Impact of Satellite and Model-based Soil Moisture Initial Conditions on Coupled NU-WRF Simulations

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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:

'LoCo Process Chain' $\Delta SM \xrightarrow{(a)} \Delta EF \xrightarrow{(b)} \Delta PBL \xrightarrow{(c)} \Delta ENT \xrightarrow{(d)} \Delta T_{2m}, Q_{2m} \blacktriangleright \Delta P/Clouds$

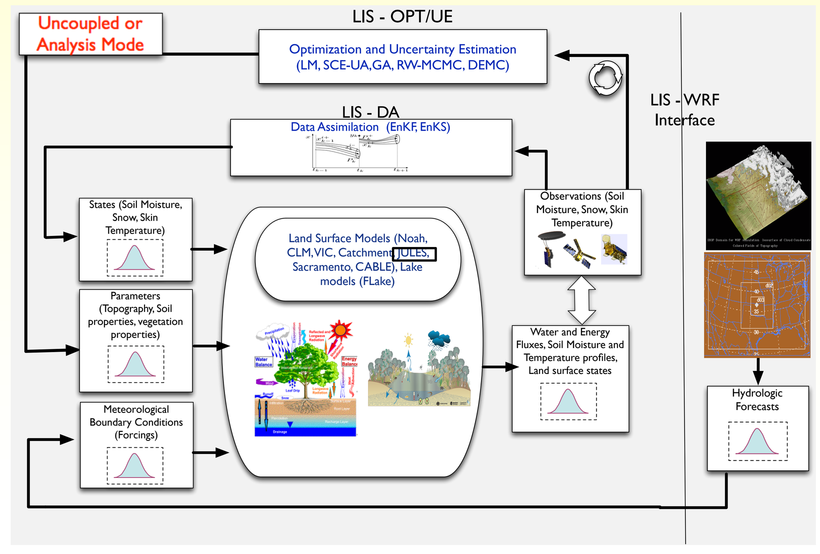
- **Impacts of soil moisture initial conditions** are therefore felt downstream during WRF forecasts.

- 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 2015
Domain: 1100x750 @ 1km over U.S. SGP
Observations: SMAP, ARM-SGP
Models: LIS-Noah (v3.3) LSM + NU-WRF

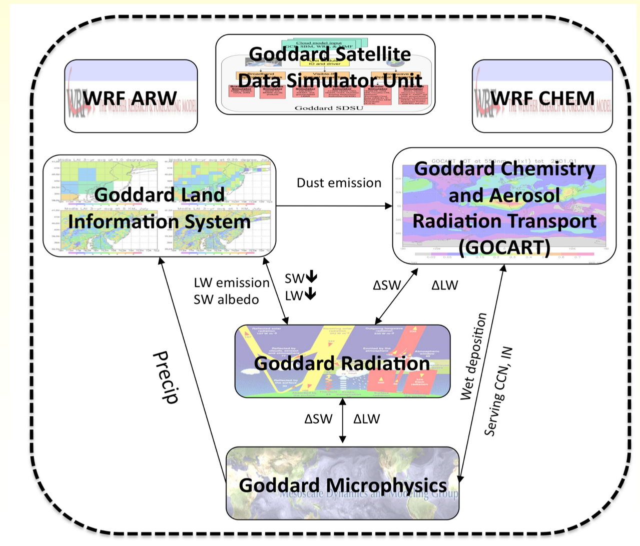
NASA's Land Information System (LIS)

- 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



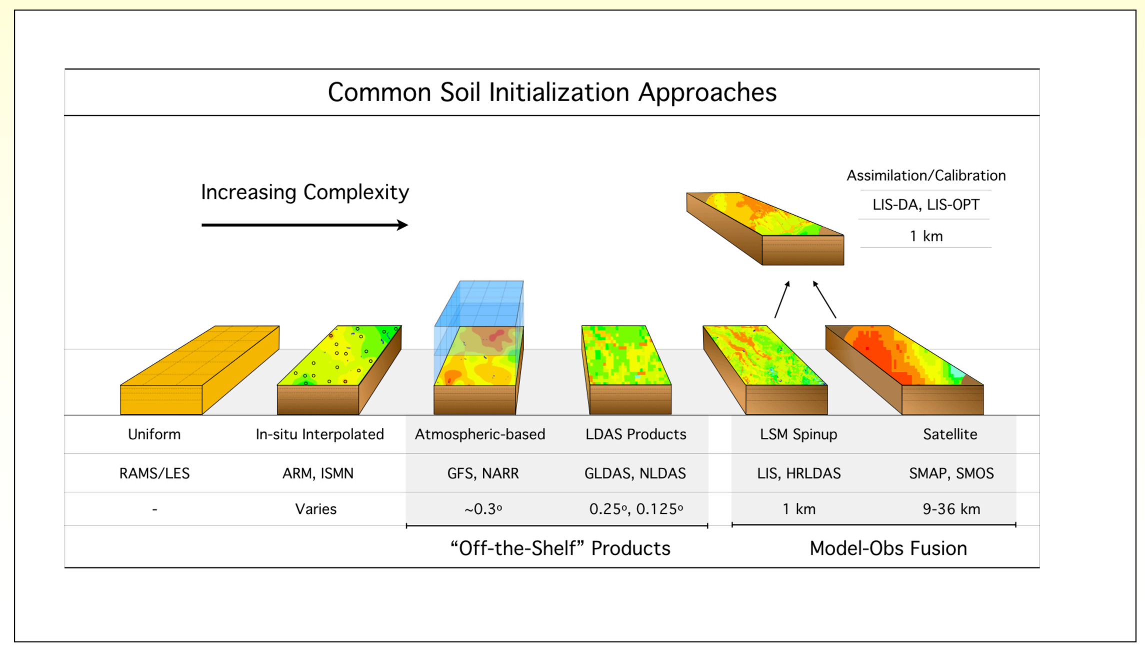
NASA Unified WRF (NU-WRF)

- 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

- Experimental Design
  - U.S. Southern Great Plains (TX, OK, KS, NE)
  - NASA's Land Information system (LIS) w/Noah LSM
  - Domain: 1100x750 @ 1km resolution
  - LIS spinup: 1 Jan 2011 - 31 Dec 2016
    - Control Run:
      - NLDAS-2 forcing
      - Climatological greenness (GVF)
    - Permutations:
      - Forcing (NLDAS-2 vs. GDAS)
      - GVF (Climatological vs. VIIRS)
      - Soil Layering (0-10cm, 0-5cm, 0-2cm)
- Datasets
  - SMAP L3 Enhanced (9km) product
  - ARM-SGP Data
    - EBBR/ECOR flux towers
    - STAMP soil moisture (2016-on)



- Three Phases:
  - **Part 1: Assess SMAP vs. LSM and in-situ soil moisture**
  - **Part 2: Intercompare a suite of soil moisture ICs for coupled WRF simulations**
  - **Part 3: Understand L-A coupling influence on 2-meter T, q statistics**

Initialization Source	Forcing	GVF
LIS (Control)	NLDAS-2	Climatology
LIS (GDAS)	GDAS	VIIRS
LIS (GVF)	NLDAS-2	VIIRS
NLDAS	NLDAS-2	Climatology
WRF	NARR	Climatology
WRF	GFS	Climatology
SMAP-NARR	NARR	-
SMAP-NLDAS	NLDAS-2	-

SMAP vs. LSM vs. In-situ Intercomparison

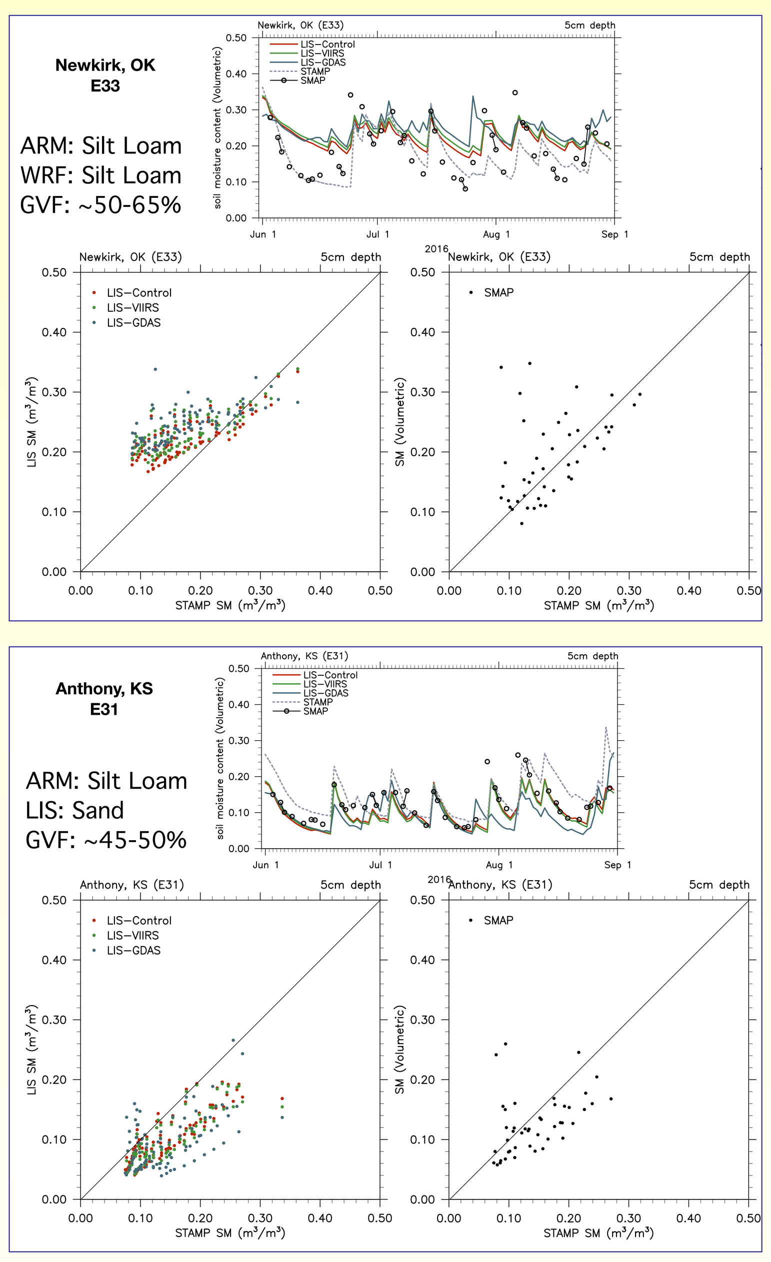


Figure 1. Time series and scatterplots of near-surface soil moisture from SMAP L2 enhanced product retrievals, LIS offline spinup simulations, and in-situ STAMP measurements at two ARM-SGP sites (E33 and E31) during JJA 2016, **showing the strong agreement of SMAP and in-situ measurements in terms of dynamic range and drydown behavior. LIS produces consistently higher soil moisture at E33 (top), which only match observations at E31 (bottom) due to artificially enhanced soil drying due to 'sand' soil type specification.**

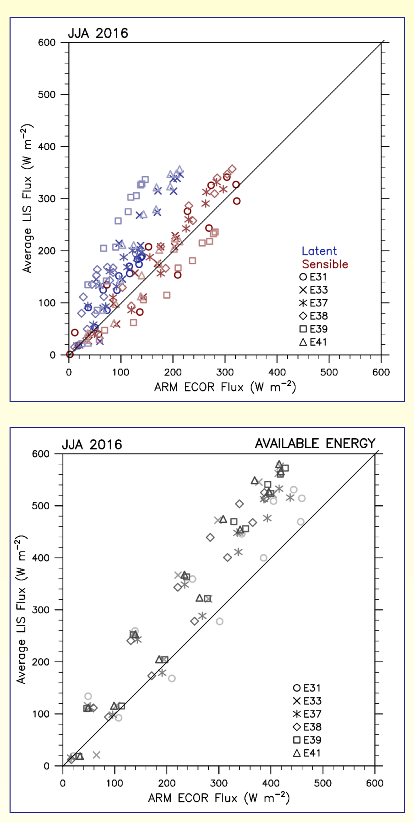


Figure 2. Mean diurnal cycle sensible and latent heat fluxes (in-situ vs. LIS) over the JJA 2016 period and 8 ARM-SGP sites, **showing the overestimation of latent heat flux and available energy in the LIS simulations, consistent with the higher soil moisture of LIS in Fig. 1 (top).**

Soil Moisture Initialization

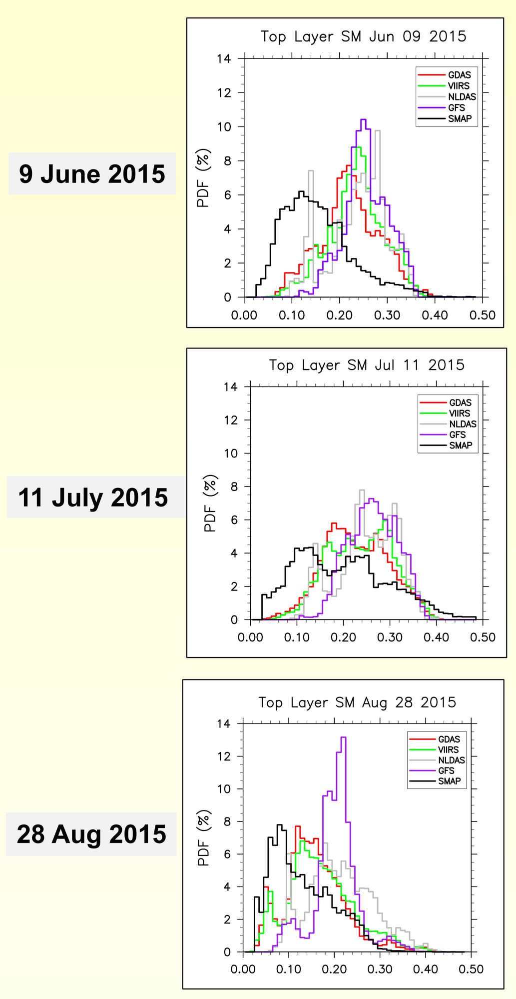


Figure 4. Spatial PDFs of the near-surface soil moisture plotted in Fig. 1 on 9 June, 11 July and 28 August 2015, **showing the tendency for SMAP to be driest especially for dry conditions, and global, coarse products to be considerably wetter.**

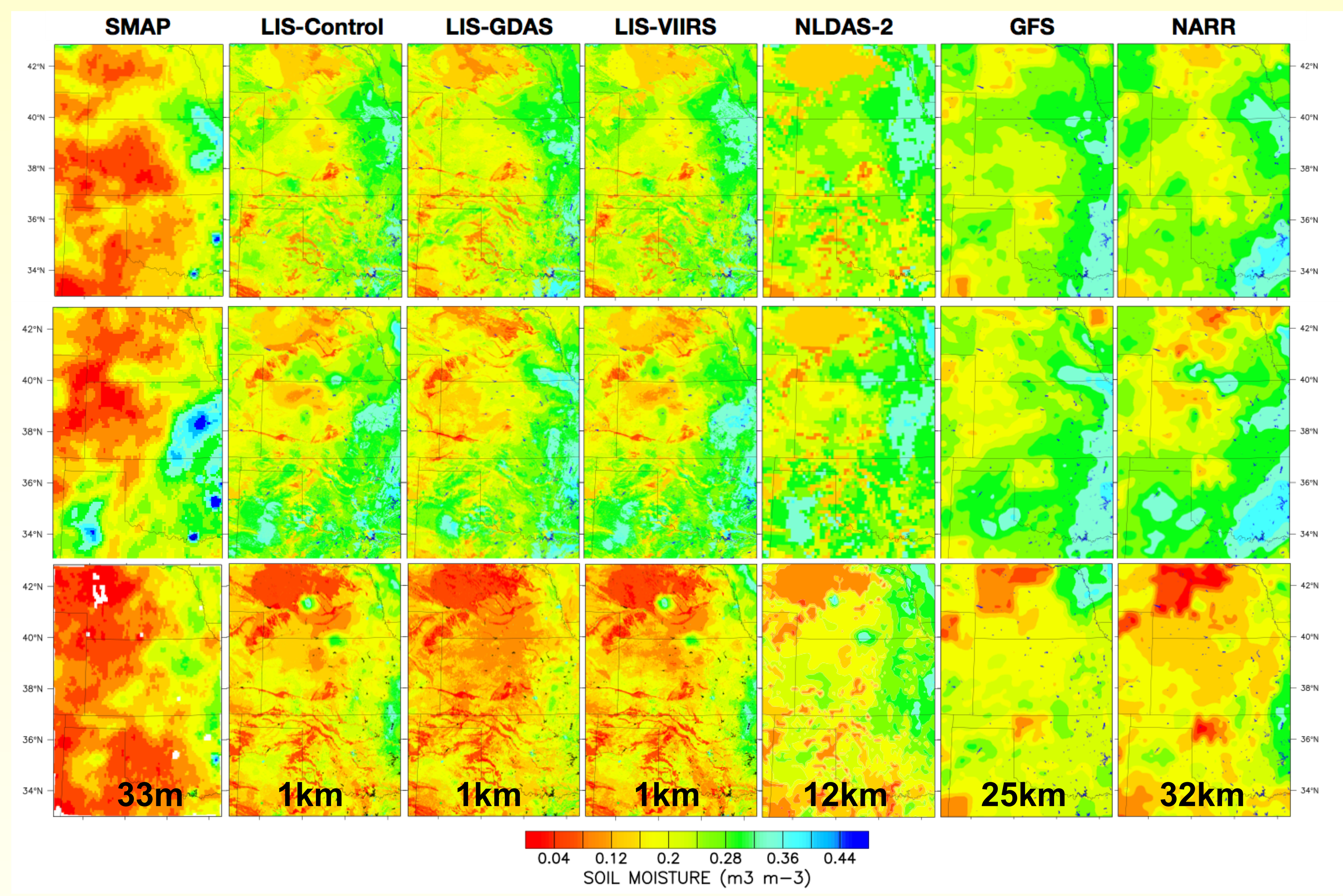


Figure 3. Near-surface soil moisture June 9, July 11, and August 28, 2015 at 12Z (morning) from **a)** the SMAP L3, 9km soil moisture product, and the array of LIS 5-year spinups using the Noah v3.6 LSM including the **b)** Control Run (NLDAS-2 forcing and VIIRS GVF), **c)** GDAS forcing, **d)** GVF Climatology, along with that from the **e)** operational NLDAS-2 product, **g)** default GFS atmospheric-based initialization, and **f)** NARR Reanalysis each using the Noah v.2.7.1 LSM.

LoCo Mixing Diagram Analysis

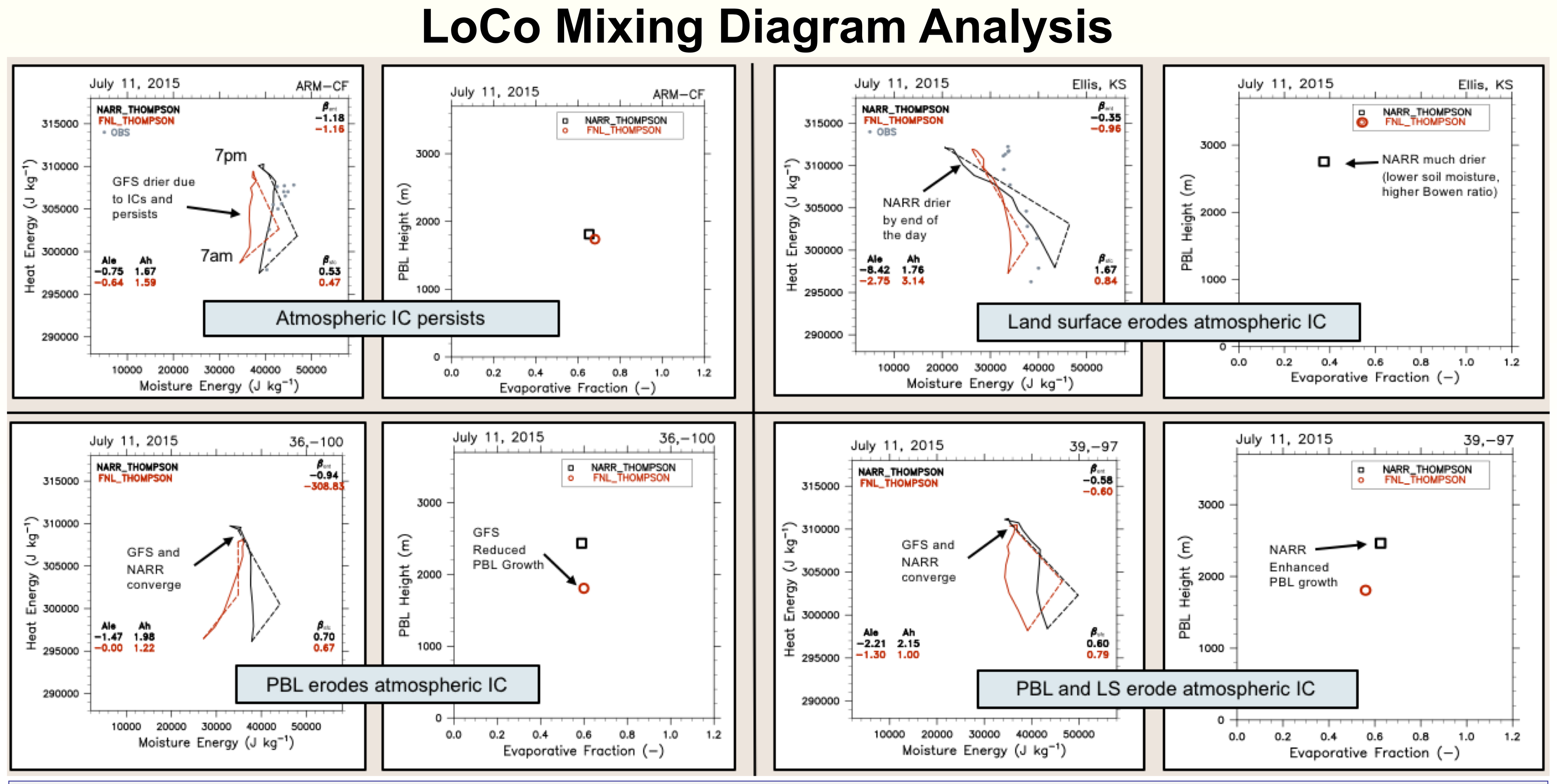


Figure 5. Mixing diagrams and evaporative fraction vs. PBL height relationship at 4 ARM-SGP sites from NU-WRF simulations with NARR vs GFS initial conditions. **The CF site (top left) shows a dry bias in GFS IC humidity relative to NARR that persists throughout the day because of their similar land and PBL characteristics. Ellis, KS (top right) shows the same GFS IC bias, but is eroded due to a much drier soil moisture IC and lower evaporative fraction in NARR. The site on the lower left shows the GFS IC bias erodes by the end of the day due to a more moist PBL in GFS, and the lower right shows the GFS bias eroded by a combination of PBL moisture in GFS and enhanced PBL growth in NARR.**

Impact on Ambient Weather Prediction

- These traditional NWP measures of forecast skill can be better interpreted through the lens of the LoCo process chain, and how soil moisture impacts the coupled system downstream through surface fluxes and PBL growth.
- In this case, GFS and NLDAS perform best in terms of temperature due to their wetter soil moisture (Figs. 1,2), and the SMAP initialized runs are worst due to inserting very dry soil moisture into an already dry coupled system.

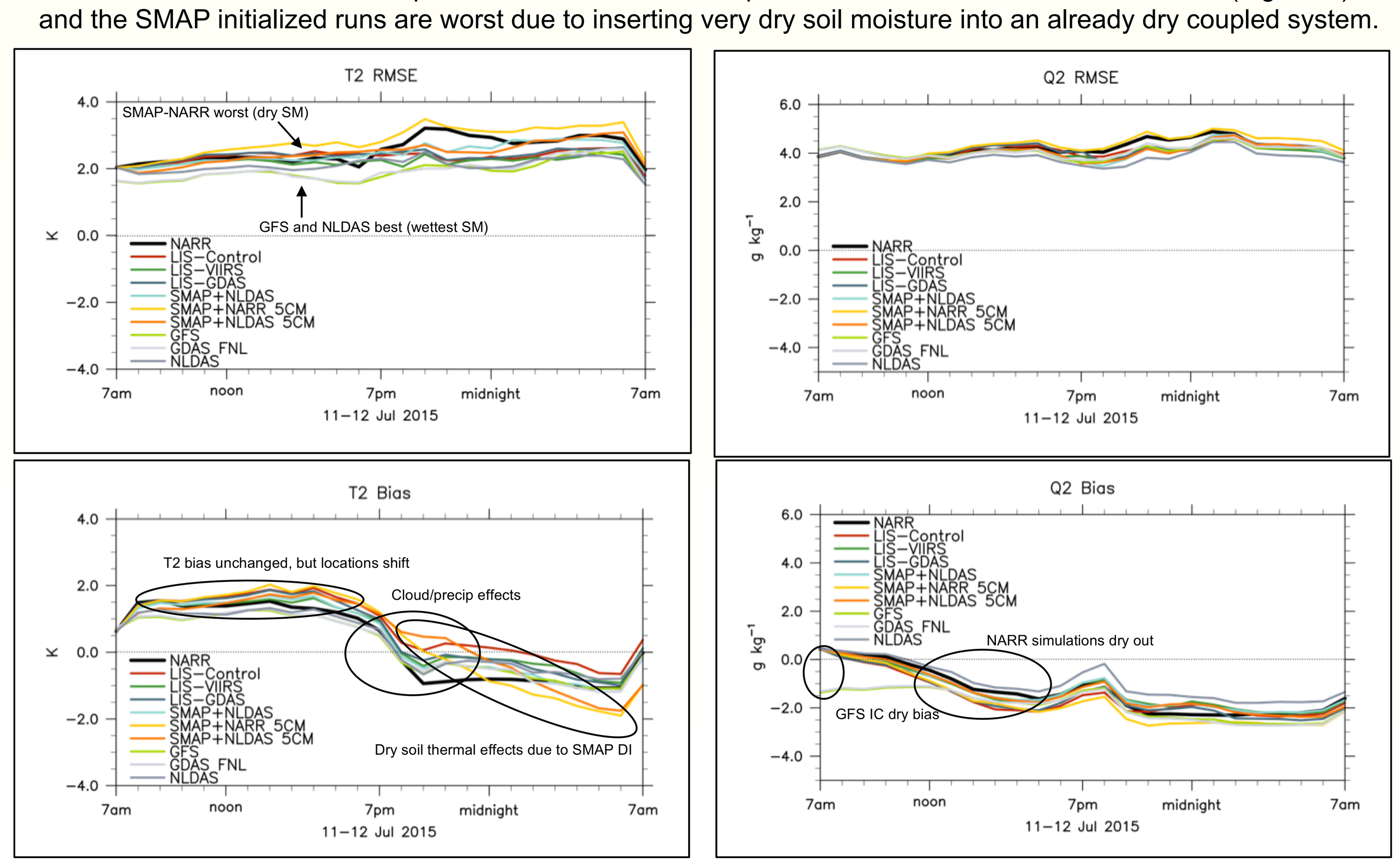


Figure 6. Statistics of 2-meter temperature and humidity (RMSE and bias) from each of NU-WRF soil moisture IC simulations on 11 July, 2015 averaged over 90 met stations across the ARM-SGP domain

Conclusions

- SMAP now offers the ability to provide realistic near-surface soil moisture conditions at 9km resolution, and performs well in terms of capturing spatial heterogeneity, dynamic range and drydown behavior.
- There is significant spread in soil moisture initialization approaches in NWP that should not be ignored, and has significant implications on L-A coupling and ambient weather.
- Bulk impacts on Fx statistics are not always straightforward or systematic, involve complex L-A feedbacks
  - ▸ Any improvement in prediction (T, RH, Precip) can be the right answer for wrong (or unknown) reasons
  - ▸ Positive impacts of soil moisture or other land/LSM developments may be diminished due to atmospheric ICs and inherent issues in the coupled model
  - ▸ Any degradation in prediction can be the wrong answer for the right reasons (e.g. improved LSM)

•**Santanello et al., 2018: Land-Atmosphere Interactions: The LoCo Perspective.** *Bulletin of the American Meteorological Society,* June 2018.

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