Assessment of Soil Moisture Initialization Approaches for NU-WRF Forecasts

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Background

- Land-atmosphere (L-A) prediction is governed by a series of processes and feedbacks, which we call **Local L-A Coupling ('LoCo')**, as follows:

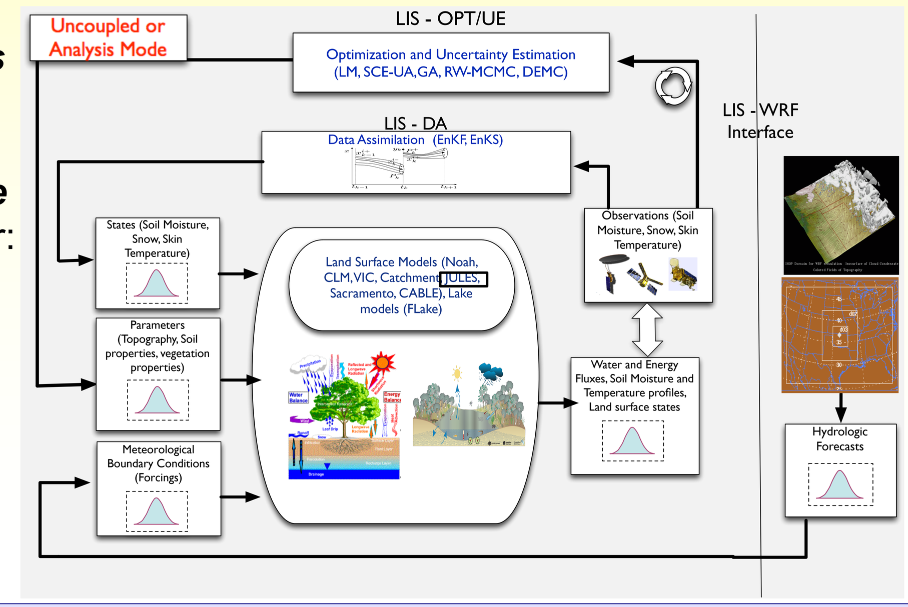
$$\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m} \rightarrow \Delta Precip/Clouds$$

- **Impacts of soil moisture initial conditions** are therefore felt downstream during WRF forecasts.
- Little attention has been paid to the variability in soil moisture initialization approaches, **including what is now possible from satellites such as SMAP**.

- **Objective:** Perform a practical assessment of the impact of soil moisture initial conditions on initialization of short-term weather forecasts.
- **Case Study:** July 11th and Aug 28th, 2015
- **Domain:** 1100x750 @ 1km over U.S. SGP
- **Observations:** SMAP Soil Moisture
- **Models:** LIS-Noah (v3.3) LSM + NU-WRF

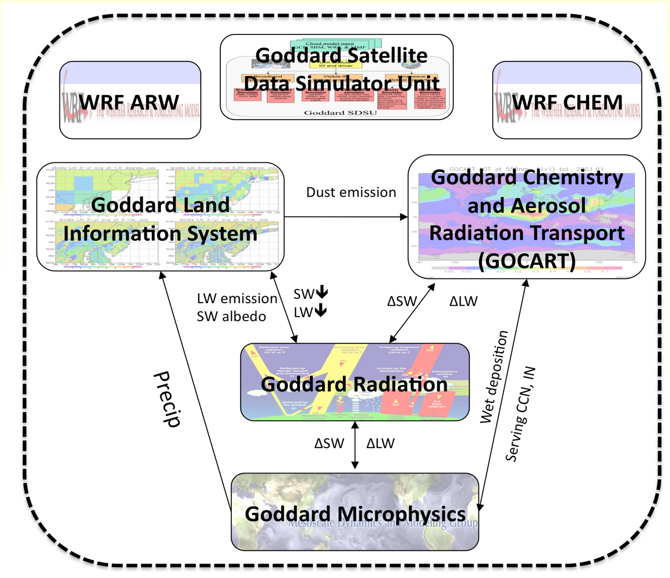
NASA's Land Information System (LIS)

- Provides a ***suite of LSMs under a consistent, high-performance computing and software framework*** that allows for:
  - Land DA, Calibration
  - Flexible Forcing, Parameters, Physics, Ensembles
  - Coupling to WRF



NASA Unified WRF (NU-WRF)

- Provides an ***observation-driven, integrated modeling system*** that represents aerosol, cloud, precipitation and land processes ***at satellite-resolved scales*** (1-4 km)
- Integrate unique NASA observation and modeling assets under one roof:
  - Satellite Data
  - Model Physics
  - Expertise/Software



LIS Runs and Experimental Design

A suite of LIS simulations was performed to isolate impacts of:

- **Atmospheric Forcing**
  - -NLDAS-2: best available, observed precipitation, 0.125-deg
  - -GDAS: coarse, global, 0.3-deg
- **Green Vegetation Fraction**
  - -Climatological: Monthly, satellite-based @ 3km
  - -Real-time: Daily, VIIRS-based @ 3km
- **DA Increment Space**
  - -Model space: on the 1km grid of the LSM (*traditional approach)
  - -Observation space: on the 36km grid of the SMAP L3-Passive data

Initialization Source	Forcing	DA-Space	GVF
LIS (Control)	NLDAS-2	No DA	VIIRS
LIS (GDAS)	GDAS	No DA	VIIRS
LIS (GVF)	NLDAS-2	No DA	Climatology
NLDAS	NLDAS-2	No DA	Climatology
WRF	NARR	No DA	Climatology
SMAP	-	-	-
LIS-DA	NLDAS-2	Model (1 km)	VIIRS
LIS-DA	NLDAS-2	Observation (36 km)	VIIRS

Suite of Initial Conditions

- LIS includes a **multi-algorithm assimilation subsystem (LIS-DA)** ranging from techniques such as:
  - Direct Insertion (DI)
  - **Ensemble Kalman Filter (EnKF)**
- LIS-DA can perform **product** or **radiance** (**LIS-RTM**) based assimilation for land surface states:
  - **Soil Moisture**
  - Surface Temperature
  - Snow (SWE, snow cover)
  - Groundwater

Spinup & Data Assimilation Runs

DA Algorithm:
- LIS Ensemble KF (size X)
- Perturbations to forcing and prognostic states

Observations:
- **SMAP L3 Passive Soil Moisture (EASE grid)**
- **9 km spatial, 2-3 day temporal revisit**

Simulations:
- **Full spinup: 1 May 2011 - 1 April 2017**
- DA performed: 1 April 2015- 1 April 2017

Results

Variability in Soil Moisture Initial Conditions

- The soil moisture fields on July 11th and Aug 28th as generated from the various model and observation sources (**Figs. 1, 2**) vary as a result of the following:

- **LIS-Noah Specifications**
  - Precipitation: GDAS has generally less precipitation than NLDAS-2 producing drier soil moisture.
  - Precipitation: NLDAS-2 has local maxima that GDAS misses entirely (implications for DA).
  - GVF: Climatology and VIIRS are similar leading to only subtle soil moisture differences.

- **Data Assimilation (in progress..)**
  - LIS-DA runs assimilating will be sensitive to the DA being performed at model (1km) vs. SMAP (9 or 36km) resolution.

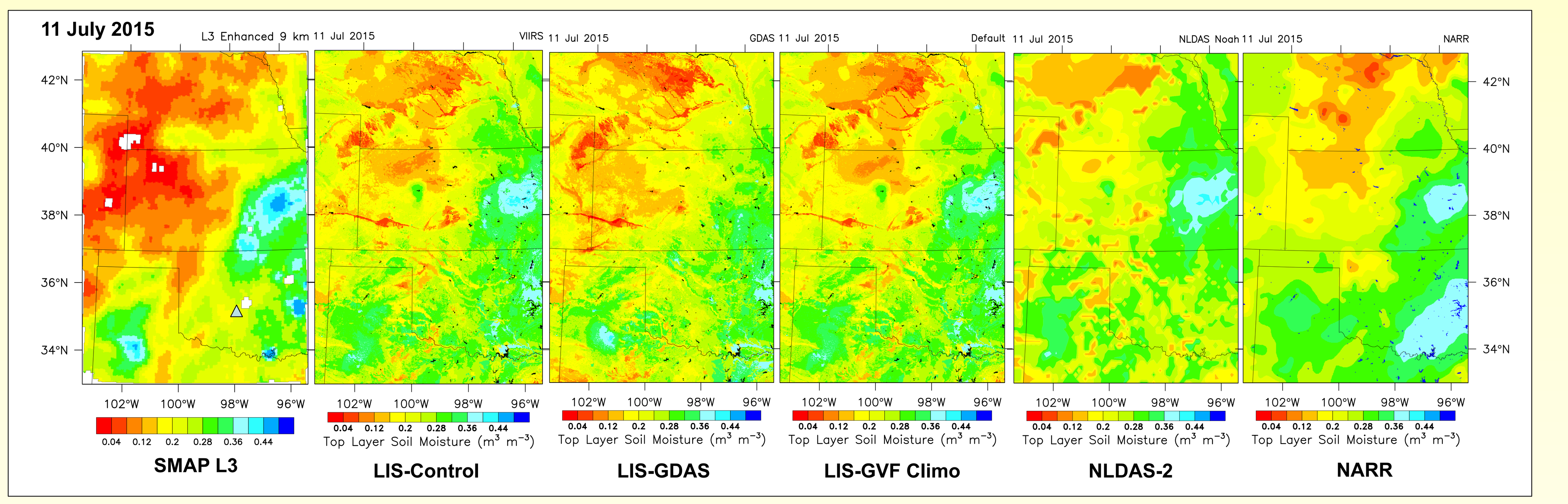
- **NLDAS-2**
  - NLDAS-Noah (v2.8) tends to be wetter than the Noah (v3.x) simulations above.

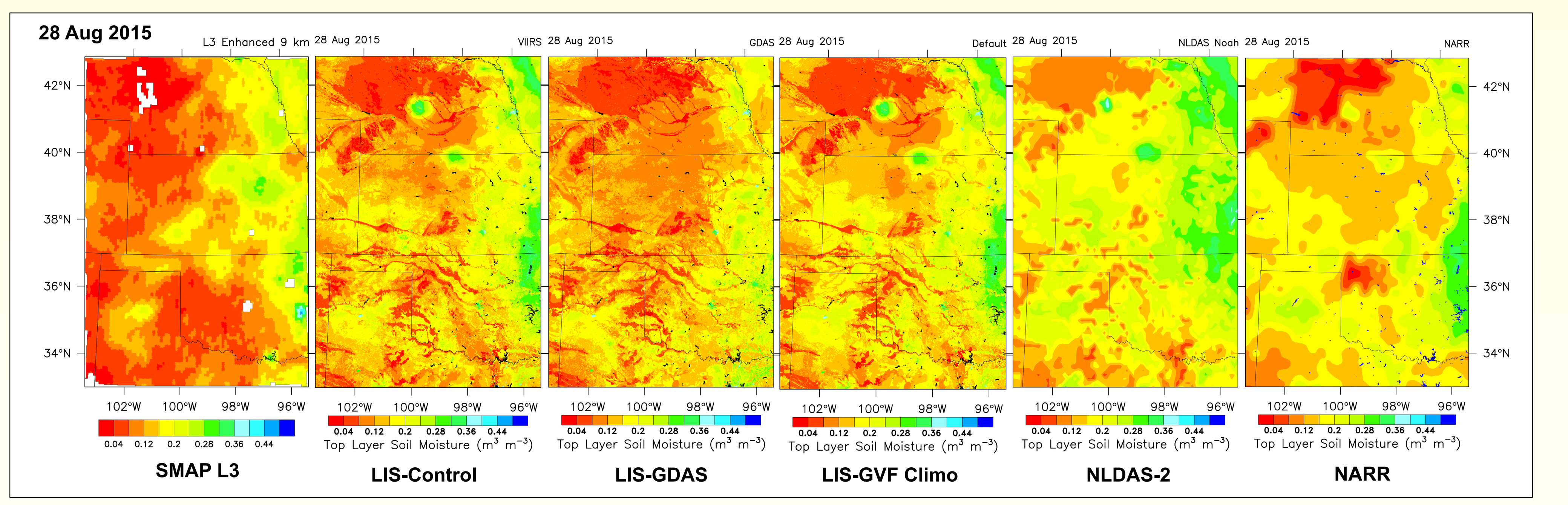
- **NARR**
  - NARR w/Noah LSM (v2.7.1) is coarser spatially but similar to NLDAS-2 in terms of soil moisture magnitude and pattern.

SMAP Performance

- Overall, **SMAP performs quite well** and looks like 'real' soil moisture both in time and space.
- Return time over a given location over the SGP is on the order of every ~2 days using the morning (6am) overpass (more frequent if evening is included).
- SMAP **captures the overall heterogeneity and gradients (E-W) of soil moisture in the region** well when compared with the other model-based products (**Figs. 1, 2**).
- **SMAP tends to be drier** especially over the western (dry/bare soil) regions than the model-based conditions (**Figs. 1-3**).
- **Wetting (precip) events are captured very well**, both in time and magnitude (**Figs. 1,2,4**).
- **Drydowns occur more rapidly** in SMAP data than in model/in-situ data (**Fig. 3**).
- Dry bias in SMAP particularly during dry regimes is likely a result of actual SMAP retrieval depth being less than 5cm (i.e. 1-3cm), as well as vegetation and emissivity impacts.

Soil Moisture Initialization Intercomparison





Figures 1 & 2. Near-surface soil moisture on July 11 and August 28, 2015 at 12Z (morning) from **a)** the SMAP L3, 9km soil moisture product, and the array of LIS 5-year spinups using the Noah v3.6 LSM including the **b)** Control Run (NLDAS-2 forcing and VIIRS GVF), **c)** GDAS forcing, **d)** GVF Climatology, along with that from the **e)** operational NLDAS-2 product using the Noah v.2.7.1 LSM and **f)** NARR Reanalysis using the Noah v.2.7.1 LSM.

Spatial Distribution of Soil Moisture

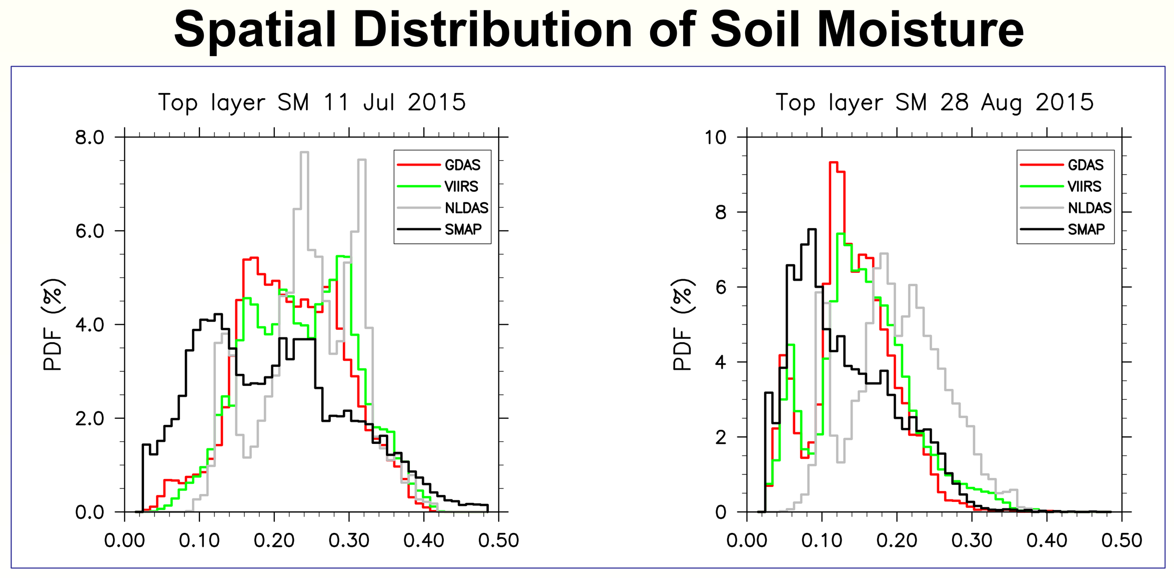


Figure 3. Spatial PDFs of the near-surface soil moisture plotted in Figs. 1 & 2 for the SMAP, LIS-Control, LIS-GDAS, and NLDAS-2 simulations on 11 July and 28 August 2015.

- The spatial distribution of near-surface soil moisture on 11 July tends to be bimodal due to a consistent antecedent precipitation gradient (NW-SE) over the region.
- The magnitude of the peaks depends on the precipitation forcing (GDAS – drier vs. NLDAS – wetter).
- SMAP is consistently drier than the models below 0.25 m3/m3, but comparable above 0.30.
- The spatial distribution on 28 August tends to be more normal with much drier peaks (~0.10) due to more uniform drying over the region by late-August.
- The operational NLDAS product is significantly wetter than the other model or observation products.

Evaluation at Little Washita

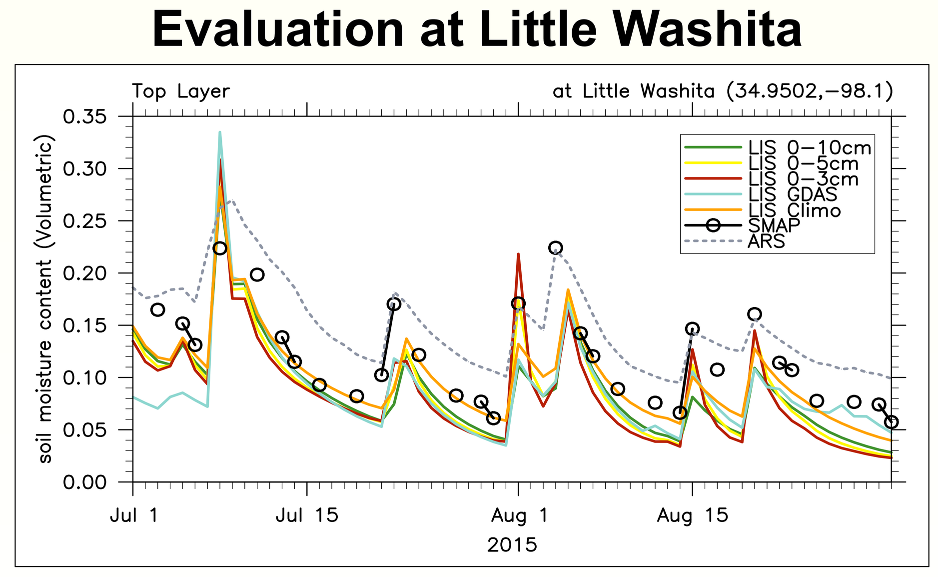


Figure 4. Time series of near-surface soil moisture at the Little Washita, OK site taken from SMAP and in-situ (ARS) observations and LIS-Control (0-10cm) and LIS simulations with the top soil layer modified to be thinner (5cm and 3cm).

- Precipitation events and drydown periods are captured well in each of the model and observation products.
- LIS is consistently drier than the in-situ (ARS; c. Mike Cosh) data regardless of the top layer thickness employed in the Noah LSM.
- SMAP performs quite well in terms of wetting events (peaks) and drydown shape, with observations every ~2 days.
- LIS and SMAP soil moisture and dynamics are similar, with LIS drying down more rapidly during dry periods in mid-late August.

Conclusions

- There is significant spread in soil moisture conditions, even for the same modeling system, based on forcing, parameter inputs, LSM version, and spatial resolution.
- SMAP now offers the ability to provide realistic near-surface soil moisture conditions at 9km resolution, and is comparable to model and in-situ products.
- The overall climatologies of soil moisture from varying model, satellite, and in-situ products still need to be reconciled, and should be a function wet vs. dry regime and wetting vs. drydown event.
- This suite of initialization approaches will be extended to include:
  - **a) LIS runs with SMAP data assimilation**
  - **b) LIS runs using SMAP to calibrate the Noah LSM**
- The full suite will then used to kick off 24h NU-WRF forecasts to evaluate their downstream and L-A coupling impacts.

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- •Santanello et al., 2016: Impact of Soil Moisture Assimilation on Land Surface Model Spinup and Coupled Land-Atmosphere Prediction. *J. Hydrometeor.*, 17, 517-540.
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- •Santanello et al., 2013: Diagnosing the Nature of Land–Atmosphere Coupling: A Case Study of Dry/Wet Extremes in the U.S. Southern Great Plains. *J. Hydromet*, 14, 3–24.

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