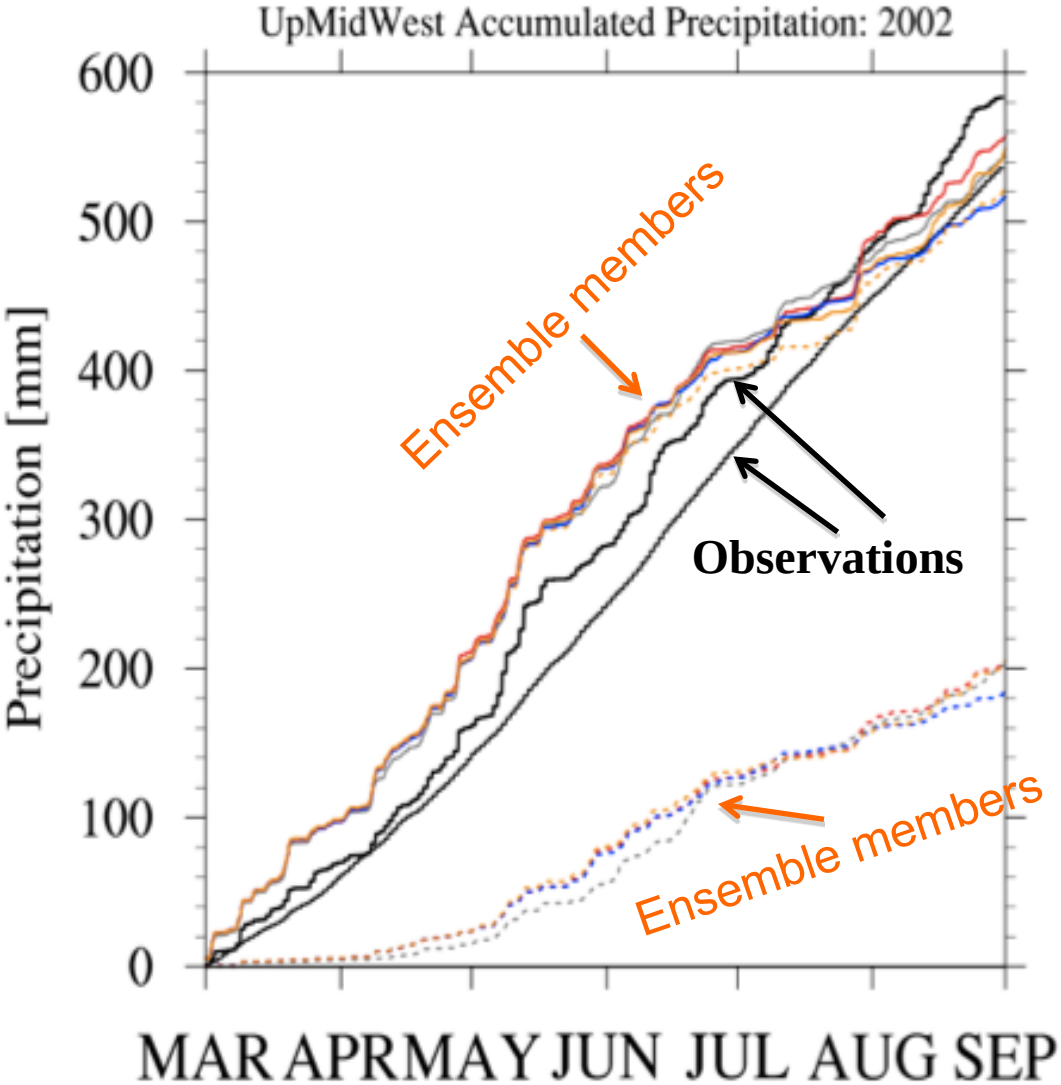
WRF

MPAS

WRF-Hydro at National Water Center

Most recent development code available to community via http://github.com/NCAR/NoahMP_release

WRF/Noah-MP Seasonal Ensemble Simulations



US Mid West six month （2002 May-Sep） accumulated precip (mm) averaged for US Mid West region.

•Color: WRF/Noah-MP Physics Ensemble members

Barlage et al., 2015, *Climatic Change*.

Science Questions

- *To what degree can the enhanced Noah-MP model improve CFS seasonal prediction skill?*

- *Is there an optimal set of Noah-MP physics options for improving CFS seasonal predictions, especially precipitation and near-surface temperature?*

- *Which are the key soil-hydrology-vegetation interactions contributing to CFS intra-seasonal and interannual prediction skill?*

1. Provide guidance to CFS/Noah-MP optimal configuration and to further improving models.
2. Final operational implementation in FY17.

Research Plan

1. **Benchmark performance of CFS v2+ hindcast using Noah V2.7.1, Noah-MP V1, and Noah-MP V2. different land models**
   - hindcast experiments for summer and winter season, using the T126 CFS for nine years.

2. **Perform CFS/Noah-MP physics-ensemble forecasting**

3. **Analyze ensemble spread and determine an optimal set of Noah-MP physics options that can maximize the CFS forecast evaluation metrics**

FY15-16 Tasks

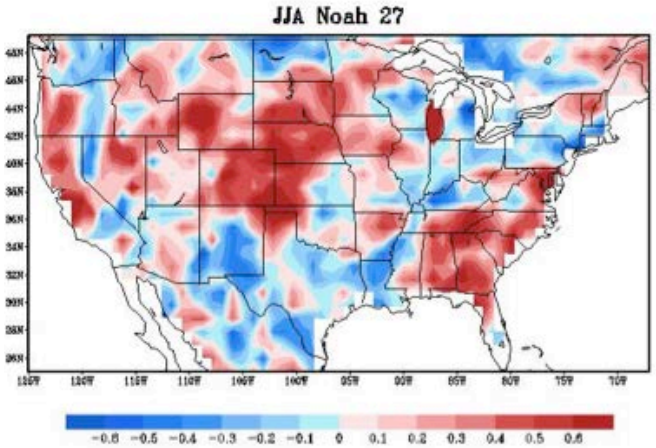
1. **Implementation of Noah-MP V2 in CFS (FY15-FY16): in progress**
   - Coupling Noah-MP V2 with improved GFS atmosphere model
   - Implementation of new land-cover and land-use (LULC) and soil-type data, and Noah LSM 3.4 in CFS
2. **Benchmark performance of CFS v2+ hindcast using different land models (FY15): nearly completed**
   - 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).
3. **Perform Noah-MP physics-ensemble forecasting: starting stage for FY16**
   - Due to computational cost, first performed a sensitivity assessment of the Noah-MP options to obtain an initial reduction in the total number of coupled ensemble simulations. Conduct off-line Noah-MP with HRLDAS using CFSR forcing on the same grid as CFS T382. We create atmospheric forcing conditions on the CFS grid.

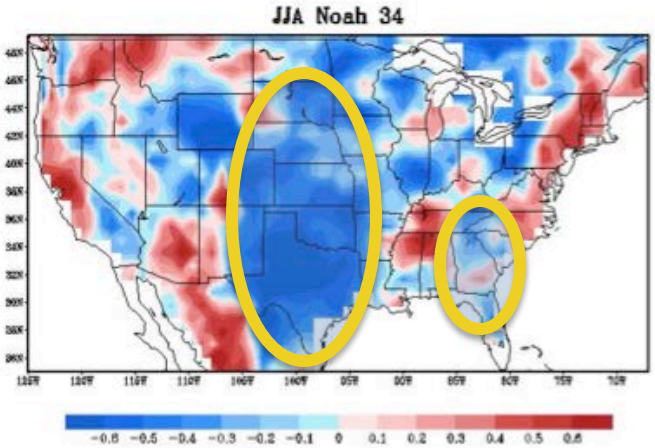
FY15 Preliminary Results

Rongqiang Yang conducted T126 CFS reforecasts using different land models: eleven years (1982, 1987, 1996, 1988, 2000, 2007, 1986, 1991,1999, 2011, 2012) with four ensemble members (00z of May 1 to May 4).

Anomaly Correlation (AC) skill of averaged JJA precipitation

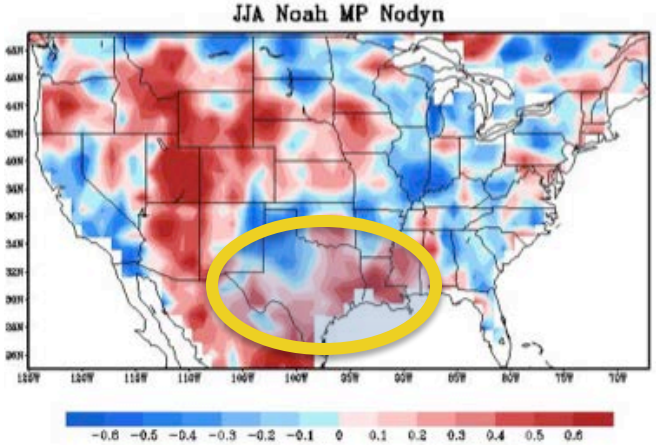
Noah 2.7

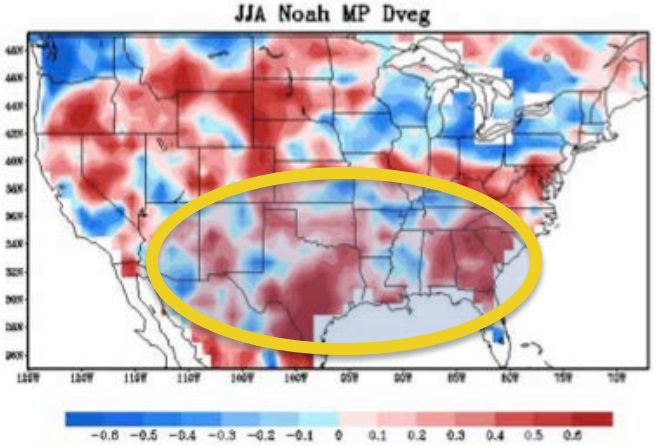




Noah 3.4

Noah-MP

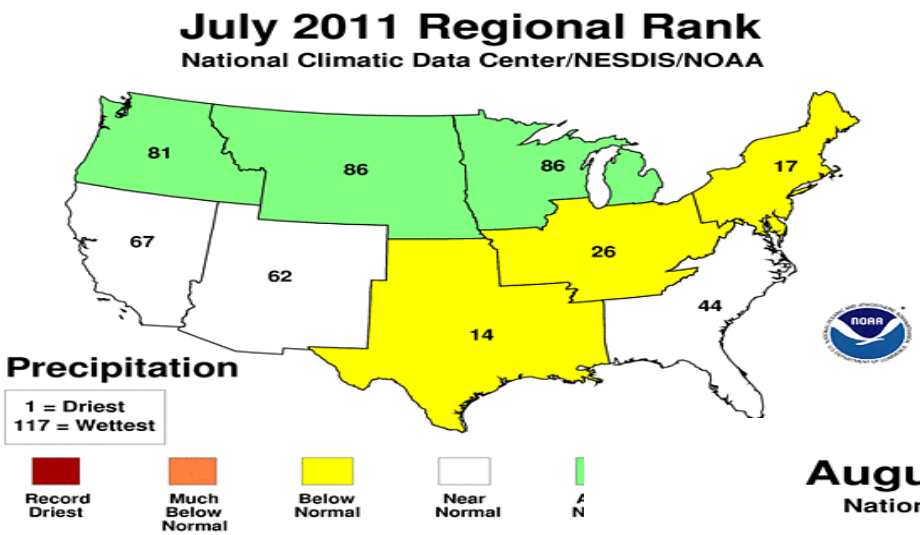


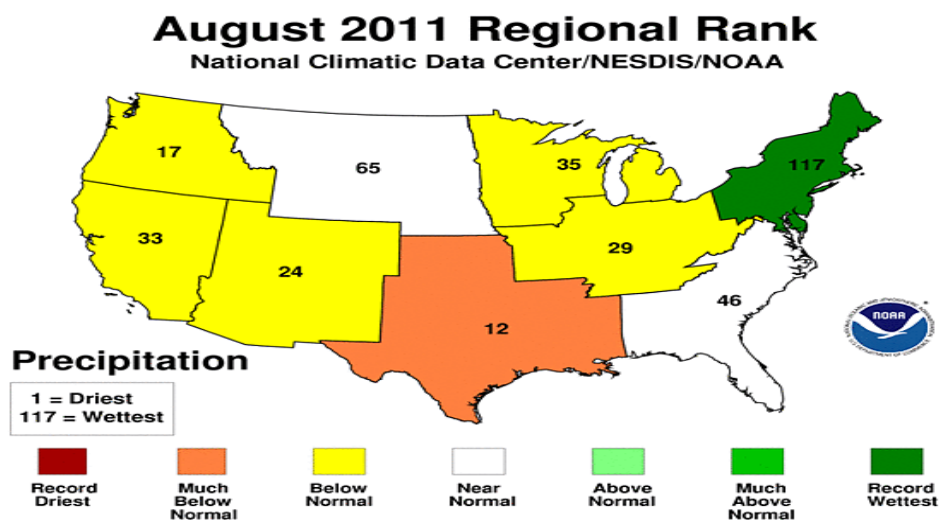


Noah-MP dyn veg.

FY15 Preliminary Results

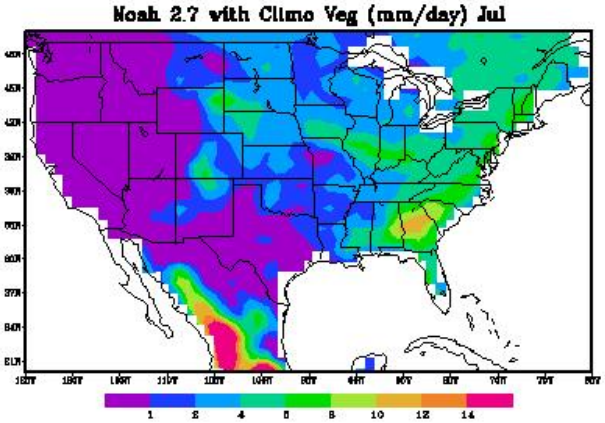
Comparison of <u>precipitation</u> and <u>T2m</u> from CFS with two different vegetation data and with Noah-MP V1 and V2. 2011 Texas Drought



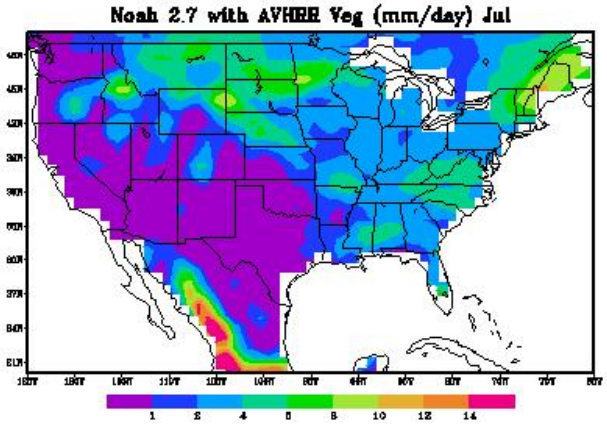


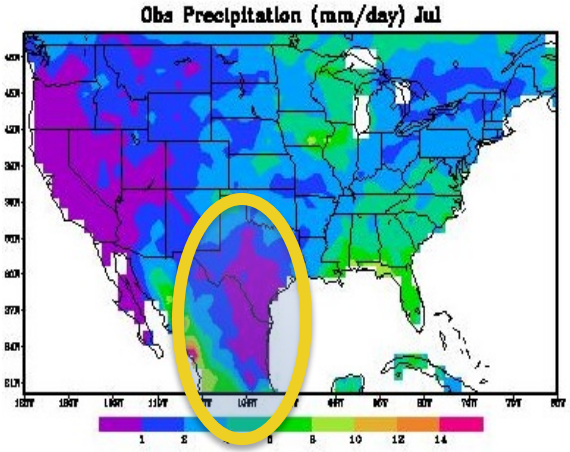
FY15 Preliminary Results: 2011 Texas Drought

Noah 2.7 Climo GVF

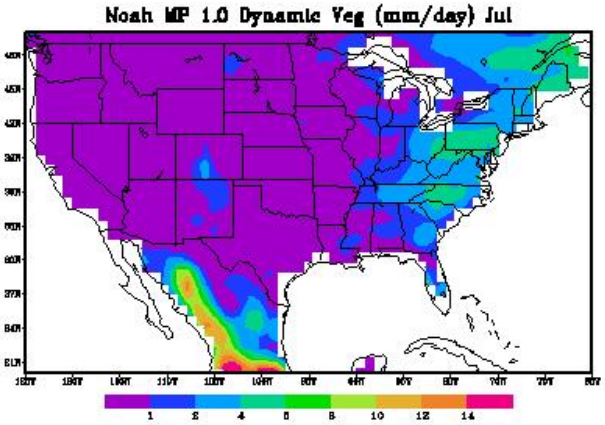


Noah 2.7 AVHRR GVF

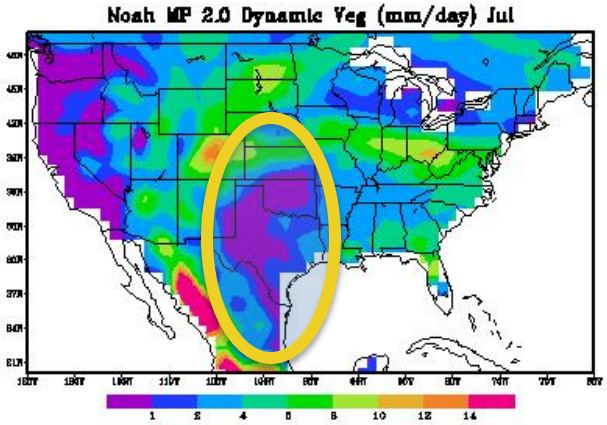




Obs



Noah-MP V1

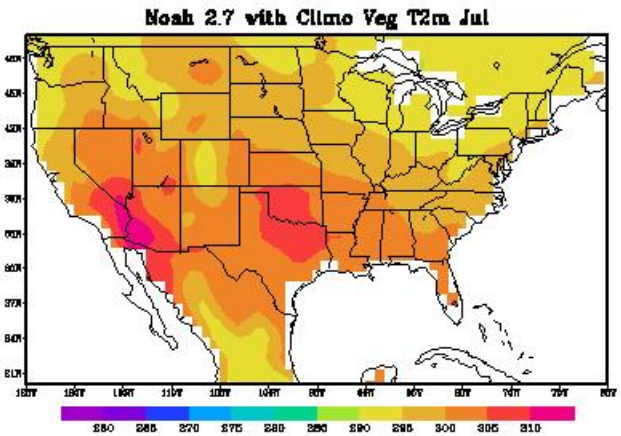


Noah-MP V2

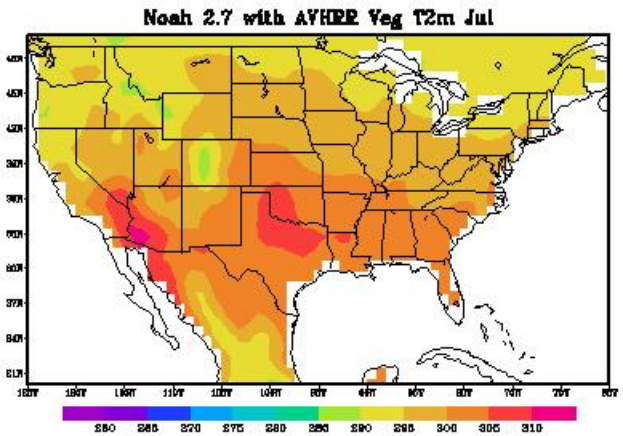
Predicted Precipitation for July 2011

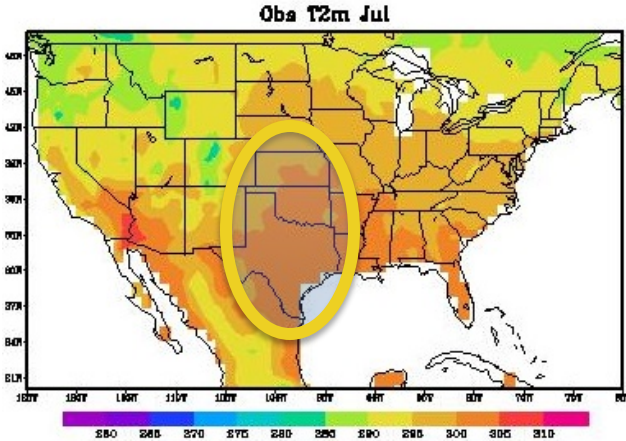
FY15 Preliminary Results: 2011 Texas Drought

Noah 2.7 Climo GVF

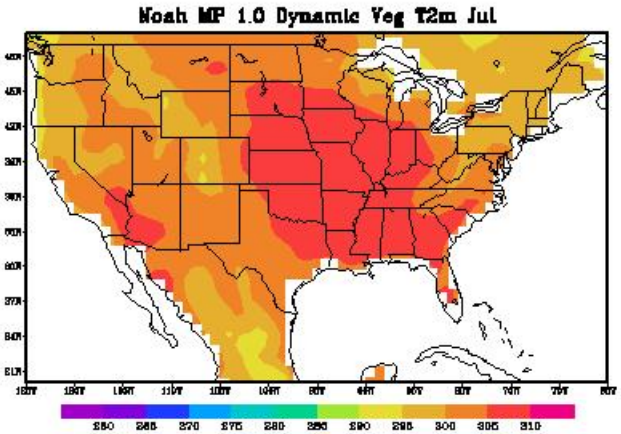


Noah 2.7 AVHRR GVF

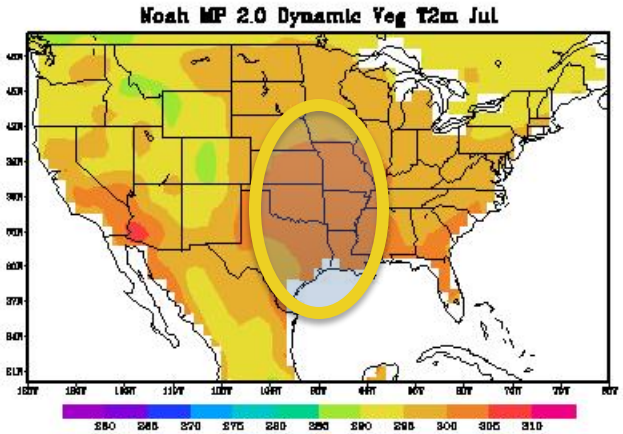




Obs



Noah-MP V1

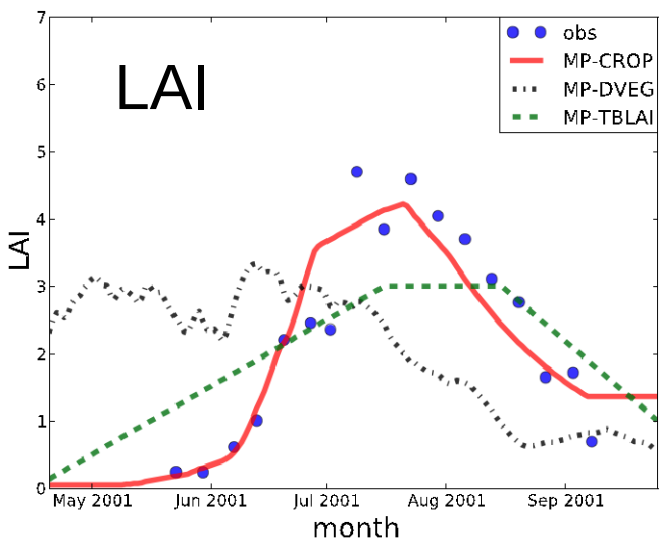


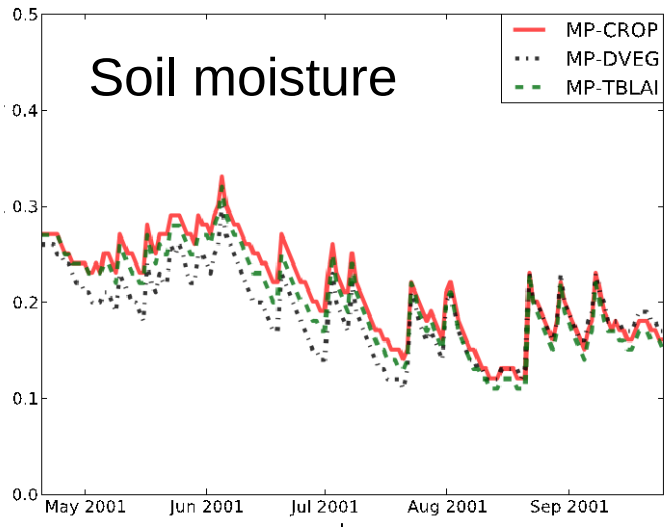
Noah-MP V2

Predicted T2m for July 2011

Future Noah-MP development: Noah-MP-Crop

- Integrate process models, crop types, and environmental and management factors
- Capture seasonal crop-weather-hydrology interactions
- Support NCEP weather prediction and agriculture applications





Noah-MP-Crop simulated 2001 rainfed corn yield at the Bondville site, IL. Red: model results Blue: obs

Liu et al. (2015, JGR, submitted)

Improving Noah-MP soil modeling capabilities

- Enabling to specify soil properties horizontally and with depth
- Increasing the use of non-standard soil properties databases and non-standard profiles

Default – 4 layers,
texture classes
no depth dependence

0.47	0.47	0.47	0.1m
0.47	0.47	0.47	0.3m
0.47	0.47	0.47	0.6m
0.47	0.47	0.47	1.0m

Example:
Clay Soil
porosity
allowed to
vary
horizontally
and
vertically

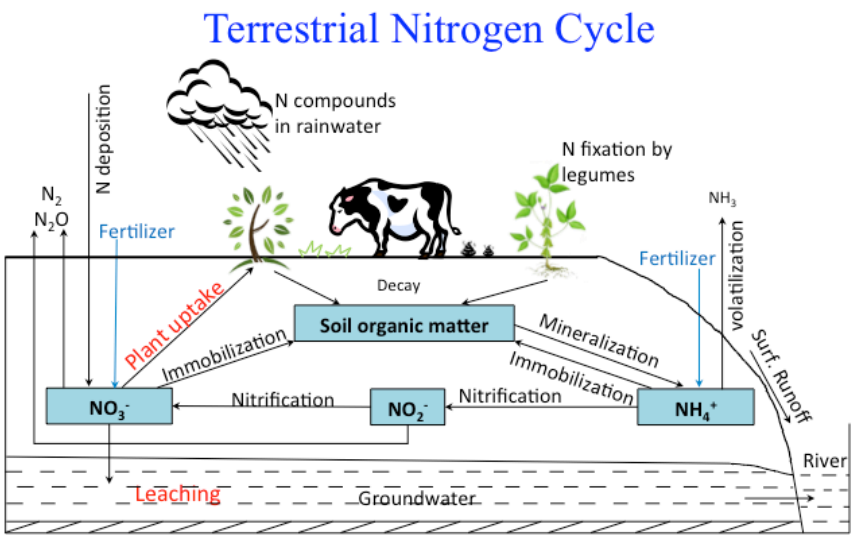
Modified – 4 layers,
no texture classes
depth dependence

0.41	0.43	0.47	0.1m
0.47	0.43	0.44	0.3m
0.42	0.42	0.41	0.6m
0.39	0.41	0.39	1.0m

- Test over East Texas with homogeneous and heterogeneous (horizontal and vertical) soils show an impact of -50 to +100 W/m^2

Biogeochemical Advancement of Noah-MP

- Lacking nitrogen constraint on LAI and soil moisture, critical for seasonal interactions.
- Advancing biogeochemistry in Noah-MP supports what "E" stands for NCEP.
  - Connecting with dry/wet deposition of N
  - Crops, fertilizer use, nutrients leaching, and riverine transport of N
  - Water quality prediction



Plant N uptake: N-limitation on carbon uptake
N leaching: Water quality

Cai, X., Z.-L. Yang, J.B. Fisher, X. Zhang, M. Barlage and F. Chen, 2015: Integration of a terrestrial nitrogen model into Noah-MP for climate and environmental predictions. (*Geoscientific Model Development,* accepted for Discussion)

Summary

- Preliminary results show promising improvements in CFS precipitation and temperature using Noah-MP.
- R2O implementation planned for FY17.
- ongoing community efforts to enhance Noah-MP have potential to improve NCEP seasonal prediction as well as water quality assessment.
- Closer collaboration with NCEP beneficial to R2O and O2R.