Initializing Numerical Weather Prediction Models with Model-Derived and Satellite-Based Soil Moisture Data

Eli J. Dennis and Joseph A. Santanello, Jr.
NASA-GSFC, Hydrological Sciences Laboratory, Greenbelt , MD

Introduction:

The NASA-Unified Weather Research and Forecasting Model (NU-WRF)[1] was initialized using varying soil moisture conditions that were derived from uncoupled Land Information System (LIS) "spin-ups", which varied in forcing quality and greenness fraction across the operational spectrum.

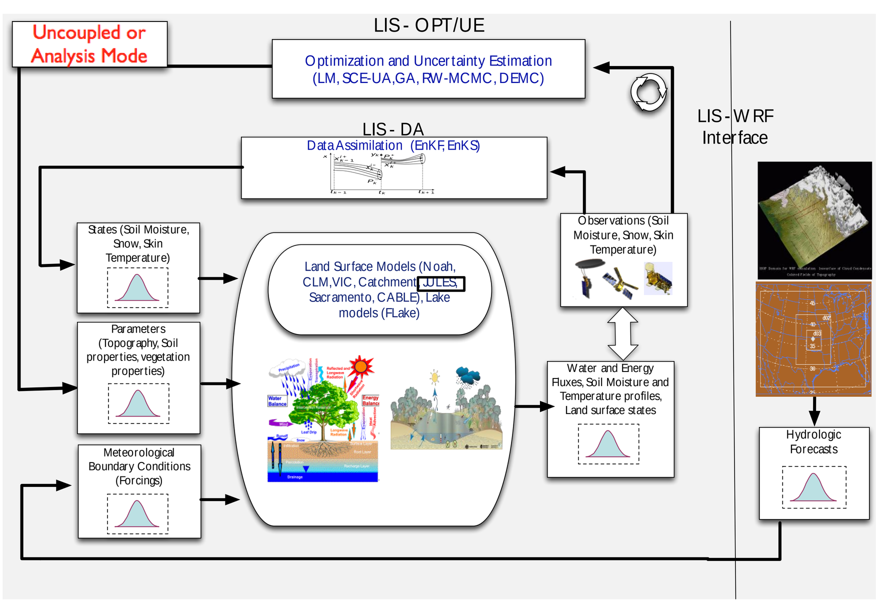
Background:

It has been shown that land-atmosphere (L-A) interactions are governed by a series of positive and negative feedback loops that can be related using the Local L-A Coupling (LoCo) process chain, as follows:

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

The current representation of soil moisture in operational numerical weather prediction models is **inadequate** for properly accounting for the effects of heterogeneity in soil moisture that can potentially impact the forecast. Therefore, we use uncoupled LIS runs to more accurately simulate the initial soil moisture field before the forecast begins.

NASA Land Information System (LIS)



LIS is a stand-alone modeling framework that includes multiple Land Surface Model (LSM) versions and applications, as well as various model physics suites and compatible DA approaches, and it is coupled to NU-WRF allowing us to smoothly transition between initial conditions.

LIS Variations:

Atmospheric Forcing:

- GDAS --- coarse, global, 0.3-deg
- NLDAS --- best available observed precip, 0.125-deg

Green Vegetation Fraction:

- Climatological --- Monthly, satellite-based @ 3 km
- Real-time --- Daily, VIIRS-based @ 3 km

Initialization Source (Name)	Forcing	GVF
LIS(GDAS)	GDAS	VIIRS
LIS(VIIRS)	NLDAS	VIRS
LIS(CLIMO)	NLDAS	CLIMATOLOGY
WRF	NARR	CLIMATOLOGY

Model Configuration:

Version: NU-WRF version: 8 patch: 4

Physics options:

- Microphysics: Goddard microphysics
- PBL Scheme: MYNN 2.5
- Radiation: RRTM
- Land Surface Model: Noah

Domain Info:

- US SGP (TX/OK/KS/NE); 1 km grid spacing
- 60 vertical levels --- eta coordinate

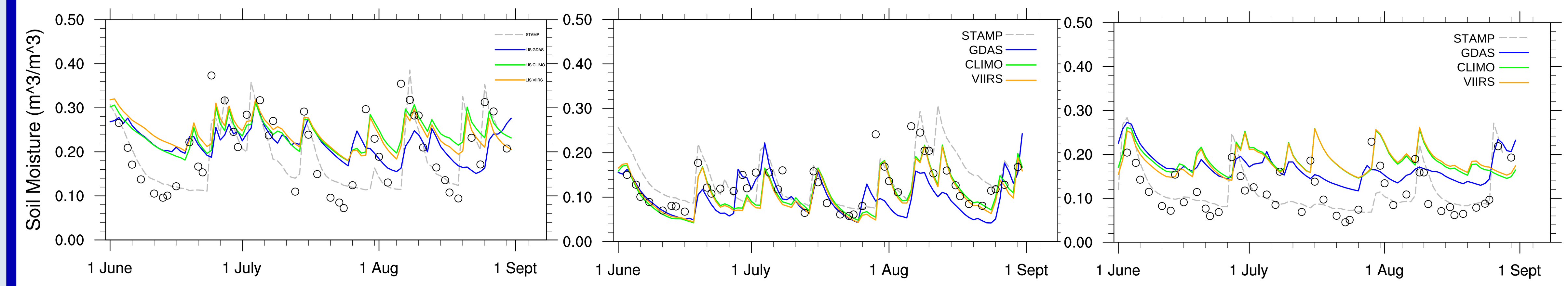
Initial Atmospheric Conditions:

- NARR

1. NASA Unified Weather Research and Forecasting (NUWRF) – a three-dimensional, non-hydrostatic, non-linear, time dependent numerical model designed for idealized studies of atmospheric phenomena and interactions with the land surface. It was developed at the National Aeronautics and Space Administration as a derivative of WRF, which utilizes a coupling of NASA derived physics packages that handle radiation (GOCART), land surface dynamics (LIS), and chemistry (WRF-CHEM).

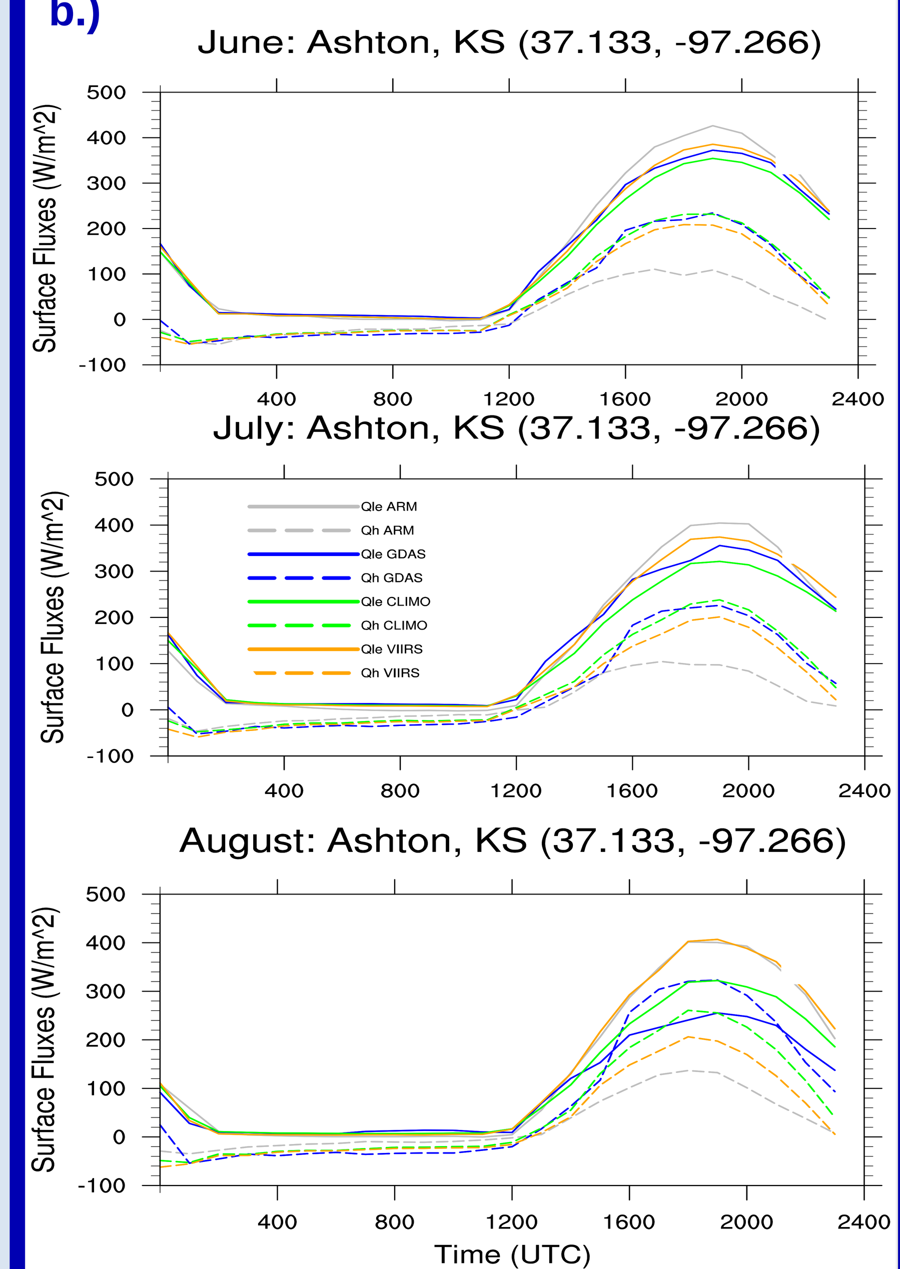
Offline Spinup Results (Fluxes and Soil Moisture) over SGP Sites

a.)



Daily soil moisture from (dashed grey) in-ground probes, (blue, green, and orange, respectively) LIS permutations GDAS, CLIMO and VIIRS, and (black circles) from the SMAP satellite mission.

b.)



Monthly-averaged diurnal cycle of (dashed) sensible and (solid) latent heat flux from the surface. (Same colors as above)

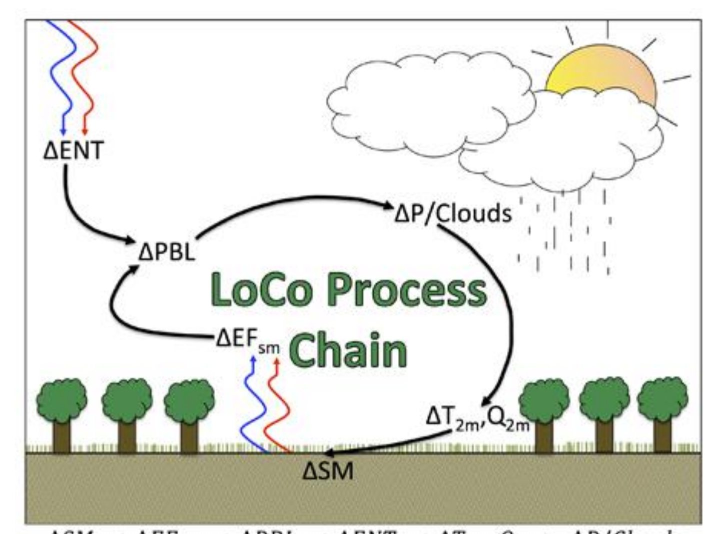
Why is this important?

Weather events are strongly related to the surface conditions:

1. Surface conditions dictate energy fluxes.
2. Energy fluxes determine the strength of convective mixing, and, therefore, the height of the planetary boundary layer (PBL).
3. The height of the PBL influences the vertical positioning of the lifting condensation level (LCL), or the height at which a parcel lifted from the surface will achieve saturation while retaining its moisture content and potential temperature.
   a. In the upper layers of the boundary layer, air interacts with the free troposphere via entrainment.
4. Once clouds are formed, the radiation budget is effected (shortwave and long-wave), and microphysical processes introduce new sources of latent heat energy

Therefore,

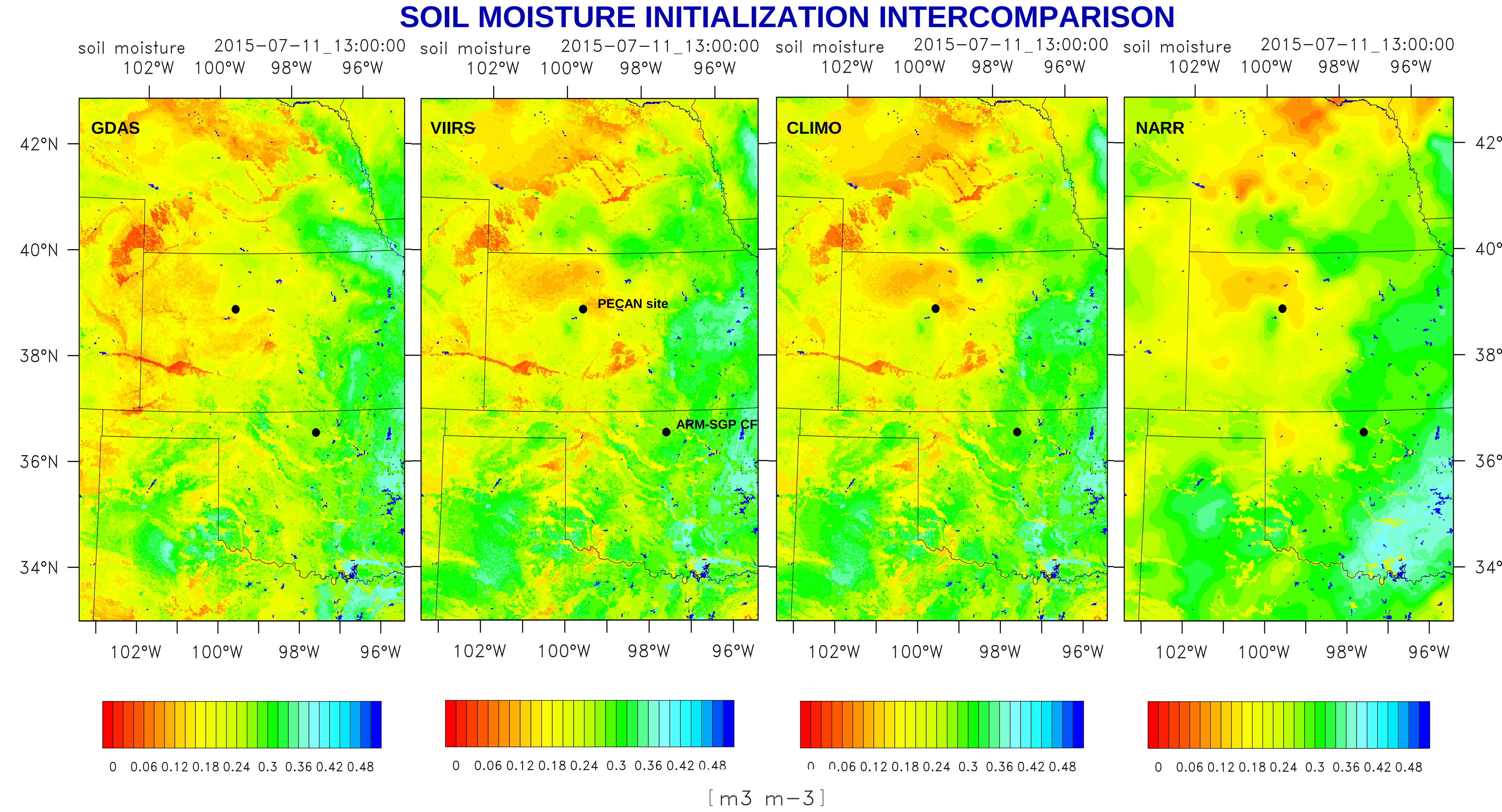
The height of the LCL is a critical component in producing a realistic forecast. Moreover, if the LCL is directly related to surface temperature and moisture, these also become critically important.



$\Delta SM \rightarrow \Delta EF_{sm} \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m} \triangleright \Delta P/Clouds$

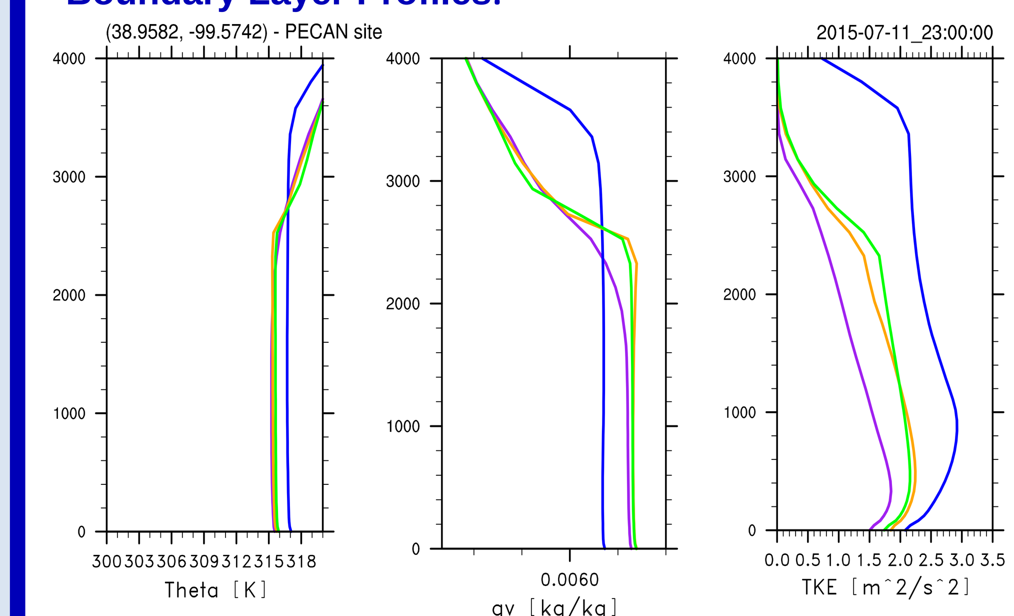
SOIL MOISTURE INITIALIZATION INTERCOMPARISON

c.)



Soil Moisture conditions for model initialization. (Left) GDAS uses a degraded forcing for the LIS spin-up. (Left Center) VIIRS has both the best available forcing (NLDAS) and the best available Greenness Vegetation Fraction (VIIRS). (Right Center) CLIMO uses the best available forcing but uses a degraded climatology based greenness vegetation fraction. (Right) NARR uses the degraded forcing and the degraded greenness fraction.

Boundary Layer Profiles:

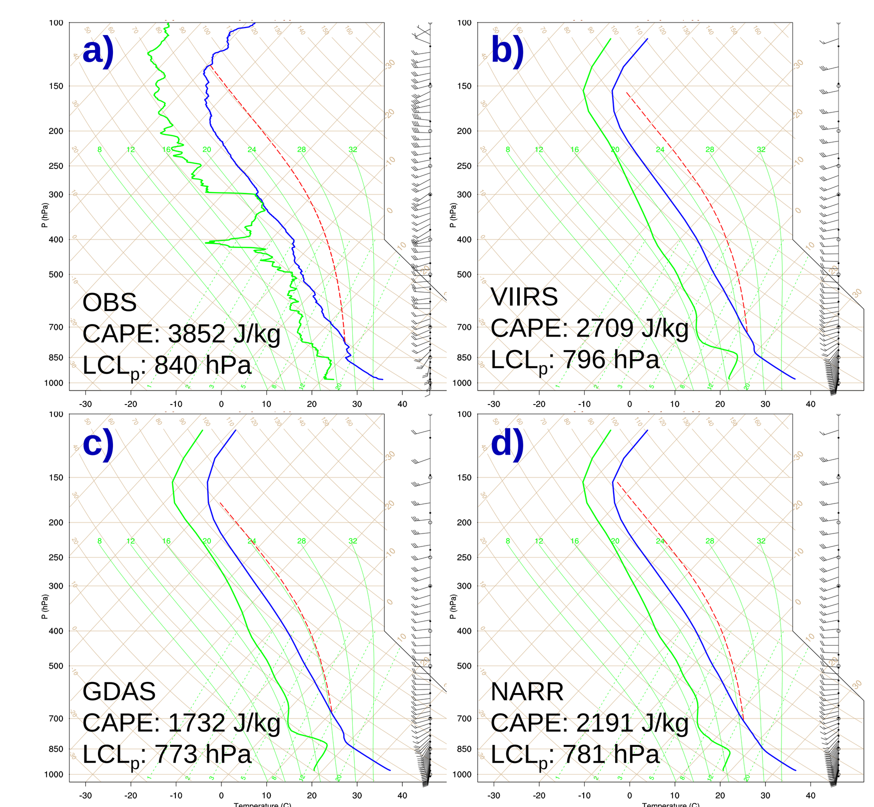


Profiles of (left) potential temperature, (center) moisture, and (right) turbulent kinetic energy (TKE) located just southwest of PECAN site. Colors are the same as previous plots with the addition of (purple) NARR.

GDAS shows a PBL height +1 km greater than any other LIS permutation. This is because this site is located in an area that GDAS is dry, but the other model runs show antecedent moisture. Instead of energy going into evaporation, the energy contributes to increasing the surface temperature, and therefore increasing the boundary layer eddies

Model Forecast Difference Examples:

SKEW-T log-P Diagrams



Observed (a) and (b-d) modeled vertical profiles located at the Atmospheric Radiation Measurement – Southern Great Plains Central Facility (ARM-SGP CF) at 2200 UTC 11 July 2015.

- CAPE differences > 2000 J/kg
- LCL vertical positioning differences ~ 60 hPa
- Still Large differences between all model runs and observations

Future Work:

- Continue investigation following LoCo Process Chain
- Follow Mixing Diagram approach to visualize both the impact from the surface and the impact from above the PBL
- Incorporate SMAP data via DA approaches
- Simulate additional case studies in more convectively active environments
- Simulate case studies with seasonal variations to highlight the impact of GVF

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