Data Assimilation of Soil Moisture in a 3-km Regional Model

Results from SMOS, Plans from SMAP

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Goals

Assimilate satellite retrievals of soil moisture into a regional (3-km) land surface model (SPoRT LIS running Noah 3.3).

- Take advantage of high-resolution geophysical properties, best available atmospheric forcing, and latest satellite measurements on soil moisture

Predicted impact

- Improved representation of fine-scale soil moisture fields
- Better depiction of gradients and structure for coupling with NWP models at convection-allowing resolution (3 km) for regional weatherforecasting

Demonstrate impact on:

  - LSM soil moisture field
  - coupled NWP forecasts

Transition a real-time version of LIS output to end users.

Use experience from SMOS assimilation to implement SMAP.

Motivation

– Improve model depiction of soil moisture and related variables

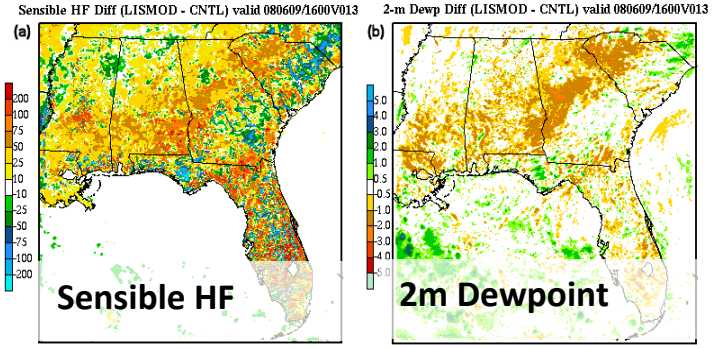
(Direct Applications)

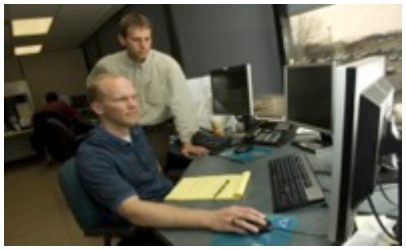
drought monitoring, flood forecasting, agriculture



– Better numerical weather forecasts using coupled NWP/LSM

Available moisture affects humidity, sensible/latent heating, diurnal heating rate, and convection.





Short-term Prediction Research and Transition (SPoRT) Center

Mission: Transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

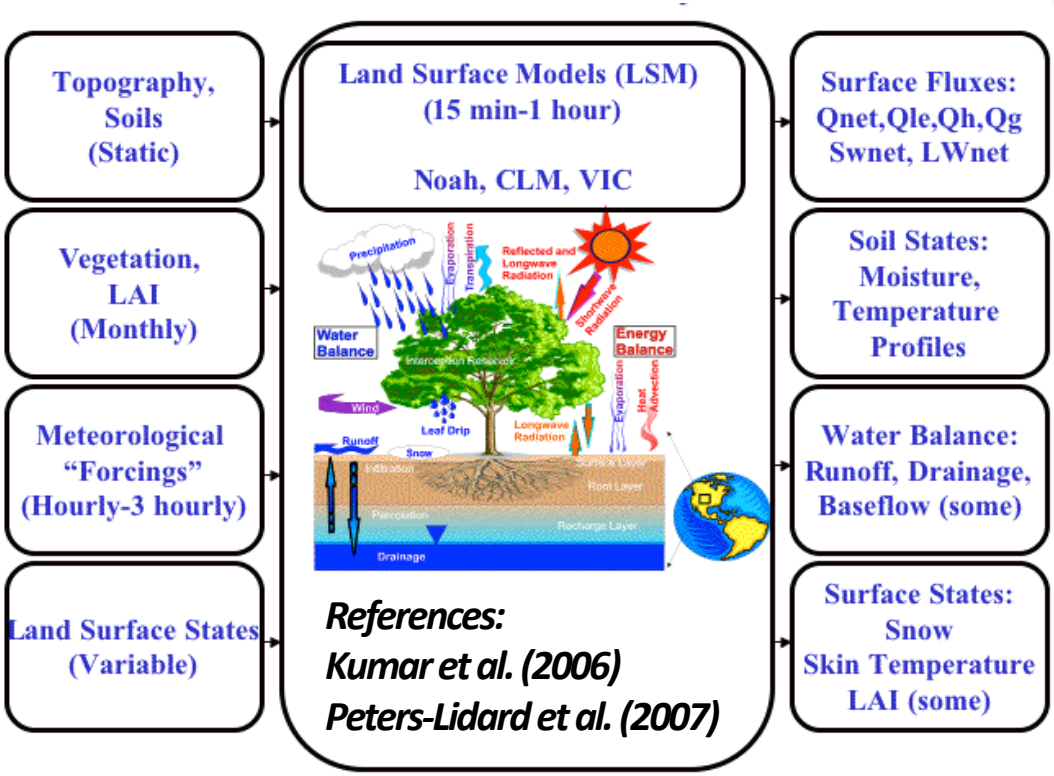
- Close collaboration with numerous WFOs and National Centers across the country
- SPoRT activities began in 2002, first products to AWIPS in 2003
- Co-funded by NOAA since 2009 through Proving Ground activities
- Proven paradigm for transition of research and experimental data to operations

Benefit:

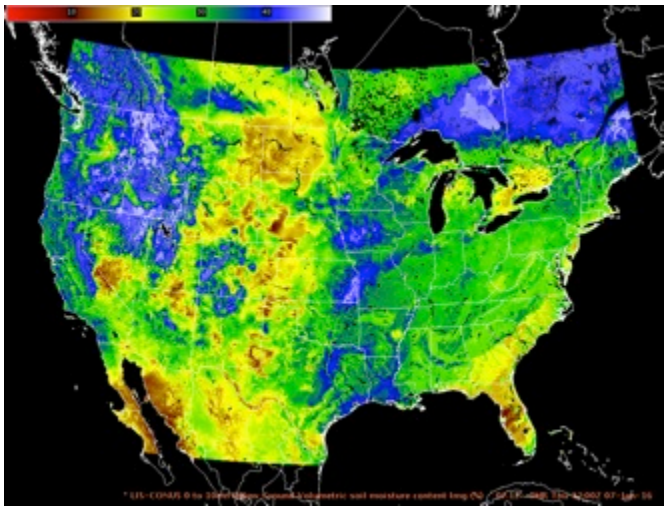
- Demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- Take satellite instruments with climate missions and apply data to solve shorter-term weather problems

NASA SPORT

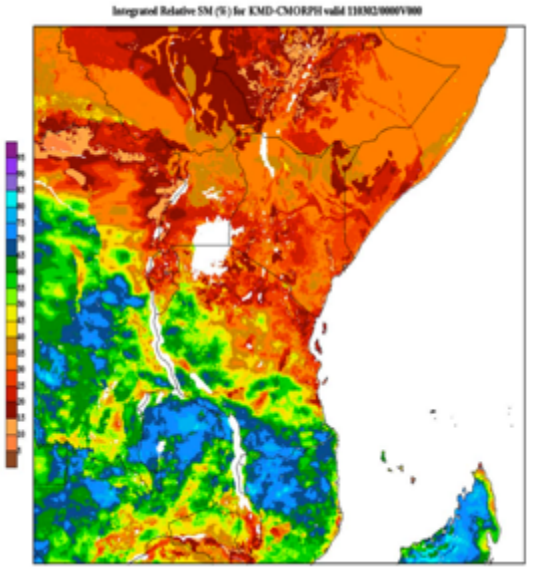
Land Information System (LIS)



References:
Kumar et al. (2006)
Peters-Lidard et al. (2007)



SPoRT-LIS total column soil moisture displayed in AWIPS II



East Africa LIS domain

- Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters
  - Developed by NASA-GSFC
  - Includes data assimilation capability.
  - Can be run coupled with Advanced Research WRF.
- Using Noah 3.3 Land Surface Model (LSM) within LIS
- SPoRT maintains near-real-time and experimental LIS runs
  - SE US (3-km), shared with WFO's
  - East Africa, shared with Kenya Meteorological Service (KMS)

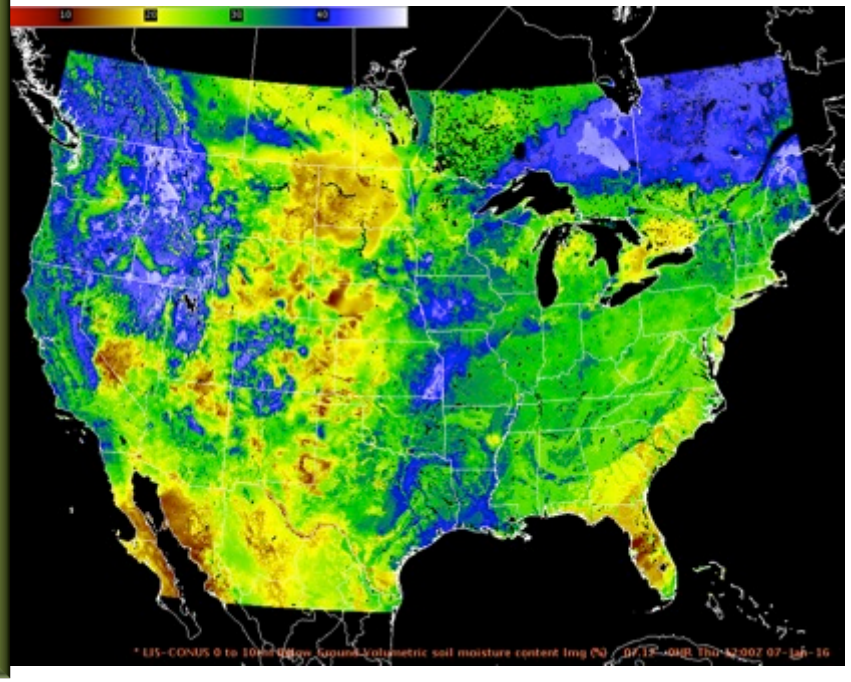
For more on SPoRT LIS, see also:

Real-time Land Information System over the Continental U.S. for Situational Awareness and Local Numerical Weather Prediction Applications (Case et al., Hydro 3.3)

Full Continental U.S. (CONUS) domain with 0.03° (lat/lon) grid resolution

Unique characteristics of SPoRT-LIS:

- Real-time S-NPP/VIIRS Green Vegetation Fraction
- Albedo scaled to input vegetation
- Restart simulation strategy to produce real-time output (timeline below)
- SPoRT-LIS ingested and displayed in AWIPS II at select NOAA/NWS weather forecast offices
- Land surface variables available to initialize modeling applications (WRF and STRC/EMS/UEMS)



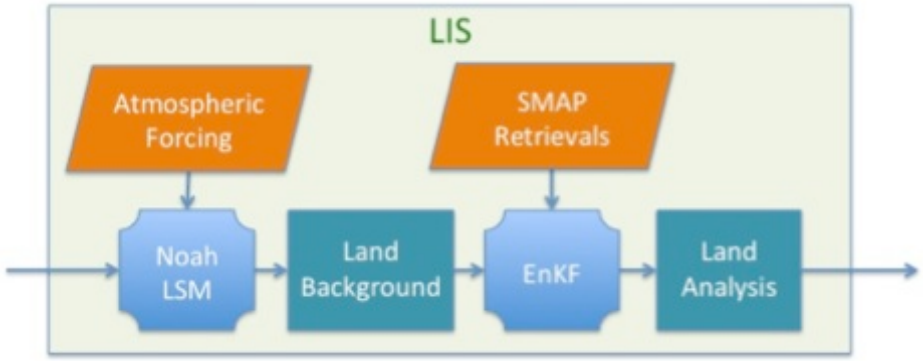
Current SPoRT-LIS CONUS domain, as displayed in AWIPS II

SMOS and SMAP

- L-band radiometers (and radars) can be used to estimate soil moisture near the surface
  - Compared to higher frequency instruments:
    - Sees deeper in the soil (~1-5 cm)
    - Better vegetation penetration
    - Higher sensitivity (accuracy)
- SMAP radar gives improved horizontal resolution
- Assimilating retrievals from Soil Moisture and Ocean Salinity (SMOS) satellite
- Preparing for assimilation of NASA Soil Moisture Active/Passive (SMAP) retrievals
  - SMAP has higher resolution product but due to failure of radar, time period is limited to a few months.

Name	AMSR-E	SMOS	SMAP		
Agency	NASA/ JAXA	ESA	NASA		
Launch	2002	2009	Jan. 2015		
Orbit	Polar	Polar	Polar		
Sensor Type	Passive	Passive	Passive	Active (Failed July 2015)	Combined (limited duration)
Frequency	6.9 GHz (C-band)	1.4 GHz (L-band)	1.41 GHz	1.2 GHz	
Resolution	56 km	35-50 km	36 km	**3 km**	9 km
Accuracy	6 cm^3/cm^3	**4 cm^3/cm^3**	**4 cm^3/ cm^3**	6 cm^3/ cm^3	**4 cm^3/ cm^3**

Data Assimilation in LIS



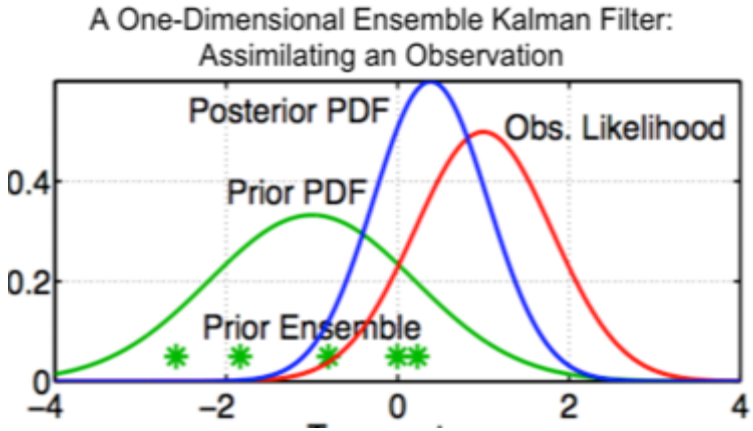


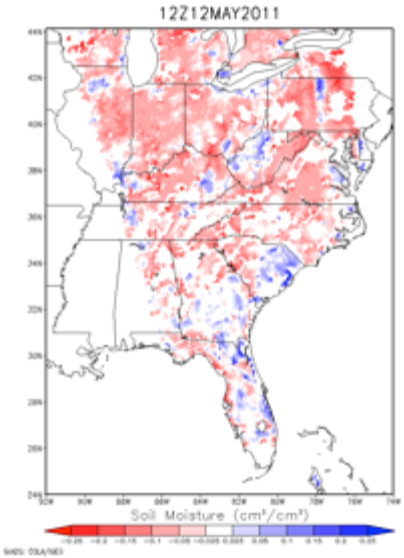
Figure from J. Anderson, NCAR.

- Uses Ensemble Kalman Filter in LIS
- Combines Background (Model) and Observations (Satellite Retrievals), weighted by their uncertainties, to provided a new analysis
- Observation operator relates the top model layer of soil moisture (0-10 cm) to the bias-corrected observations (~5 cm).
- Better depiction of top layer can improve deeper layers through infiltration and diffusion.

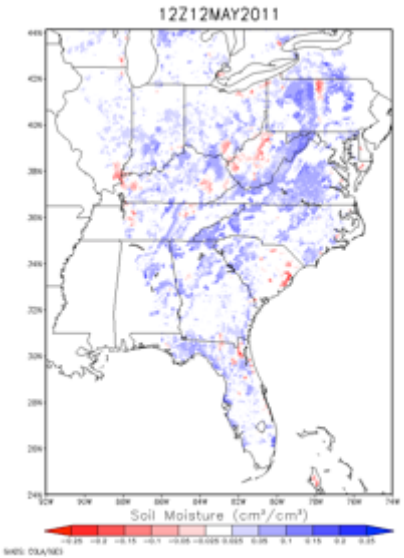
Bias Correction

- Data assimilation systems generally assume unbiased observations.
- In general, SMOS observations (retrievals) are drier than the model but have a higher dynamic range.
- CDF-matching is commonly used in land surface modeling (forcing observations to match model distribution)

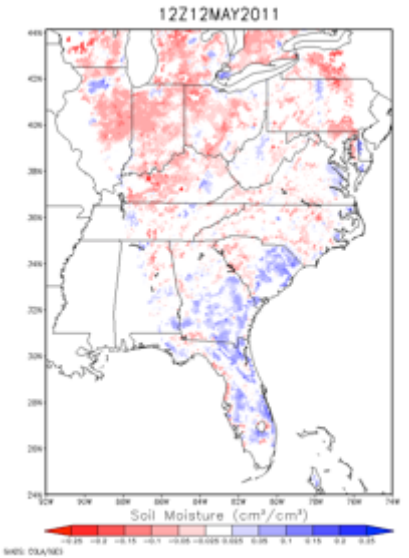
Innovations (Obs-Bkgd) (Uncorrected)



Bias Correction

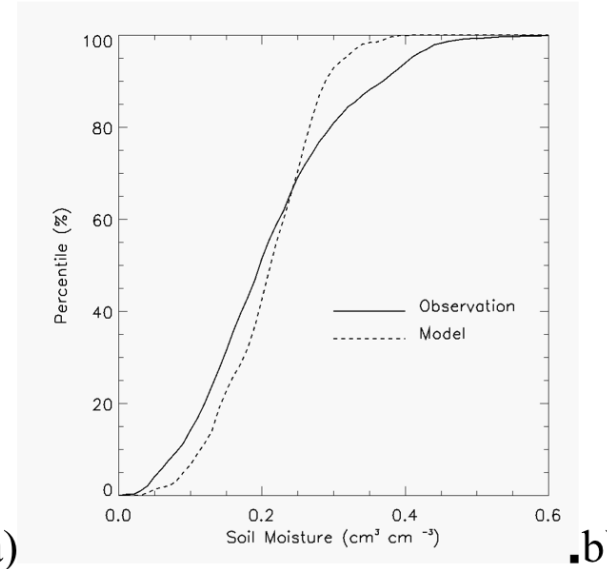


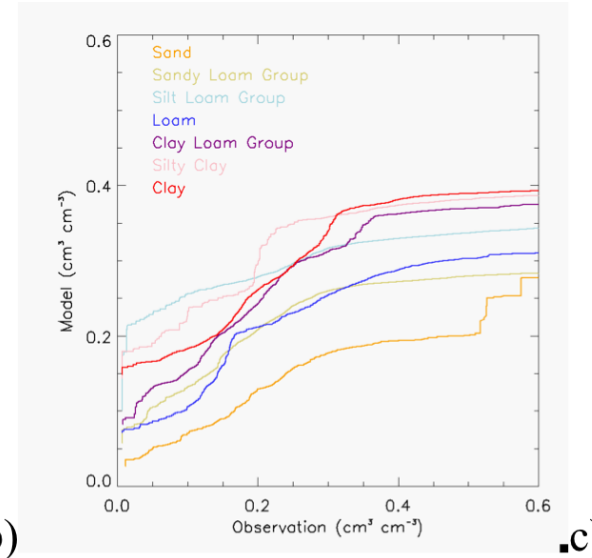
Innovations (Corrected)

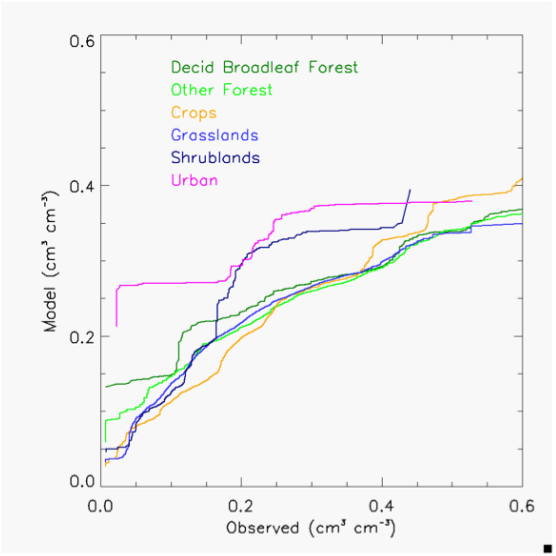


Bias Correction

Correction Curves

a) 

b) 

c) 

- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- We tested three variations of CDF matching, aggregating spatially to increase sample size.
  - Single uniform correction
  - Soil-type based
  - Vegetation-based

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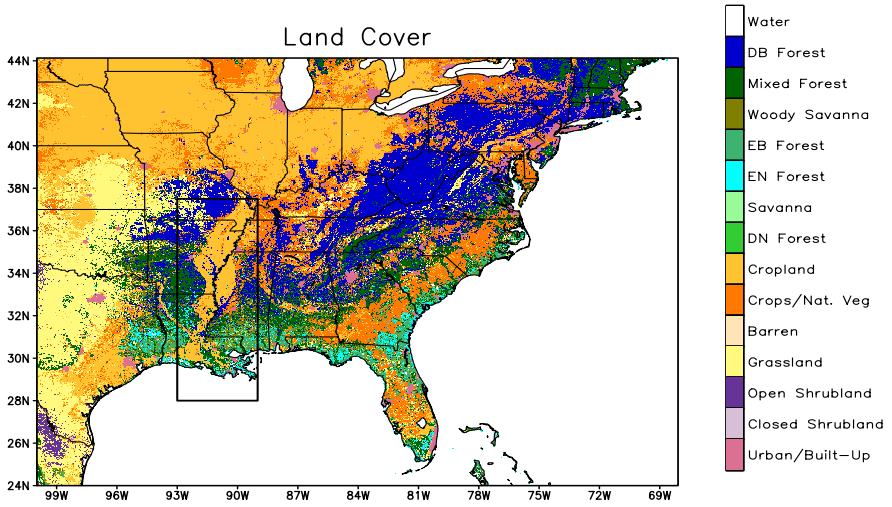
SMOS Experiment

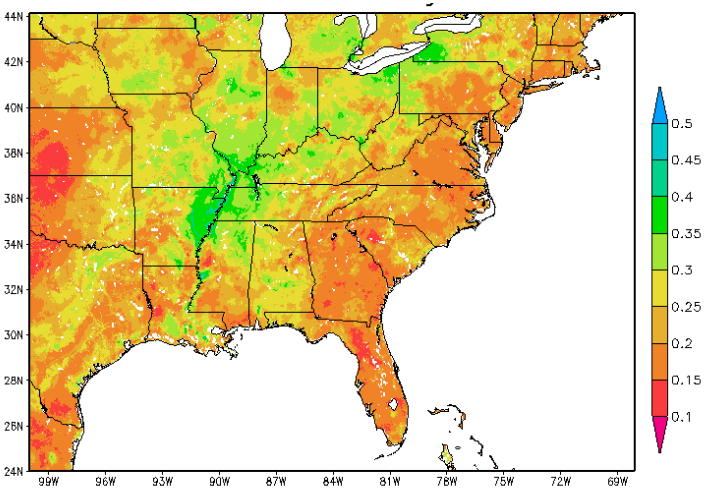
- Precursor to SMAP
- Southeastern/Central USA 3-km domain



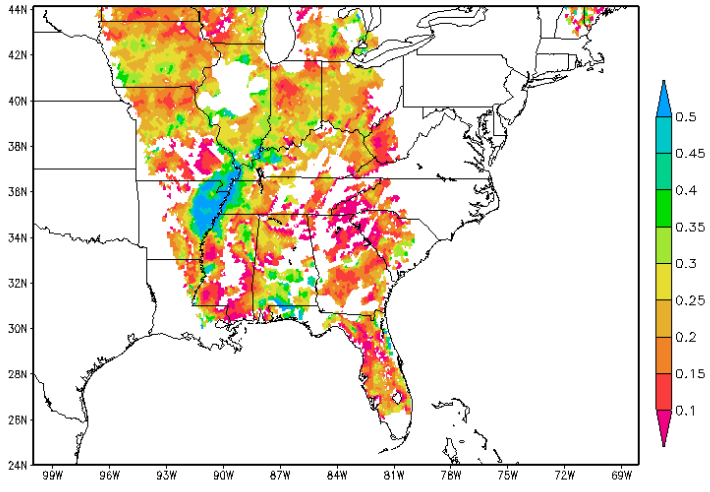
- MODIS/IGBP Vegetation Type
- STATSGO Soil Type
- Daily MODIS GVF
- North American Land Data Assimilation 2 (NLDAS-2) forcing
- Precip: Stage IV (radar+gauge)

- 1-yr spinup, 1 month perturbations, 32 ensemble members
- Experiment run March-October 2011
- Control (Open loop with perturbations)
- DA run (3 different bias corrections + no correction)
- Validation
  - North American Soil Moisture Database
  - Due to scale mismatch, expect correlations to be most useful metric

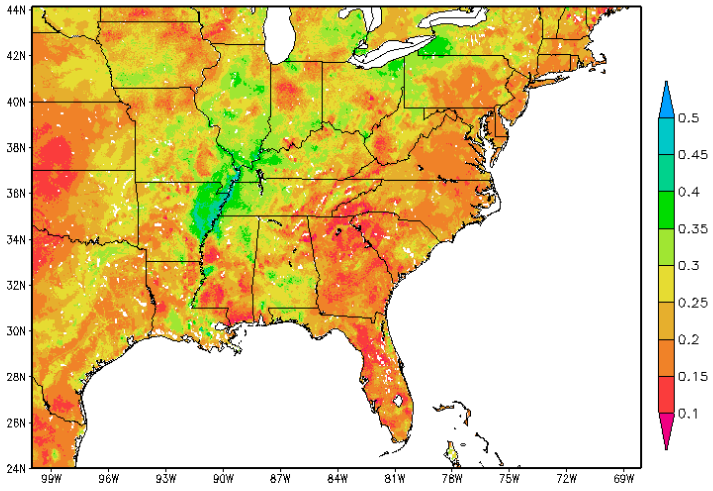
3-km results (14 May 2011)



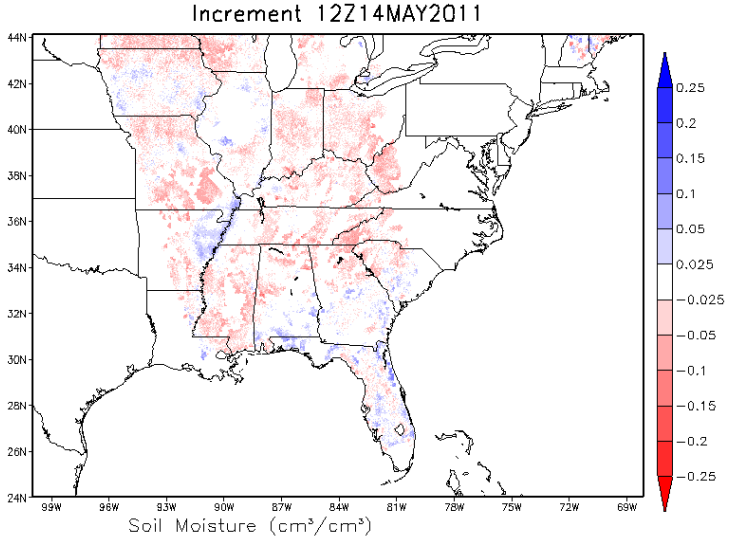
BACKGROUND



OBSERVATIONS

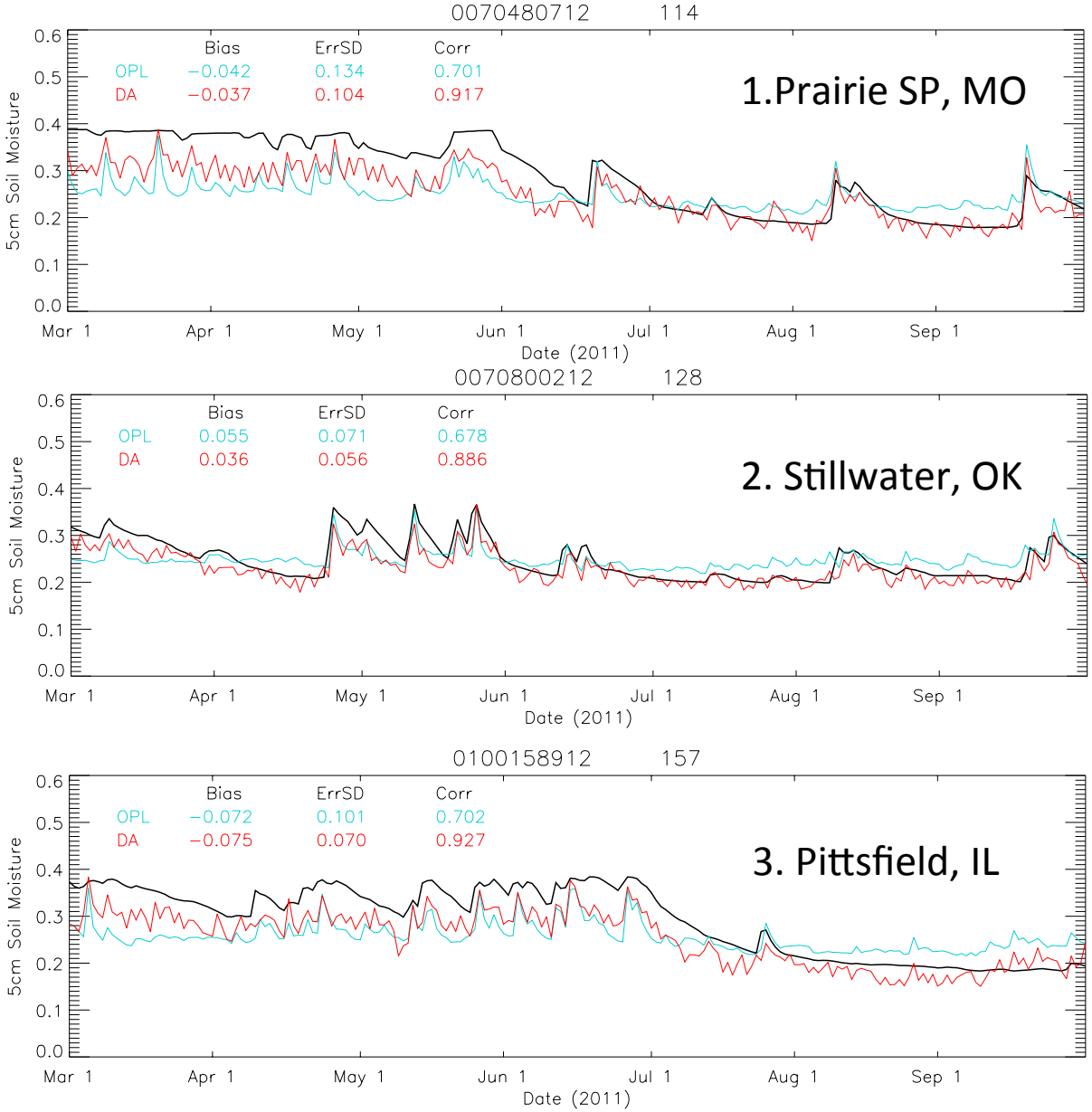


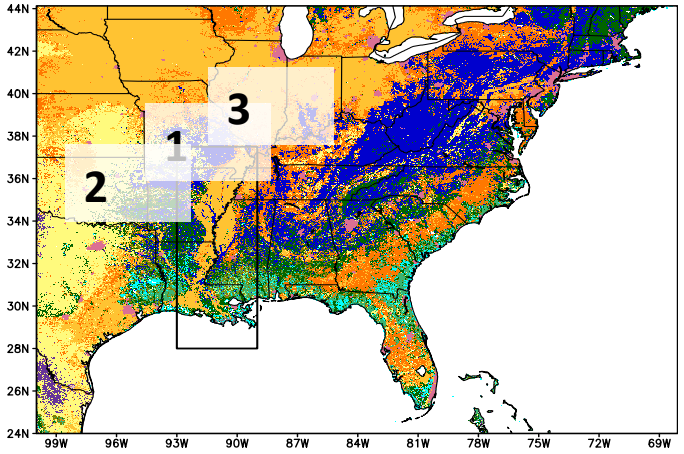
ANALYSIS



INCREMENT

SMOS DA Validation



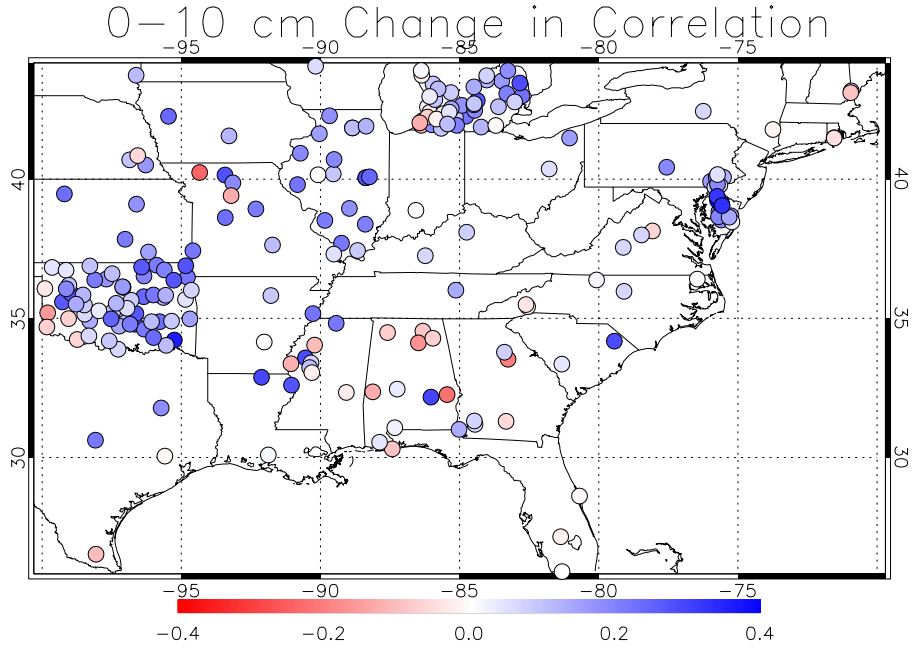


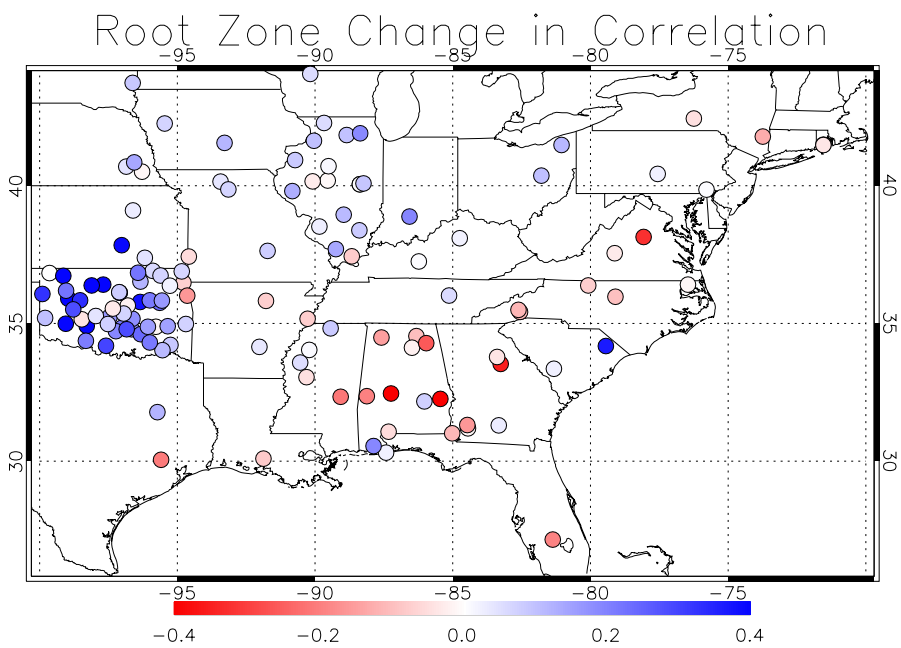
- 0-10 cm model soil moisture
- Compared open loop run to SMOS DA run.

Results from validation against soil moisture networks in US (North American Soil Moisture Database)

- Better correlations
- Improved dynamic range

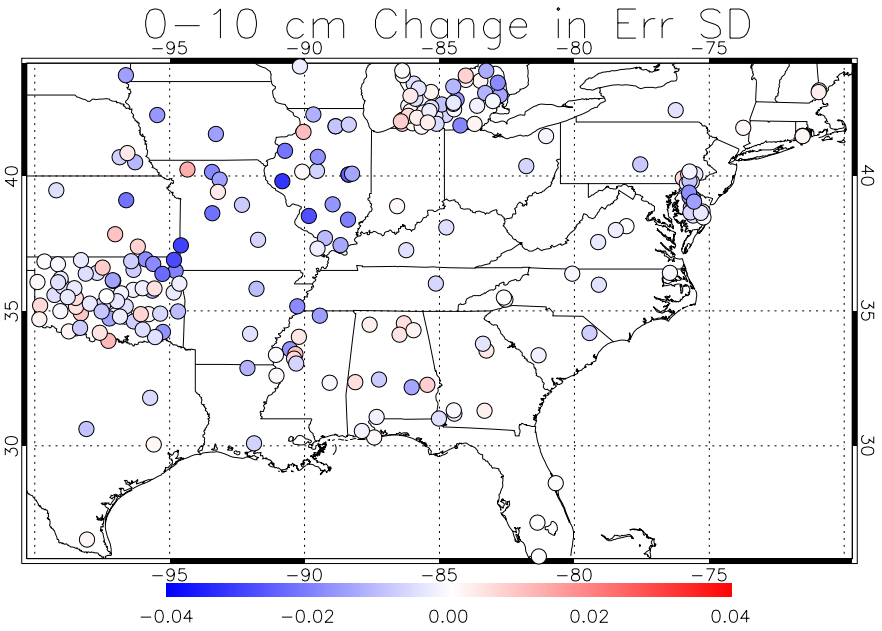
SMOS DA Validation

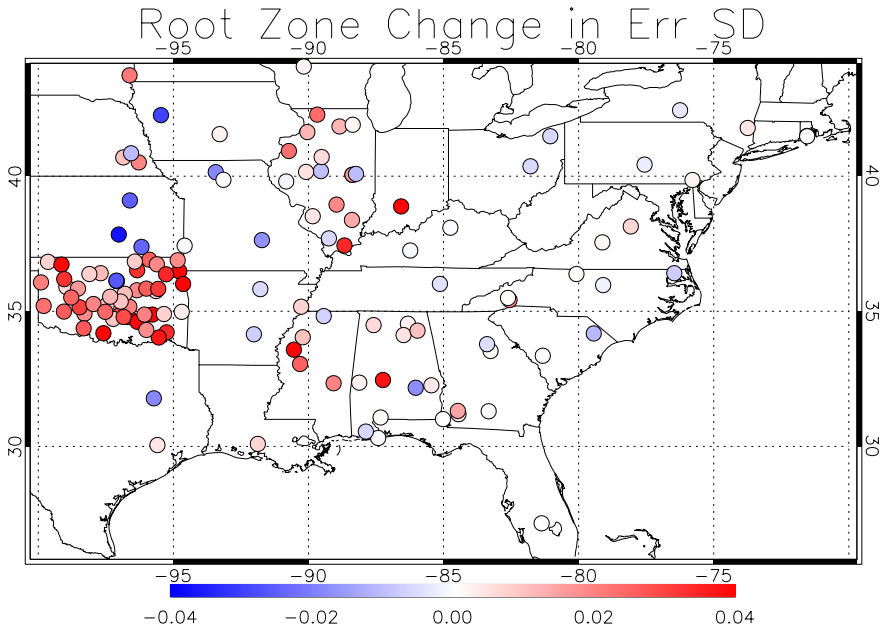




	Near Surface (0-10 cm)			**Root Zone (10-100 cm)**		
	Bias	Err SD	**Corr.**	Bias	Err SD	**Corr.**
Control	3.6%	23.5%	**0.47**	4.0%	10.6%	**0.61**
SMOS DA	-0.5%	21.8%	**0.57**	10.6%	11.8%	**0.67**

SMOS DA Validation





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Summary of Bias Correction Results

Variable	**0-10 cm Soil Moisture**				
# Stations	194				
Experiment	**OPL**	**NOBC**	**BC1**	**BCS**	**BCV**
Bias	**-0.000** ± 0.011	-0.026 ± 0.011	-0.023 ± 0.011	-0.005 ± 0.011	-0.025 ± 0.011
RMSE	**0.082** ± 0.005	0.087 ± 0.006	0.086 ± 0.005	**0.082** ± 0.005	0.087 ± 0.006
Unbiased RMSE	0.046 ± 0.003	**0.043** ± 0.002	**0.043** ± 0.002	0.044 ± 0.003	**0.043** ± 0.002
Correlation	0.451 ± 0.023	**0.573** ± 0.027	0.569 ± 0.026	0.539 ± 0.025	0.561 ± 0.026

Variable	**Root Zone Soil Moisture**				
# Stations	137				
Experiment	**OPL**	**NOBC**	**BC1**	**BCS**	**BCV**
Bias	0.038 ± 0.015	-0.013 ± 0.016	**-0.002** ± 0.016	0.014 ± 0.016	-0.009 ± 0.017
RMSE	0.093 ± 0.008	0.094 ± 0.008	**0.092** ± 0.008	**0.092** ± 0.008	0.094 ± 0.008
Unbiased RMSE	0.037 ± 0.003	0.040 ± 0.003	**0.036** ± 0.002	0.038 ± 0.003	0.038 ± 0.003
Correlation	0.672 ± 0.040	**0.685** ± 0.043	0.680 ± 0.043	0.667 ± 0.042	0.677 ± 0.045

Experimental error statistics with 95% confidence intervals for 0-10 cm layer soil moisture, verified against Texas A&M North American Soil Moisture Database in situ observations from 1 April to 1 October 2011. OPL: Open Loop; NOBC: Data Assimilation Only; BC1: single bias correction; BCS: soil-based bias correction; BCV: vegetation-based correction. The best statistics in each category are in bold font.

- All DA runs improved correlation signficantly in upper zone (0-10 cm).
- Soil type correction did best job of reducing bias **(as compared to stations)**
- Representativeness error could be reduced in future by comparing against COSMIC probes.

SMAP soil moisture assimilation

- Original plan: assimilate combined active/passive (L2) retrievals (9 km)
- SMAP radar failed July 2015
- New plan: assimilate passive (L2) retrievals (36 km)
- *Alternative: possible higher resolution products from SMAP science team?*

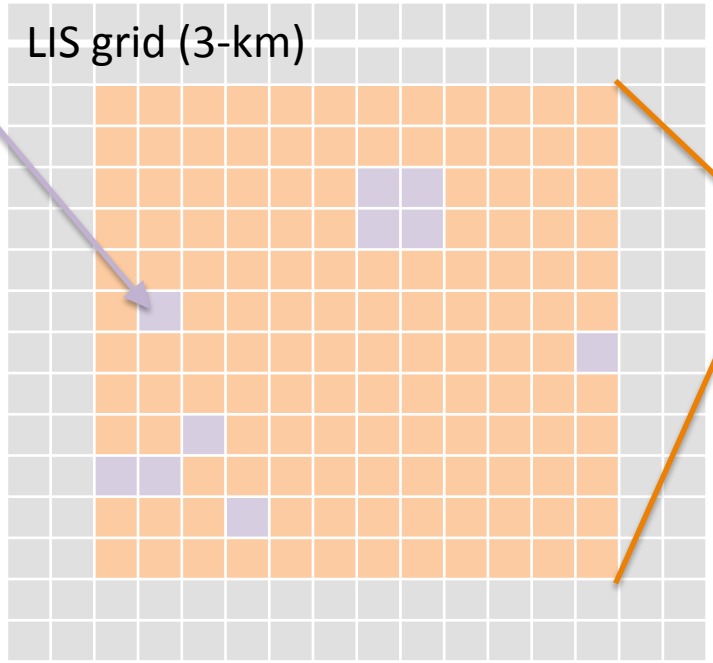
Name	SMAP		
Launch	Jan. 2015		
Orbit	Polar		
Sensor Type	Passive	Active (Failed July 2015)	Combined (limited duration)
Frequency	1.41 GHz	1.2 GHz	
Resolution	36 km	**3 km**	9 km
Accuracy	**4 cm^3/cm^3**	6 cm^3/cm^3	**4 cm^3/cm^3**

Sampling Strategy

- Level 2 data are available on 36-km EASE grid
- To take advantage of high resolution geophysical properties (topography, vegetation, soils), running model at 3-km
- SMAP observations are assimilated at each model grid point in their FOV

Some QC applied on LIS grid
Depends on LSM/variable (e.g. Noah3.3+soil moisture)

- Precip (changed to 1 mm/hr)
- Frozen ground
- Snow on ground
- GVF>0.7
- Extreme values (new in LIS 7)
- "Forest" land class



SMAP (passive)
36-km cell

Data flag-based QC applied at observation resolution

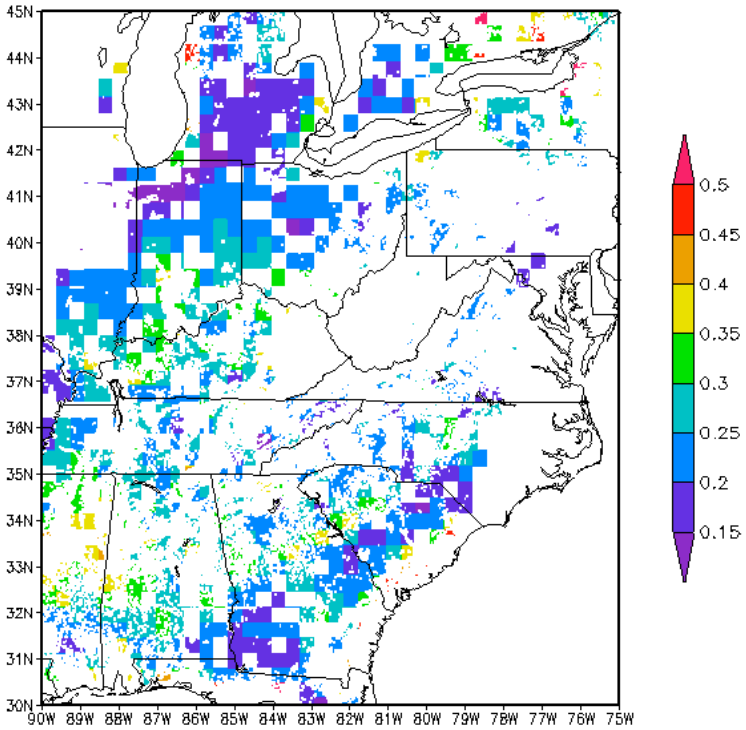
- **Retrieval Quality Flag**
- Vegetation Opacity
- Vegetation Water
- Frozen Ground Fraction

Bias correction will be applied on LIS grid.

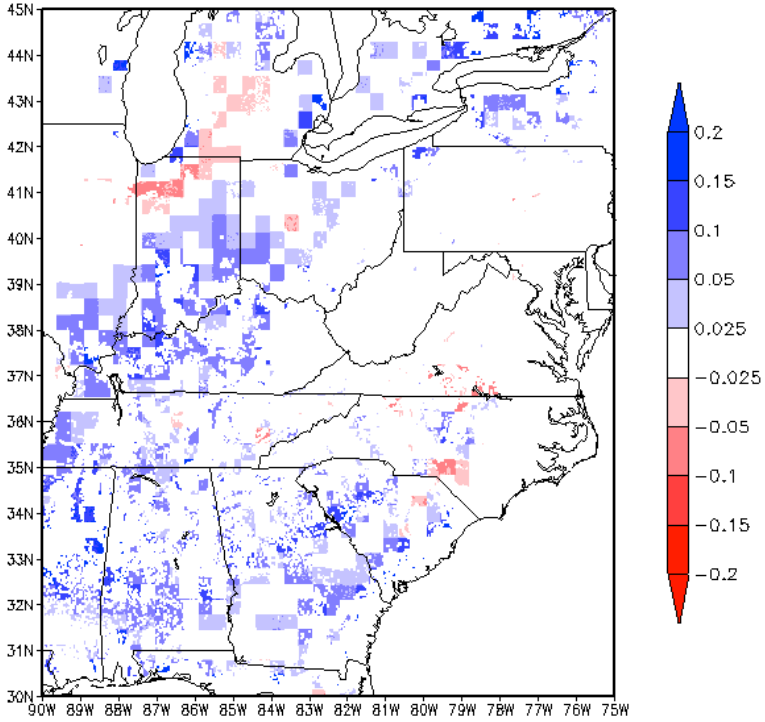
SMAP and LIS grids are not aligned. Near boundaries, keep only one observation per cell (closest good ob)

First assimilation results

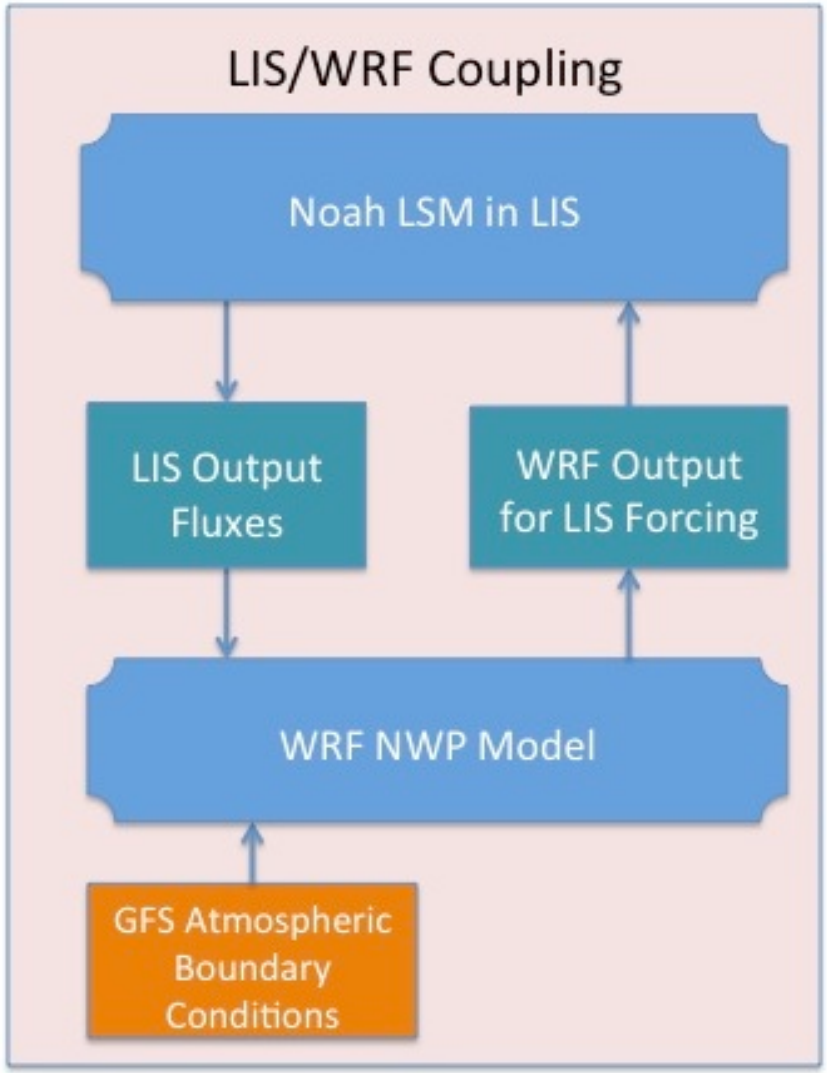
SMAP Soil Moisture Observation
18Z 1 May 2015



SMAP Soil Moisture Innovation (Ob-Bk)
18Z 1 May 2015



WRF impact tests (planned)



- Coupled LIS/WRF runs
  - NWP provides forcing for LSM
  - LSM provides fluxes and surface conditions to NWP model
- Assess impact of SMAP DA on NWP for coupled runs
  - Verify NWP forecasts against surface obs, soundings, and precipitation analyses
  - Examine impact on significant events

Validation Datasets		
Domain	**T, q, wind**	**Precipitation**
CONUS	MADIS	MRMS
East Africa	WMO network	GPM IMERG

Summary and Plans

Implemented SMOS data assimilation in Noah LSM within LIS

- Improved correlations with ground observations for upper layer (0-10 cm) and root zone (10-100 cm).

Currently testing SMAP assimilation (passive 36 km L2 product)

Future Plans

- Validation against NASMD including COSMIC probes (reduced representativeness error) using LIS Validation Toolkit
- Implement SMOS/SMAP DA in near-real-time SPoRT LIS product
- Validation of bias correction methodology
- Coupled LIS-WRF experiments using NU-WRF
  - NWP validation over US and East Africa
  - Expect more dramatic improvement over Africa where observing networks are less extensive.
- Implement DA in near-real-time SPoRT LIS runs
  - Transition products to NWS and international partners

Questions and Comments?

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