Real-time Land Information System and Soil Moisture Data Assimilation for Situational Awareness and Local NWP Applications

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NASA Short-term Prediction Research and Transition (SPoRT) Center

[1]Universities Space Research Association,[2]ENSCO, Inc.; [3]NOAA/National Weather Service (NWS) Huntsville, AL; [4]NOAA/NWS Albuquerque, NM; [5]NOAA/NWS Tucson, AZ;; [6]NASA/Marshall Space Flight Center; [7]NOAA/NWS Houston, TX; [8]NOAA/NWS Raleigh, NC

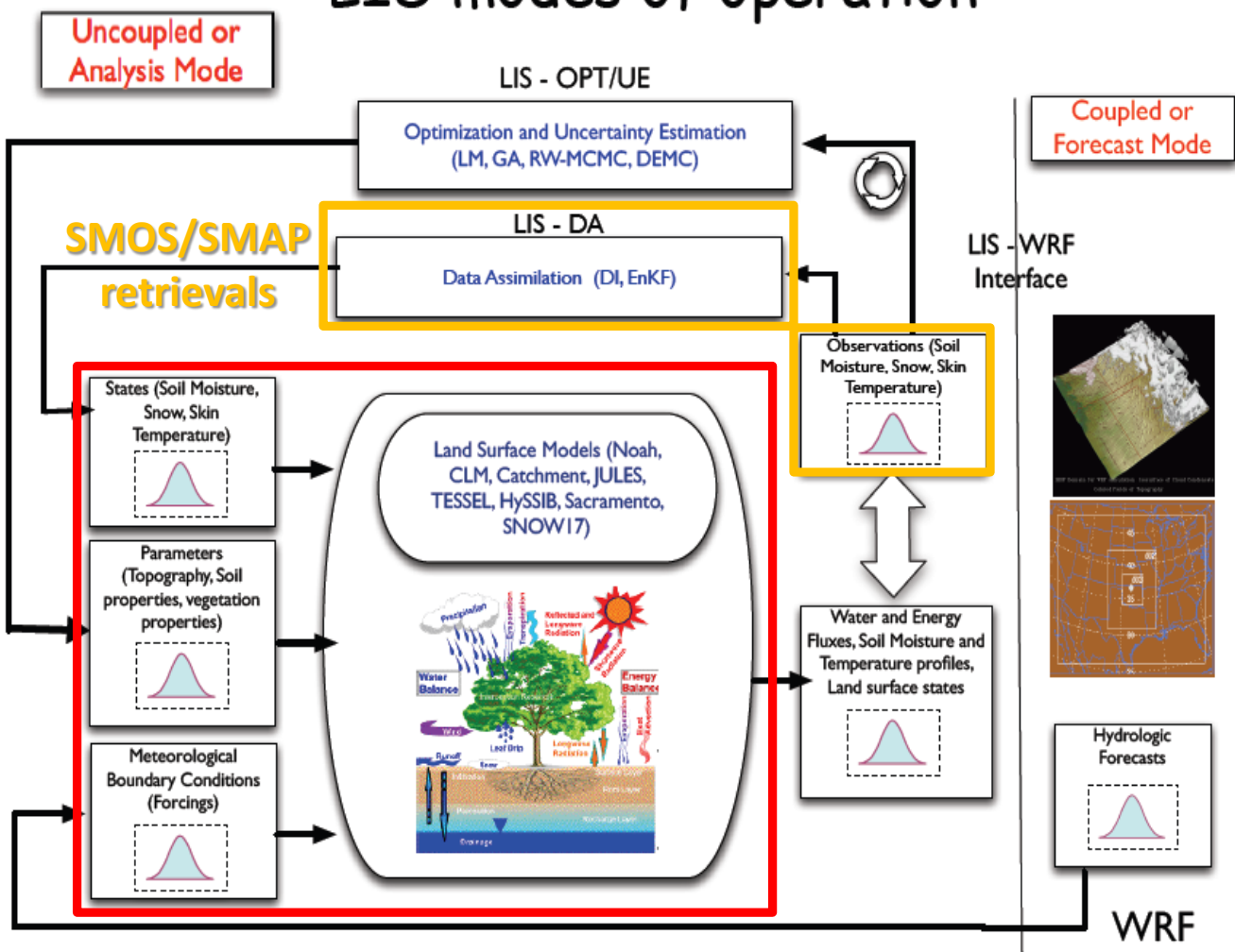# NASA Land Information System (LIS)

High-performance land surface modeling & data assimilation system

Uncoupled/analysis mode

Forecast mode coupled to WRF model

Currently run Noah LSM v3.3 in analysis mode

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

LIS modes of operation

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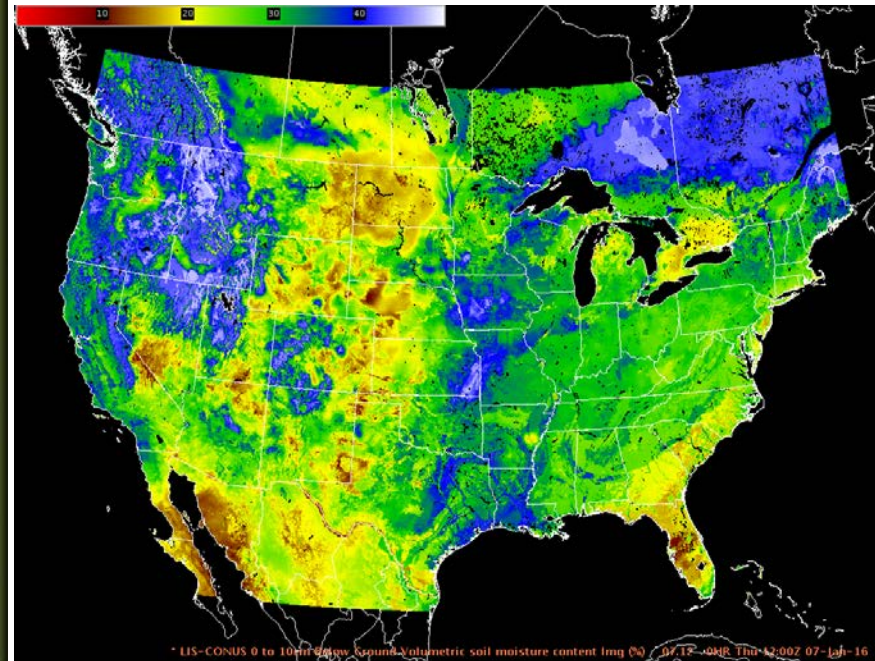
SPoRT Real-time LIS Running Noah LSM

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

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)

NLDAS-2 forcing   *GDAS + MRMS forcing*   *GFS forcing*

Jan 1979   **t – 4 days**   **t = current**

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# LIS-Noah 33-yr Soil Moisture Climatology

LIS-Noah run from Jan 1979 to Dec 2013

- CONUS+ domain at 0.03-deg resolution (~3 km)
- IGBP/MODIS 20-class land use, STATSGO 16-class soil
- MODIS/FPAR 30-sec resolution monthly GVF climatology (Barlage; from community WRF v3.5.1+)
- Atmos. forcing: NARR-based NLDAS-2 hourly data
- 30+ year spin-up (1979-2010), then re-ran for 1979 to 1 Jan 1981 to ensure soil equilibrium
- Restart on 1 Jan 1981 with output soil fields once daily
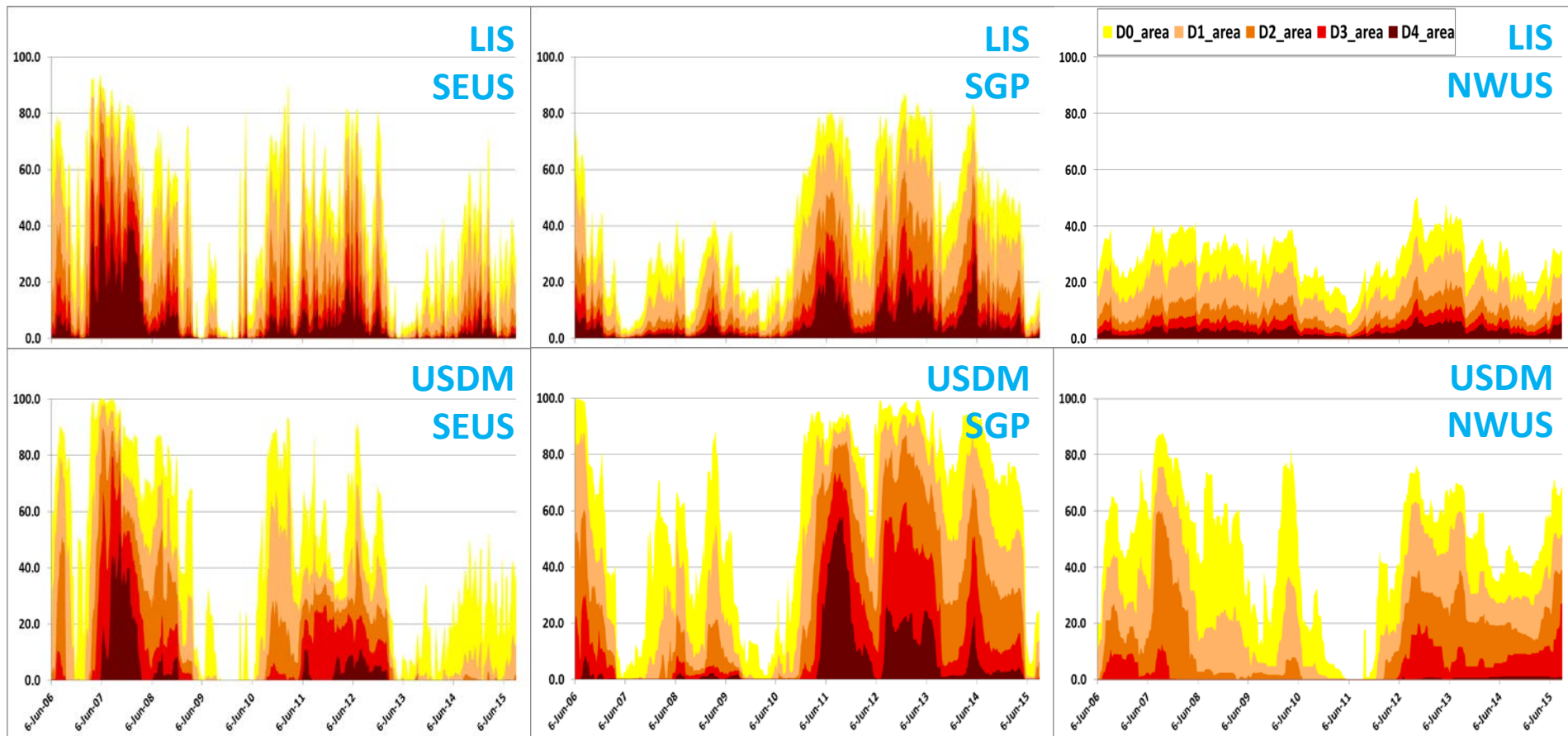- Climatology spans 1 Jan 1981 to 31 Dec 2013 for 33 years of data

SPoRT–LIS 0–2 m RSM percentile valid 06 Dec 2015

SPORT

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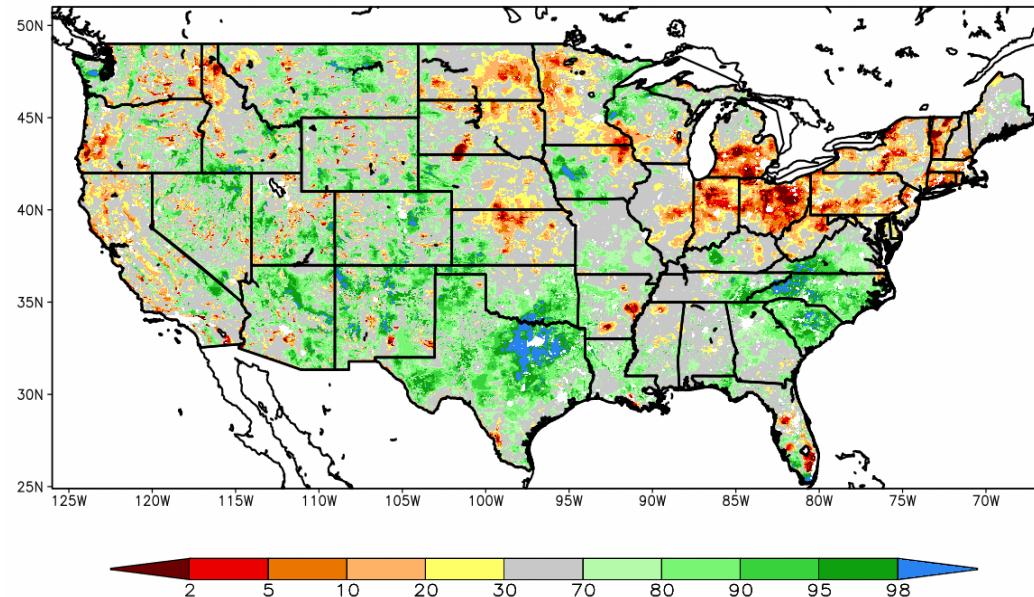
Daily Histogram Animations

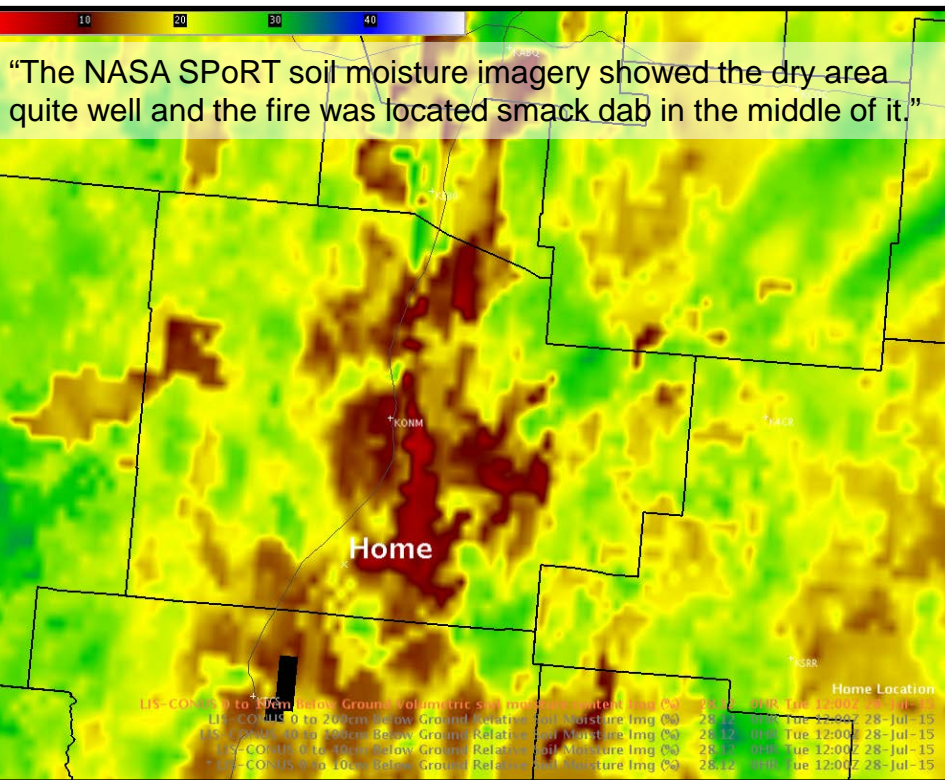transitioning research data to the operational weather community
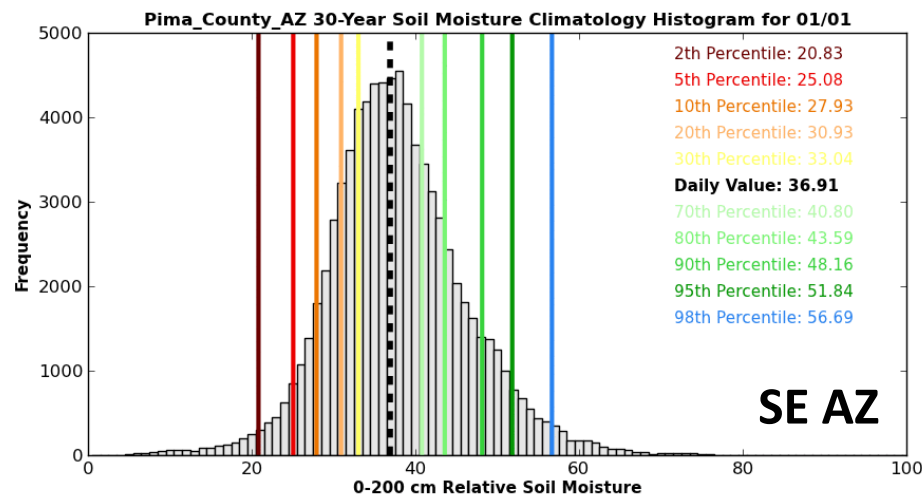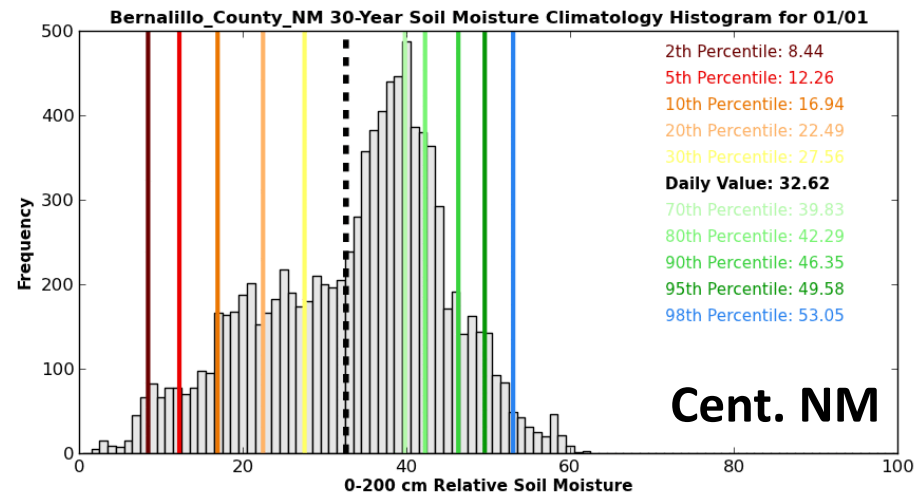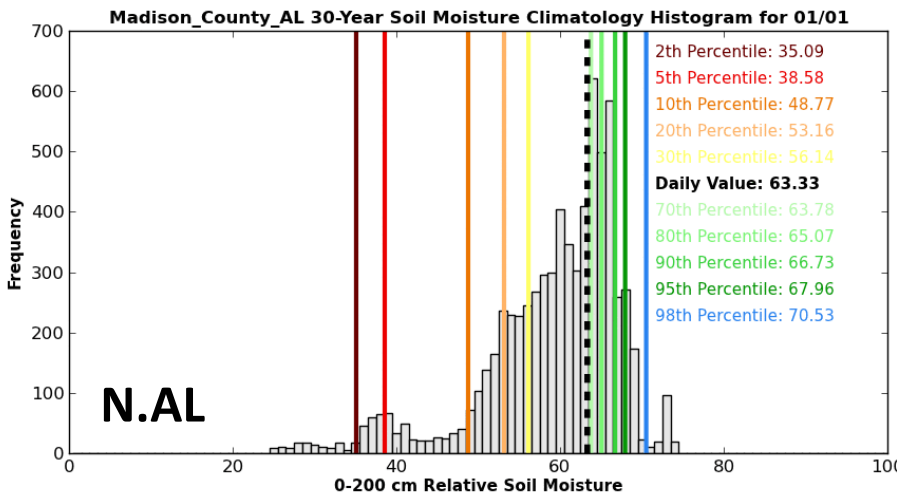
Percentile Validation (% area in drought; 2006-2015)

- Captures documented major droughts (SEUS in 2007; SGP in 2011 through 2014)
- Generally captures the overall magnitude of total drought area
- SEUS is noisier due to more frequent and scattered nature of precipitation, esp. in summer
- Northwest is not as well represented because factors defining drought are often different (future work will add snow water equivalent to climatology)

SPoRT-LIS 2015 Evaluation:
Soil Moisture Associated with Wildfire (NWS ABQ)

"The NASA SPoRT soil moisture imagery showed the dry area quite well and the fire was located smack dab in the middle of it."

Fort Craig, NM wildfire at 830am 27 July 2015. Wildfire grew to ~700 acres over 2 days.

[Photo credit: Dave DuBois, NM state climatologist]

0-10 cm SPoRT-LIS volumetric soil moisture valid 12z 28 Jul 2015.

"The SPoRT LIS products have become a valuable tool for drought monitoring during our monthly drought workshops. Several state and federal partners noted on our most recent call in late July that these new products provided an additional layer of situational awareness and infuse more science into the drought monitoring process."

"The high resolution imagery could be useful in determining fuel dryness for potential fire starts from human activities, cloud to ground lightning ignitions, as well as highlight potential active fire behavior areas."
--from ABQ NWS post on SPoRT blog (Aug 4, 2015)

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SPoRT-LIS 2015 Evaluation:
Soil Moisture Change in South Carolina Flooding

SPoRT–LIS 0–2 m RSM percentile valid 27 Sep 2015

SPoRT–LIS 0–2 m RSM percentile valid 04 Oct 2015

Total column relative soil moisture percentile before and after event (right images)
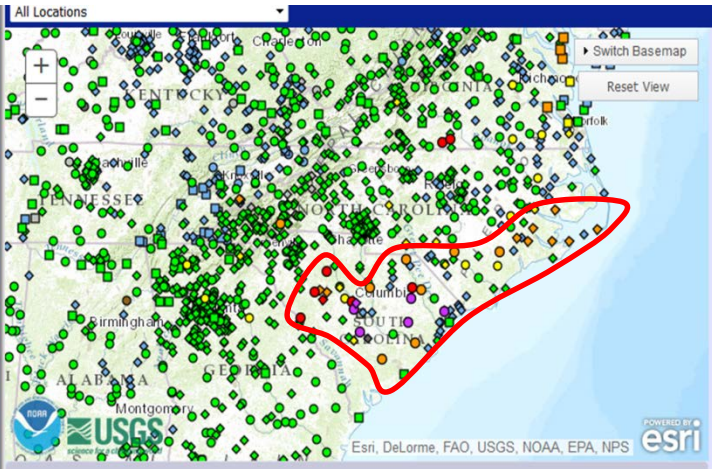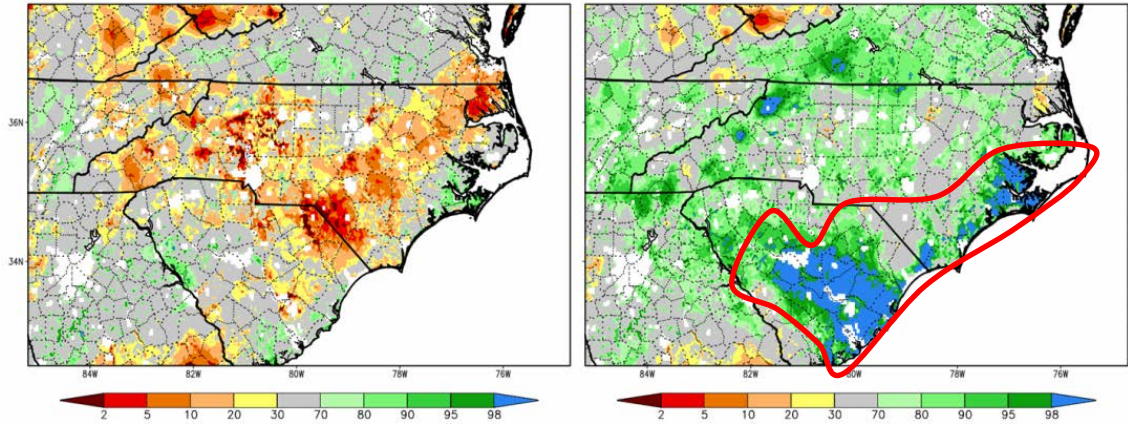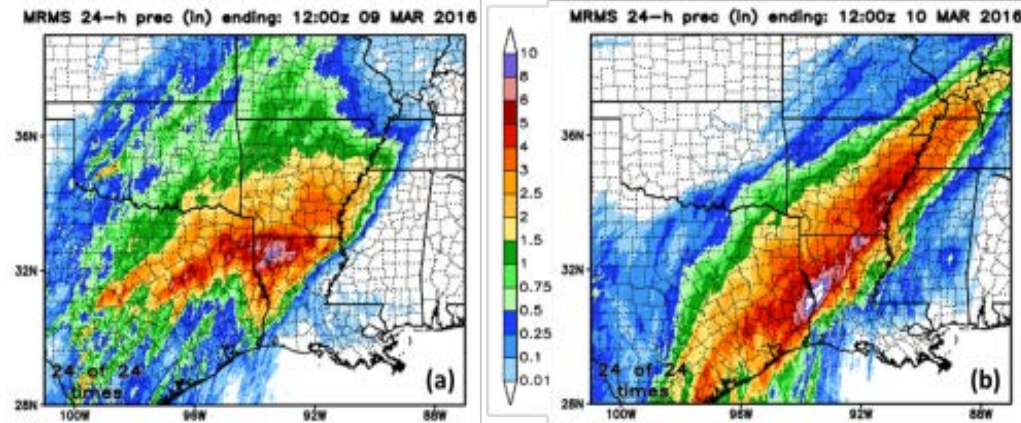
USGS river gauges indicating minor to major flooding (left);

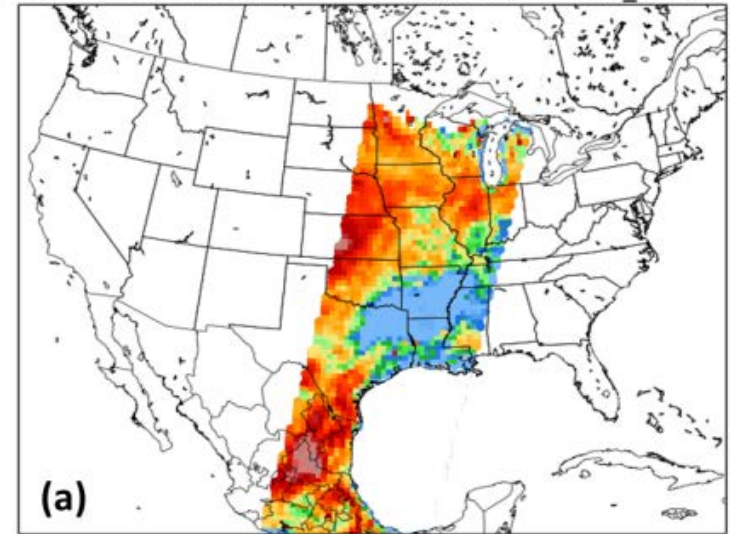**One-week change in total column relative soil moisture displayed in NWS Huntsville AWIPS II (right)**

100-200%+ increase

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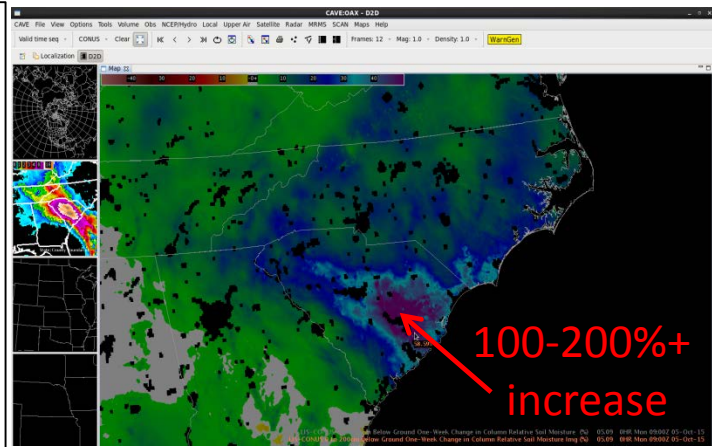
SMAP / SPoRT-LIS: early March Flood

Mar 9-10 Precipitation

0-5 cm SMAP Soil Moisture valid 20160309_1223 UTC

- 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 right) compared to SPoRT-LIS 0-10 cm volumetric soil moisture at 12z (lower-right)

Soil Moisture Data Assimilation

Data assimilation combines model data and observations

Using Ensemble Kalman Filter in LIS

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 soil moisture fields

- Better initialization of land surface for coupling with NWP models at convection-allowing resolution (~1-4 km) for regional weather forecasting

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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)

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

Soil Moisture and Ocean Salinity

SMOS

Soil Moisture Active/Passive

SMAP

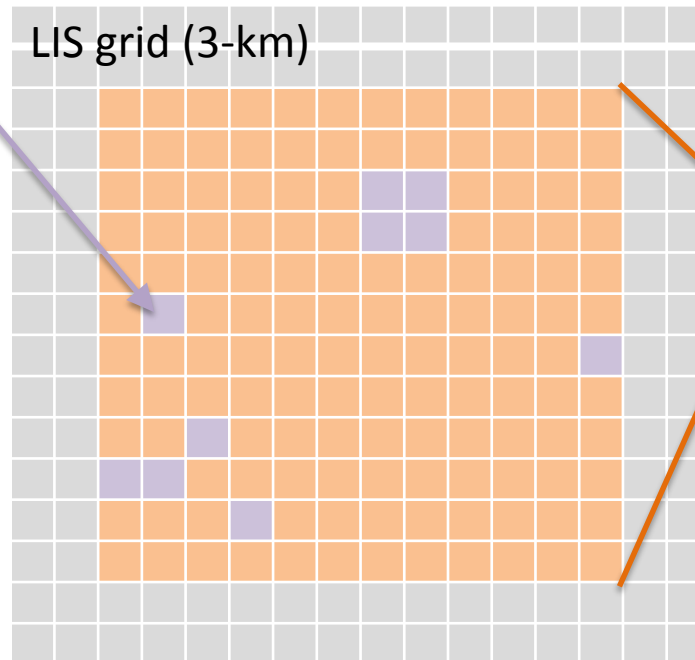| Name	AMSR-E	SMOS	SMAP		
Agency	NASA/JAXA	ESA	NASA		
Launch	2002	2009	Jan. 2015		
Orbit	Polar	Polar	Polar		
Sensor Type	Passive	Passive	Passive	Active (Failed July 2015)	Combined (limited duration)
Frequency	6.9 GHz (C-band)	1.4 GHz (L-band)	1.41 GHz	1.2 GHz	
Resolution	56 km	35-50 km	36 km	**3 km**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

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

LIS grid (3-km)

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
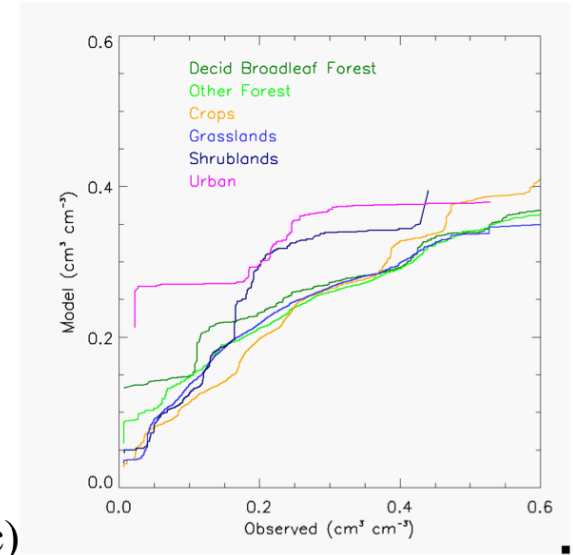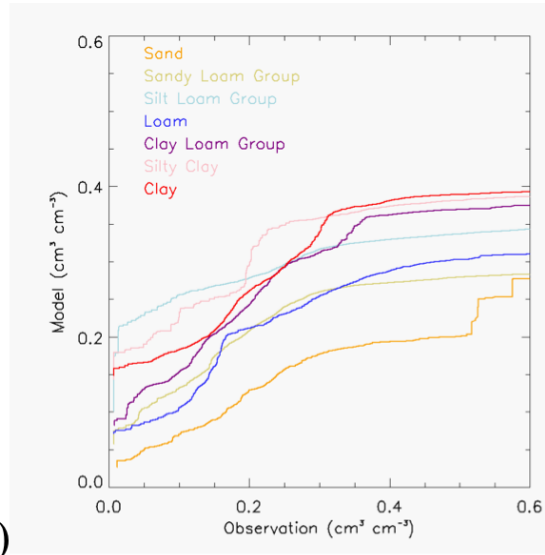- Vegetation Water
- Frozen Ground Fraction

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

Cumulative Distribution Functions

Correction Curves

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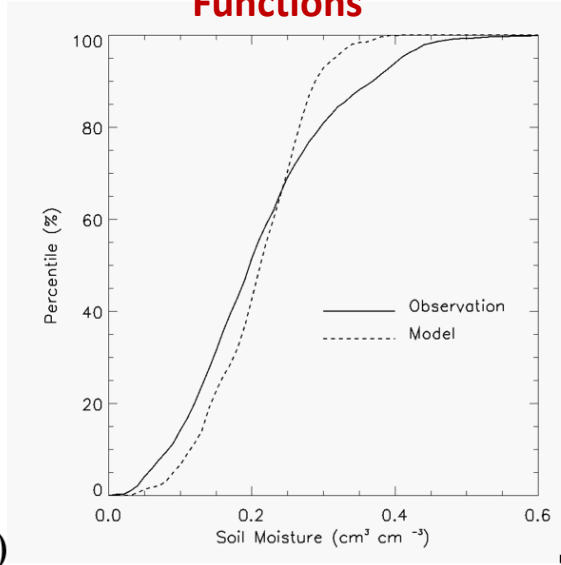
- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- Tested three variations of CDF matching, aggregating spatially to increase sample size
  - Single uniform correction
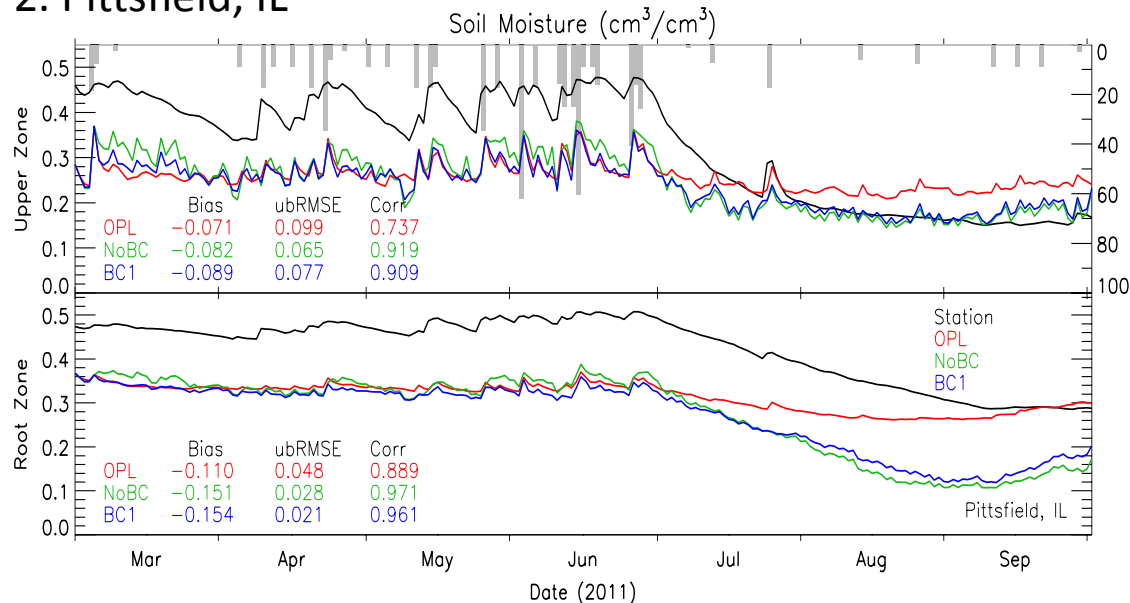 - Soil-type based
  - Vegetation-based

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SMOS DA Validation

1. Stillwater, OK
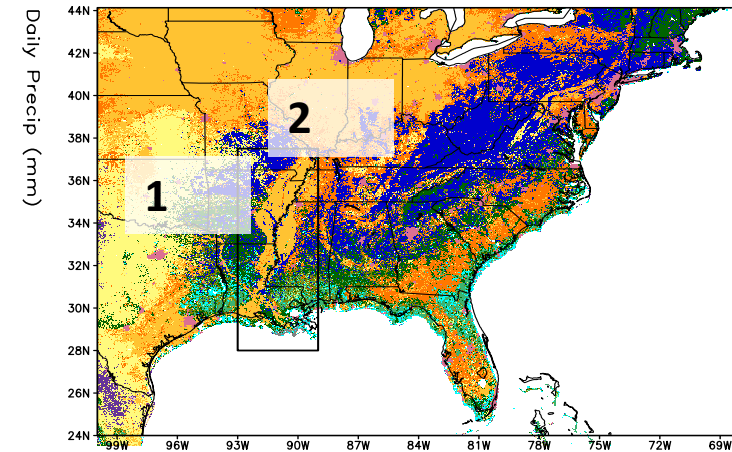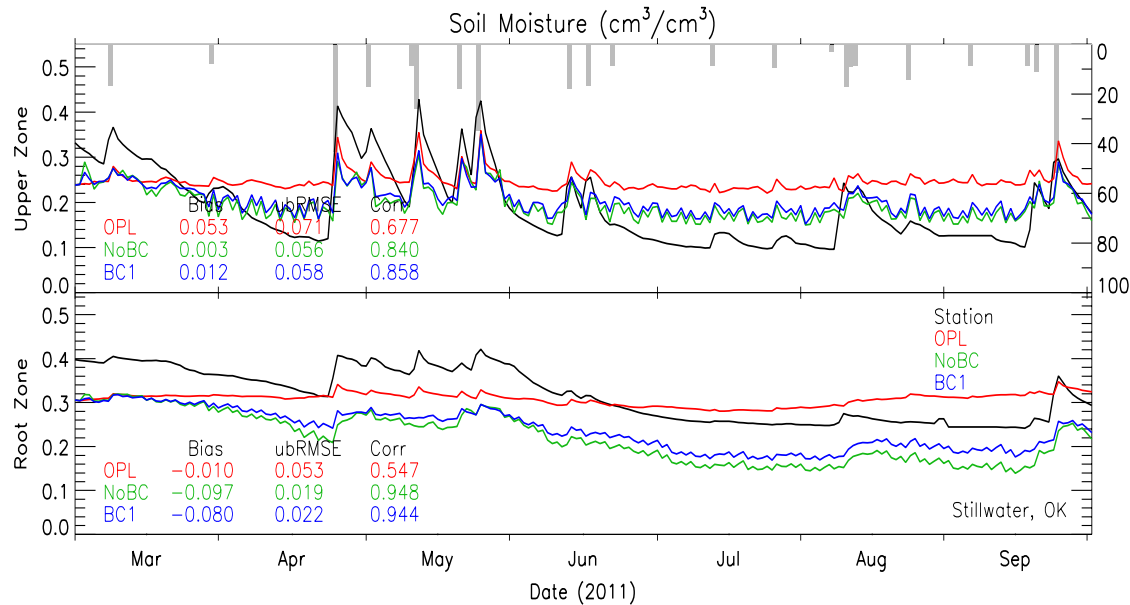
2. Pittsfield, IL

- 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**
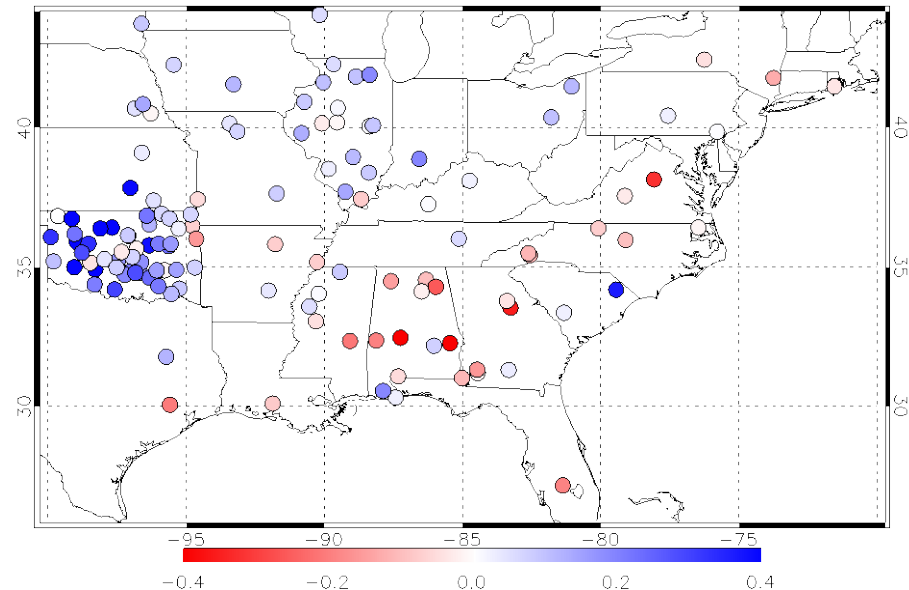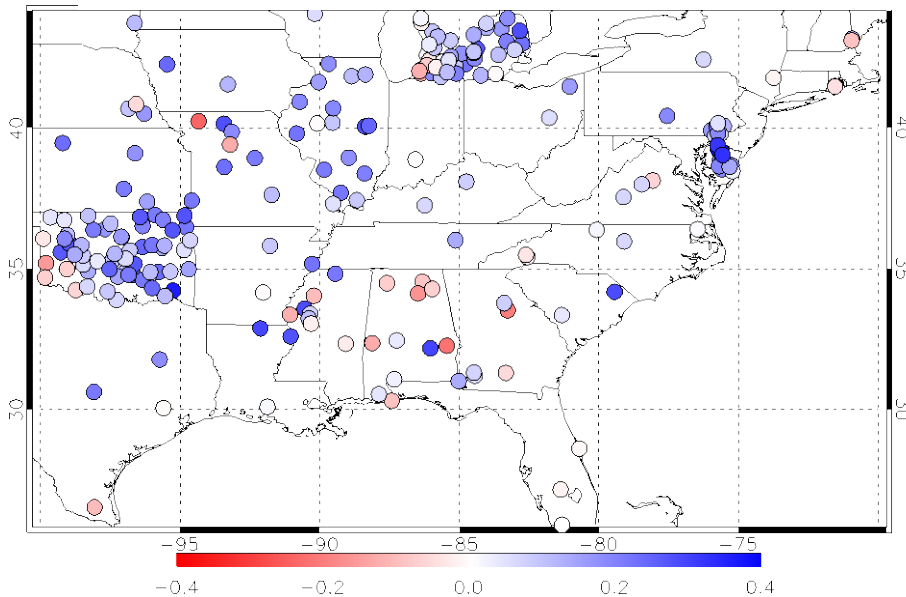- **Improved dynamic range**
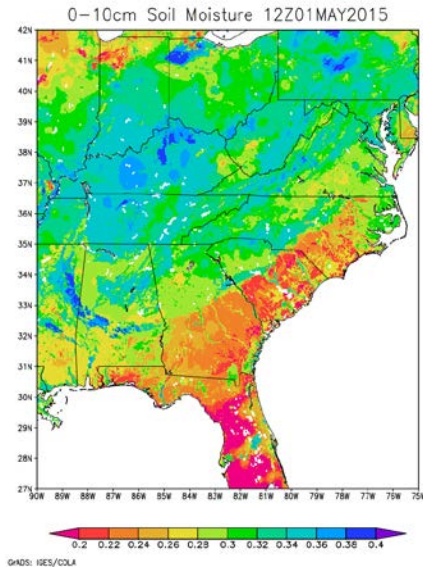
SMOS DA Validation

Correlation

	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

SMAP DA in progress

0-10cm Soil Moisture 12Z01MAY2015

SMAP DA Results
as of May 2016

- Successful test of
  SMAP DA
- Now tuning
  perturbations and
  implementing bias
  correction
- Will refine QC
- Plan to implement
  downscaling

12Z01MAY2015 Innovation

12Z01MAY2015 Increment

Obs (SMAP Retrieval) 12Z01MAY2015

0-10cm Soil Moisture 15Z01MAY2015

17
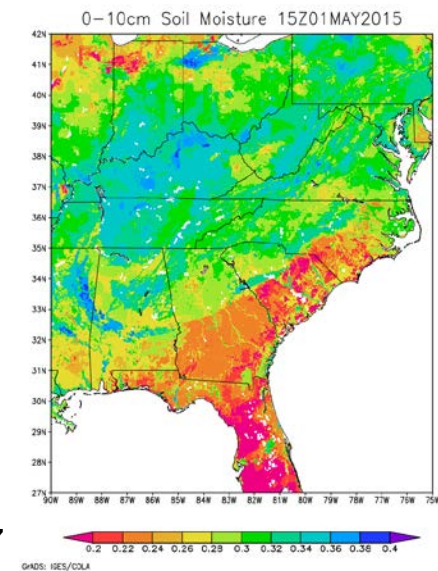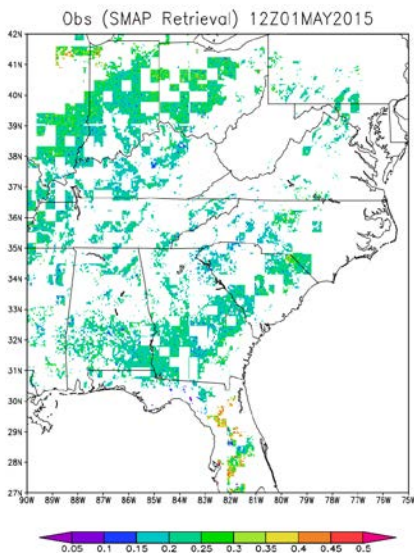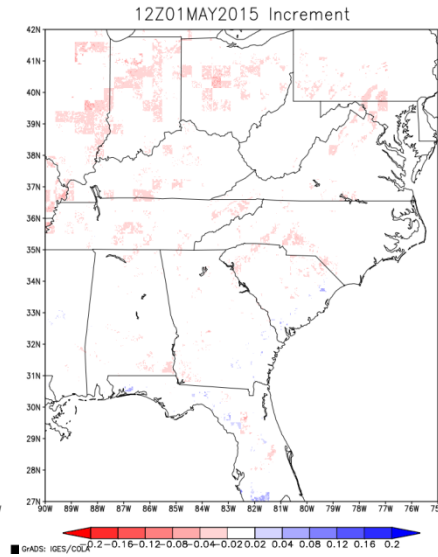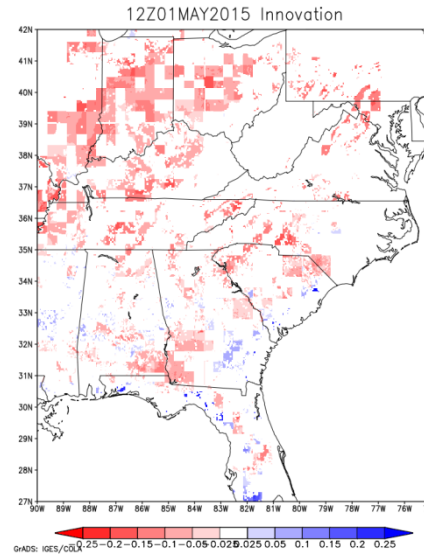
Plans for SPoRT-LIS

- **Data Assimilation**
  - SMOS & SMAP data assimilation (current activity)
  - Assimilate total terrestrial water, SWE/snow fraction, others
- **Run SPoRT-LIS coupled to regional NWP (i.e., NASA Unified-WRF)**
  - Just received NASA funding
- **Use WRF-Hydro for streamflow analysis**
- **Verification:**
  - Use Land surface Verification Toolkit with available near-real time soil moisture observations (Texas A&M QC database)
  - Monitor impacts of data assimilation on regional NWP
  - Test in East Africa where forcing data is not as extensive (so potential gains are greater)

Questions and Comments?

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