Impact of Soil Moisture Initial Conditions Derived from Models and Observations on Short-Term Weather Prediction

Joseph Santanello, Patricia Lawston, Sujay Kumar, and Eli Dennis

NASA-GSFC
Hydrological Sciences Laboratory

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Motivation

- The complexity of land-atmosphere (L-A) interactions can be synthesized into simple processes chain of **Local L-A Coupling ('LoCo')**:

'LoCo $\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m}$ ▶ $\Delta P/Clouds$' Process Chain'

(a) (b) (c) (d)

- Overarching Goal: Better understand the how/why of soil moisture impacts on NWP via understanding links in the LoCo process-chain.

- 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**

LAND–ATMOSPHERE INTERACTIONS

The LoCo Perspective

JOSEPH A. SANTANELLO JR., PAUL A. DIRMEYER, CRAIG R. FERGUSON, KIRSTEN L. FINDELL, AHMED B. TAWFIK, ALEXIS BERG, MICHAEL EK, PIERRE GENTINE, BENOIT P. GUILLOD, CHIEL VAN HEERWAARDEN, JOSHUA ROUNDY, AND VOLKER WULFMEYER

Metrics derived by the LoCo working group have matured and begun to enter the mainstream, signaling the success of the GEWEX approach to foster grassroots participation.

The role of land–atmosphere (L-A) interactions in weather and climate prediction has emerged over the last two decades as important but inherently challenging and complex. One reason is that L-A interaction research has proceeded "in reverse" compared to most science. Typically in Earth system sciences, observations inform theory, which then leads to the development and gradual refinement of conceptual and numerical models based on elucidated physical processes. The benchmark for such models' success, and the progress of the underlying science, is when they begin to consistently outperform purely statistical approaches inherently not based in the representation of physical processes (Best et al. 2015).

Conversely, coupled L-A (i.e., weather and climate) models arose well before the theoretical basis for

AFFILIATIONS: SANTANELLO—Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland; DIRMEYER—Center for Ocean–Land–Atmosphere Studies, George Mason University, Fairfax, Virginia; FERGUSON—Atmospheric Sciences Research Center, University at Albany, State University of New York, Albany, New York; FINDELL—Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey; TAWFIK—National Center for Atmospheric Research, Boulder, Colorado; BERG—Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey; EK—National Centers for Environmental Prediction, College Park, Maryland; GENTINE—Earth and Environmental Engineering, Columbia University, New York, New York; GUILLOD—Institute for Environmental Decisions, and Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland; VAN HEERWAARDEN—Meteorology and Air Quality Group, Wageningen University, Wageningen, Netherlands; ROUNDY—Civil, Environmental and Architectural Engineering, University of Kansas, Lawrence, Kansas; WULFMEYER—Institute of Physics and Meteorology, University of Hohenheim, Stuttgart, Germany
CORRESPONDING AUTHOR: Dr. Joseph A. Santanello Jr., joseph.a.santanello@nasa.gov

The abstract for this article can be found in this issue, following the table of contents.
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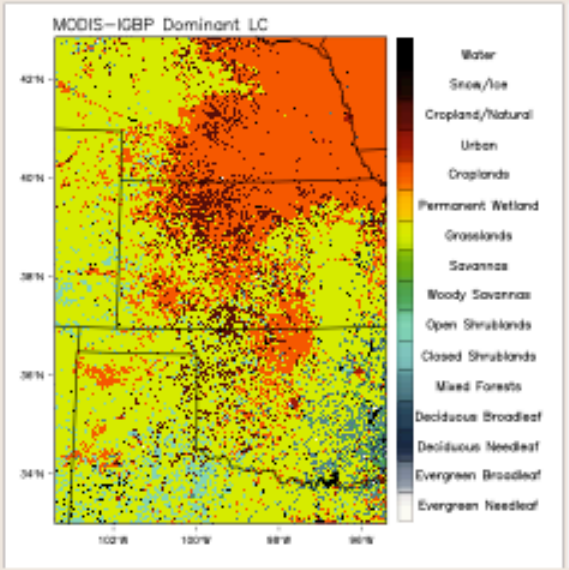
Santanello, J. A., et al. (2018): **Land-Atmosphere Interactions: The LoCo Perspective**. *Bulletin of the American Meteorological Society*, June 2018 (in press).

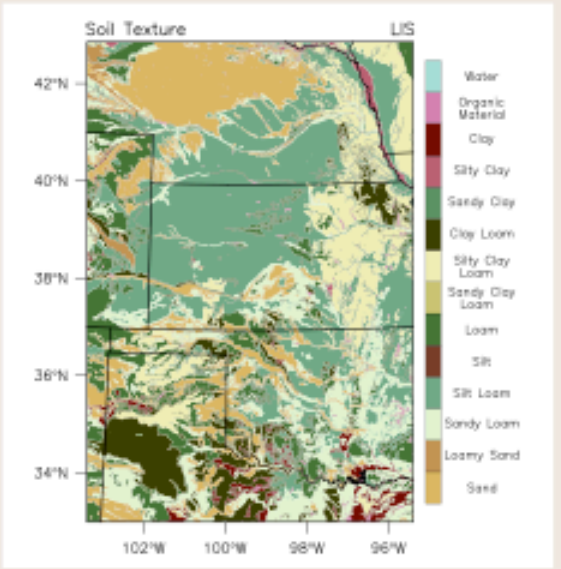
Part 1: Explore SMAP Soil Moisture Products

> **Understand the behavior and variability of SMAP soil moisture retrievals and their relationship to offline LSM output and in-situ data.**

- 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)



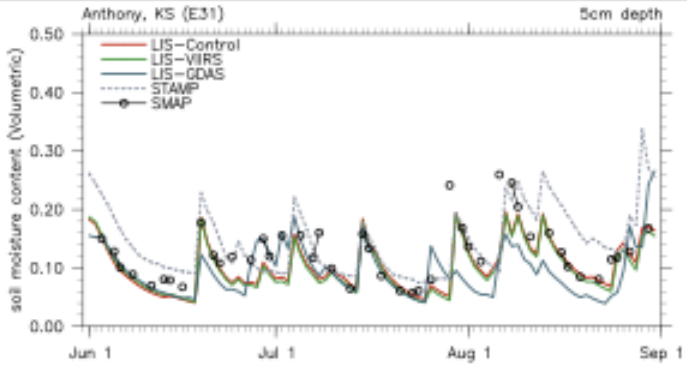


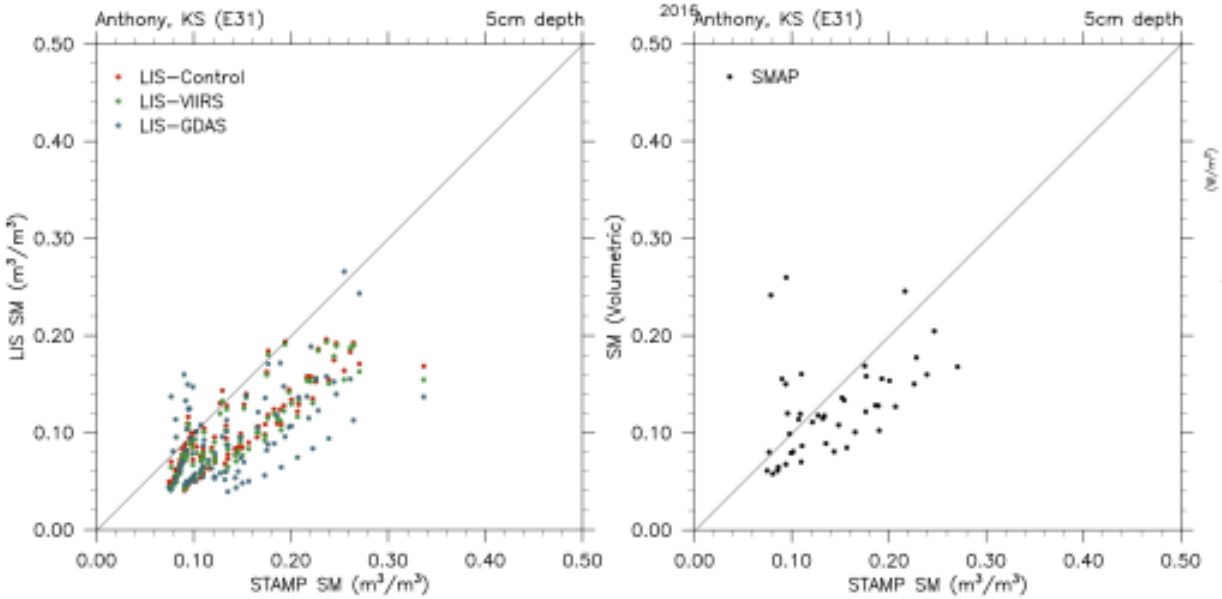
SMAP vs. LSM vs. In-situ Soil Moisture & Fluxes

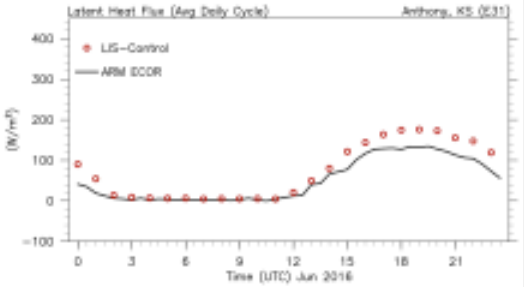
**Shellito et al:
12pm Thursday

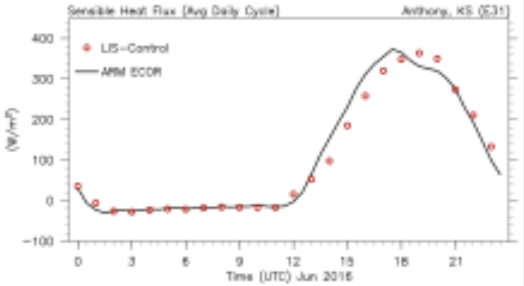
Anthony, KS
E31

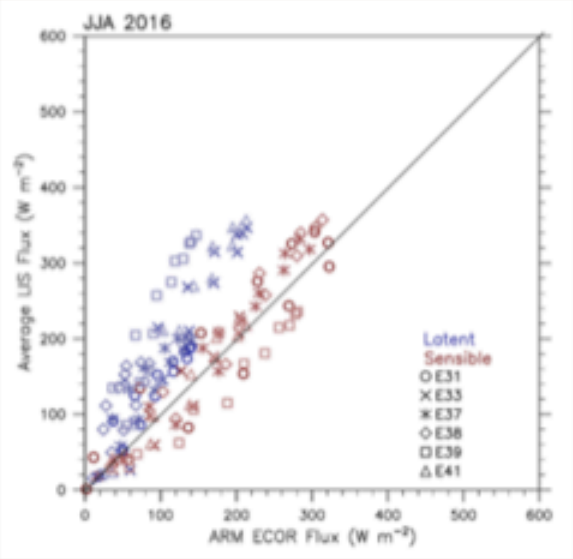
ARM: Silt Loam
LIS: Sand
GVF: ~45-50%

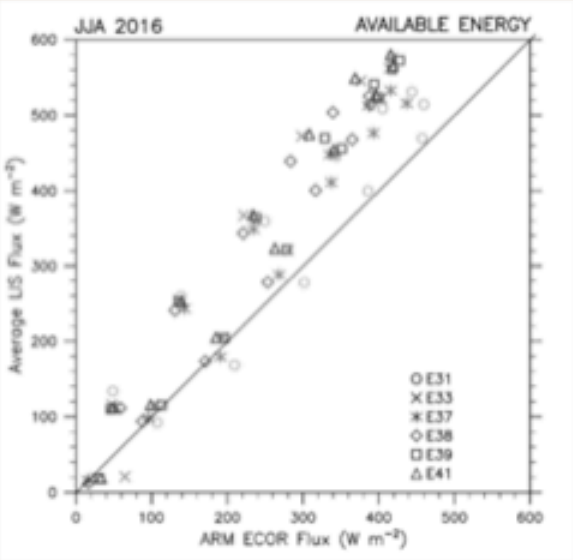






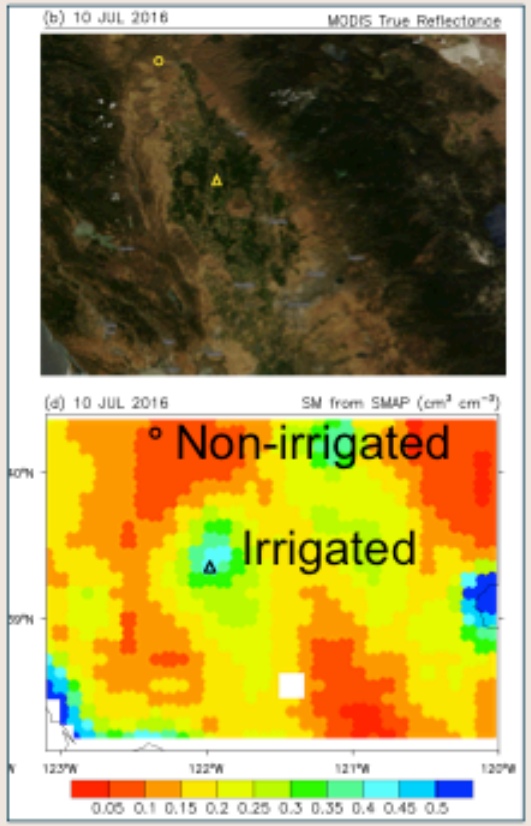


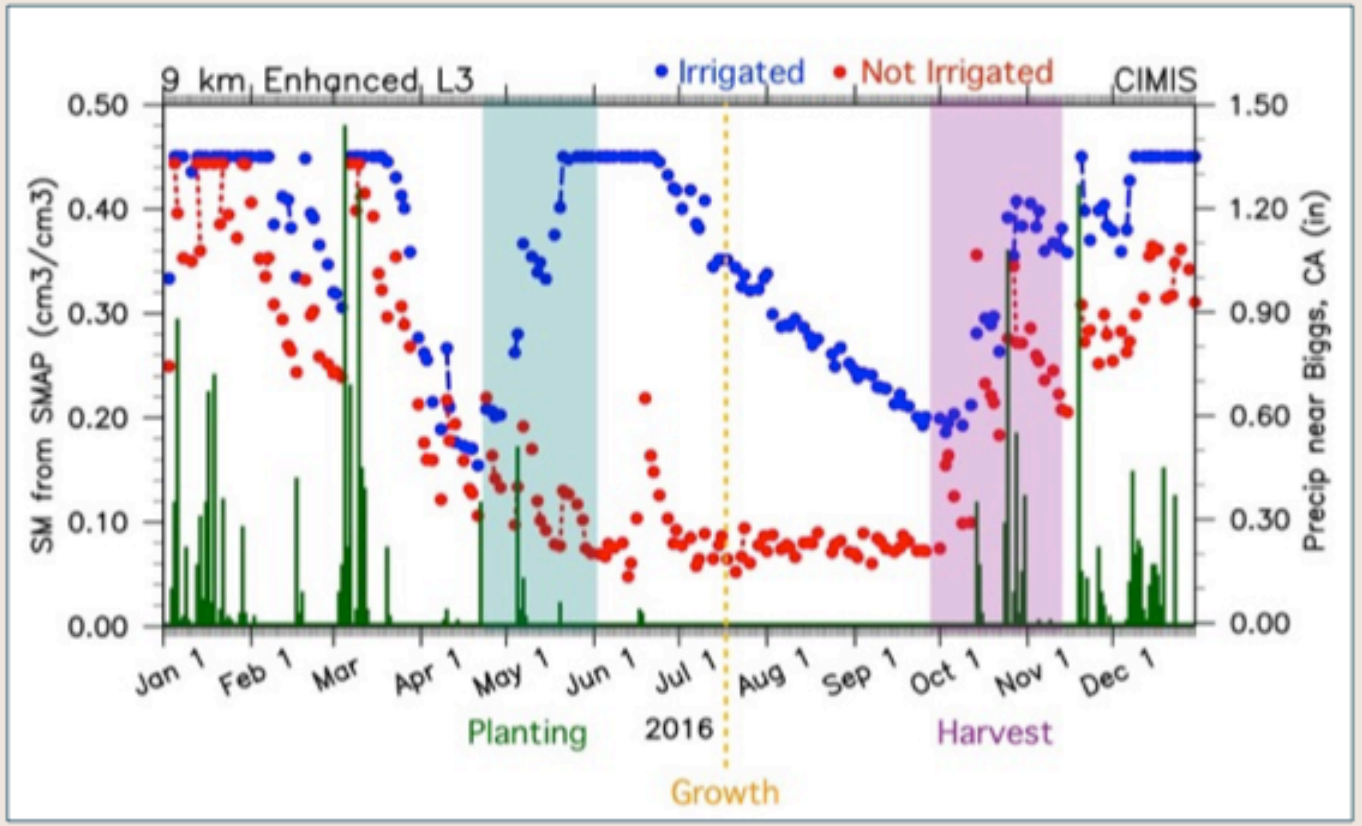


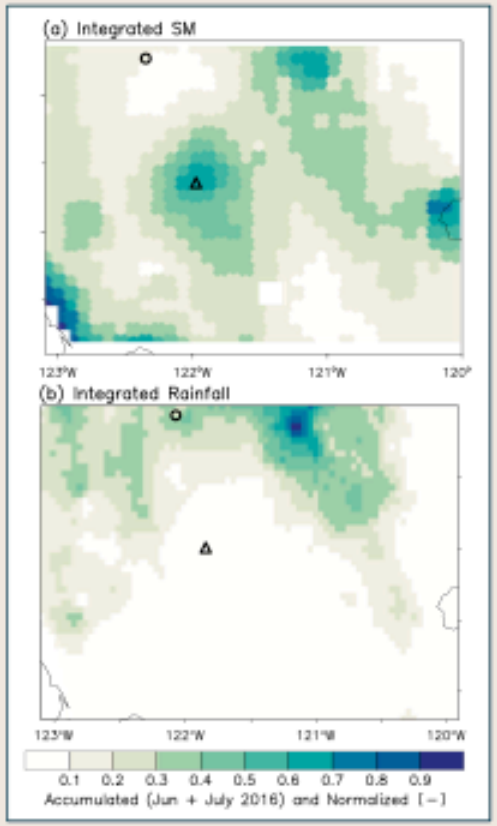


Irrigation Detection

**Lawston et al:
Poster Session 3
on Wednesday







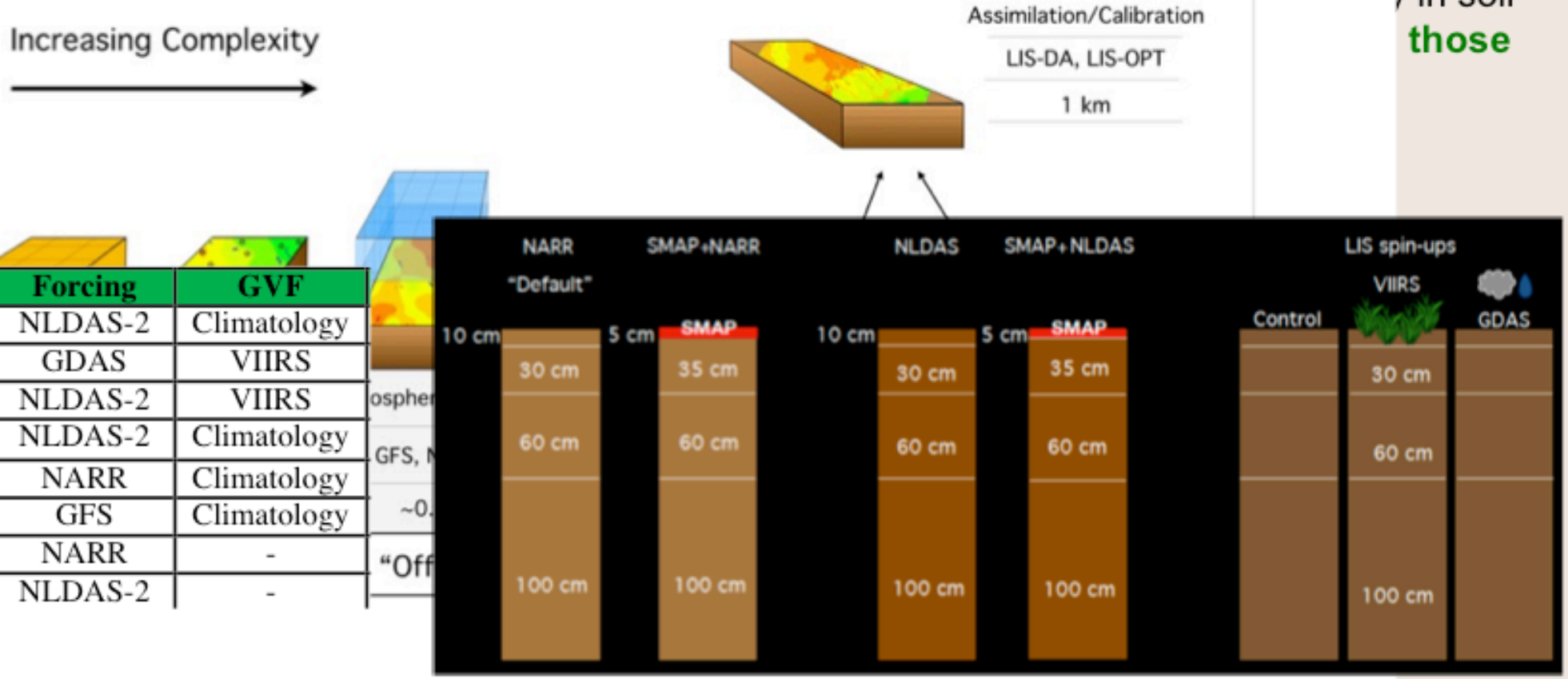
- To date irrigation detection from satellite has proven difficult even over well known, expansive regions
- SMAP Enhanced SM can detect irrigation timing and areal extent in three, semi-arid regions

Lawston, P. M., Santanello, J. A., Jr, & Kumar, S. V. (2017). **Irrigation signals detected from SMAP soil moisture retrievals.** Geophysical Research Letters, 44. https://doi.org/10.1002/2017GL075733

Part 2: Impacts of Soil Moisture ICs on NWP

- Impac… / in soil
  downs… those

Common Soil Initialization Approaches

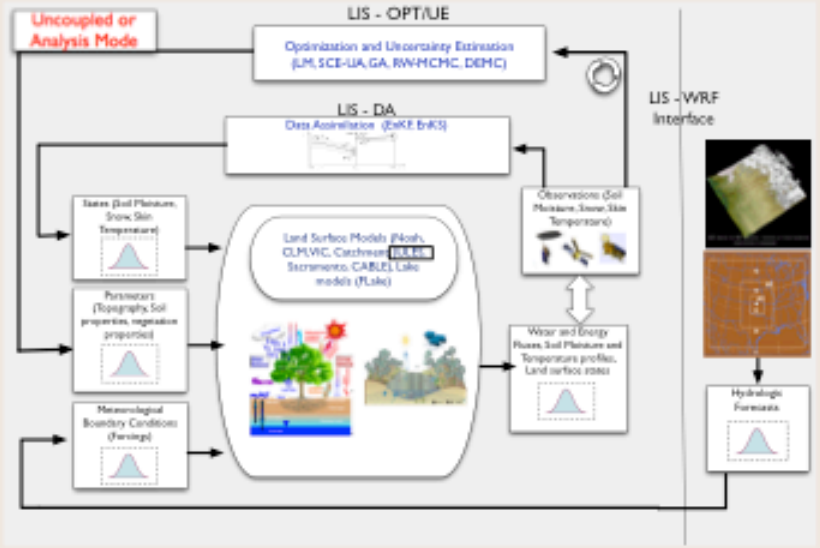


Initialization Source	Forcing	GVF
LIS (Control)	NLDAS-2	Climatology
LIS (GDAS)	GDAS	VIIRS
LIS (GVF)	NLDAS-2	VIIRS
NLDAS	NLDAS-2	Climatology
WRF	NARR	Climatology
WRF	GFS	Climatology
SMAP-NARR	NARR	-
SMAP-NLDAS	NLDAS-2	-

Modeling Tools & Experimental Design

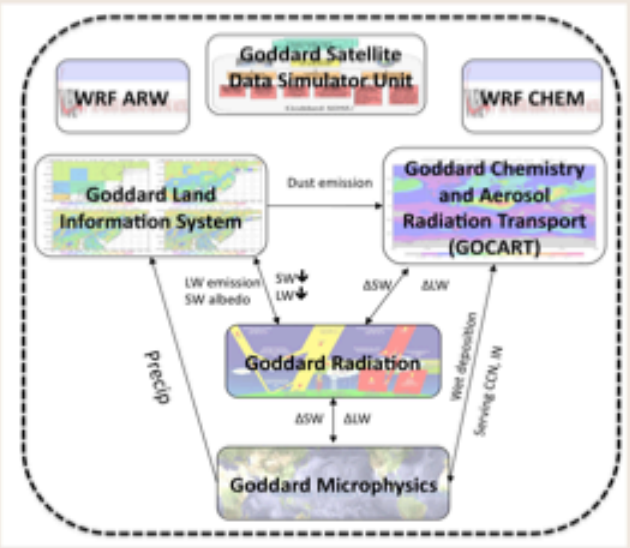
NASA's Land Information System (LIS)

- 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

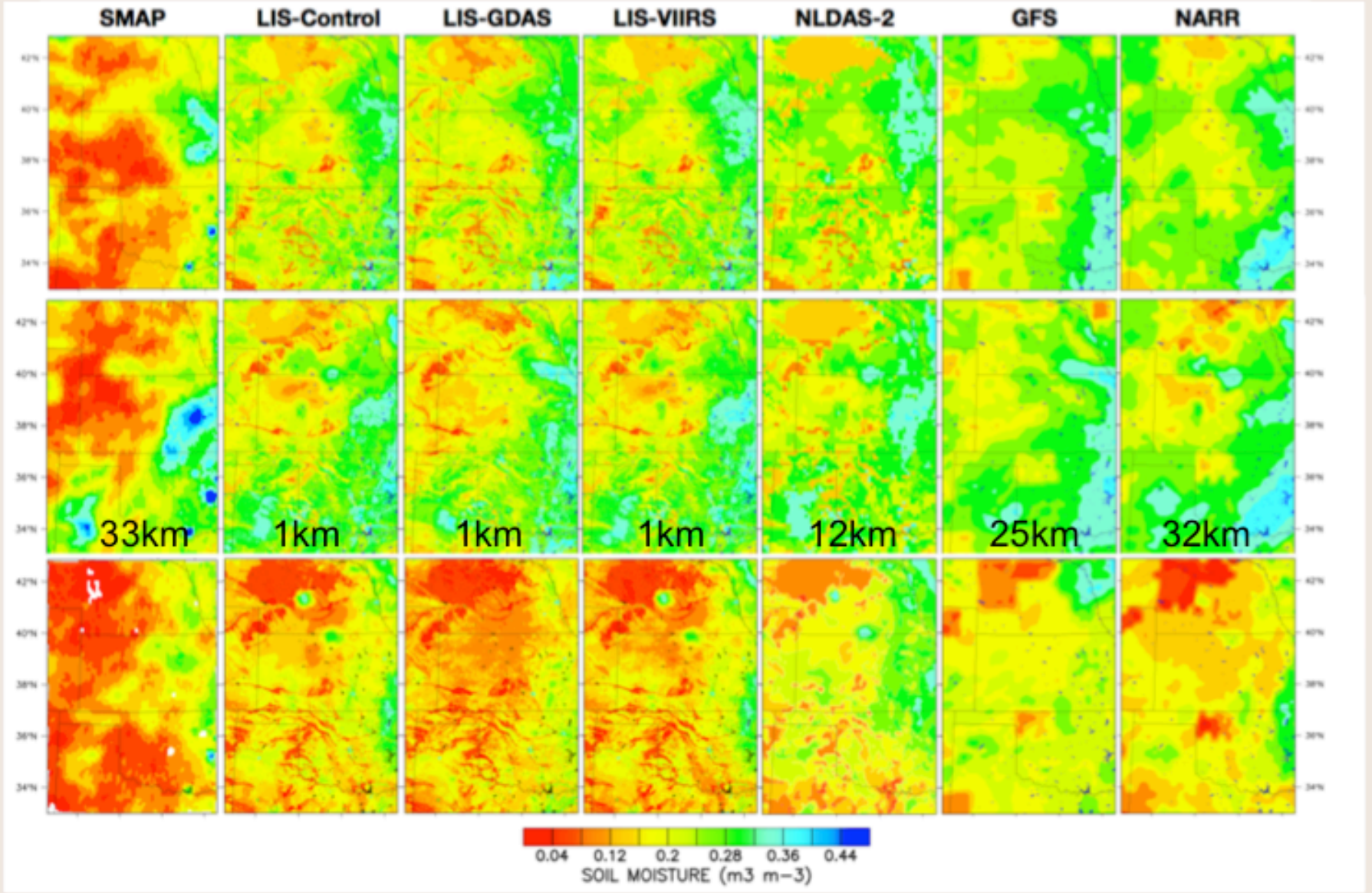


NASA Unified WRF (NU-WRF)

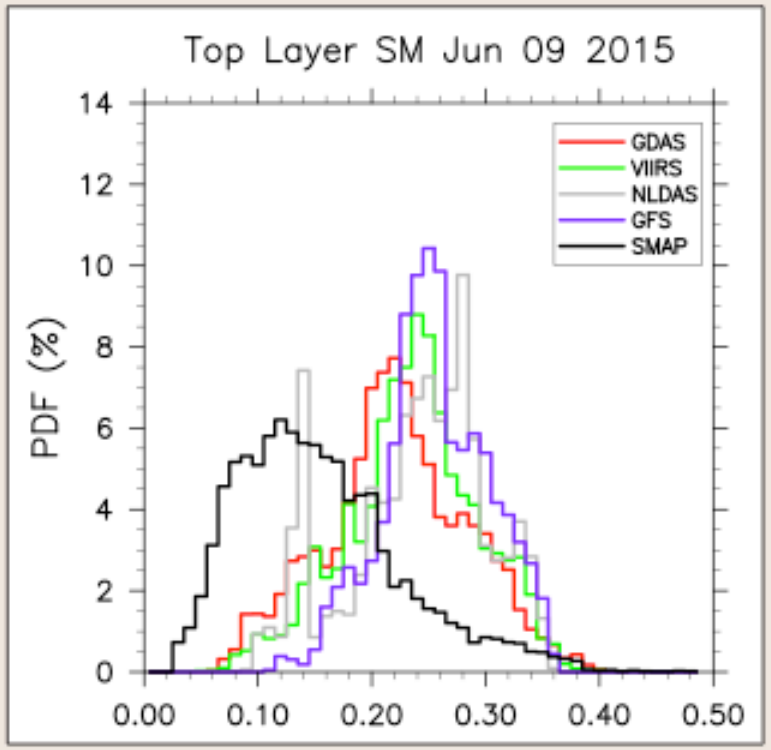
- Provides an ***observation-driven, integrated modeling system*** that represents aerosol, cloud, precipitation and land processes *at* ***satellite-resolved scales*** (1-4 km)
- Integrate unique NASA observation and modeling assets under one roof:
  - Satellite Data
  - Model Physics
  - Expertise/Software



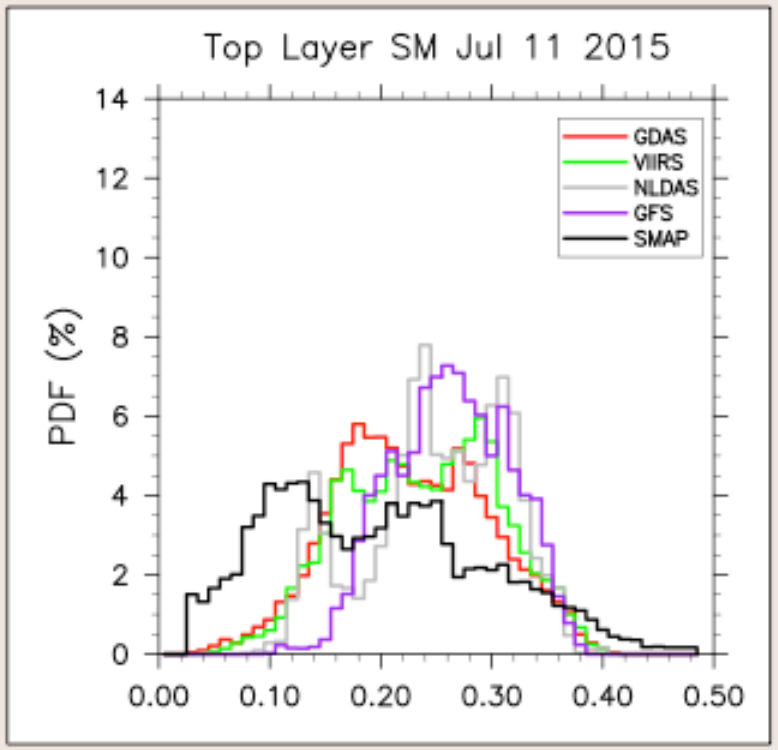
Soil Moisture Initialization



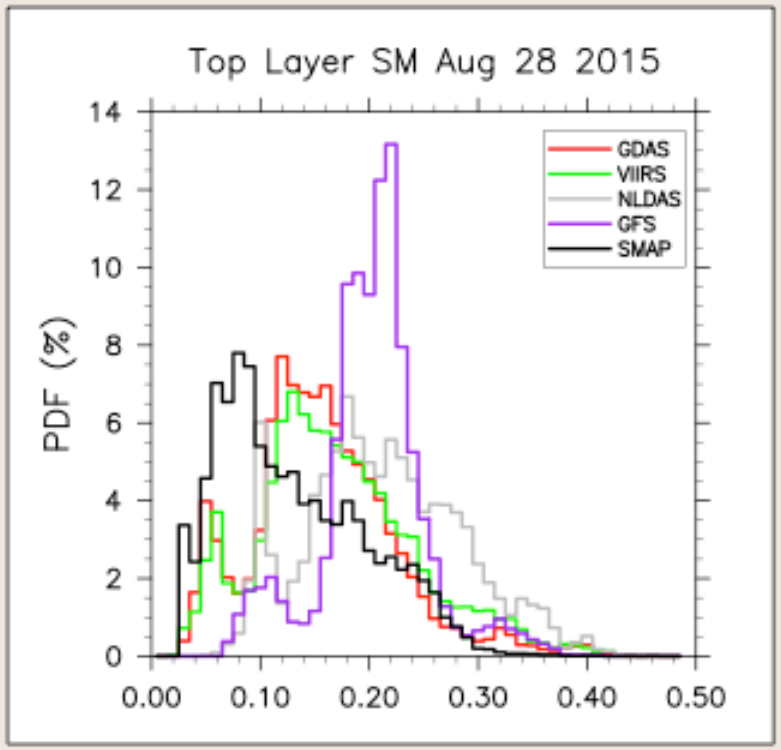
Spatial Distribution of Soil Moisture



- SMAP tends to be drier than the model, especially at lower soil moisture regimes (<0.15 volumetric).

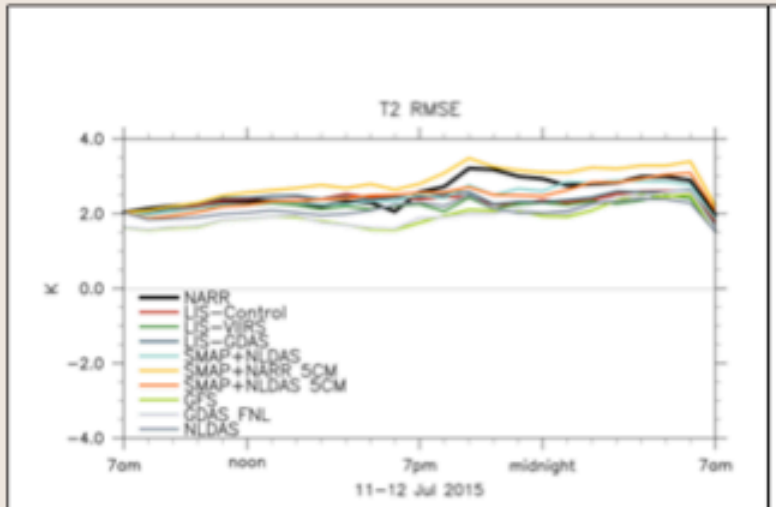


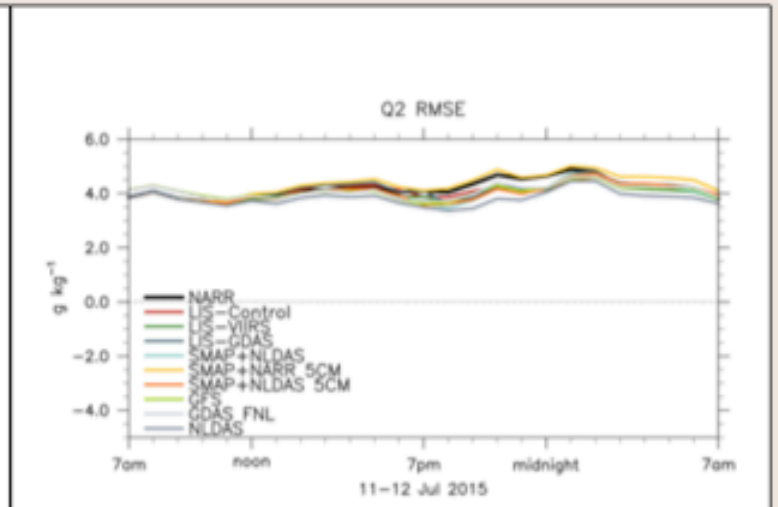
- Bimodal distribution due to antecedent precipitation gradient (NW-SE) over the region, except for GFS.

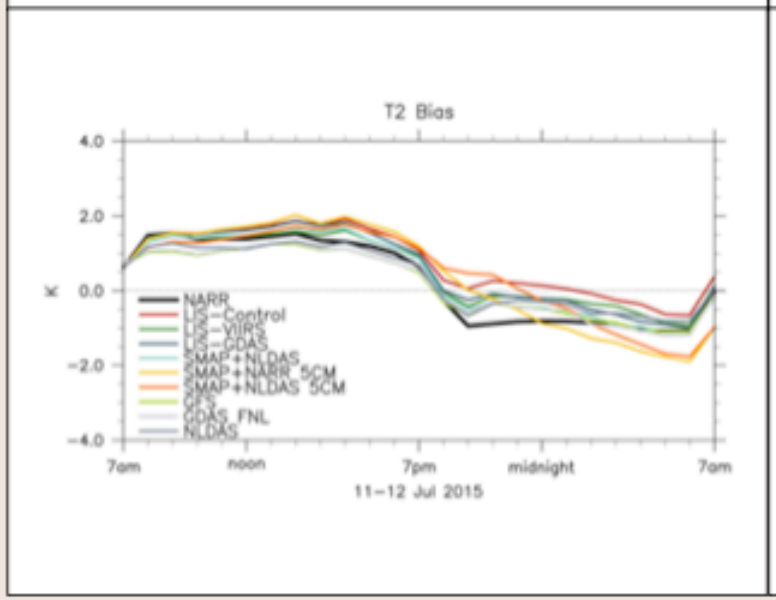


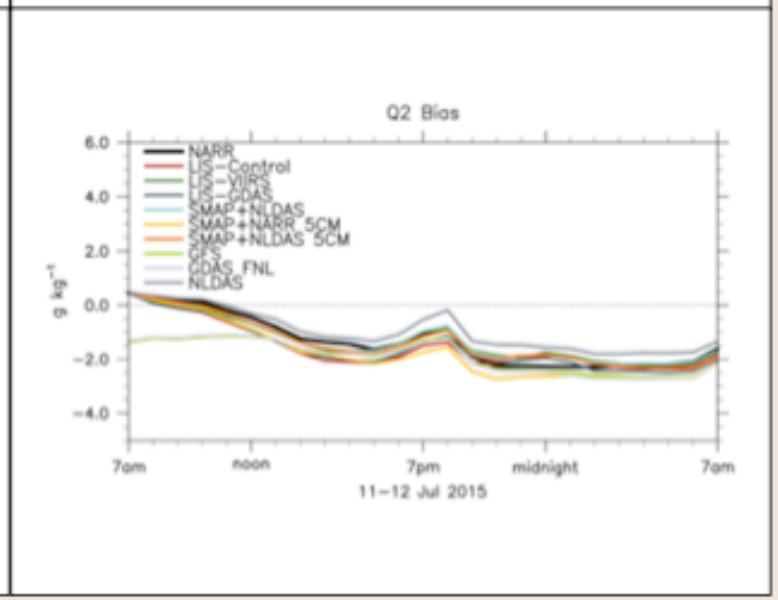
- The operational NLDAS and GFS products are significantly wetter than the other LIS runs or SMAP.

Part 3: L-A Coupling Influence on Ambient Weather

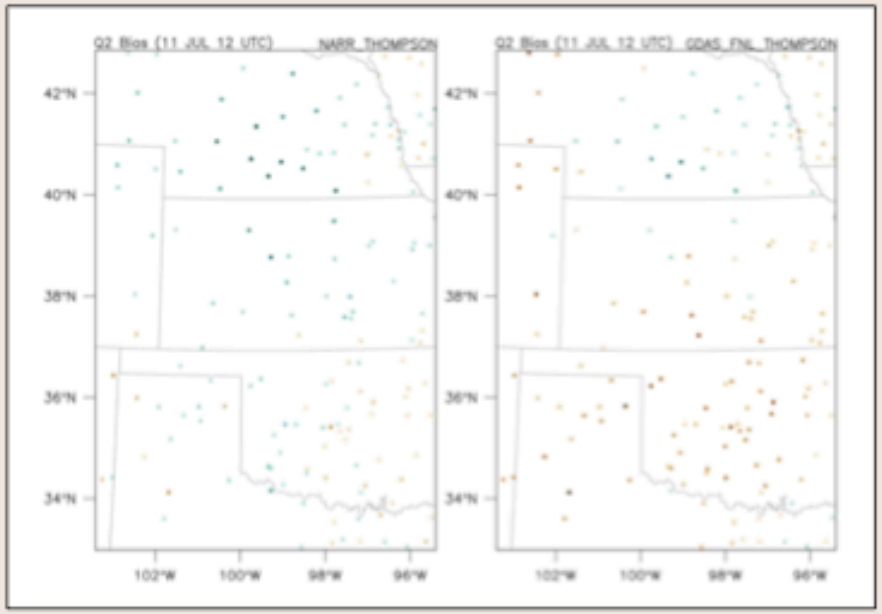






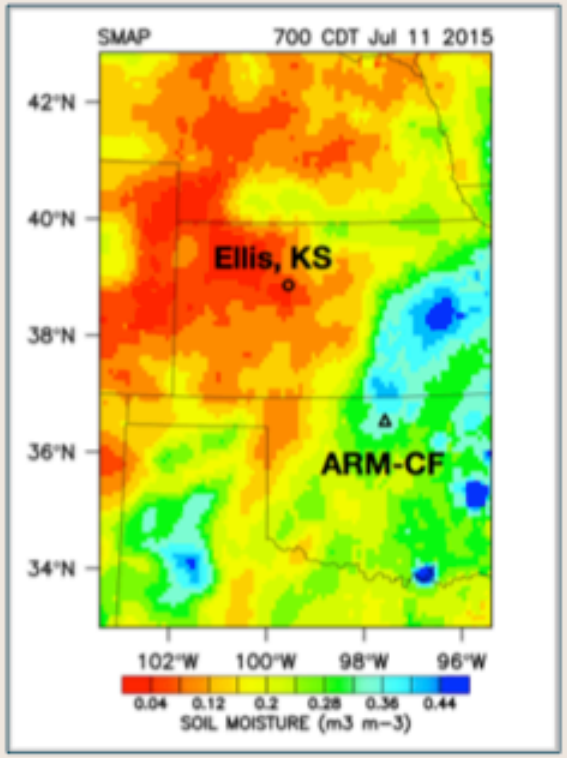


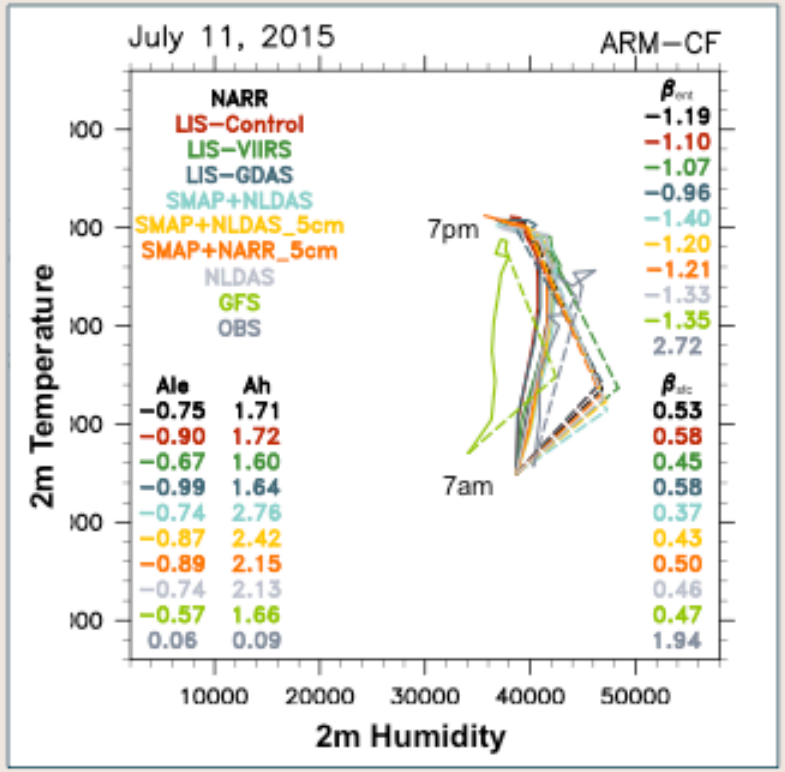
MET Verification Sites

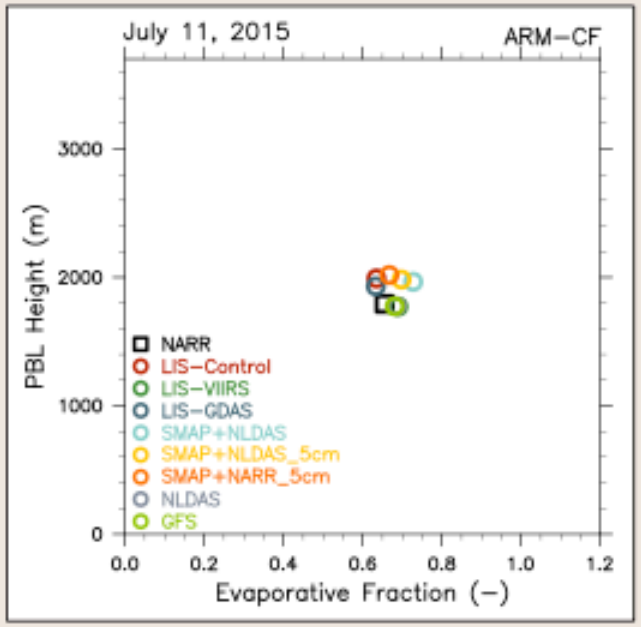


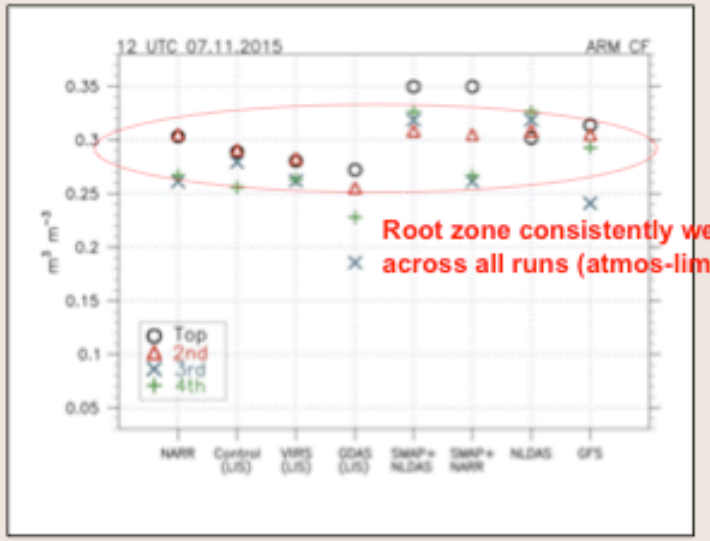
Mixing Diagram Analysis

Mixing Diagrams show integrated impacts of ICs on local coupling



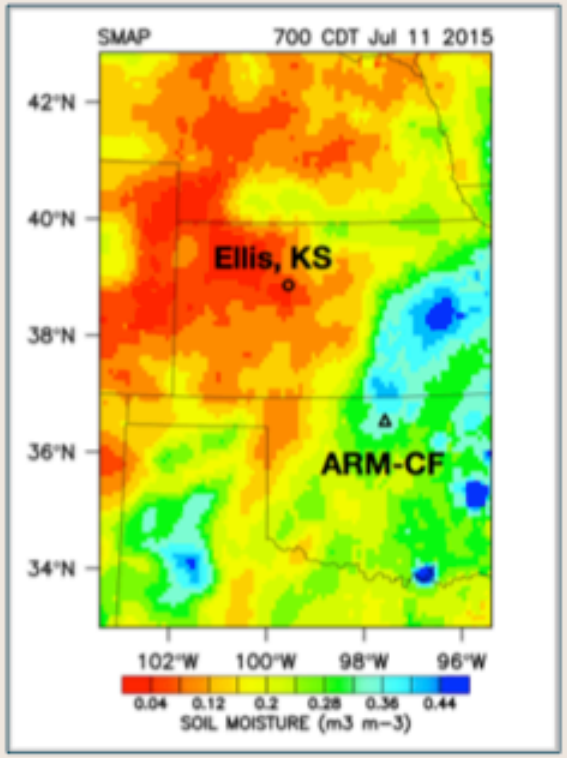


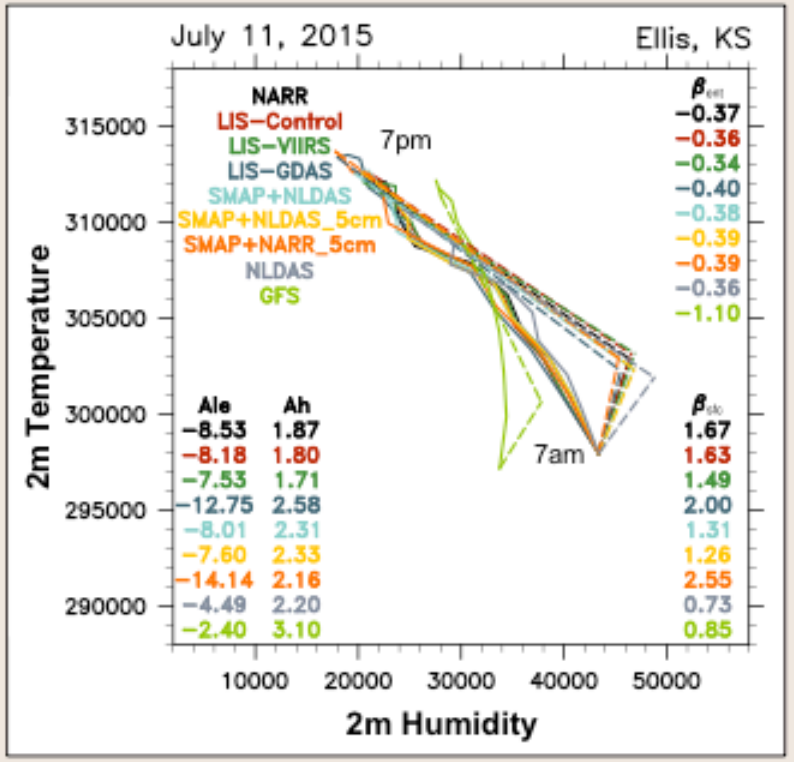


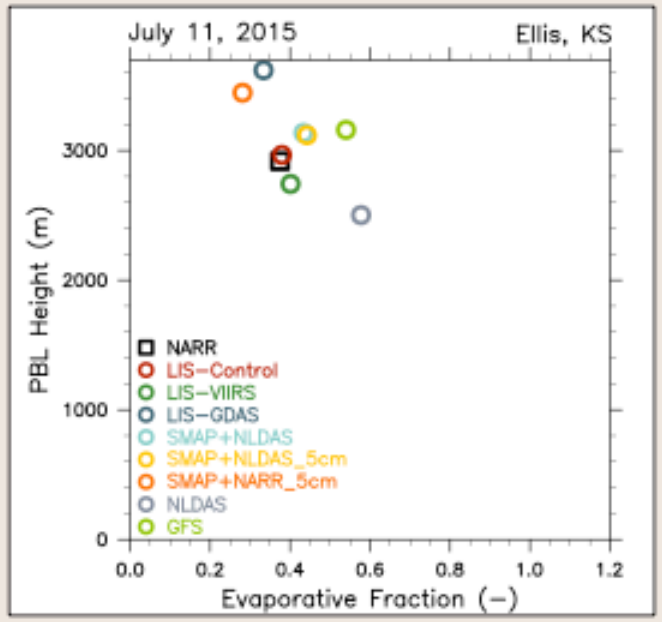


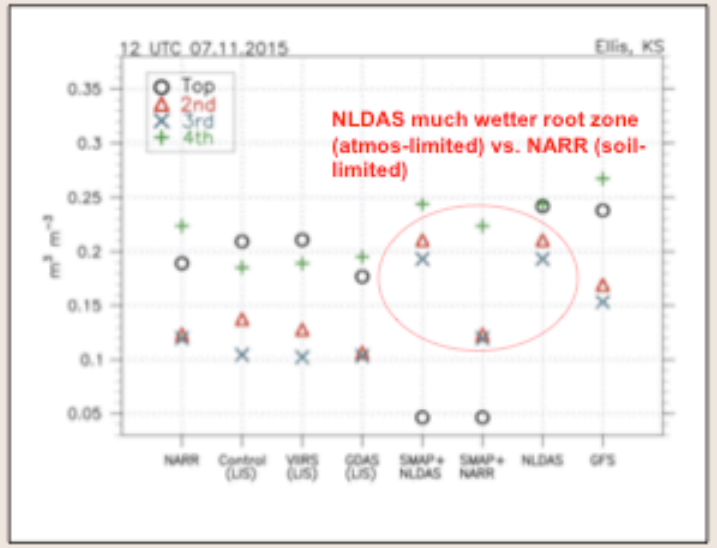
Root zone consistently wet across all runs (atmos-limited)

Mixing Diagram Analysis



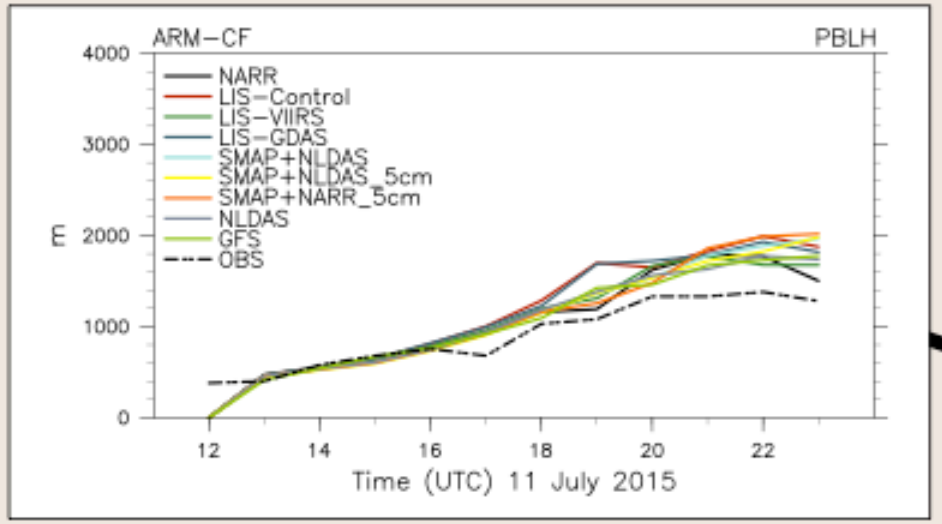


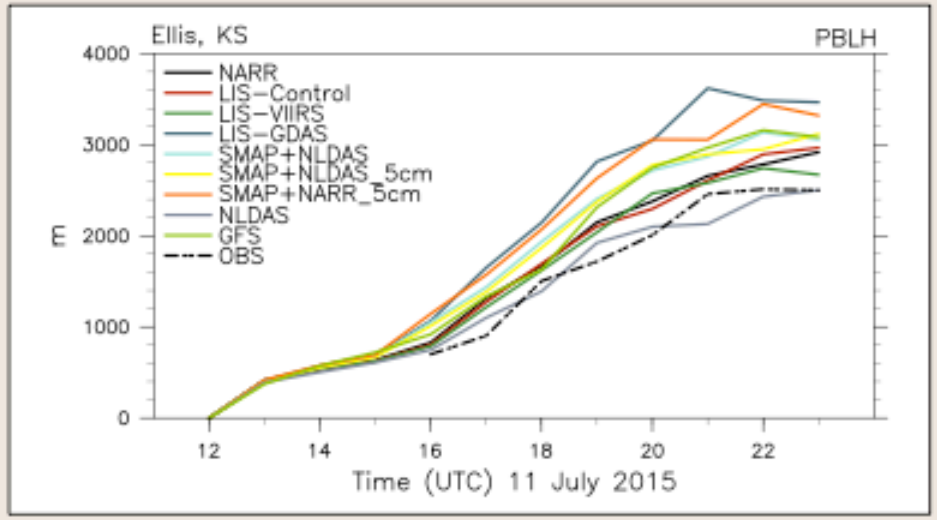


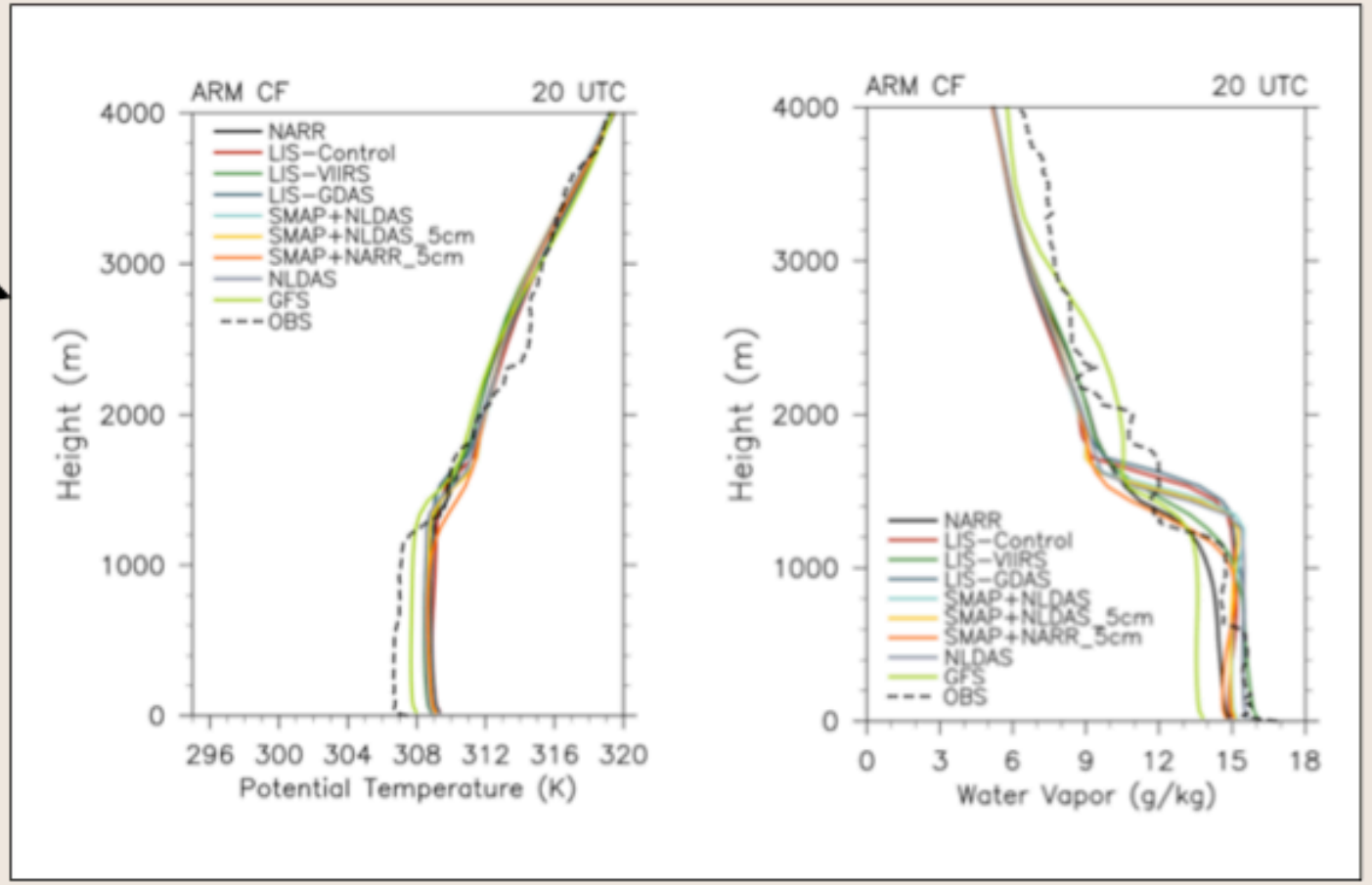


PBL Impacts

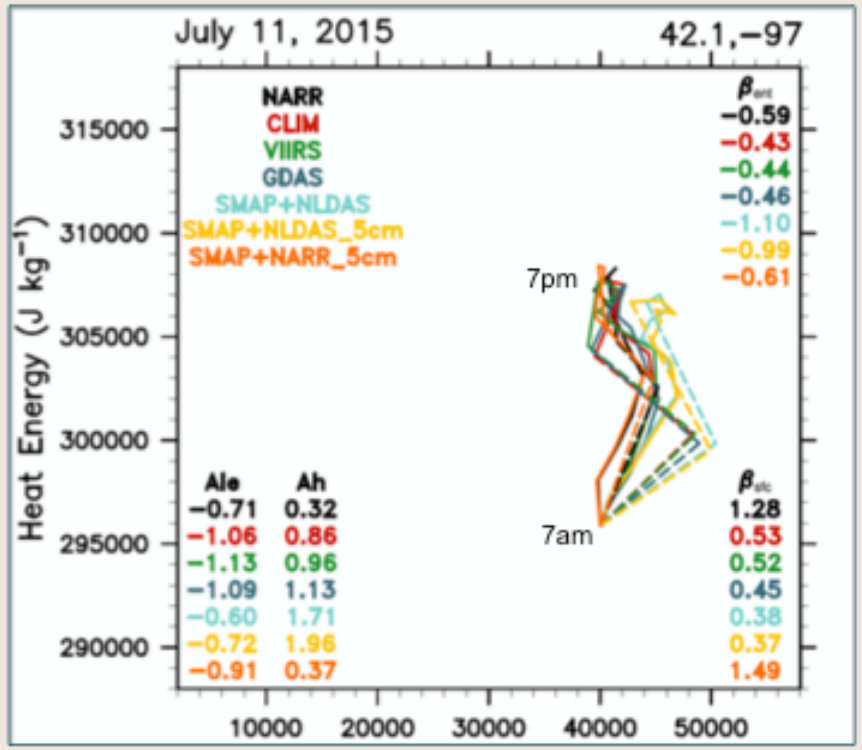
PBL Height Evolution

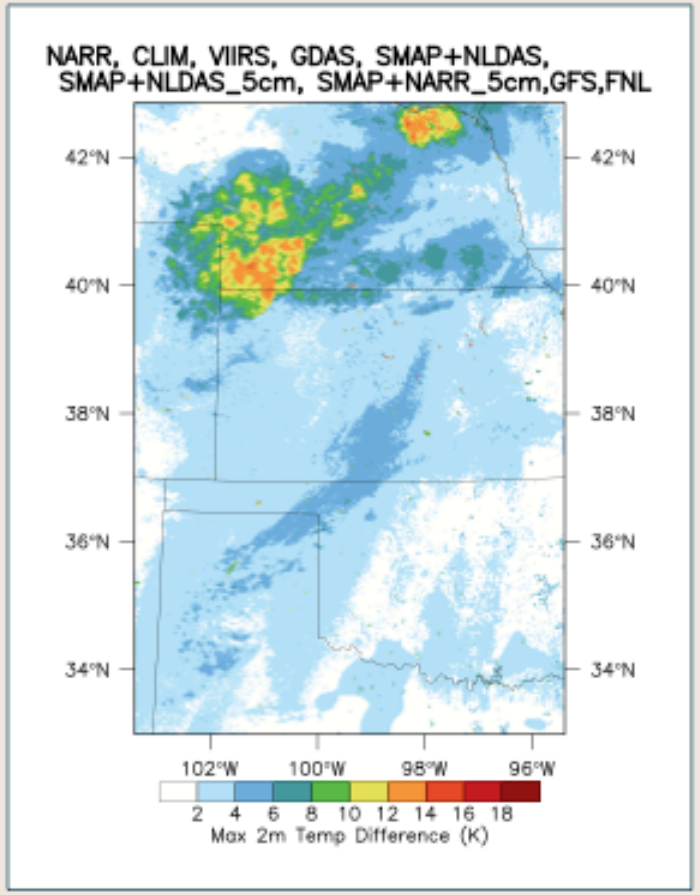


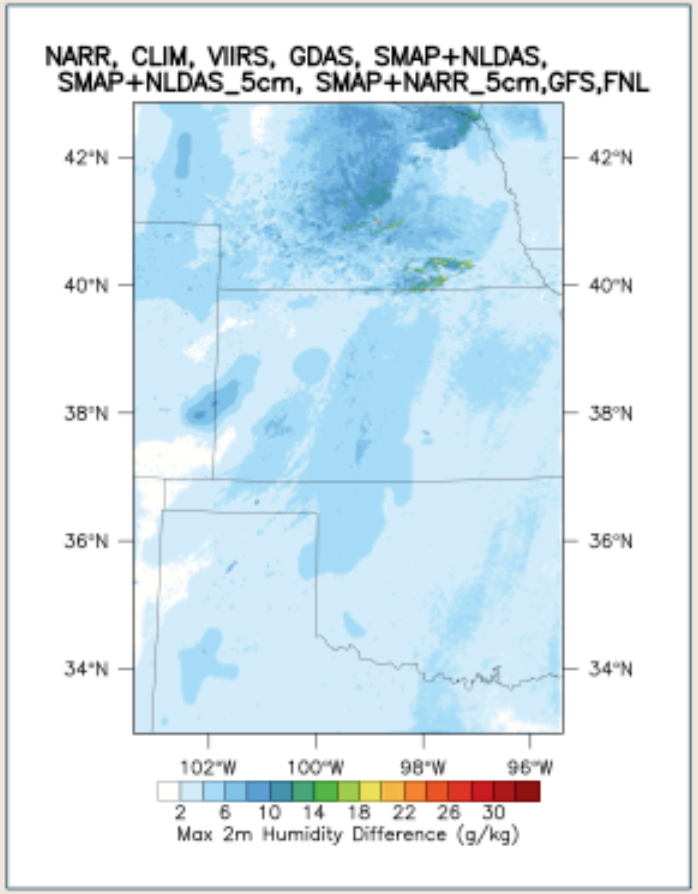




Domain-wide Impacts on Ambient Weather

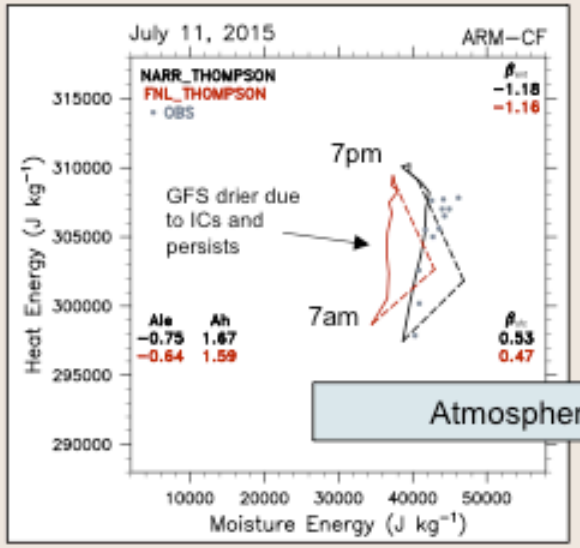


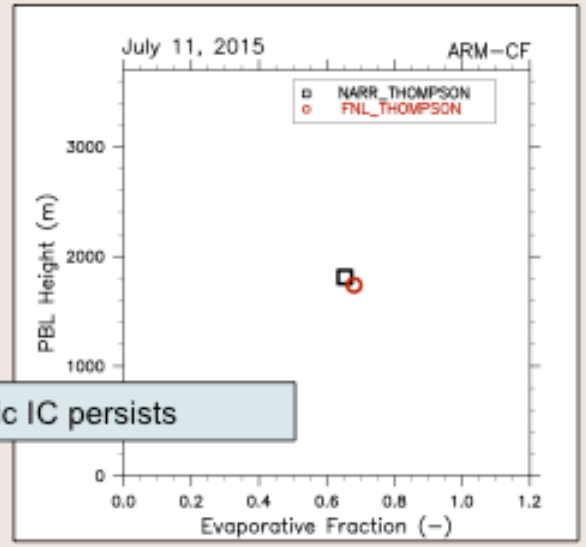




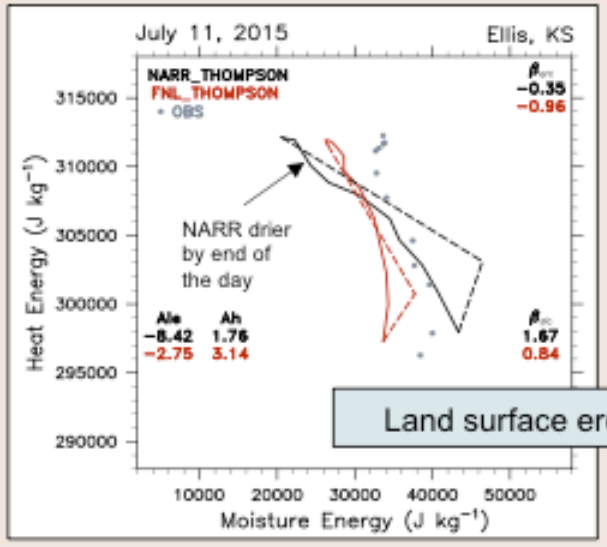
Maximum differences in 2-meter temperature and humidity as a result of varying soil moisture ICs

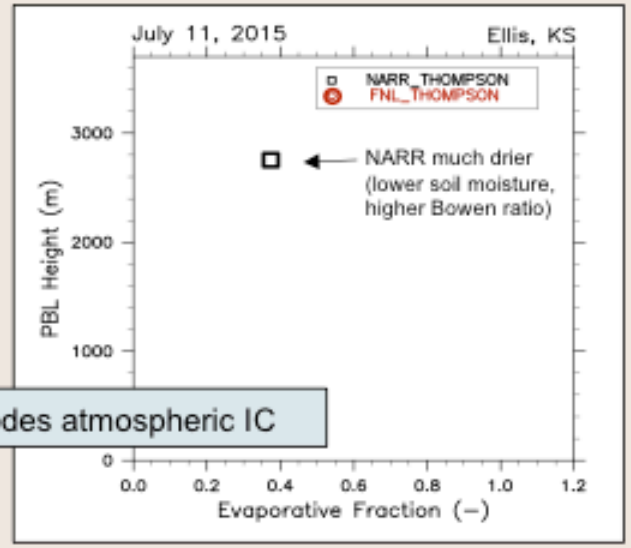
Impact of Atmospheric vs. Land Surface ICs



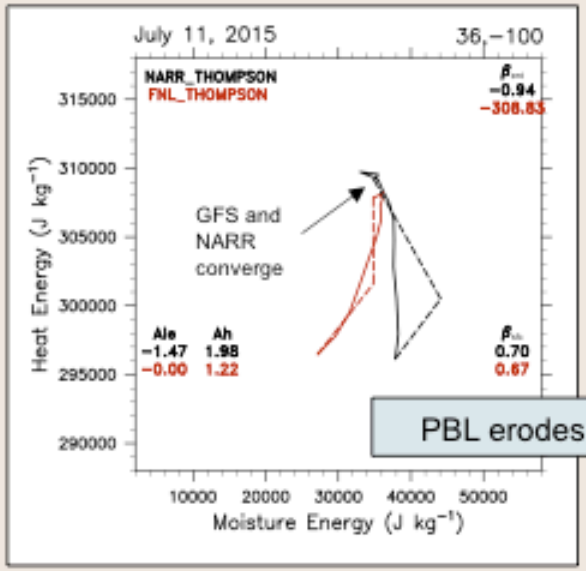


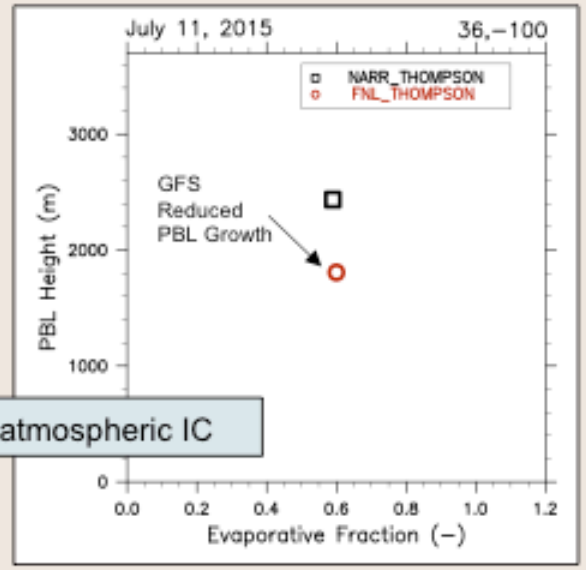
Atmospheric IC persists



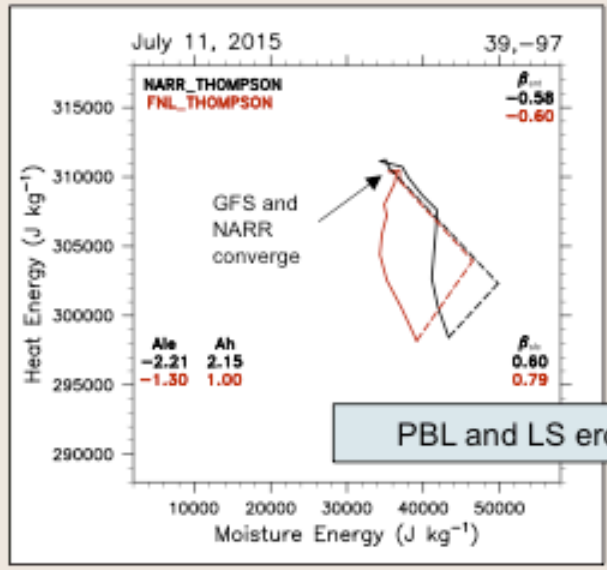


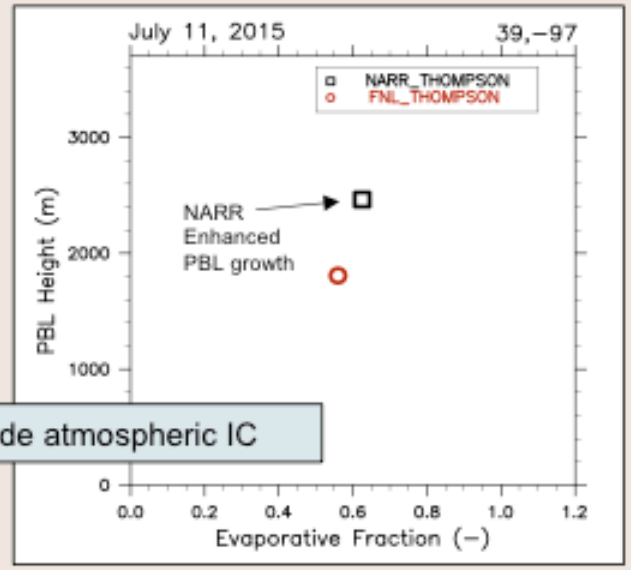
Land surface erodes atmospheric IC





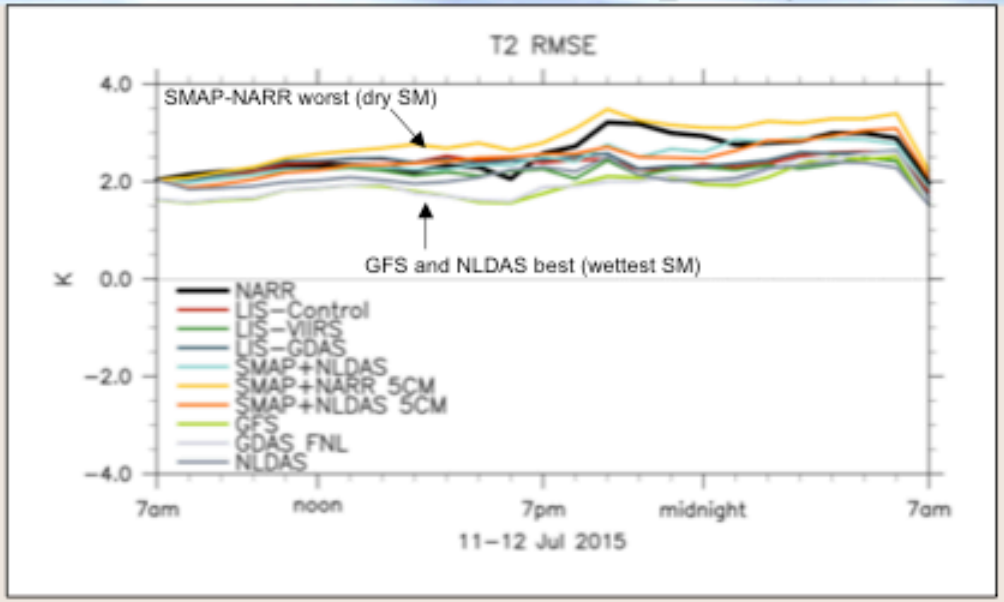
PBL erodes atmospheric IC

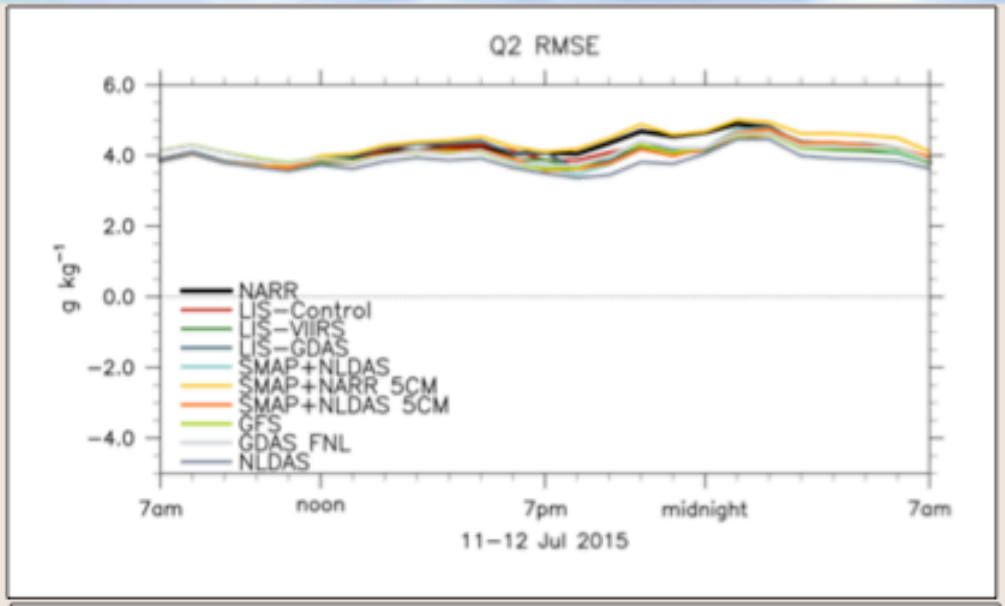


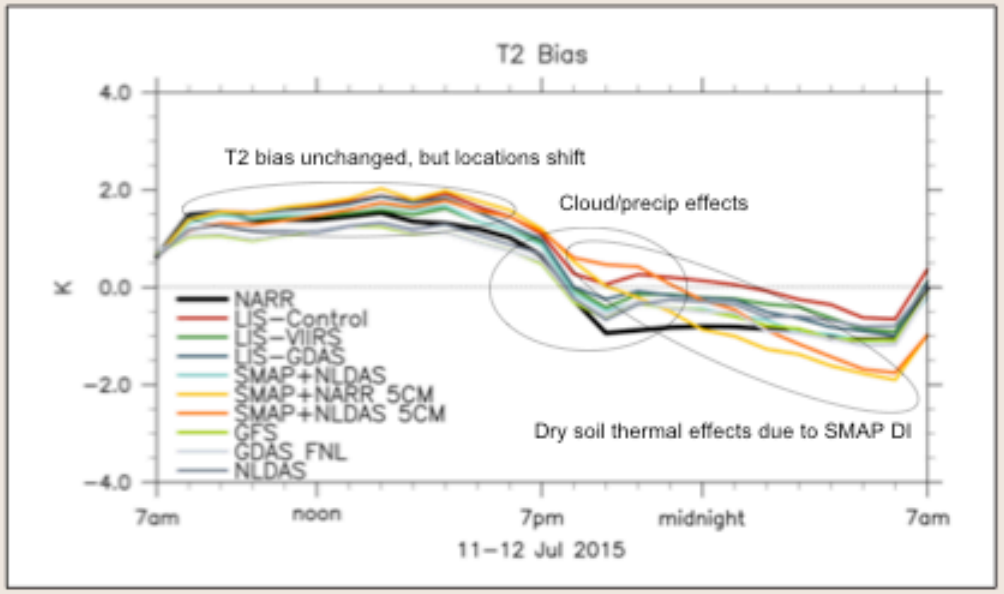


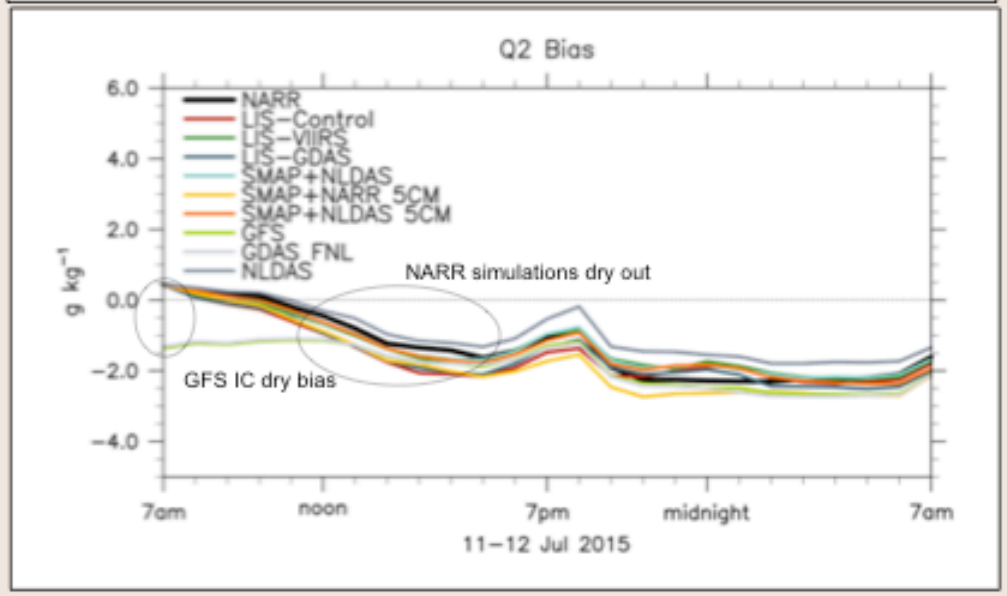
PBL and LS erode atmospheric IC

L-A Coupling Influence on Ambient Weather









Discussion

- **SMAP products look good overall compared to LSMs, in-situ, and for irrigation detection**
  - Looks like 'real' soil moisture
  - Captures the overall heterogeneity and dynamics of soil moisture in the region
  - There remains an 'observability' issue between LSM and observed soil moisture

- **Impact of soil moisture ICs can be understood via process-level analysis (LoCo)**
  - 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)
  - Understanding the coupling therefore becomes critically important to identifying the how/why of Fx impacts

Integrated, process-level analyses and diurnal cycles are not unique to these models/scales!