Diagnosing the Nature of Land-Atmosphere Coupling During the 2006-7 Dry/Wet Extremes in the U. S. Southern Great Plains

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Background

Hypothesis: ***Land-atmosphere interactions (L-A) play a critical role in supporting and modulating extreme dry and wet regimes, and must therefore be quantified and simulated correctly in coupled models.***

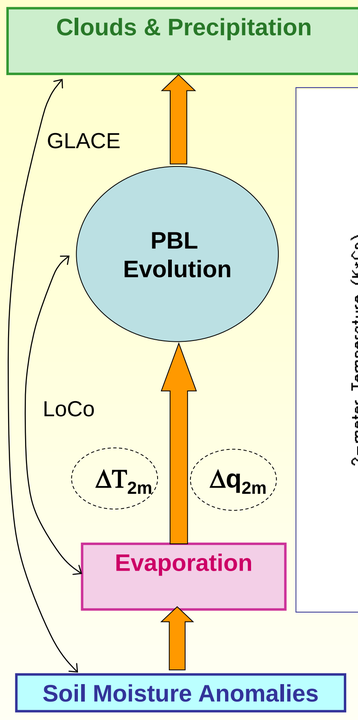
Objectives:

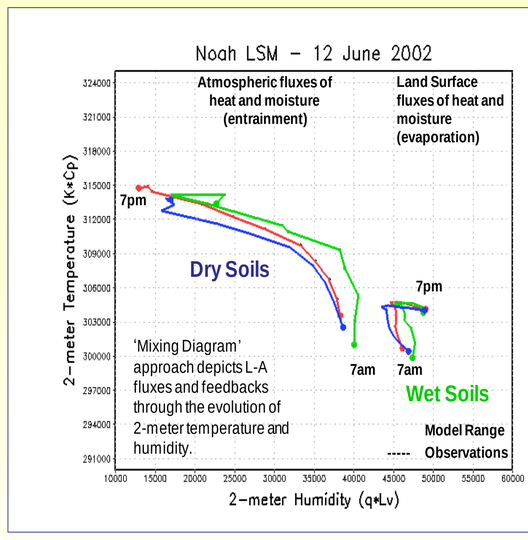
- Address deficiencies in NWP/climate models by **developing diagnostics** to quantify the strength and accuracy of the land-PBL coupling.
- Diagnose the nature of the **Local L-A Coupling ('LoCo')** during dry/wet extremes using a combination of models and obs during the summers of 2006-7 in the SGP.

Contribution to GEWEX-GLASS/iLEAPS:

- Diagnostics that can be applied to any model, scale, or observation (in-situ or RS).
- Development of **LIS-WRF system** as a testbed for LoCo studies employing a suite of land and PBL schemes.
- **Assessment of coupled model components** and their integrated impacts across the process-chain connecting the land to the PBL and then clouds/precip.

LoCo Diagnostics





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

- A diurnal ***land-PBL balance*** is created each day that is a function of on the nature and strength of L-A interactions in each coupled model.
- The diurnal evolution of T_{2m} and q_{2m} can be used to diagnose the balance reached for a particular LSM + PBL scheme coupling.

→ **Thermodynamics (e.g. Theta-e, Plcl, q*sat, and RH)** to assess the land impact on clouds and precipitation.

→ **Advection** as third vector to quantify the full PBL budget and diagnose how 'local' is the LoCo.

Goals of LoCo

- Diagnose the components of GLACE at the *diurnal process level*:

$$\frac{d(P)}{d(SM)} = \frac{d(EF)}{d(SM)} \times \frac{d(P)}{d(EF)}$$

- Evaluate the '**links in the chain**' and their sensitivities to land - PBL perturbations as follows:

'LoCo Process-Chain'

$\Delta SM \rightarrow \Delta EF_{sm} \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta EF_{pbl}$ ► ΔP/Clouds

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

SM: Soil Moisture PBL: Mixed-layer quantities ENT: Entrainment fluxes EF: Evaporative Fraction P/Cloud: Moist processes

LIS-WRF System

Exp. Design

- 1-km resolution
- NARR forcing
- 43 vertical levels (~42m sfc)
- **3 PBL + 3 LSM schemes**

Land Information System (LIS)

- Suite of LSMs w/flexible resolution, forcing, parameters
- Provides spinup capability for improved initialization of land surface states
- Plug-in design supports model calibration and DA

PBLs in WRF

YSU (Yonsei University)
- Counter-gradient fluxes
- Explicit entrainment

MYJ
- Level 2.5
- TKE

MRF
- Based on YSU scheme
- Implicit vertical diffusion

LSMs in LIS

Noah(v2.7.1)
- 4 soil layers
- NCEP operational

CLM(v2)
- 10 soil layers
- Extensive canopy/veg

H-TESSEL (ECMWF)
- 4 soil layers
- Tiled soil, canopy, snow surfaces

Model Evaluation

2006 - Dry Year

2007 - Wet Year

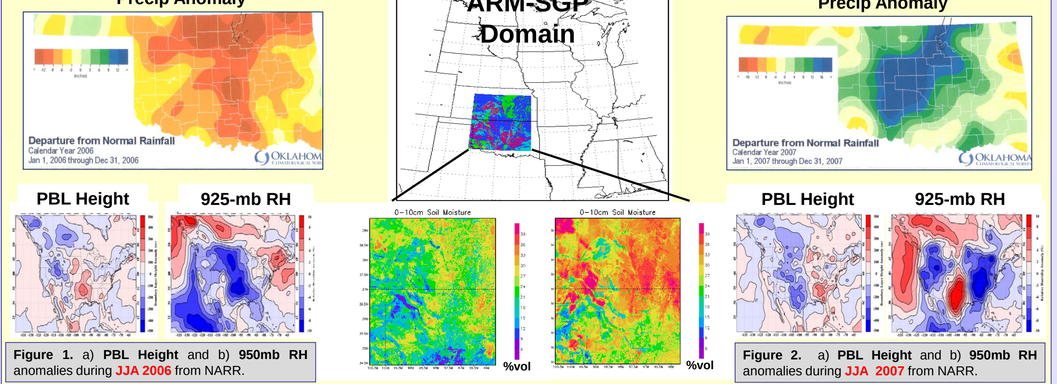
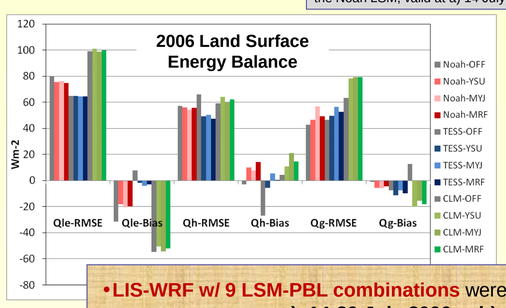
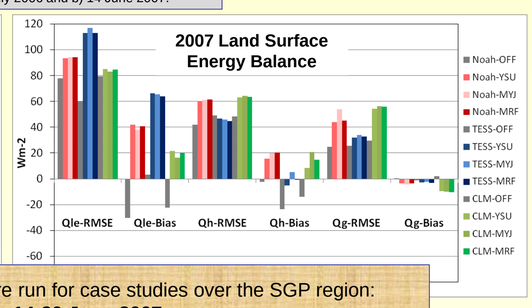


Figure 1. a) **PBL Height** and b) **950mb RH** anomalies during **JJA 2006** from NARR.

Figure 3. 0-10cm Soil Moisture simulated by a 3.5 years spinup of the Noah LSM, valid at a) 14 July 2006 and b) 14 June 2007.

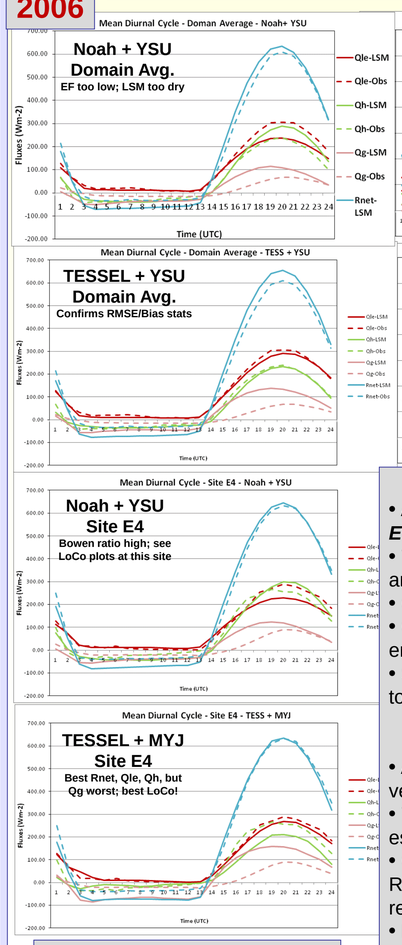
Figure 2. a) **PBL Height** and b) **950mb RH** anomalies during **JJA 2007** from NARR.

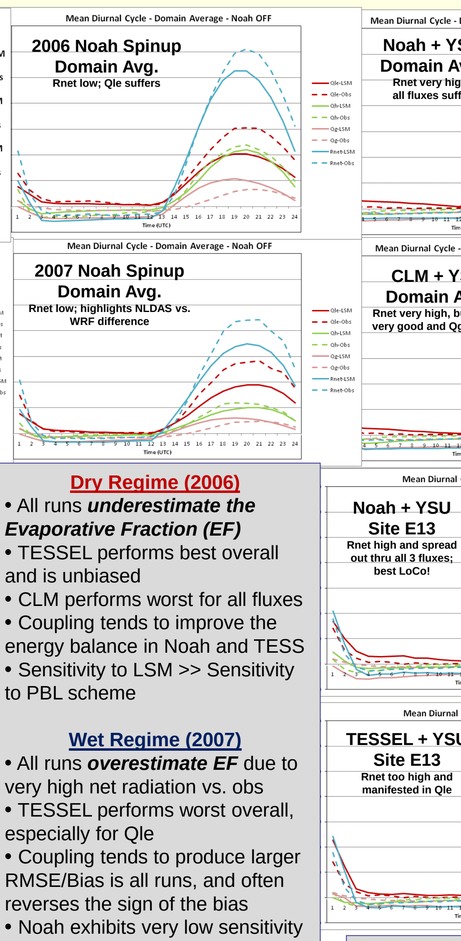


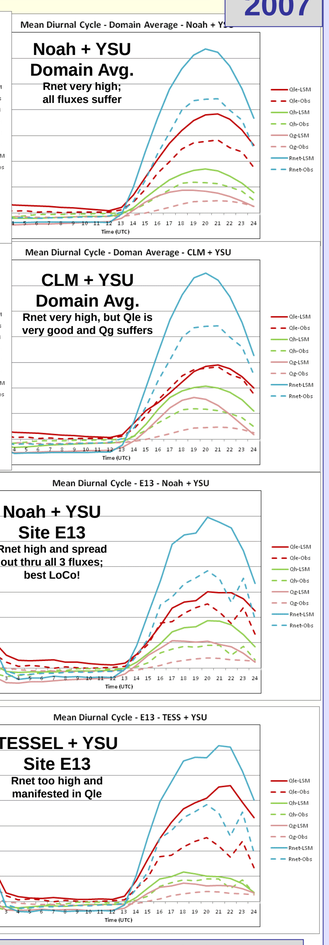


- **LIS-WRF w/ 9 LSM-PBL combinations** were run for case studies over the SGP region:
  a) 14-20 July 2006 b) 14-20 June 2007
- Each LSM was spun-up offline for 4 years prior to LIS-WRF initialization w/NLDAS forcing.
- Evaluation performed using LIS' Land surface Verification Toolkit (LVT)

2006







2007

Dry Regime (2006)
- All runs ***underestimate the Evaporative Fraction (EF)***
- TESSEL performs best overall and is unbiased
- CLM performs worst for all fluxes
- Coupling tends to improve the energy balance in Noah and TESS
- Sensitivity to LSM >> Sensitivity to PBL scheme

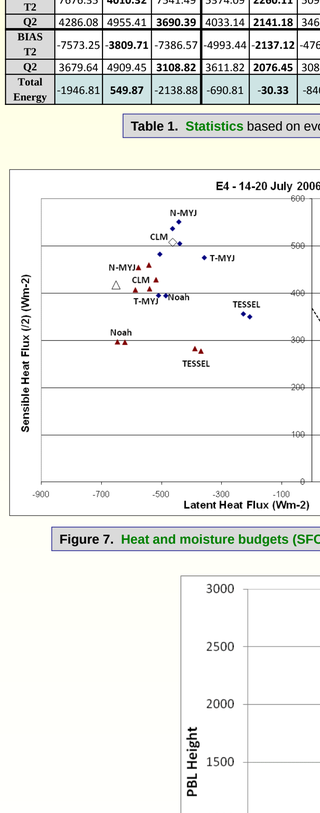
Wet Regime (2007)
- All runs ***overestimate EF*** due to very high net radiation vs. obs
- TESSEL performs worst overall, especially for Qle
- Coupling tends to produce larger RMSE/Bias is all runs, and often reverses the sign of the bias
- Noah exhibits very low sensitivity to soil type or Czil parameter specification (not shown)

Figs 4. Mean diurnal cycles for the **14-20 July 2006** period for different LSM-PBL couplings evaluated across ARM-SGP sites..

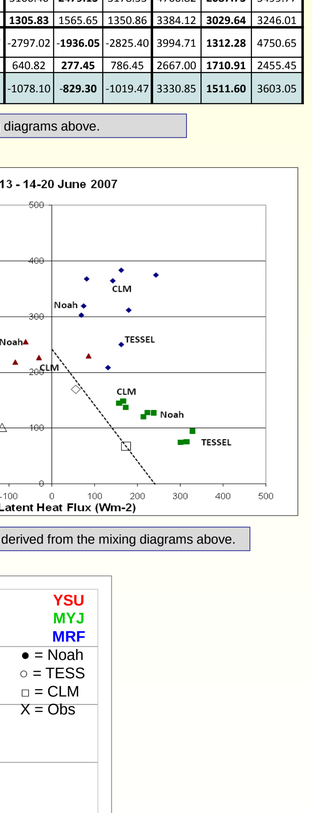
Figs 5. Mean diurnal cycles for the **14-20 June 2007** period for different LSM-PBL couplings evaluated across ARM-SGP sites.

LoCo Diagnosis

2006



2007



Mixing Diagrams
- 7-day composites of 2006 vs. 2007 shows overall behavior for each LSM-PBL pair
- Overlays of Theta-e and q*sat show tendency towards/away from saturation and clouds/precipitation

Energy Statistics
- Derived from T/q evolution vs. obs
- Total energy of the system computed

PBL Budgets
- Full components (surface, entrainment, total) of the heat and moisture budgets of the land-PBL
- Derived directly from Mixing Diagrams

EF vs. PBL Height
- Integrative measure of the impact of the surface condition on the atmosphere
- Sensitivity to choice of LSM vs. PBL scheme

Figure 6. **Mixing Diagrams** from the LIS-WRF simulations of Noah, TESSEL, and CLM composited over the 7-day case studies of 2006 (14-20 July) and 2007 (14-20 June), and overlain with lines of constant equivalent potential temperature (Theta-e) and saturation humidity (q*sat) deficit.

	Noah+ YSU	Noah+ MYJ	Noah+ MRF	TESS+ YSU	TESS+ MYJ	TESS+ MRF	CLM+ YSU	CLM+ MYJ	CLM+ MRF
RMSE T2	7676.35	**4010.32**	7541.49	5374.09	**2260.11**	5095.88	**3328.06**	4118.45	4494.36
Q2	4286.08	4955.41	**3690.39**	4033.14	**2141.18**	3467.70	4821.05	**4238.01**	4705.49
BIAS T2	-7573.25	**-3809.71**	-7386.57	-4993.44	**-2137.12**	-4763.65	**-3239.87**	-4075.62	-4432.84
Q2	3679.64	4909.45	**3108.82**	3611.82	**2076.45**	3082.27	4777.64	**3898.18**	4628.91
Total Energy	-1946.81	**549.87**	-2138.88	-690.81	**-30.33**	-840.69	768.88	**-88.72**	98.04

	Noah+ YSU	Noah+ MYJ	Noah+ MRF	TESS+ YSU	TESS+ MYJ	TESS+ MRF	CLM+ YSU	CLM+ MYJ	CLM+ MRF
RMSE T2	2002.19	**1931.68**	2191.51	3100.40	**2479.13**	3178.33	4700.82	**2087.73**	5499.77
Q2	**2174.83**	3907.56	2197.26	**1305.83**	1565.65	1350.86	3384.12	**3029.64**	3246.01
BIAS T2	-1948.28	**1311.79**	-2130.07	-2797.02	**-1936.05**	-2825.40	3994.71	**1312.28**	4750.65
Q2	**1655.55**	3314.64	1705.91	640.82	**277.45**	786.45	2667.00	**1710.91**	2455.45
Total Energy	**-146.37**	2313.21	-212.08	-1078.10	**-829.30**	-1019.47	3330.85	**1511.60**	3603.05

Table 1. **Statistics** based on evolution of T2m and Q2m vs. observations, derived from the mixing diagrams above.

Figure 7. **Heat and moisture budgets (SFC, ENT, and TOTAL)** from the LIS-WRF simulations vs. observed, derived from the mixing diagrams above.

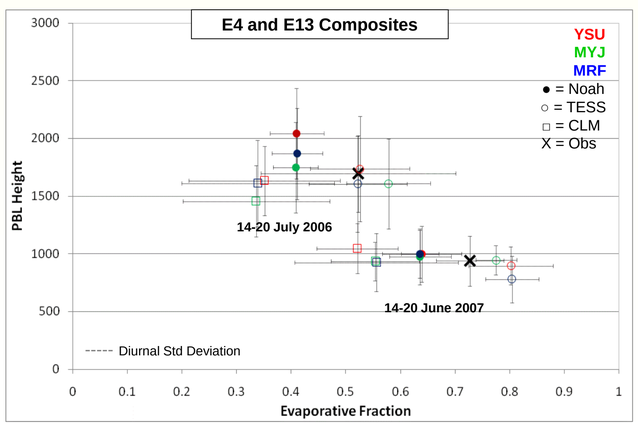


Figure 8. **Evaporative Fraction vs. PBL Height** for each simulation vs. observed, along with the diurnal standard deviation through the 7-day period

Summary

- Significant errors exist in land surface energy balance simulations that depend on LSM and dry/wet regime.
- LoCo Diagnostics can be used to evaluate LSM and PBL scheme behavior simultaneously in the context of their diurnal co-evolution.
- The sensitivity of L-A coupling is stronger towards the land during dry conditions.
- Noah exhibits large insensitivity to soil and flux parameters during wet conditions.
- MYJ produces best total energy and PBL budgets in dry regime for all LSMs.
- CLM overestimates and TESSEL underestimates total energy in both regimes.
- PBL height largely insensitive to surface fluxes during wet regime.

Future Work

Diagnostics:
- Soil moisture perturbations
- LCL Deficit

Extend methodologies:
- MERRA, IFS, NARR
- Links to GLASS-LoCo

NASA connections:
- Incorporate satellite remote sensing of PBL and LS properties into diagnostics
- AIRS/IASI soundings and radiances
- Land Data Assimilation (coupled vs. offline)

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

Santanello, J. A. et al., 2011: Diagnosing the Sensitivity of Local Land-Atmosphere Coupling via the Soil Moisture-Boundary Layer Interaction. *J. Hydromet.,* **in press.**