Toward Improved Real-Time Modeled Soil Moisture Estimates by Assimilating SMOS and SMAP Retrievals

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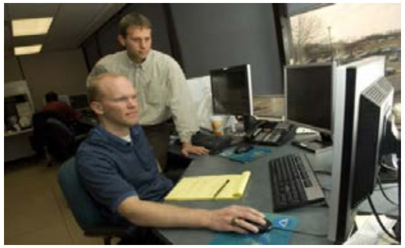
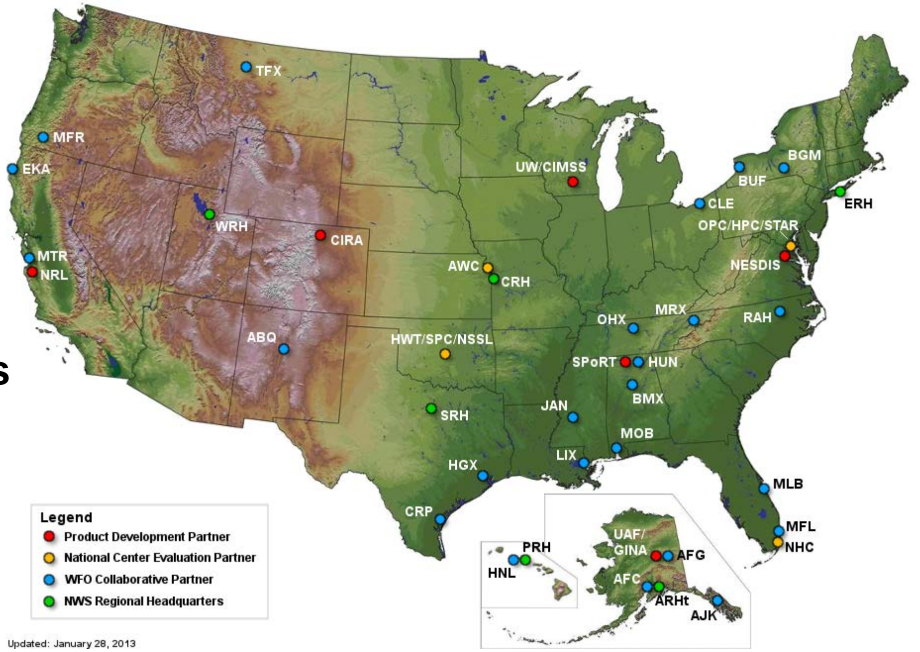


Short-term Prediction Research and Transition (SPoRT) Center

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**
- **Co-funded by NOAA since 2009 through Proving Ground activities**
- **Proven paradigm for transition of research and experimental data to operations**
- **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**



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 of soil moisture

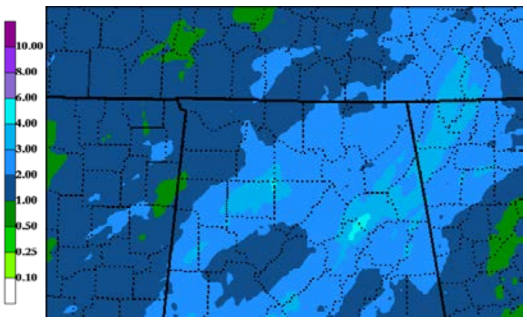
Predicted impact

- Improved representation of fine-scale soil moisture fields
- Better depiction of gradients and structure for coupling with NWP models at convection-allowing resolution (~1-4 km) for regional weather forecasting
- Transition a real-time version of LIS output to end users.

Applications

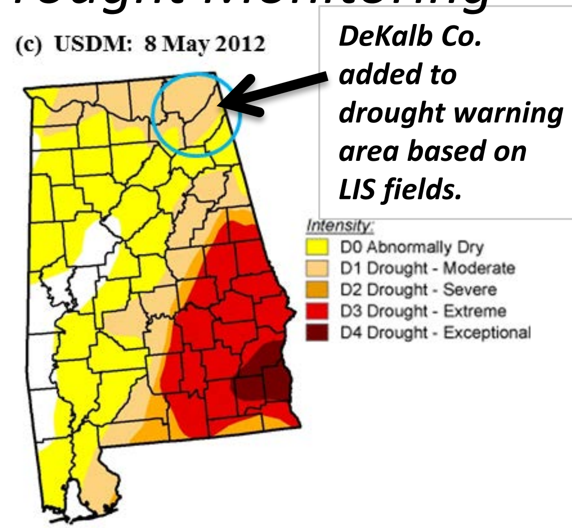
Specific applications of the SPoRT-LIS product:

Flood Potential



Public Health

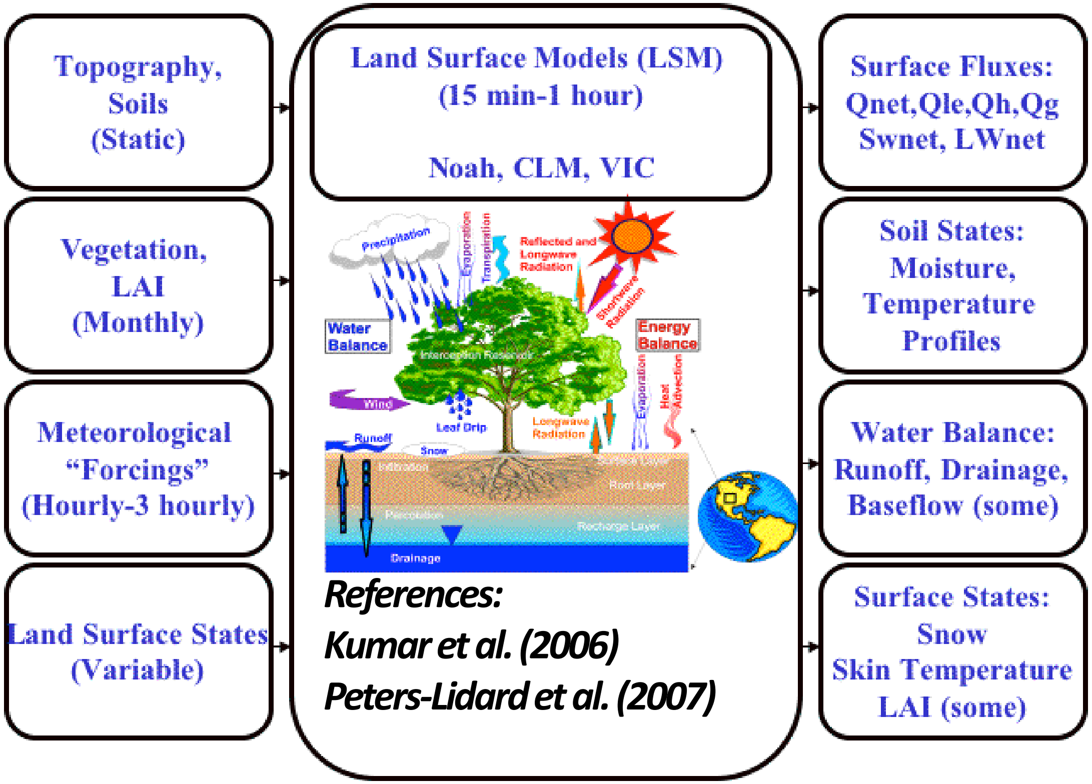
Drought Monitoring

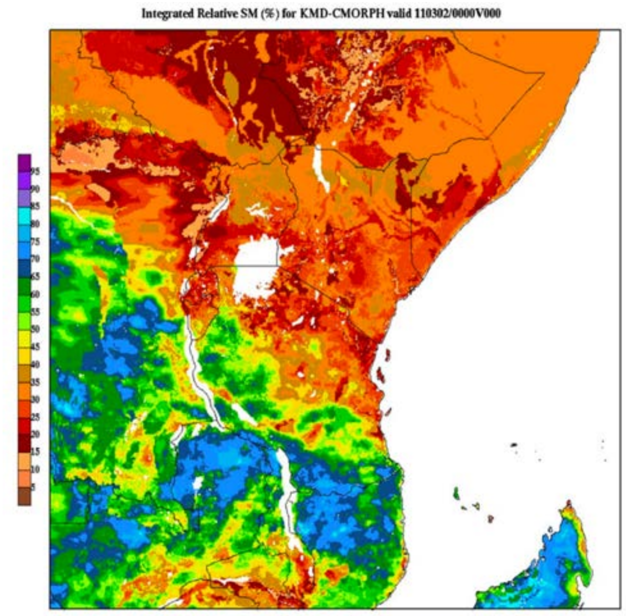


NWP

Coupled LSM/NWP supplies more accurate surface fluxes and boundary conditions to the NWP, improving prediction of humidity, sensible/latent heating, diurnal heating rate, and convection

Land Information System (LIS)





East Africa LIS domain

- Framework for running LSMs incorporating a wide variety of meteorological forcing data, land surface parameters, and includes data assimilation capability
  - Developed by NASA-GSFC
  - Can be run coupled with Advanced Research WRF model
- Using Noah 3.3 Land Surface Model (LSM) within LIS
- SPoRT maintains near-real-time and experimental LIS runs
  - CONUS and SE US (3-km), shared with NOAA/NWS WFOs
  - East Africa, shared with Kenya Meteorological Department (KMD)
  - New 1-km Caribbean run to support NWP for Public Health outlooks (Dengue/Zika virus)

SPoRT-LIS

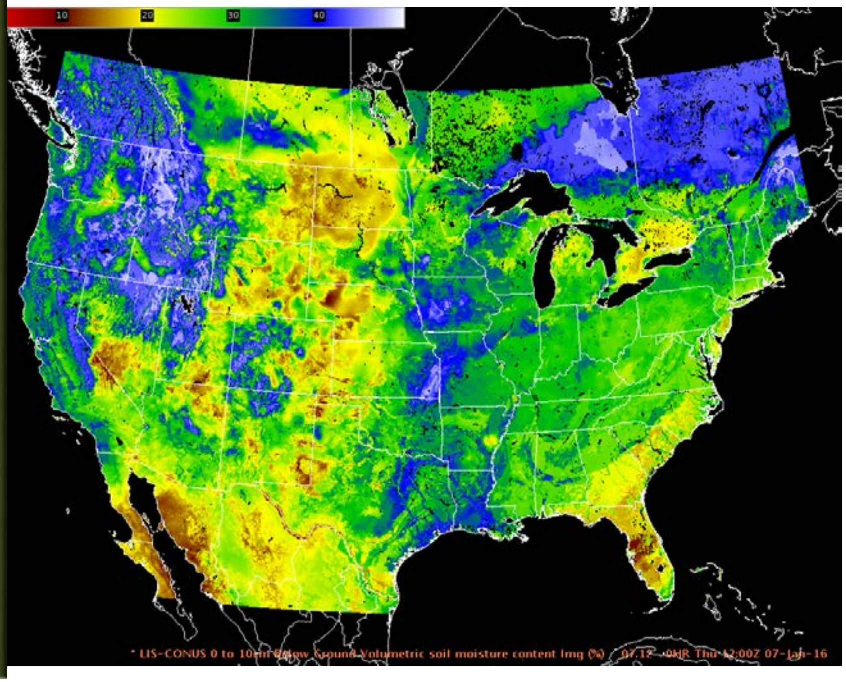
LIS products available in near real-time from SPoRT

- Available at http://weather.msfc.nasa.gov/sport/modeling/
- Used by partner Weather Forecast Offices (WFOs) for situational awareness for flooding and for drought monitoring

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
- 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)
    - Larger footprint (~36 km)

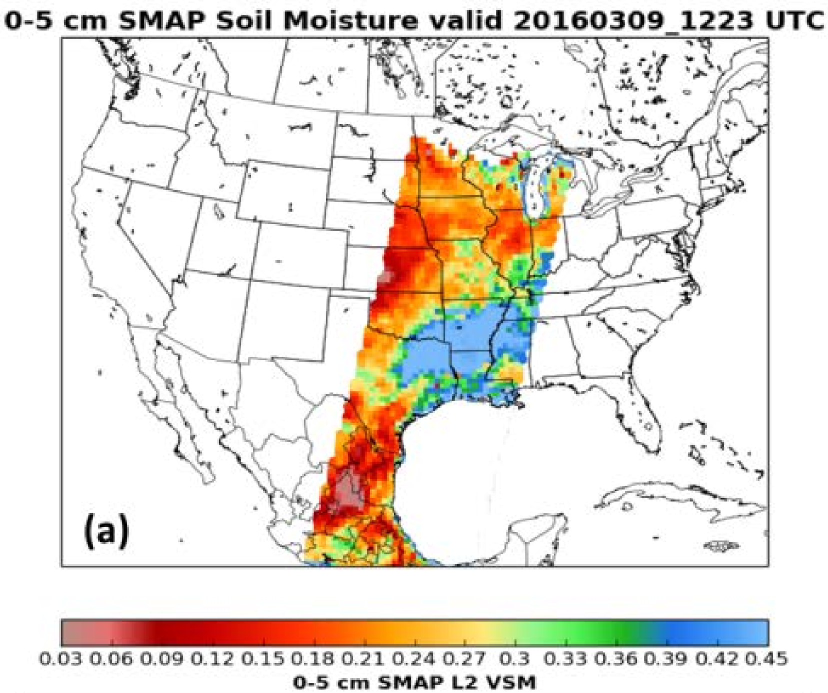
Soil Moisture and Ocean Salinity

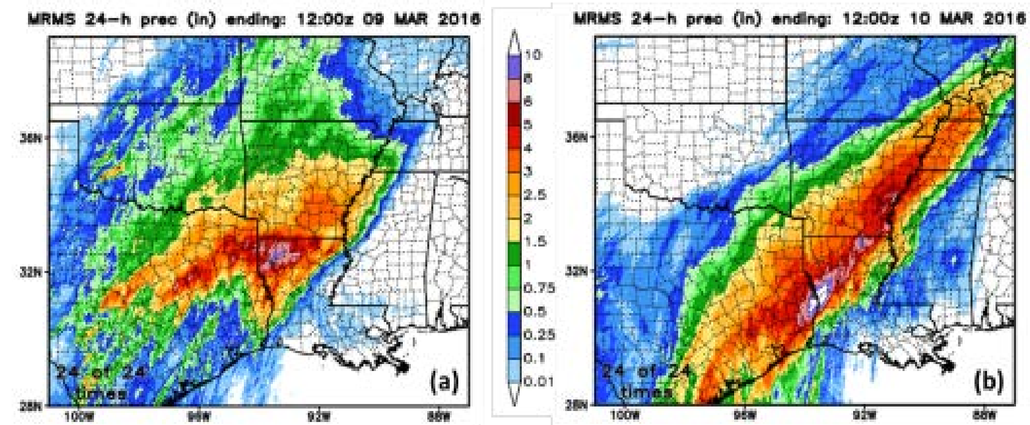
Soil Moisture Active/Passive

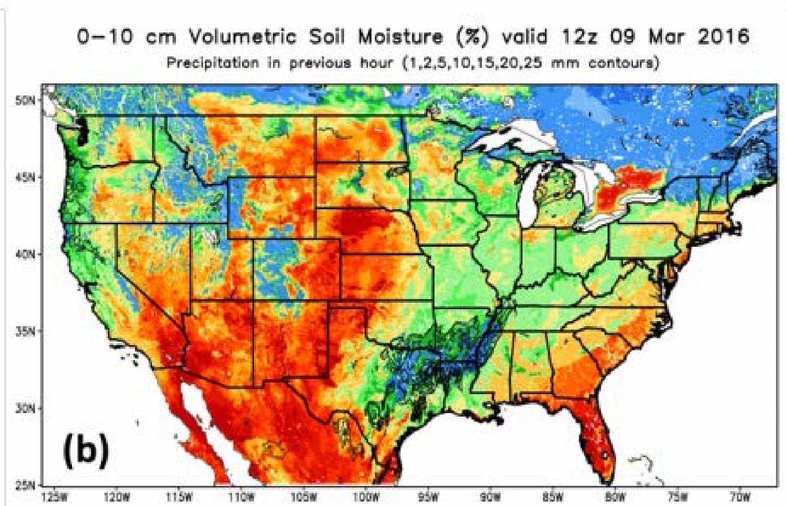
Name	AMSR-E	SMOS	SMAP		
Agency	NASA/JAXA	ESA	NASA		
Launch	2002	2009	Jan. 2015		
Orbit	Polar	Polar	Polar		
Sensor Type	Passive	Passive	Passive	Active (Failed July 2015)	Combined (limited duration)
Frequency	6.9 GHz (C-band)	1.4 GHz (L-band)	1.41 GHz	1.2 GHz	
Resolution	56 km	35-50 km	36 km	**3 km**	9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

- Tested retrievals from Soil Moisture and Ocean Salinity (SMOS) satellite
  - TGRS paper in review
- Implementing 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.

SMAP / SPoRT-LIS: early March Flood



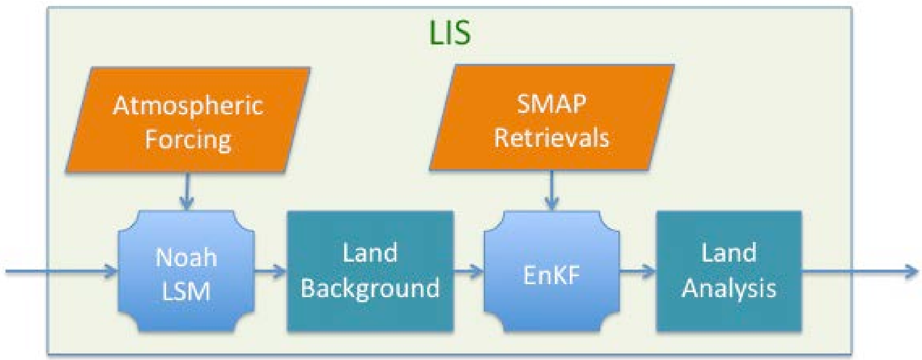




- 9-10 March 2016 flooding rains in NE TX/north LA/AR
  - MRMS 24-h rainfall ending 12z 9 March (above-left)
  - MRMS 24-h rainfall ending 12z 10 March (above-right)

- SMAP L2 swath from 1223 UTC 9 March (upper-left) compared to SPoRT-LIS 0-10 cm volumetric soil moisture at 12z (lower-left)

Data Assimilation in LIS



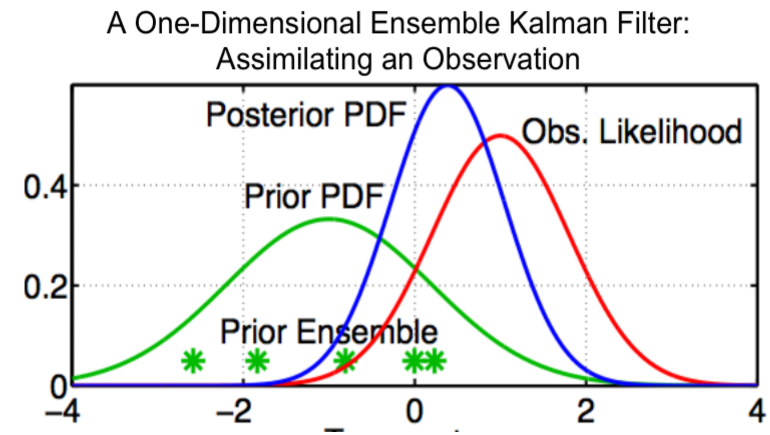


Figure from J. Anderson, NCAR.

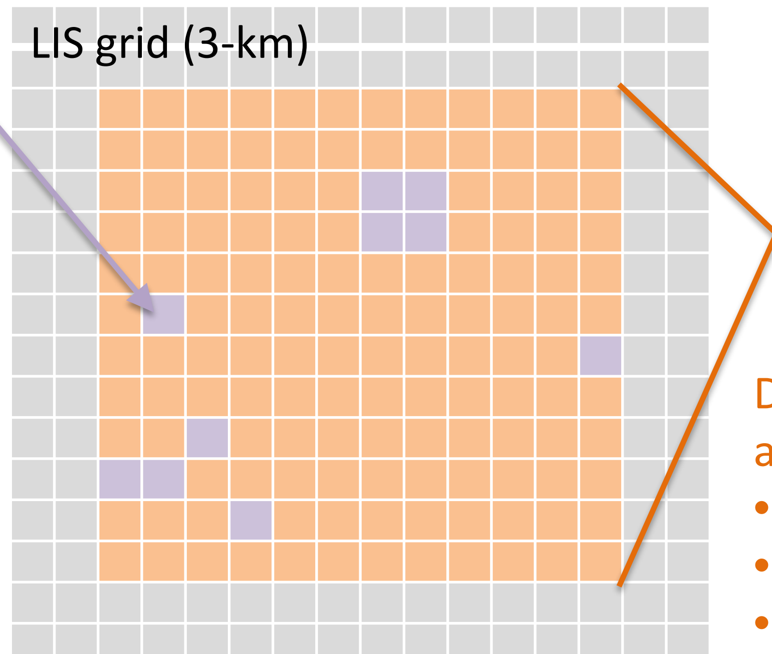
- Uses Ensemble Kalman Filter in LIS
- Combines Background (Model) and Observations (Satellite Retrievals), weighted by their uncertainties, to provided a new analysis
- Observation operator relates the top model layer of soil moisture (0-10 cm) to the bias-corrected observations (~5 cm).
- Better depiction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

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

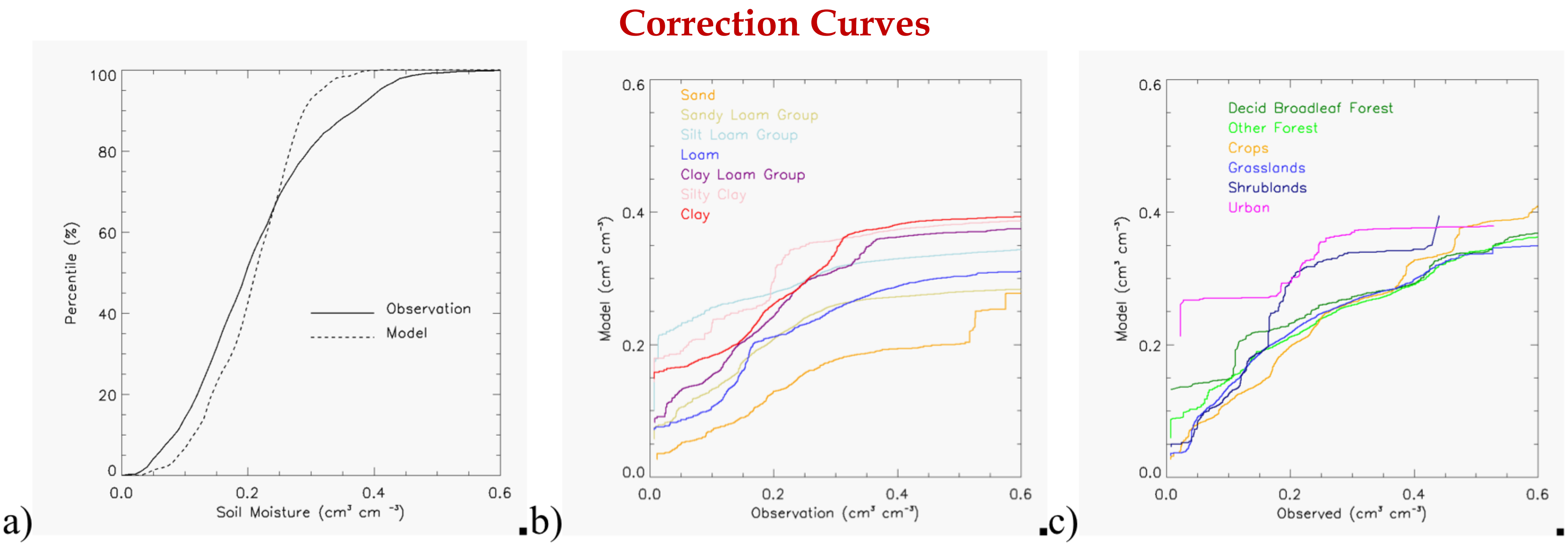
Data flag-based QC applied at observation resolution

- **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)

Bias Correction

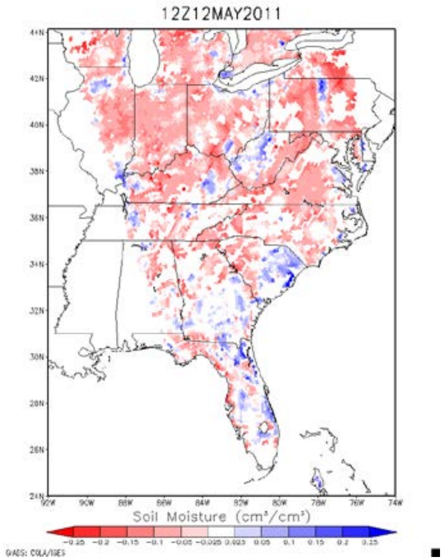


- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- We tested three variations of CDF matching, aggregating spatially to increase sample size.
  - Single uniform correction
  - Soil-type based
  - Vegetation-based

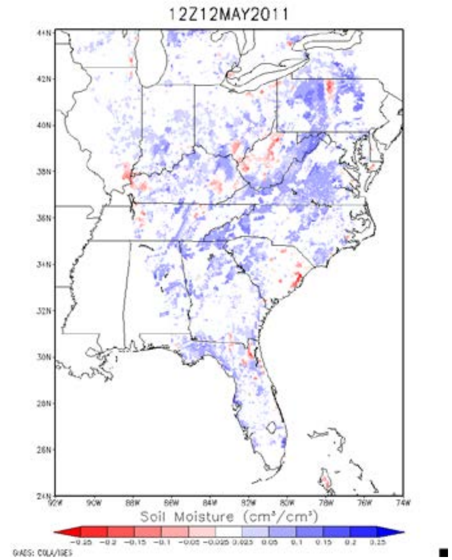
Bias Correction

- 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)

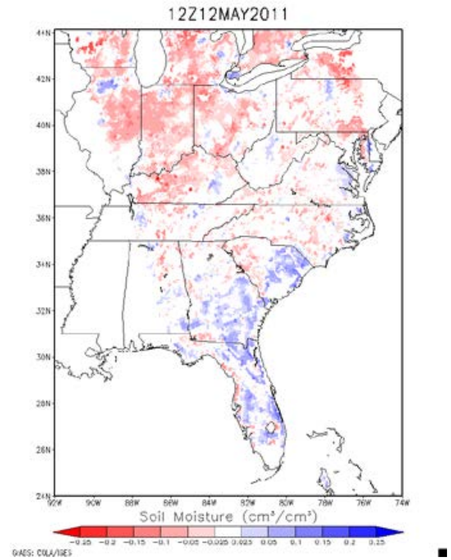
Innovations (Obs-Bkgd) (Uncorrected)



Bias Correction



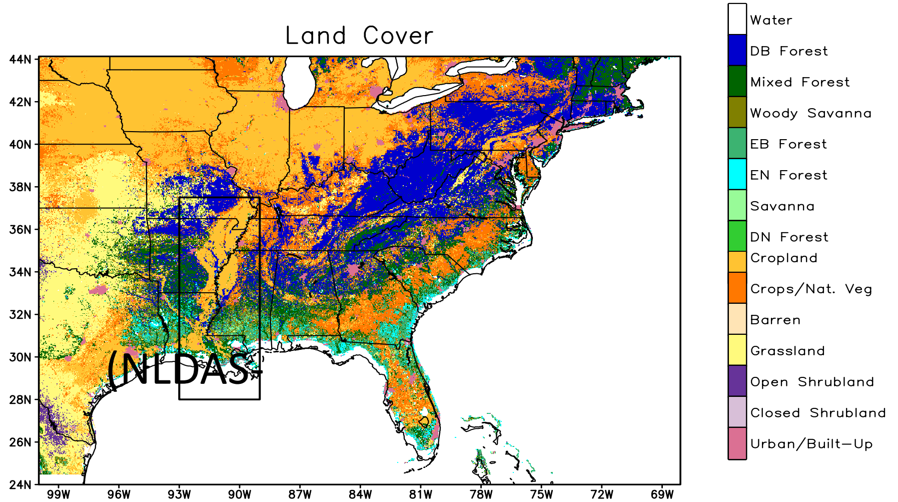
Innovations (Corrected)



SMOS Experiment

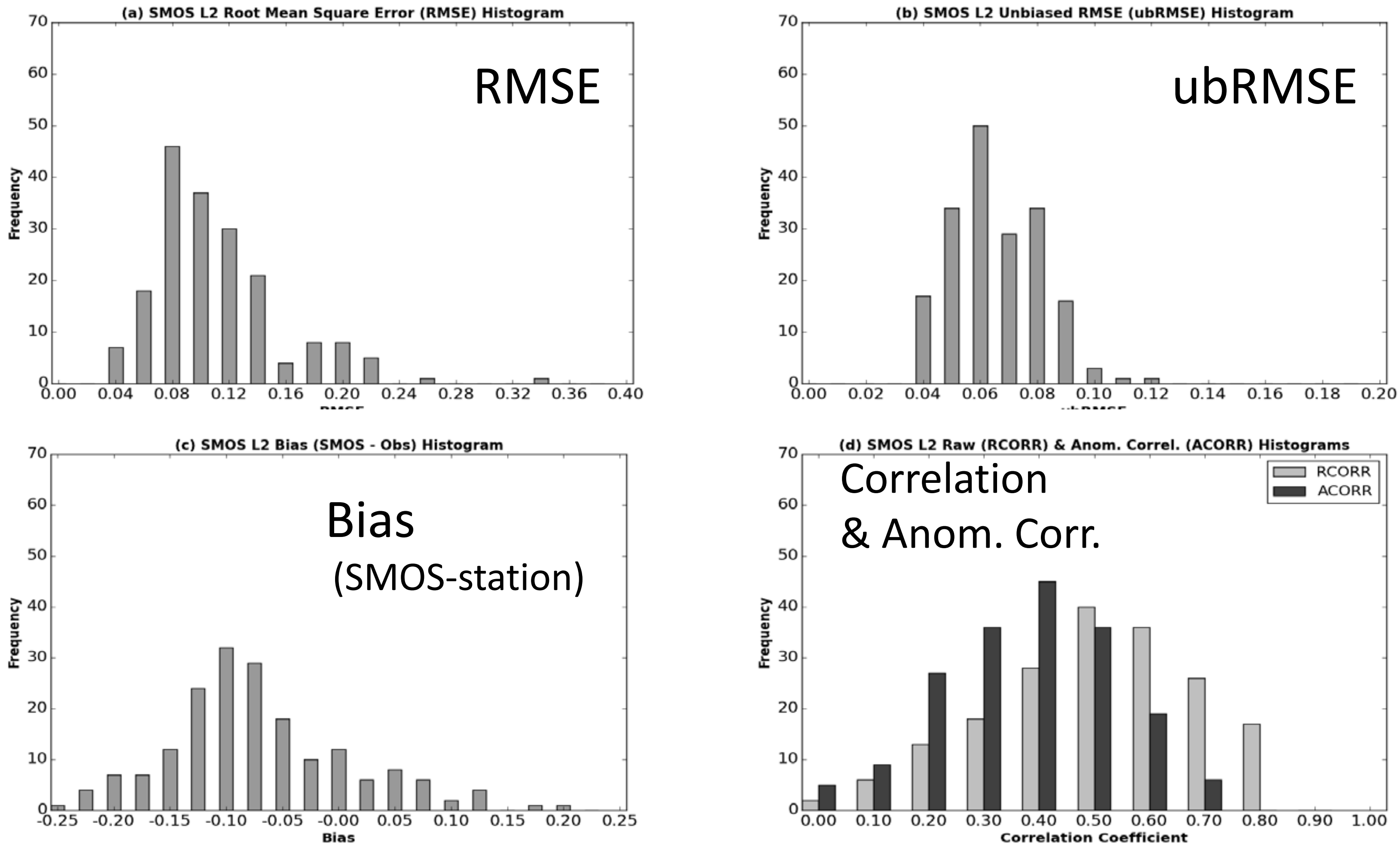
- Precursor to SMAP
- Southeastern/Central USA 3-km domain

- 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 April-September 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 and ubRMSE to be most useful metric

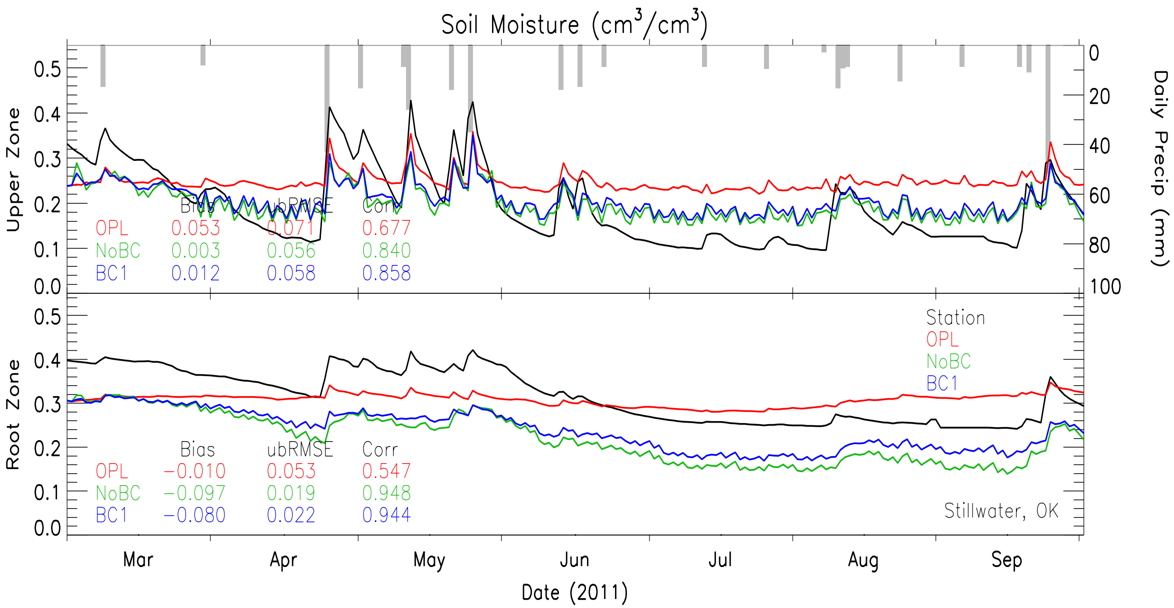
SMOS vs. Station Comparisons



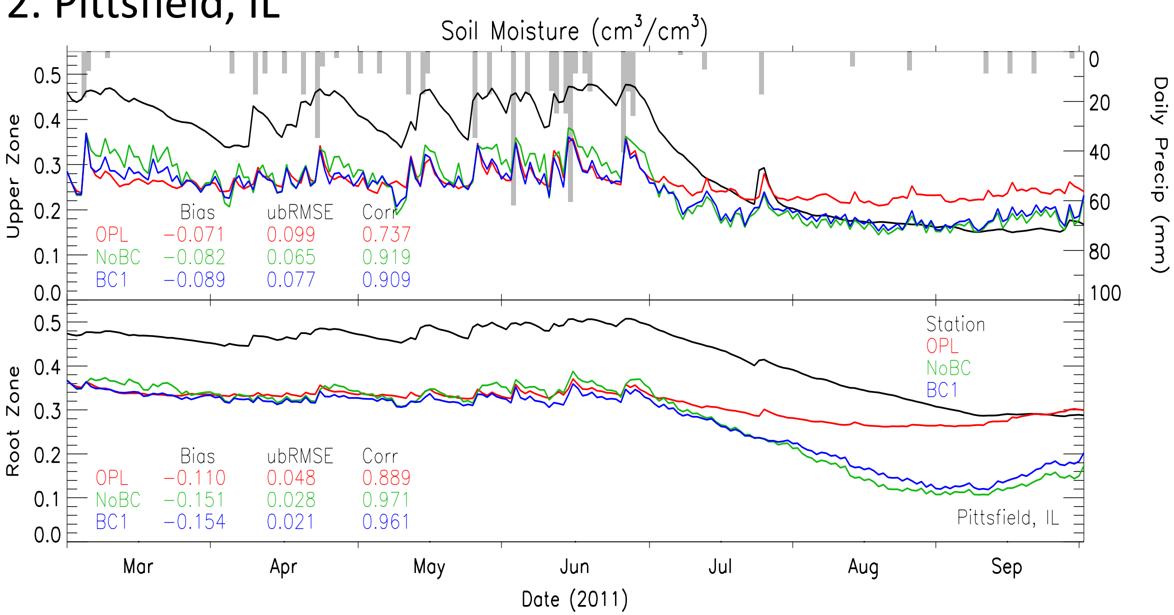
- SMOS comparison performance varies widely with stations
- Due to a combination of factors (station errors, retrieval errors, systematic differences
- “Best case” results (~4% RMSE, ~.7 r) perhaps indicative of satellite/retrieval limitations

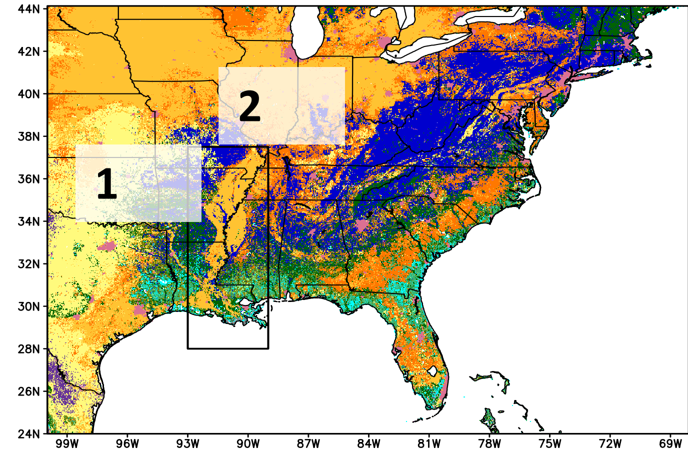
SMOS DA Validation

1. Stillwater, OK



2. Pittsfield, IL





- 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

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

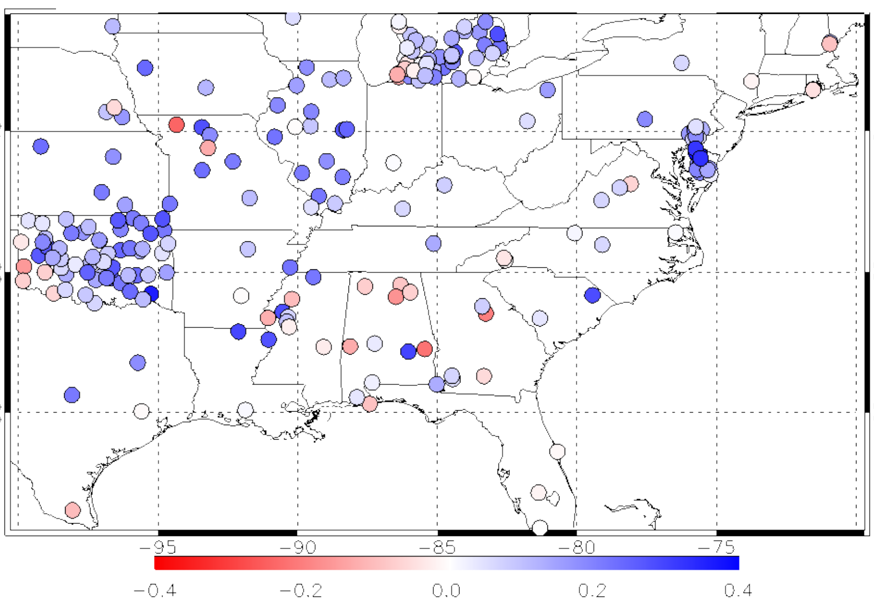
Experimental error statistics with 95% confidence intervals for 0-10 cm layer soil moisture, verified against Texas A&M North American Soil Moisture Database in situ observations from 1 April to 1 October 2011. OPL: Open Loop; NOBC: Data Assimilation Only; BC1: single bias correction; BCS: soil-based 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).
- ubRMSE slightly improved (not at 95% confidence level)
- Remember satellite-station biases can be very large.
- Soil type correction did best job of reducing bias **(as compared to stations)**

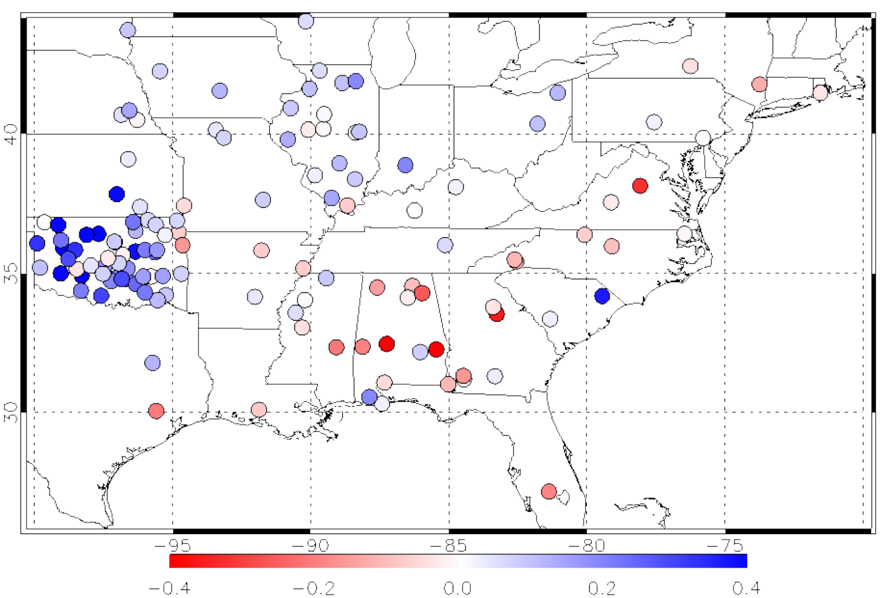
SMOS DA Validation

Correlation

0-10 cm



Root Zone

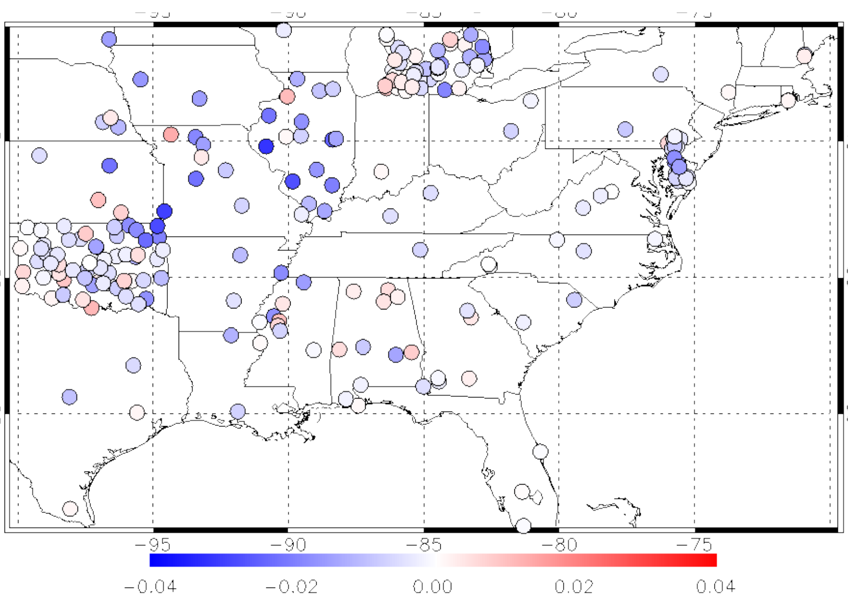


	Near Surface (0-10 cm)			Root Zone (10-100 cm)		
	Bias	ubRMSE	Corr.	Bias	ubRMSE	Corr.
Open Loop	0.00	0.046	0.45	0.038	0.037	0.67
SMOS DA	0.00- -0.02	0.043- 0.044	**0.54- 0.57**	-0.002- 0.014	0.036- 0.040	0.66- 0.68

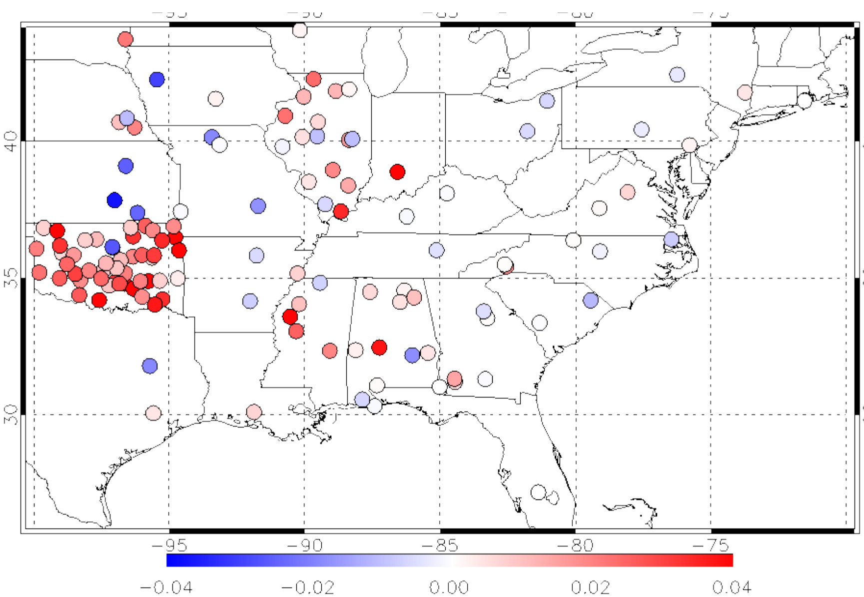
SMOS DA Validation

Unbiased RMSE

0-10 cm



Root Zone



	Near Surface (0-10 cm)			Root Zone (10-100 cm)		
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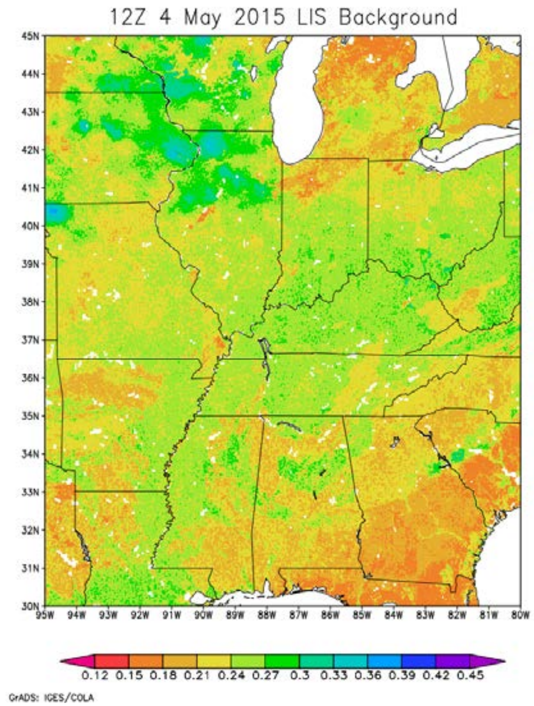
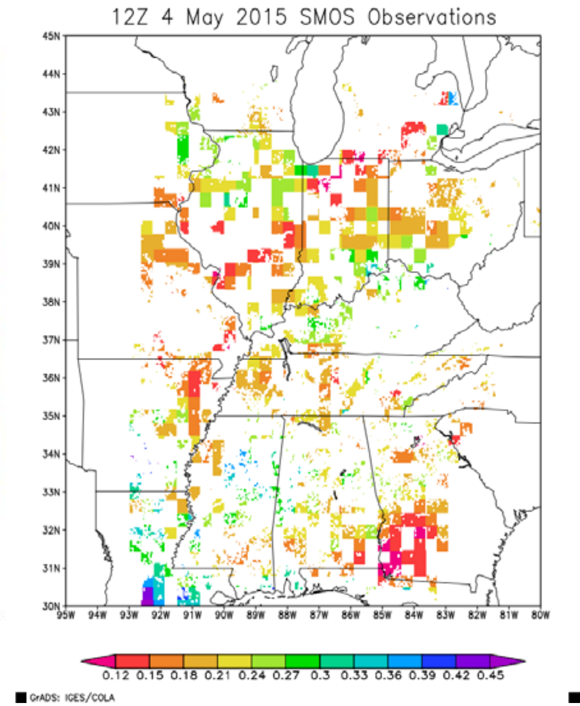
SMOS DA	0.00- -0.02	0.043- 0.044	**0.54- 0.57**	-0.002- 0.014	0.036- 0.040	0.66- 0.68

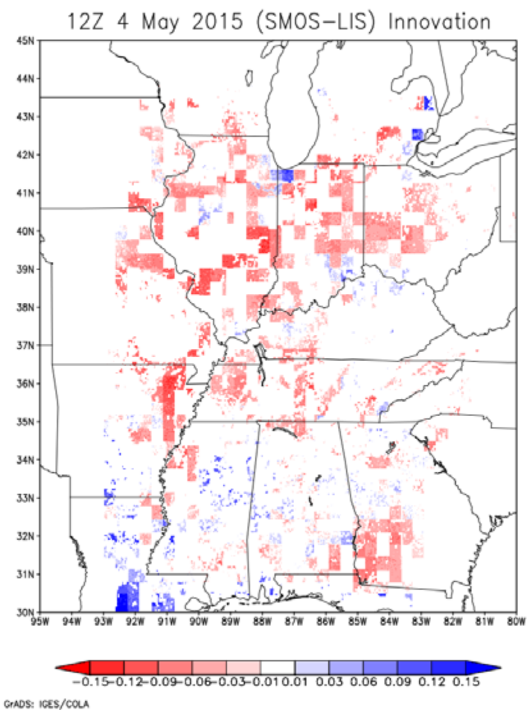
SMAP assimilation results

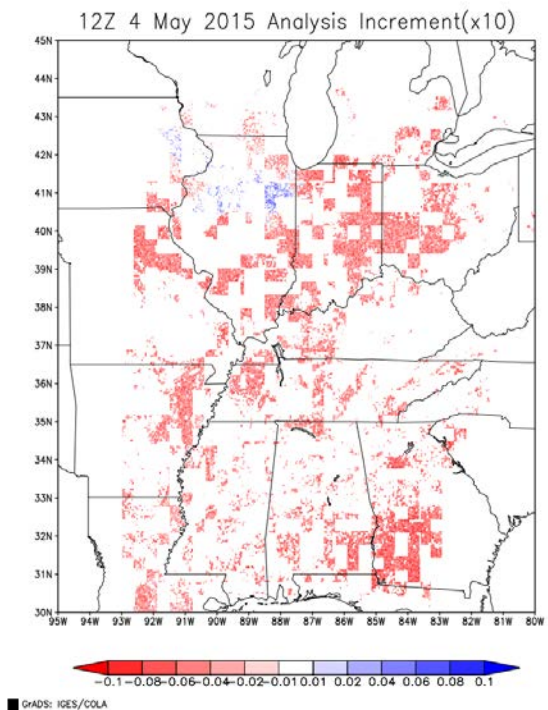
12Z May 4, 2015

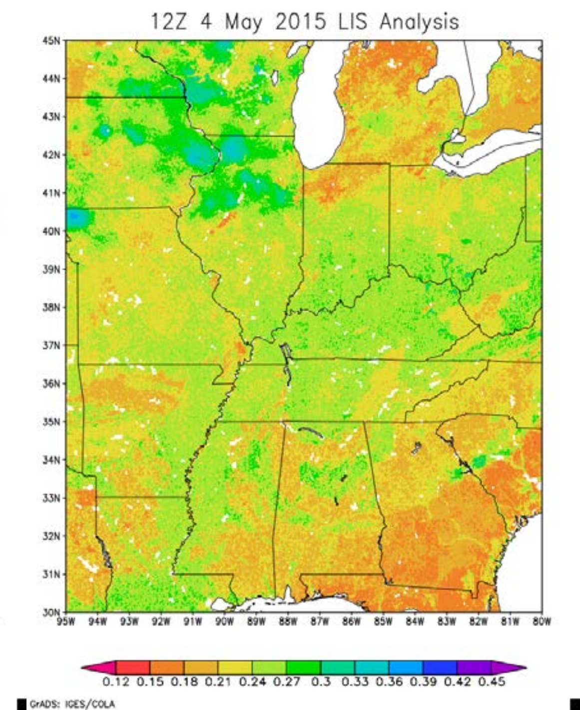
- *Preliminary, no Bias Correction*
- *Increments too small....*



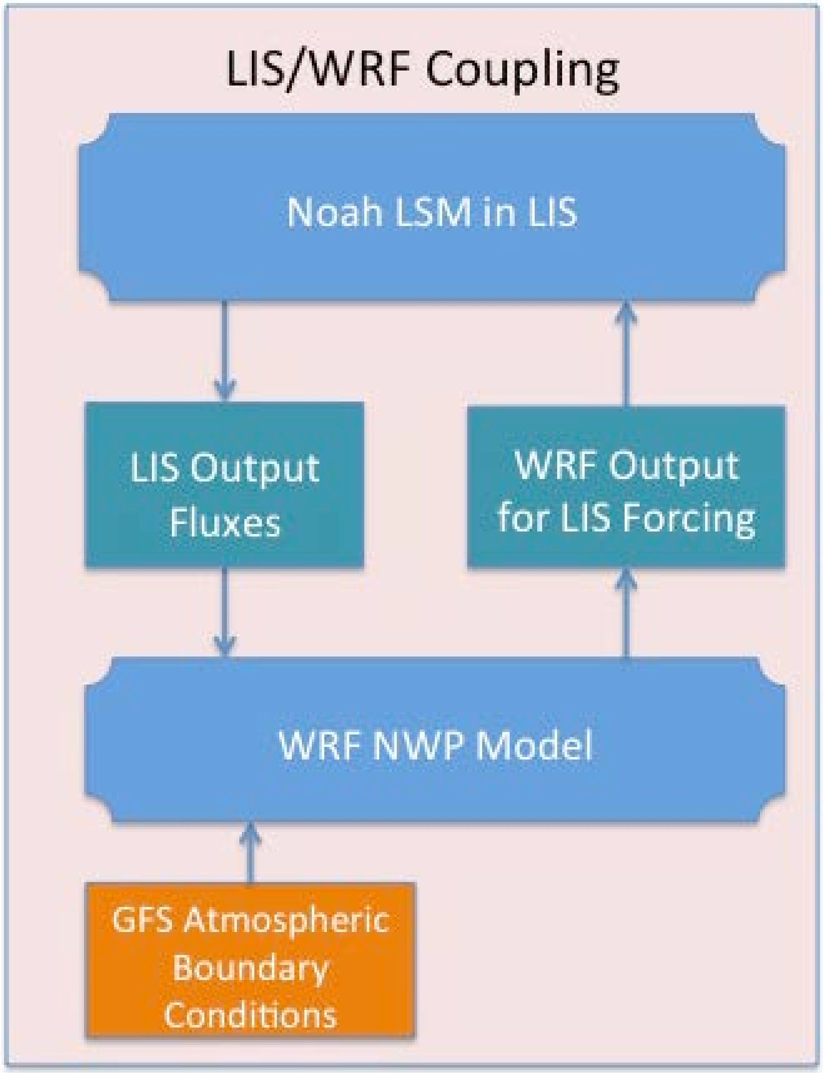








Future Science Plans



- 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
  - Previous studies show influence of surface fluxes on moisture, sensible heating, convection...
  - 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

Tested SMOS data assimilation in Noah LSM within LIS

- Significantly improved correlations with ground observations for upper layer (0-10 cm) and root zone (10-100 cm).
- Currently implementing SMAP assimilation (passive 36 km L2 product) in LIS 7.1
  - Initial tests show expected innovations but increments are small

Future Plans

- Finish implementing and testing SMAP assimilation (inc. bias correction)
- Implement SMOS and SMAP DA in near-real-time SPoRT-LIS runs
  - Transition products to NWS and international partners
- Further validation against NASMD including COSMIC probes (reduced representativeness error) using LIS Validation Toolkit
- 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.

Questions and Comments?

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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?*
- Implementing in LIS 7.1

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**