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

*Results from SMOS, Plans from SMAP*



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# Project Overview

**Goal:** Assimilate high-quality satellite retrievals of soil moisture into SPoRT LIS

- 3-km SPoRT LIS running Noah 3.3 LSM
- SMOS and SMAP soil moisture retrievals
- Combine high-resolution geophysical properties and forcing data with satellite estimates of soil moisture

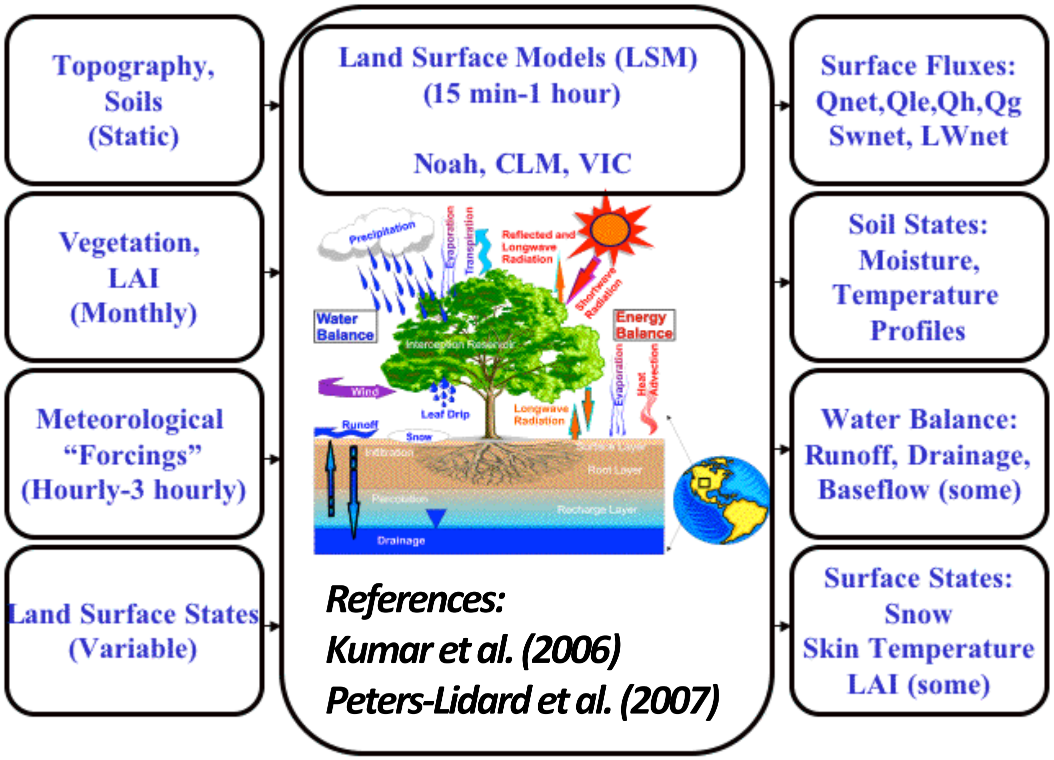
**Predicted impact**

- Improved representation of soil moisture fields
- Better depiction of structure for coupling with NWP models at convection-allowing resolution (3 km) for regional weather forecasting

**Milestones**

- SMOS assimilation
- SMAP assimilation
- Implement in near-real-time product

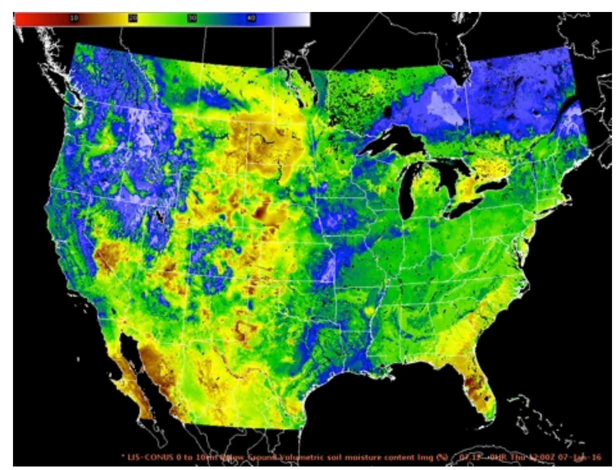
# Land Information System (LIS)




- 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.
- SPoRT maintains near-real-time and experimental LIS runs
  - CONUS (3-km), shared with WFO's
  - East Africa, shared with Kenya Meteorological Service (KMS)

For details about the near-real-time SPoRT LIS product:

- 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)



NASA SPORT

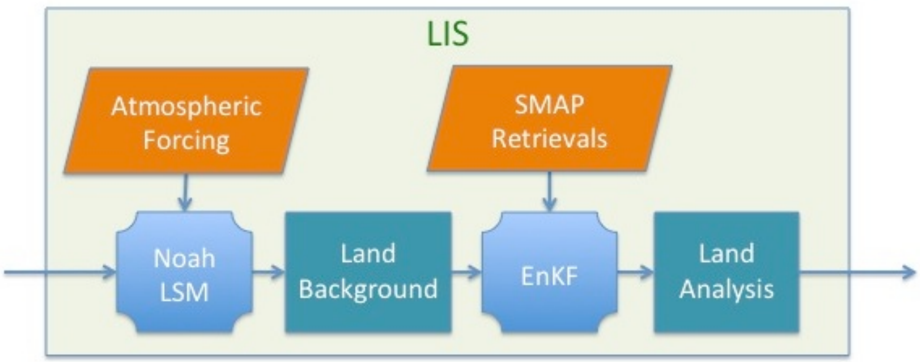
# SMOS and SMAP

- 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
- Assimilated retrievals from **Soil Moisture and Ocean Salinity** (SMOS) satellite
- 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.



| 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



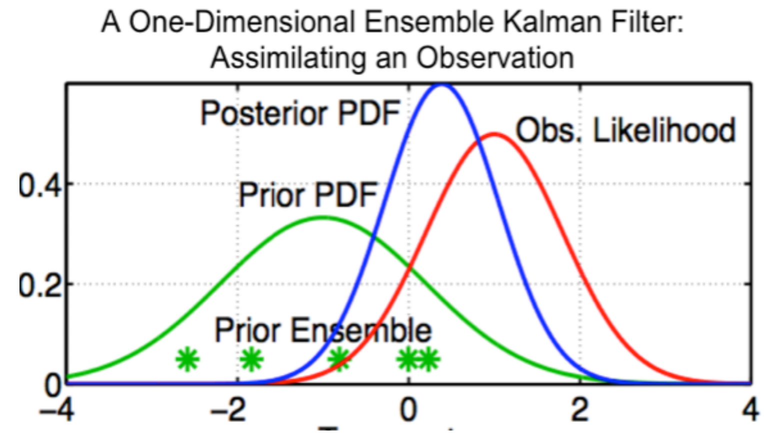




Figure from J. Anderson, NCAR.

- Implemented SMOS assimilation in LIS
- Ensemble Kalman Filter 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.

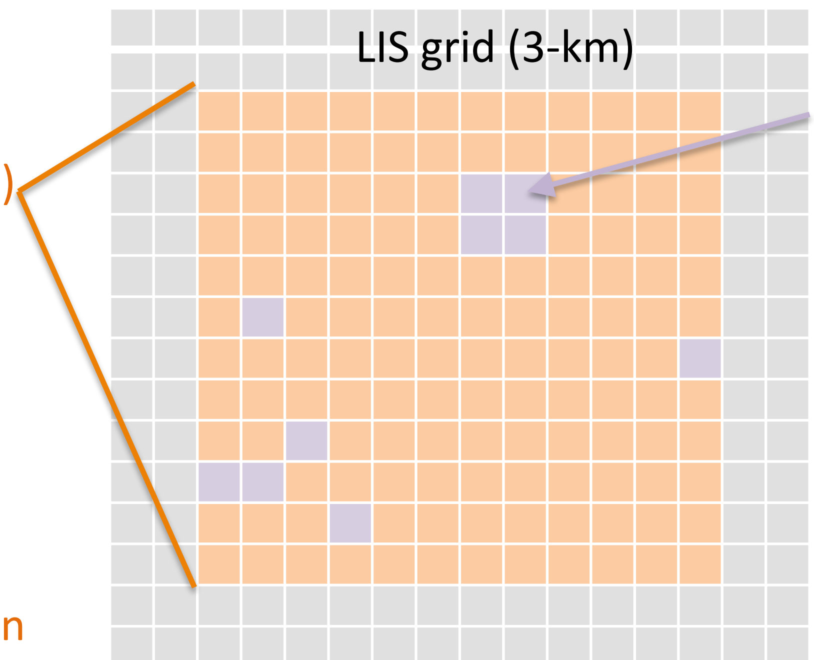
# Sampling Strategy

- LIS grid is 3-km to take advantage of high resolution geophysical properties (topography, vegetation, soils)
- SMOS/SMAP radiometer resolution is ~30-50 km
- Satellite soil moisture retrievals are assimilated **at each model grid point in their FOV**

Retrieval FOV
(36 km for SMAP)

**Data flag-based QC applied at observation resolution**

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



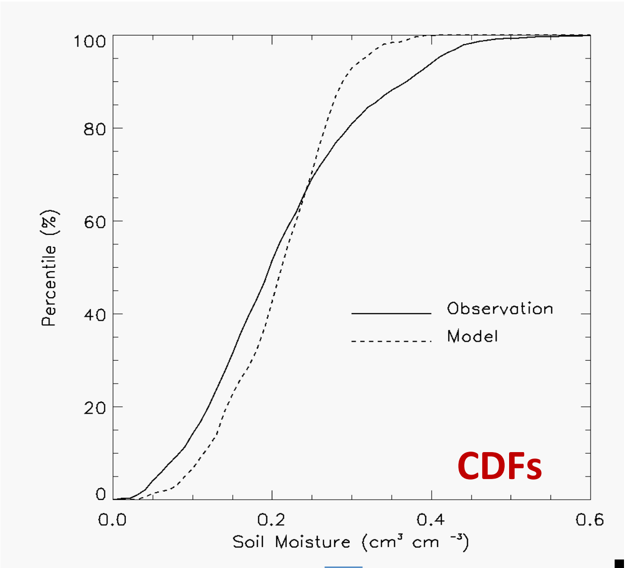

**Some QC applied on LIS grid**

*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

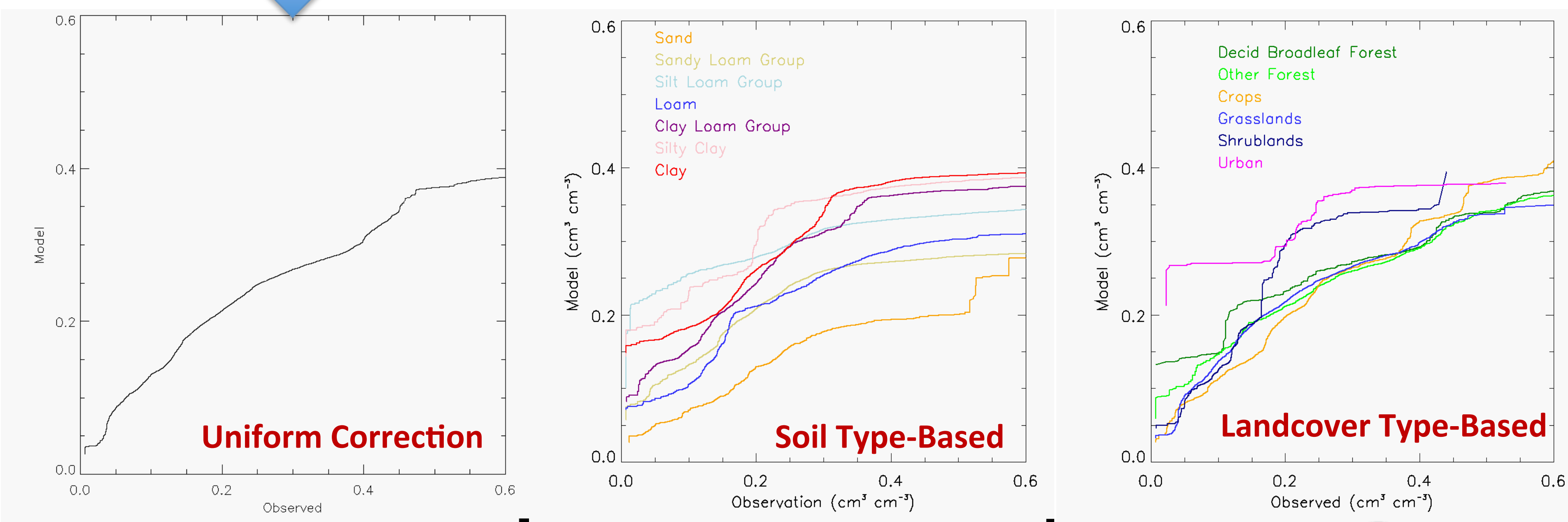
*SMAP and LIS grids are not aligned. Near boundaries, keep only one observation per cell (closest good ob)*

*Bias correction will be applied on LIS grid.*



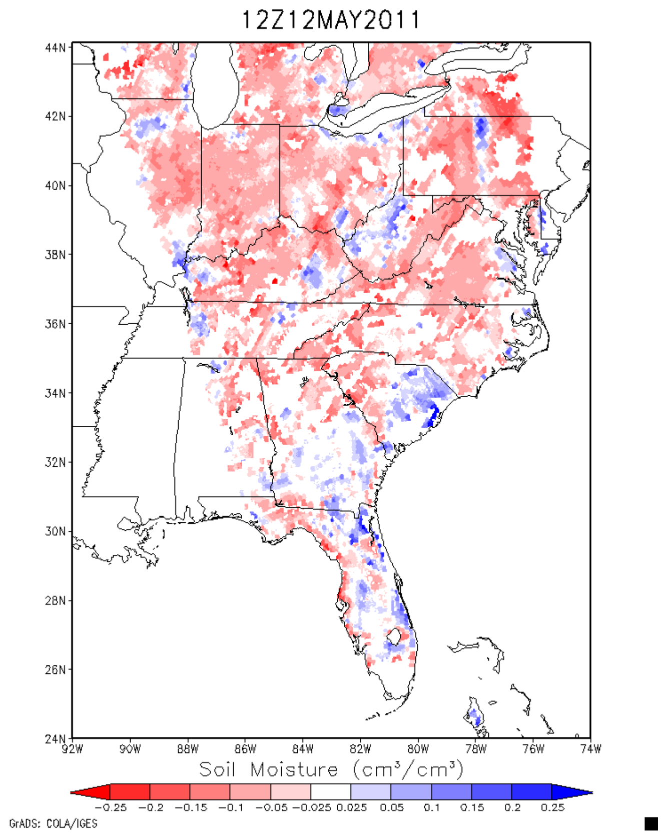

# Bias Correction

- Data assimilation systems generally assume unbiased observations.
- In general, SMOS observations (retrievals) are drier than the model and have a higher dynamic range.
- CDF-matching is commonly used in land surface modeling (forcing observations to match model distribution)
- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and observations at each grid point.
- We tested three variations of CDF matching, aggregating spatially to increase sample size.

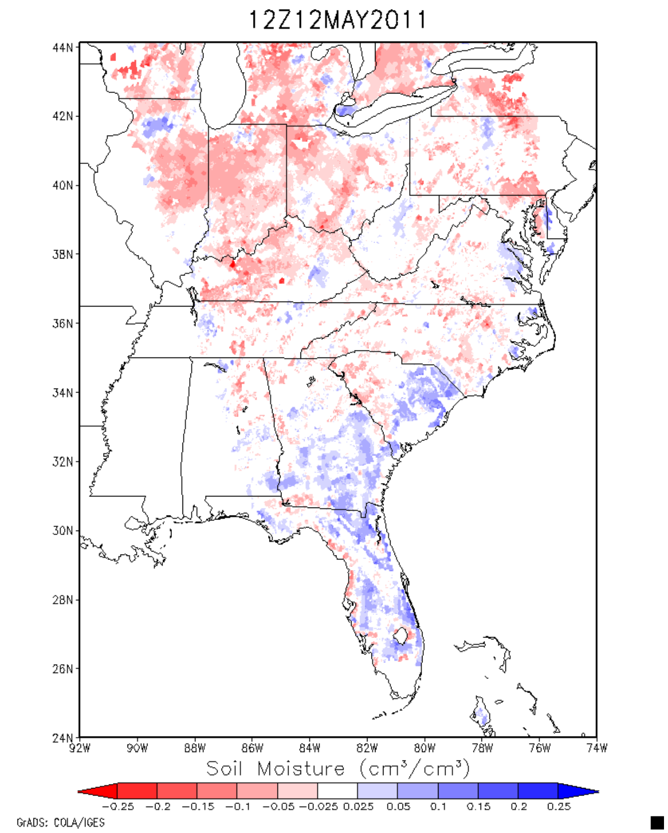


# Bias Correction

**Innovations (Obs-Bkgd) (Uncorrected)**



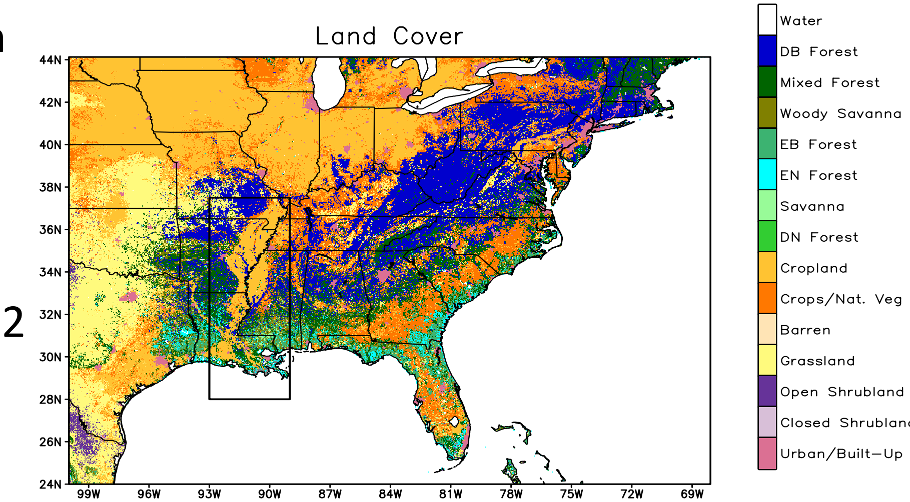

**Innovations (Corrected)**



# SMOS Experiment

- Southeastern/Central USA 3-km domain

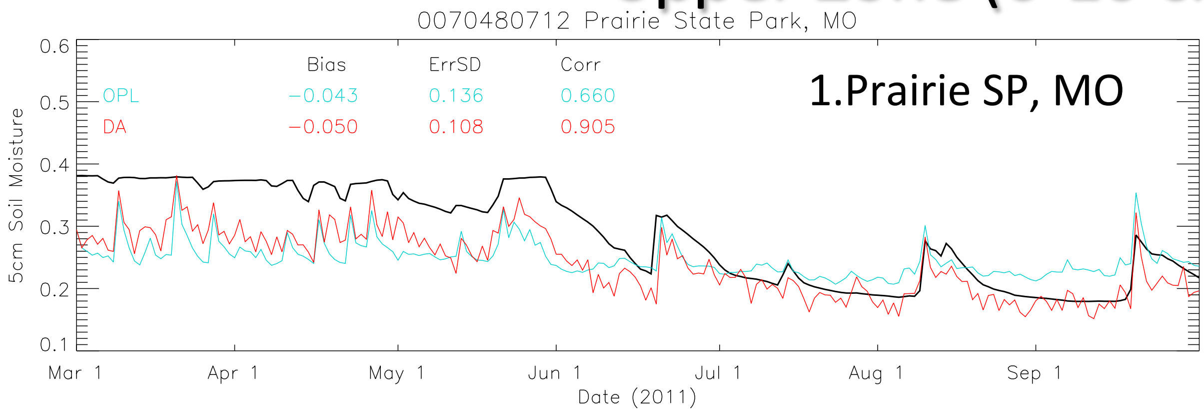
- MODIS/IGBP Vegetation Type
- STATSGO Soil Type
- Daily MODIS GVF
- North American Land Data Assimilation 2 (NLDAS-2) forcing
- Precip: Stage IV (radar+gauge)

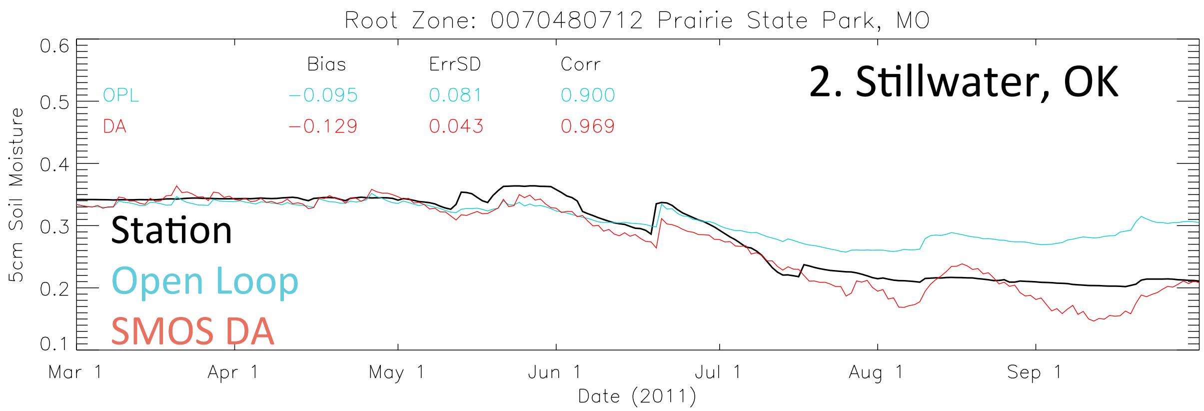


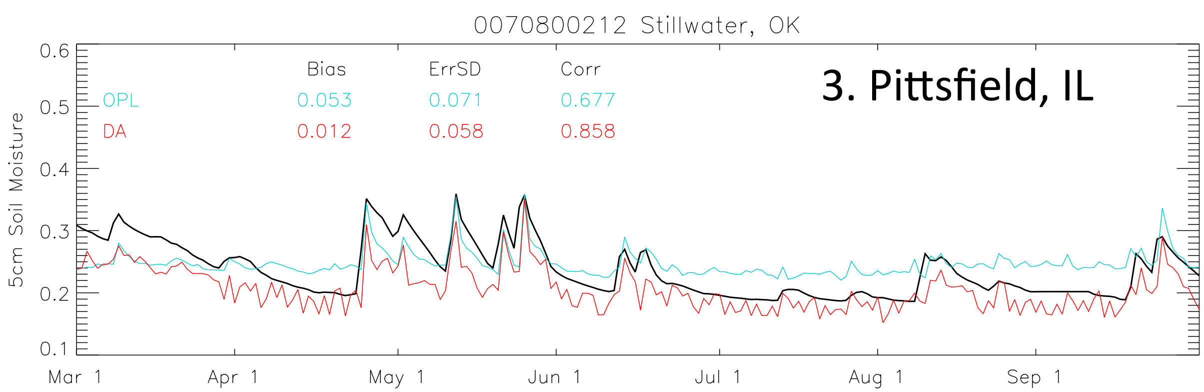

- 32 ensemble members
- multi-year spinup, 1 month perturbations
- Experiment run March-October 2011
  - Control (Open loop with perturbations)
  - DA runs (3 different bias corrections + no correction)
- Validation
  - Ground stations from North American Soil Moisture Database
  - Due to scale mismatch,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

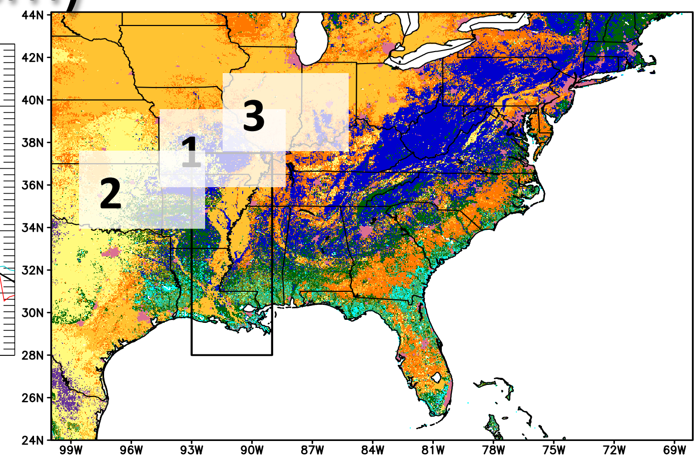
# SMOS DA Validation

## Upper Zone (0-10 cm)



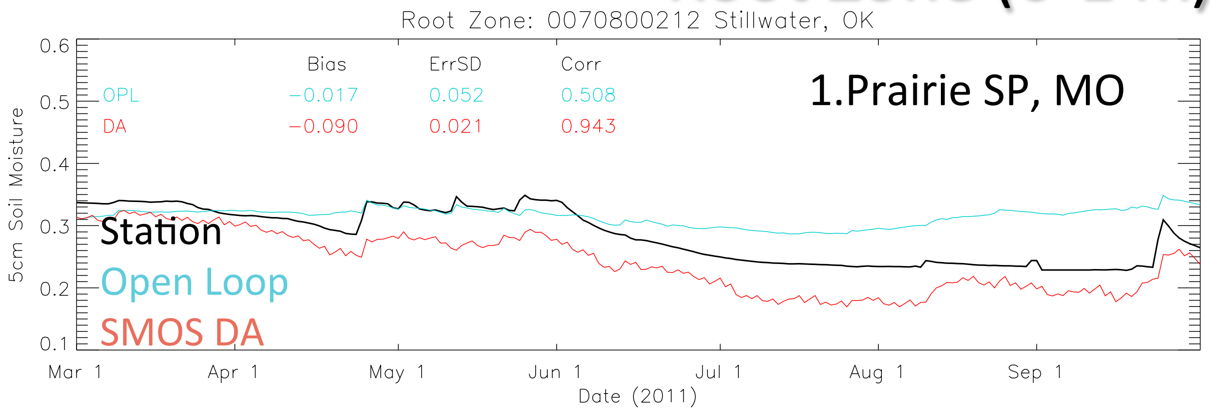



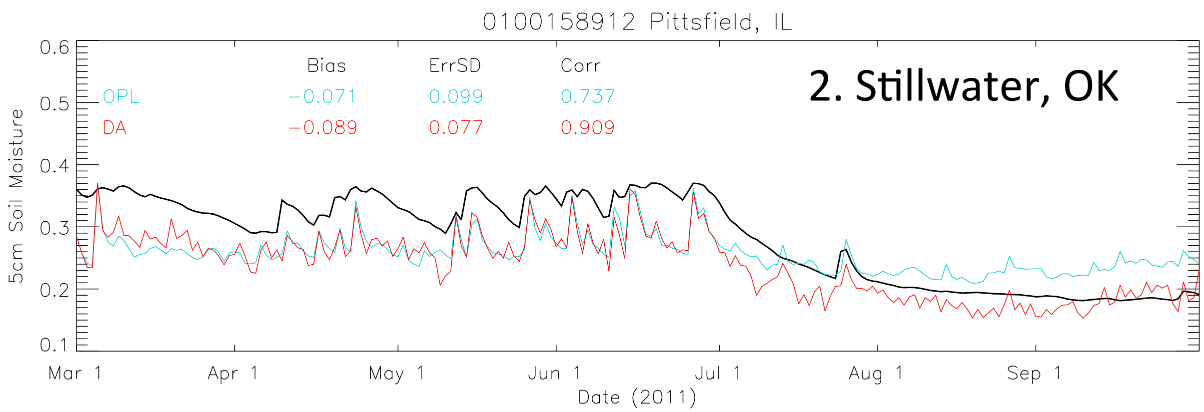

**Validation against soil moisture stations from North American Soil Moisture Database**

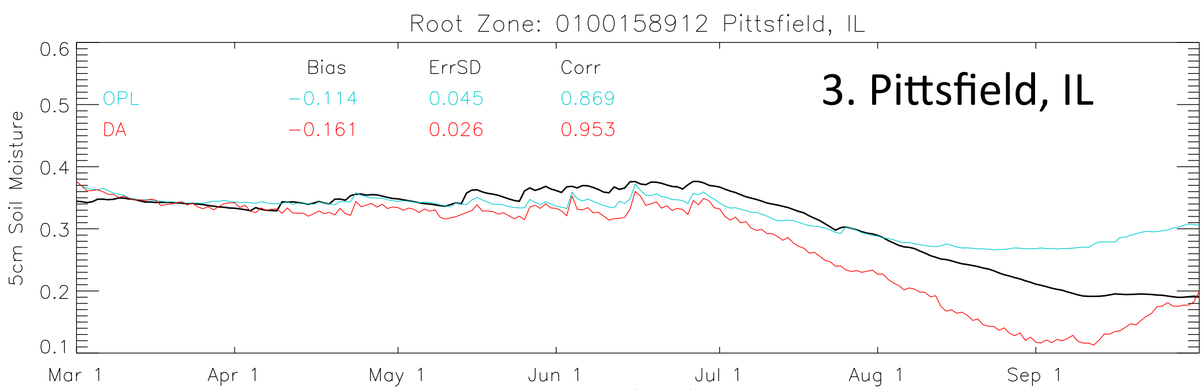
- Plots compare open loop run and SMOS DA run (uniform correction).
- *Other bias corrections not shown here.*
- Significantly better correlations
- Larger (improved) dynamic range

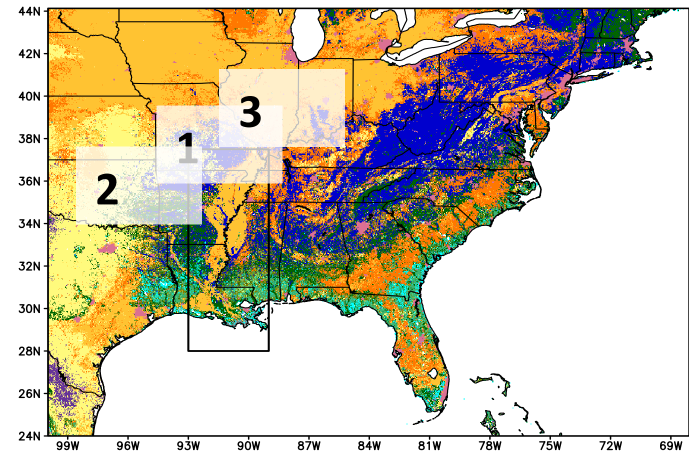
# SMOS DA Validation

## Root Zone (0-1 m)



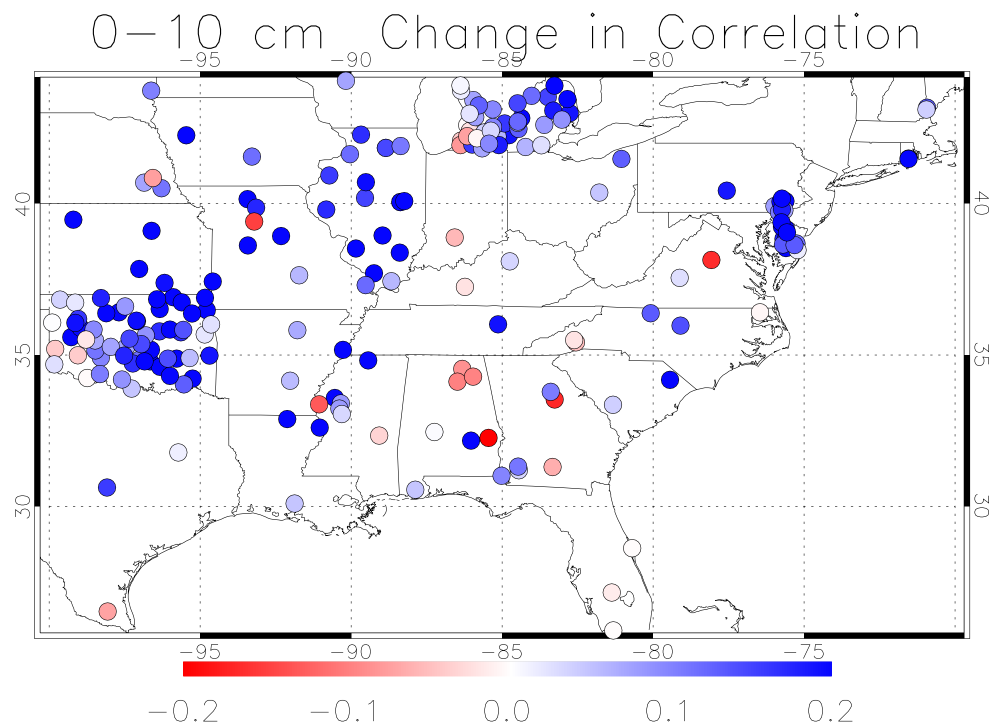

Root zone validation results

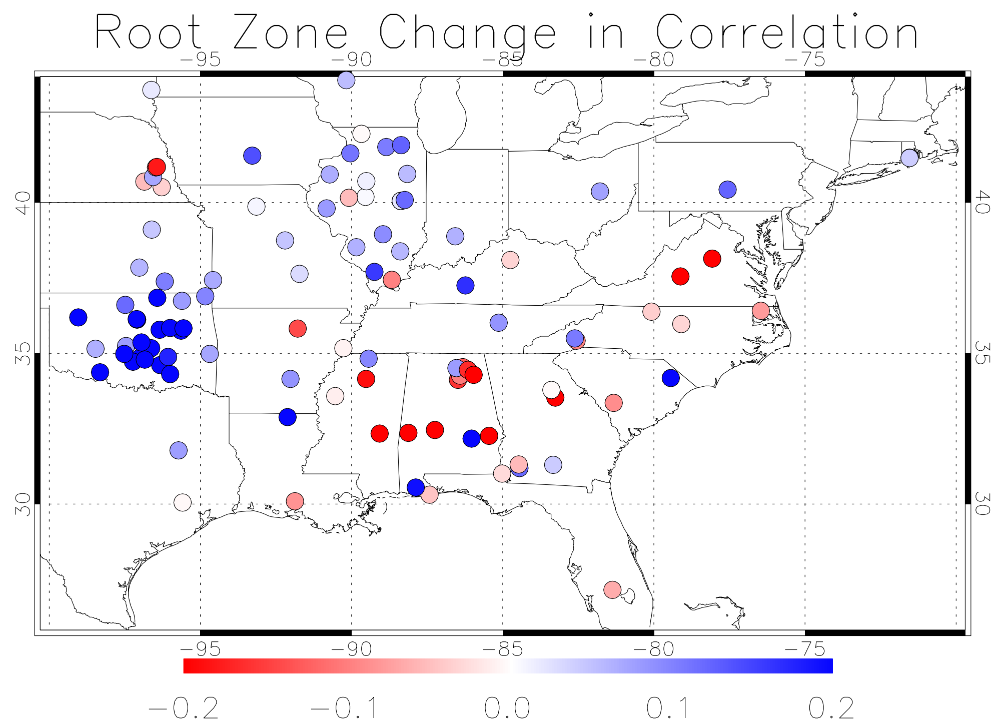
- Smaller statistical impact (bias, rms, correlation)
- Maintains increased dynamic range

# SMOS DA Validation

## *Correlation*

| Experiment Results | | | |
|---|---|---|---|
| **Upper Zone (10 cm)** | **Bias** | **ubRMSE** | **Correlation** |
| Open Loop | 0.000 | 0.082 | **0.57** |
| DA (uniform BC) | -0.002 | 0.092 | **0.68** |
| **Root Zone (1 m)** | | | |
| Open Loop | 0.038 | 0.037 | 0.67 |
| DA (uniform BC) | -0.002 | 0.036 | 0.68 |



# Summary of SMOS experiment results including bias correction

| 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 |

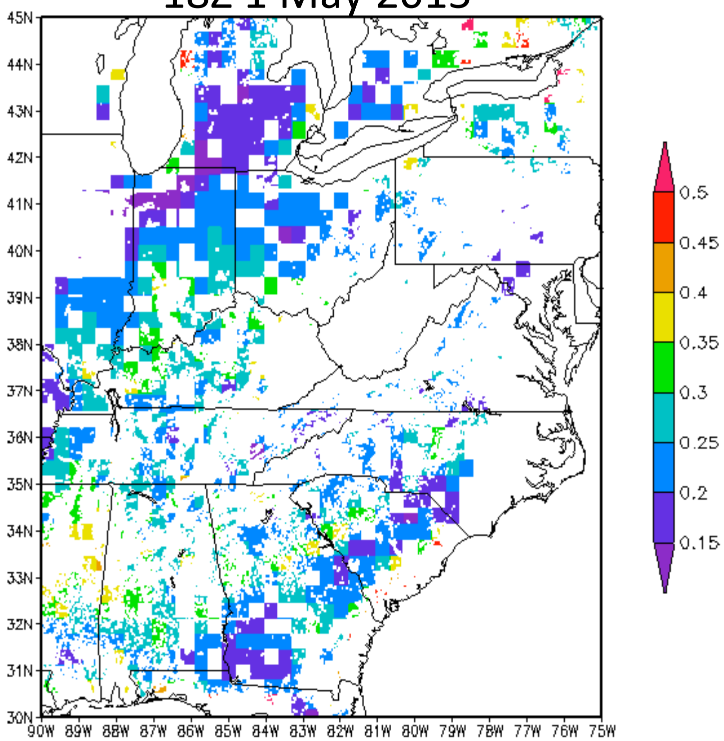
*Experimental error statistics with 95% confidence intervals for 0-10 cm layer soil moisture, verified against Texas A&M North American Soil Moisture Database in situ observations from 1 April to 1 October 2011. OPL: Open Loop; NOBC: Data Assimilation Only; BC1: single bias correction; BCS: soil-based 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)**
- Much reduced impact in root zone.
- Representativeness error could be reduced in future by comparing against COSMIC probes.

# First SMAP Results

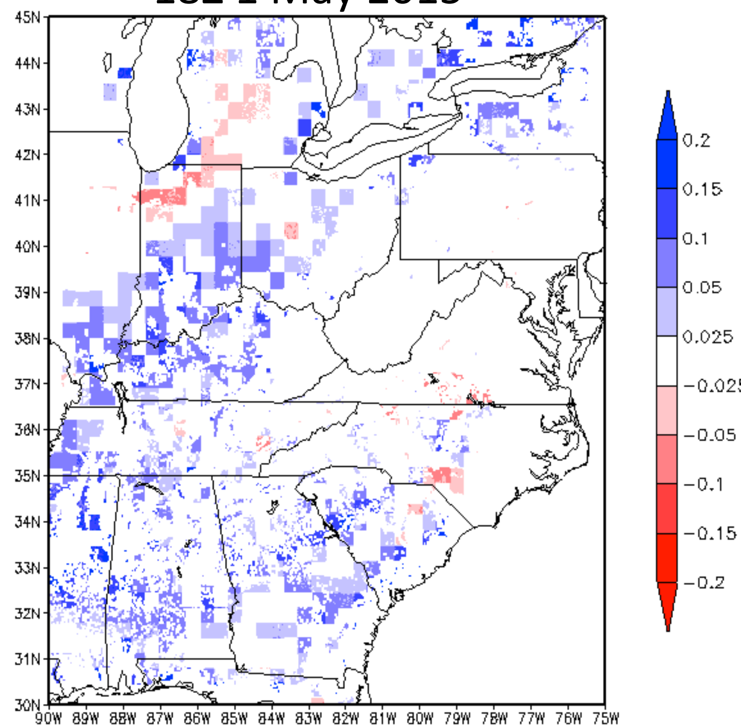

- Original plan: assimilate combined active/passive (L2) retrievals (9 km)
- SMAP radar failed July 2015
- New plan: assimilate passive (L2) retrievals (36 km)

SMAP Soil Moisture Observation
18Z 1 May 2015




*Some QC applied at LIS grid resolution.*

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




*Preliminary case (cold start)*

# Summary and Plans

- Implemented SMOS data assimilation in Noah LSM within LIS
  - Significantly improved correlations with ground observations for upper layer (0-10 cm)
  - Soil type-based bias correction did best job of reducing bias *(compared to stations)*
  - Small impact in root zone (10-100 cm).
- Currently implementing and testing SMAP assimilation (passive 36 km L2 product)

***Future Plans***

- Validation against NASMD including COSMIC probes (reduced representativeness error) using LIS Validation Toolkit
- Further refinement/testing 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 SMOS/SMAP DA in near-real-time SPoRT LIS product
- Transition products to NWS and international partners

# Questions and Comments?

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