Impact of LSM Parameter Estimation and Data Assimilation on Short-term WRF Forecasts

Joseph A. Santanello, Jr.[1], S. Kumar[2,1], C. Peters-Lidard[1], K. Harrison[3,1] and S. Zhou[1]
1 – NASA-GSFC Hydrological Sciences Branch, Greenbelt, MD, USA
2 – Science Applications International Corporation, McLean, VA, USA; 3 – Earth System Science Interdisciplinary Center, College Park, MD

Background

Motivation:

- Land-atmosphere (L-A) interactions play a critical role in determining the diurnal evolution of both planetary boundary layer (PBL) and land surface temperature and moisture states and anomalies.
- Recent efforts to quantify the strength of **Local L-A Coupling ('LoCo')** in prediction models have produced diagnostics that integrate across both the land and PBL components of the system.
- In this study, we examine the impact of **improved specification of land surface states and fluxes** on coupled WRF forecasts during the summers of extreme **dry (2006)** and **wet (2007)** conditions in the U.S. Southern Great Plains.

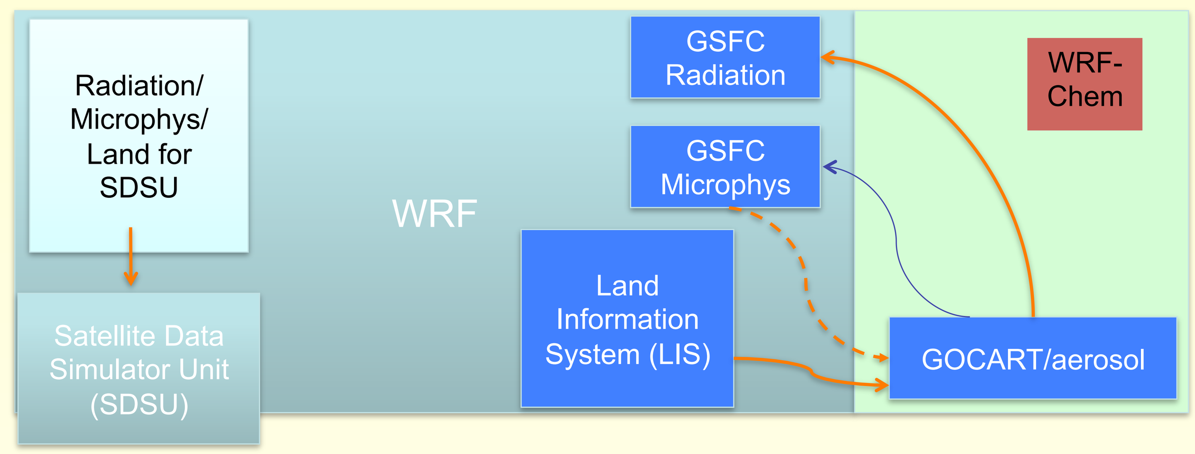
Methodology:

- The improved land initializations for WRF are obtained through the use of new modules in **NASA's Land Information System (LIS)** to calibrate LSM parameter sets (**LIS-OPT/UE**) and assimilate land surface states (**LIS-DA**).
- LIS is then run in coupled mode as a core component of the **NASA Unified Weather Research and Forecasting (NU-WRF)** system for different dry/wet regime case studies.
- The impact of land model calibration on the following are then assessed:

  a) spinup of land surface states used as initial conditions
  b) heat and moisture fluxes of the coupled simulations (Land + PBL)
  c) ambient weather

- Land data assimilation using both radiance and product-based approaches shows promise in improving offline LSM states and fluxes. The impact of on coupled forecasts is currently in progress.

NU-WRF System



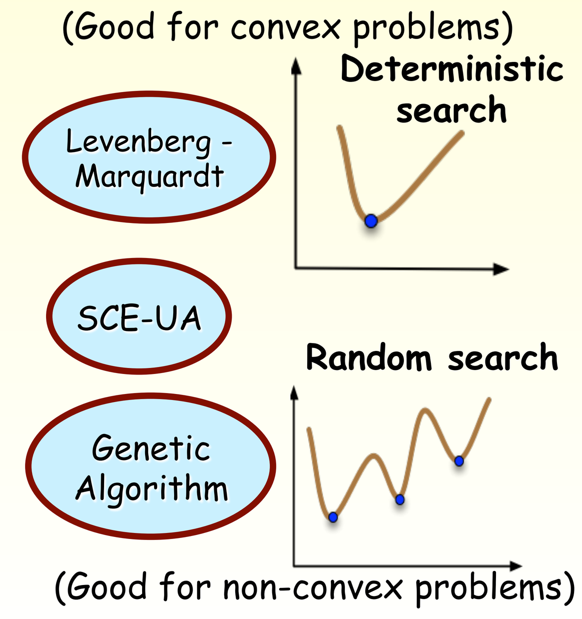
Overarching Goal
The NU-WRF project aims to develop, validate and provide the community with an observation-driven integrated modeling system that represents aerosol, cloud, precipitation and land processes *at satellite-resolved scales.*

Integrates NASA-oriented capabilities into WRF-ARW:

- **GSFC's Land Information System (LIS)**
- WRF/Chem enabled version of the GOddard Chemistry Aerosols Radiation Transport (GOCART) model
- Goddard Satellite Data Simulator Unit (G-SDSU)
- Goddard microphysical schemes
- Radiative transfer processes (and explicit interaction between clouds radiation)
- Land data assimilation system (through LIS)
- GOCART global aerosol transport model
- Real-time forecasting system using GEOS global analyses as init/bdy conditions

LIS Optimization & Uncertainty Module

- LIS includes a **multi-algorithm optimization subsystem (LIS-OPT/UE)** that captures the spectrum of search strategies, ranging from techniques such as:
  - Levenberg-Marquardt (LM)
  - Genetic Algorithms (GA)
  - Shuffled Complex Evolution from the University of Arizona (SCE-UA)



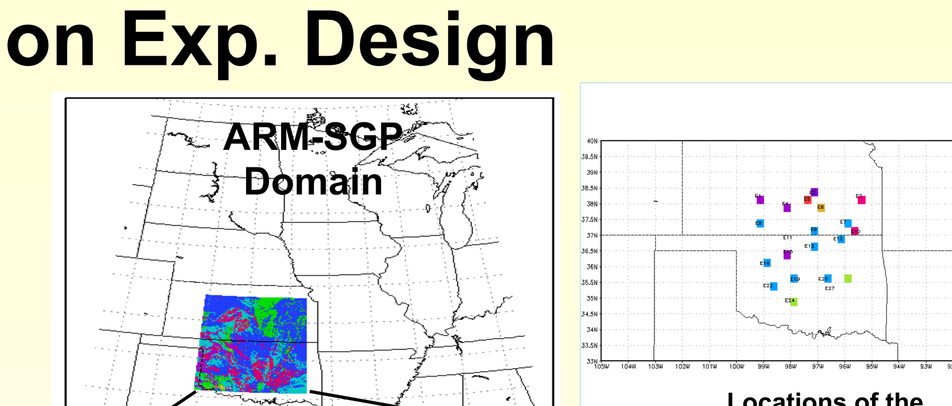
LIS Data Assimilation Module

- 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 (near-sfc, root zone)
  - Surface Temperature
  - Snow (SWE, snow cover)
  - Groundwater

Calibration Exp. Design

- **2006-7 Dry/Wet Extremes**
  - Domain: U. S. Southern Great Plains (SGP)
    - 500x500 @ 1km resolution
  - **Noah (v3.2) LSM** + YSU PBL
- **Optimization Runs**
  - Algorithm: GA
  - Calibration Periods: 1 May – 1 Sept 2006 and 2007
  - Parameter set: 32 soil, vegetation, and general
  - Observations: 20 EBBR and ECOR flux tower sites
  - Objective Fn: Cumulative RMSE of sensible (Qh), latent (Qle), and soil (Qg) heat flux
- **Parameter Classification**
  - Sorted by land cover (UMD) and soil type (STATSGO) at the 20 sites
  - Each parameter averaged across common types and assigned to remainder of full domain
- **Case Studies:**
  - **14 July 2006** (dry; NU-WRF test case)
  - **18-19 July 2006** (dry; peak of dry-down)
  - **16-17 June 2007** (wet; little precip)
  - **19-20 June 2007** (wet; scattered precip)

	Exp.	Description	Noah Parameters in LIS Spinup	Noah Parameters in NU-WRF
1	DEF	Default parameters in LIS & NU-WRF	Default	Default
2	CPL	Impact of calibrated parameters in NU-WRF ONLY	Default	Calibrated
3	SPN	Impact of calibrating LIS spinup (ICs) ONLY	Calibrated	Default
4	SCP	Impact of full calibration (LIS and NU-WRF)	Calibrated	Calibrated



Locations of the ARM-SGP flux towers

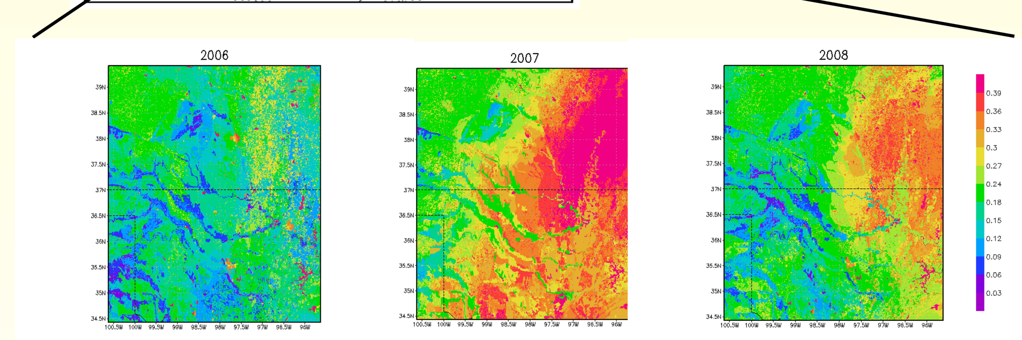


Figure 1. 0-10cm Soil Moisture (m3/m3) simulated by a 3.5 year spinup of the Noah LSM, valid at a) 14 July 2006, b) 14 June 2007, and c) 14 July 2008.

Methodology

1. Use LIS-OPT and ARM-SGP fluxes to calibrate Noah LSM parameters for each year.
2. Generate new lookup tables of soil, vegetation, and general parameters based on optimization results
3. Run a suite of offline LIS-Noah spinup runs with both default and calibrated parameters.
4. Run coupled NU-WRF initialized w/spinup for each case study and different parameter set.

Summary

- LSM parameters can be calibrated and averaged across vegetation and soil classifications for full domain distribution.
- Optimal offline surface flux partitioning often leads to better L-A coupling and forecasts.
- The impact and improvement due to OPT and DA is dependent on the regime (e.g. dry vs. wet) and its strength.
- Soil Moisture DA shows more modest improvements in offline LSM states and fluxes.

Future Work

- Coupled DA experiments.
- Sensitivity of OPT and DA to the period of calibration (dry, wet, normal).
- Sensitivity of OPT to the land cover and soils classifications.
- Impact of calibrating to multiple observational datasets and types.
- Feasibility of performing coupled (online) land DA.
- Feasibility of simultaneous LSM calibration and data assimilation.

•**Santanello et al., 2013: Impact of Land Model Calibration on Coupled Land-Atmosphere Prediction. *J. Hydromet.*, accepted.**

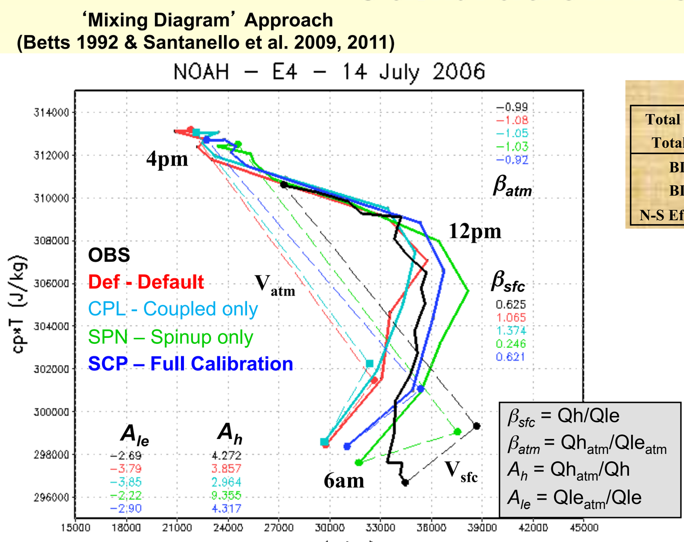
•**Santanello et al., 2013**: Diagnosing the Nature of Land–Atmosphere Coupling: A Case Study of Dry/Wet Extremes in the U.S. Southern Great Plains. J. Hydrometeor, 14, 3–24.

•**Santanello et al., 2011:** Diagnosing the Sensitivity of Local Land-Atmosphere Coupling via the Soil Moisture-Boundary Layer Interaction. J. Hydrometeor., 12, 766-786.

•**Santanello et al., 2009:** A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales. *J. Hydromet,* 10, 577-599.

Calibration Results

'Mixing Diagram' Approach
(Betts 1992 & Santanello et al. 2009, 2011)



	DEF	CPL	SPN	SCP
Total RMSE	6288.60	6161.24	4665.10	**5314.07**
Total MAE	5231.25	5181.39	4044.50	**4541.69**
BIAS Q2	-6022.76	-5743.49	-3159.91	**-4196.35**
BIAS T2	4244.72	4458.54	3336.54	**3919.27**
N-S Efficiency	-1.78	-1.67	-0.53	**-0.98**

Fig. 1: Mixing diagram showing the diurnal co-evolution (6am-4pm LST) of 2m-specific humidity and 2m-potential temperature on 14 July 2006 at the E4 site for the set of default and calibrated NU-WRF simulations. Also shown are the Bowen and entrainment ratios as defined in S09 and described by the surface and atmospheric response vectors (dashed lines).

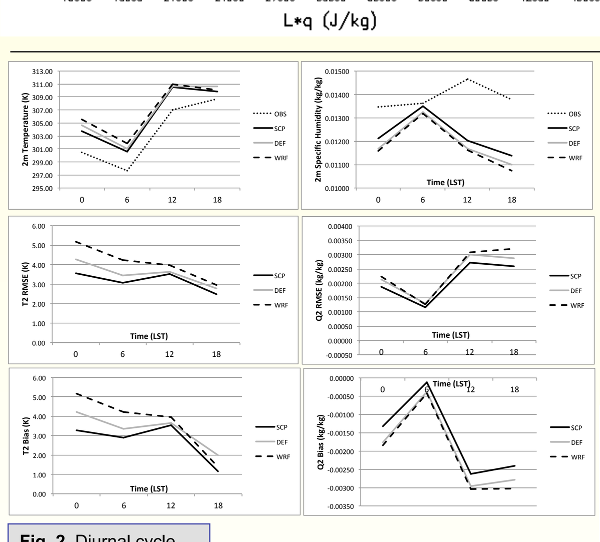
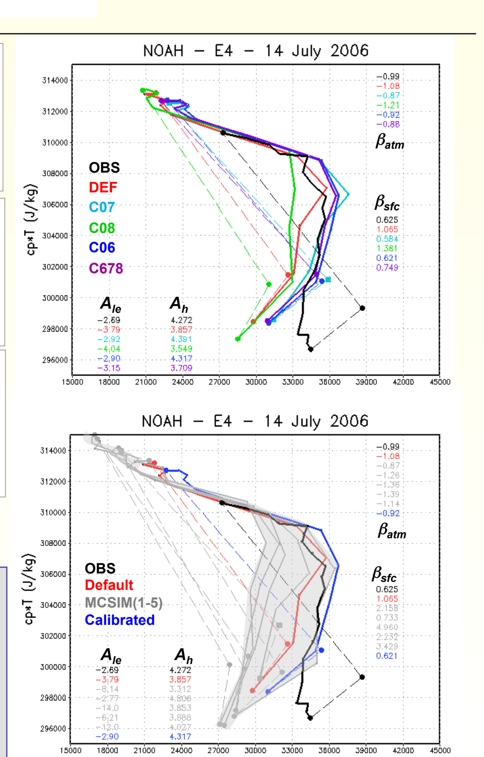


Fig. 2. Diurnal cycle and error statistics (RMSE, Bias) of 2-meter temperature (T2) and humidity (Q2) for the 14 July 2006 case evaluated at 214 station pairs across the ARM-SGP domain for each 6-hourly increment (using WRF-MET).



TOP RIGHT. Mixing diagram for the 14 July case (Fig. 1), but with Noah parameters calibrated during different years (2006, 07, 08, and combined 2006-7-8) versus observations and the default parameters. **BOTTOM RIGHT.** Same as above, but for 5 random Noah parameter sets generated by LIS-OPT/UE versus observations and the default and C06 simulation.

Summary of Results

Offline Calibration

- Offline calibration using a surface flux network is successful in **reducing LSM biases and improving diurnal cycles** of Qle and Qh.
- Sensible **(H),** Latent **(LE),** and Soil **(G)** Heat Fluxes are improved at nearly all individual sites and over the full domain.
- Largest improvement is seen in H for the dry and LE for the wet regime.
- Little/mixed impacts on G due to limited observations and objective function.

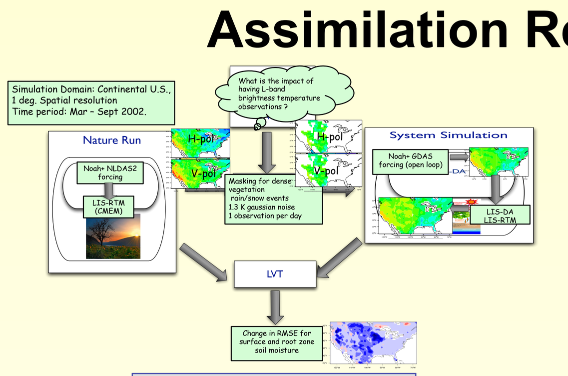
Calibration Impact on Coupling

- Calibrated parameter sets can improve fluxes and states during both dry and wet regimes, and **extend their impact to PBL fluxes and ambient weather** (T2 and Q2).
- **Largest impacts** of offline calibration on coupled runs are seen during the dry regime when the turbulent fluxes are larger and atmospheric and precipitation forcing is weak.
- A **calibrated spinup by itself** can produce more accurate temperature and humidity forecasts regardless of the parameter sets used in the coupled simulation; though **consistency in parameter sets between spinup and coupled runs is critical** to improving performance and maintaining physical consistency in both states and fluxes
- Calibration during primarily **dry and/or wet periods** corrected more of the inherent LSM bias and led to better coupled predictions in the dry regime.
- Significant **variability in hydrometeorological prediction** can result from LSM parameter uncertainty, but can be reduced using observations and calibration approaches.

Land Data Assimilation

- LIS can be used in an **OSSE-like setup** to quantify the impacts of various land DA approaches on both offline and coupled simulations.
- Improvements due to soil moisture DA can be seen for 1, 3, 7, or 14 days **return time of the satellite**, but with little difference between 1 and 3 days.
- AMSR-E **DA impacts vary in magnitude and sign** across the SGP domain.
- The initial conditions generated by the offline spinups indicate that DA in general tends to **cause the soil moisture fields to be drier** on those dates.
- Comparison of **fluxes indicate marginal improvement** due to DA, with a bit larger impact seen in the wet year (2007).
- The coupled LIS-WRF simulations are in progress, and will also focus on the relative impact of DA vs. calibration and sensitivity to the period/length of DA.

Assimilation Results



LIS-DA Experimental Design

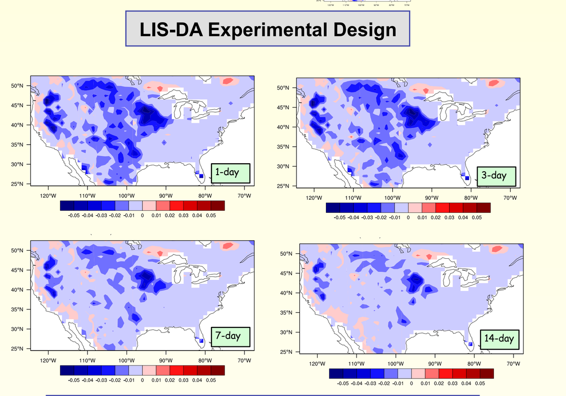
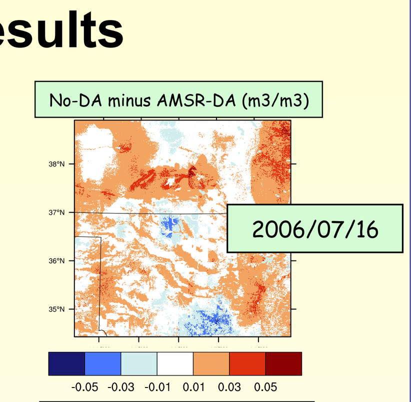


Figure 4. Impact of **satellite repeat time** on near surface (0-10cm) *synthetic* soil moisture DA during a LIS-Noah spinup.



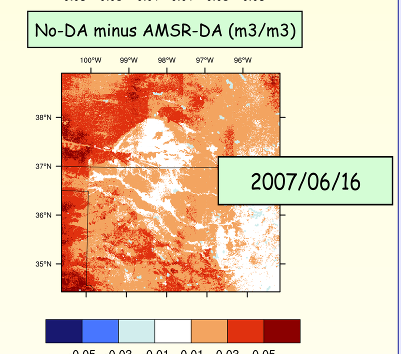


Figure 3. Impact of AMSR-E DA on offline LIS-Noah spinups, valid at the initial times of the 2006 and 2007 WRF case studies (above).

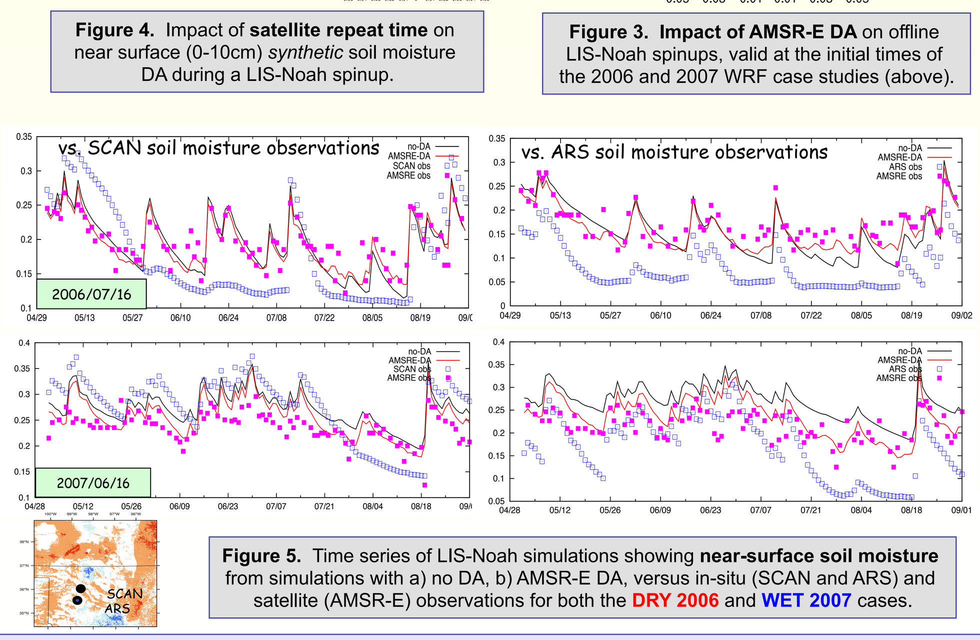


Figure 5. Time series of LIS-Noah simulations showing **near-surface soil moisture** from simulations with a) no DA, b) AMSR-E DA, versus in-situ (SCAN and ARS) and satellite (AMSR-E) observations for both the **DRY 2006** and **WET 2007** cases.

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