Land-Atmosphere Coupling Studies Using the LIS-WRF System

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NASA ENERGY AND WATER CYCLE STUDY

Project Description

Hypothesis:

Uncoupled systems (e.g., LDAS/LIS) or experiments (e.g., PILPS) may lead to inaccurate water and energy cycle process understanding by neglecting feedbacks due to Local Land-Atmosphere Coupling ('LoCo').

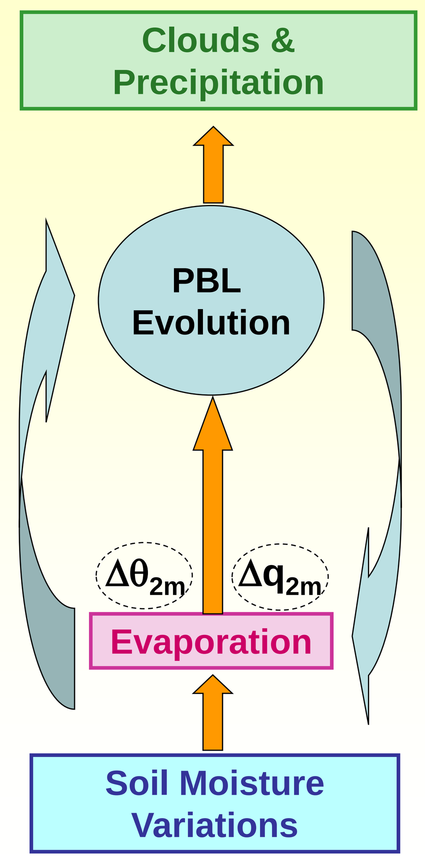
Objectives:

- To accurately understand, model and predict the role of **LoCo** of land–atmosphere interactions in the evolution of PBL/land fluxes and state variables.
- Develop a methodology to study factors controlling LoCo, using the coupled **LIS-WRF** system as a testbed to evaluate coupling diagnostics within community PBL and land surface models.

Contribution to the GEWEX-GLASS Community:

- **Understanding** and **quantification** of the processes controlling LoCo and their representation in offline, single-column, and fully-coupled models.
- **Diagnostic approach** that can be applied to any model (MERRA, MMF, GEOS-5) and observations.
- Determine the impact of the spatial and temporal scales of land surface physics and heterogeneities on convective initiation, clouds, and precipitation.
- Assess the impact of LoCo on **assimilation** of NASA observations into WEC predictions.

Diagnostic Framework



- The degree of LoCo between the land surface and PBL must be represented accurately in models, but remains largely undiagnosed due to the complex interactions and feedback processes present across a range of scales.
- A PBL-LS *balance* is created each day that depends on the nature and degree of L-A interactions in each coupled model
- The diurnal evolution of:
  - **2m pot. temperature**
  - **2m humidity**

  can be used to diagnose the Surface and PBL (entrainment) fluxes
- $\Delta\theta_{2m}$, Δq_{2m} reflect the heat and moisture equilibrium reached for a particular PBL + LSM coupling
- **Advection** can be added as a third vector to quantify the full PBL budget and its 'locality'.

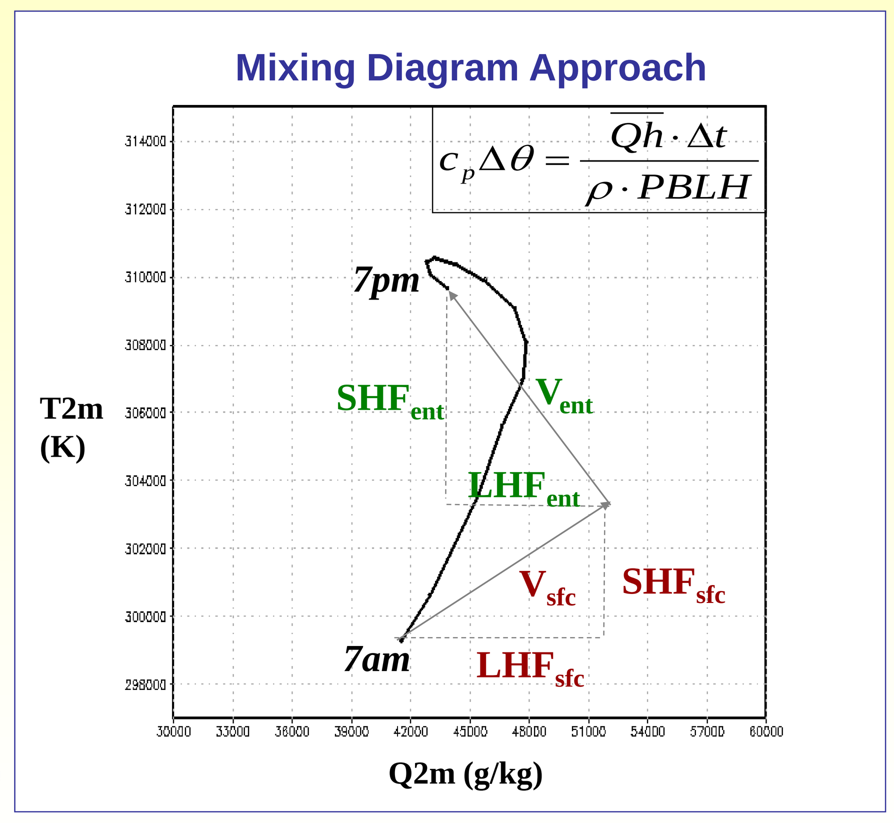


Figure 1: Diurnal evolution of 2m-potential temperature ($C_p\theta$) vs. 2m-specific humidity (Lq) from a representative day during June 2002 in the U.S. SGP as simulated by LIS-WRF.

Model and Experimental Design

Coupled LIS-WRF

- 1-km horizontal resolution
- NARR forcing
- 43 vertical levels (~42m sfc)
- 3 PBL + 3 LSM schemes:
  → **9 combos of L-A coupling**
- Case studies:
  → **IHOP02, C99, Cabauw**

Land Information System

- Developed at NASA-GSFC
- 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

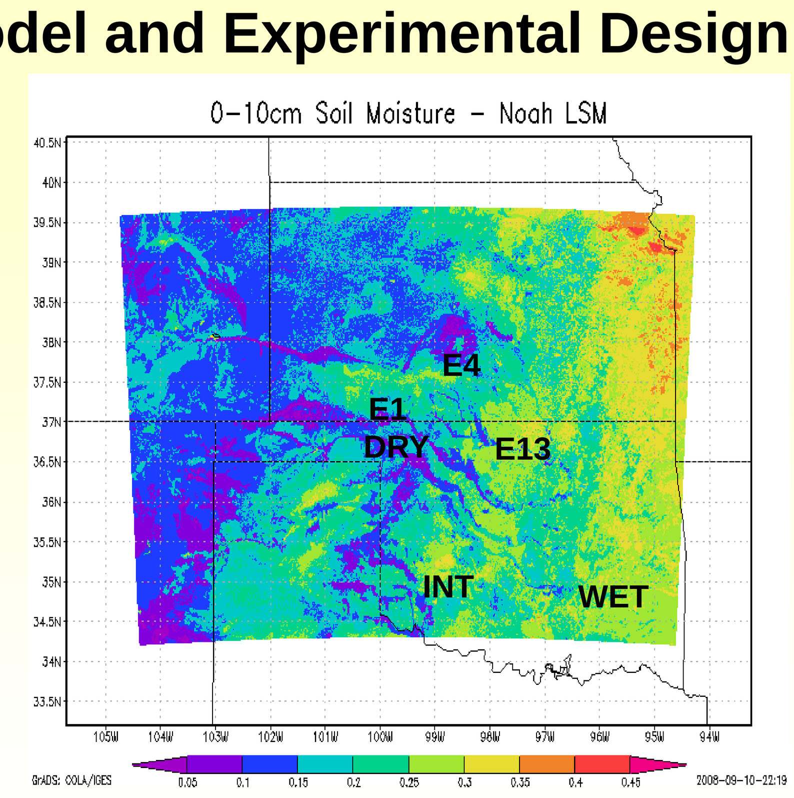


Figure 2: Initial soil moisture for the LIS-WRF (Noah LSM spinup) on a1km-domain with locations of the dry, intermediate, and wet analysis regions and ARM-SGP Extended Facilities.

LIS

WRF – THE WEATHER RESEARCH & FORECASTING MODEL

PBLs in WRF

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

MYJ (Mellor-Yamada)
- Level 2.5 closure
- TKE

MRF
- Based on YSU scheme
- Implicit vertical diffusion

LSMs in LIS

Noah (NCEP)
- 4 soil layers
- NCEP operational

CLM (Community Land Model)
- 10 soil layers (2 cm upper)
- Extensive canopy/veg

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

Results

LoCo Diagnostic Connections

- 'Links in the chain' are being better understood and quantified.
- Hierarchy approach (similar to Dirmeyer but at diurnal process level):
  d(P)/d(SMC) = d(EF)/d(SMC) + d(P)/d(EF) but: **d(EF) = f(PBL entrainment feedback on LS)**
- Our focus (employing scales and flexibility of **LIS-WRF**):
  Evaluating the dry air entrainment feedback and impact on PBL-LS equilibrium:

Mixing Diagrams and RH Tendency

Ω, $r_{a,s}$ — CTP-HI_{low} — r_{bl} — **Δ(LCL/LFC - PBLH)**

ΔSMC → ΔEF → ΔML → ΔENT → ΔEEF ► **ΔP/Clouds**

[θ_e] [γ] [PBLH] [θ_{ee}] [PBLH = LCL/LFC]

[P_{LCL}] [ΔZ_{RL}] [β_{ent}, Δq_{top}] [P_{LCL}]

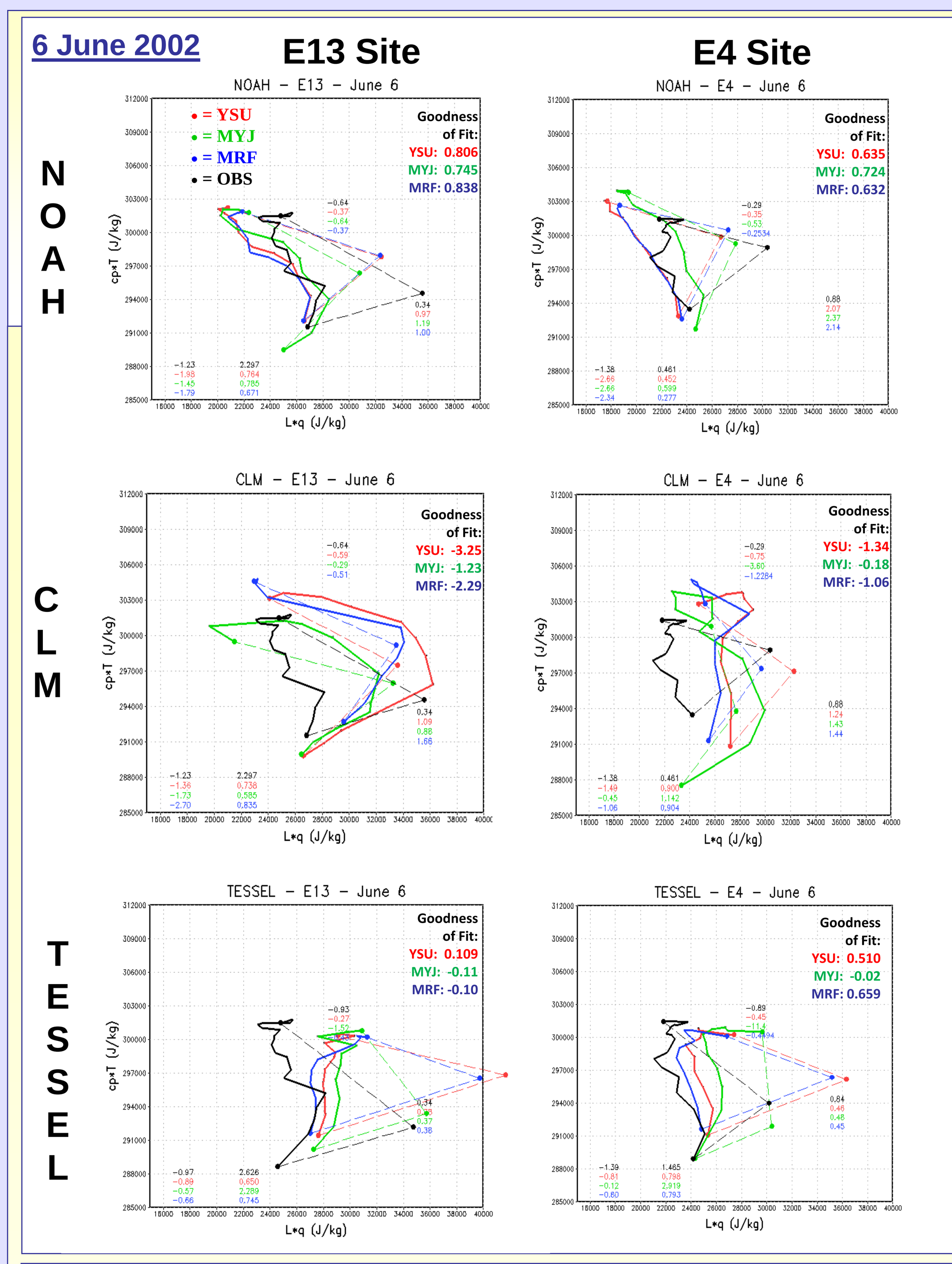


Figure 4: Same as Fig. 3, but simulated at the ARM-SGP site at Lamont, OK (**E13**) and Plevna, KS (**E4**) on 6 June 2002 and overlain with **observations.** The **Nash-Sutcliffe efficiency coefficient** is also listed for each PBL-LSM combination.

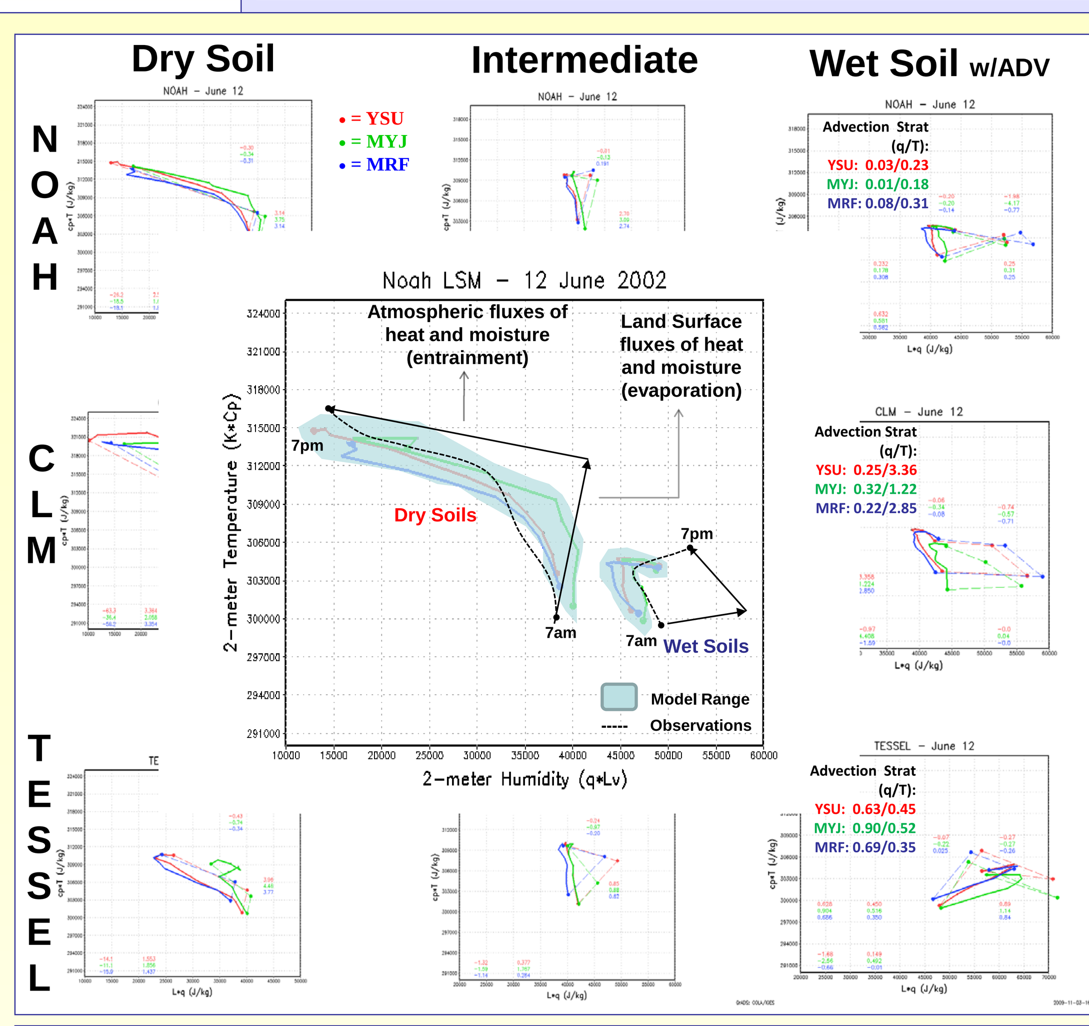
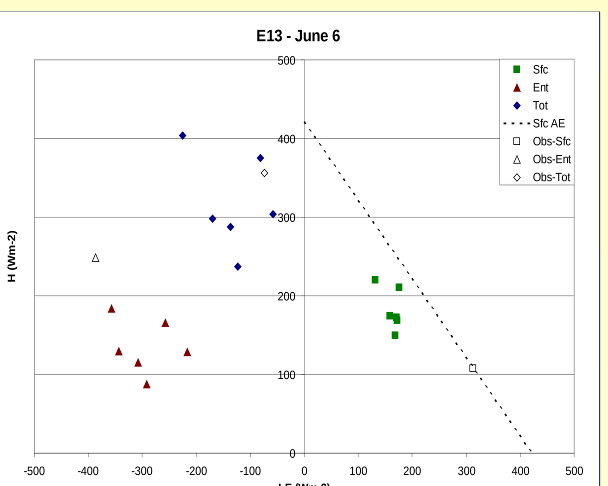
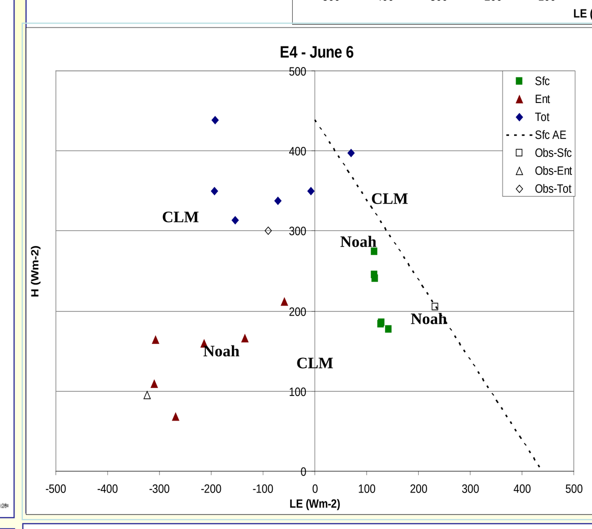


Figure 3: Mixing diagrams and derived metrics simulated by LIS-WRF using the **Noah**, **CLM**, and **TESSEL** land surface models coupled with the **YSU**, **MYJ**, and **MRF** PBL schemes for the dry, intermediate, and wet soil locations (Fig. 2).

PBL Budgets

- The *fluxes* that compose the **total heat and moisture budgets** in the PBL can be derived from mixing diagrams and compared against observations.

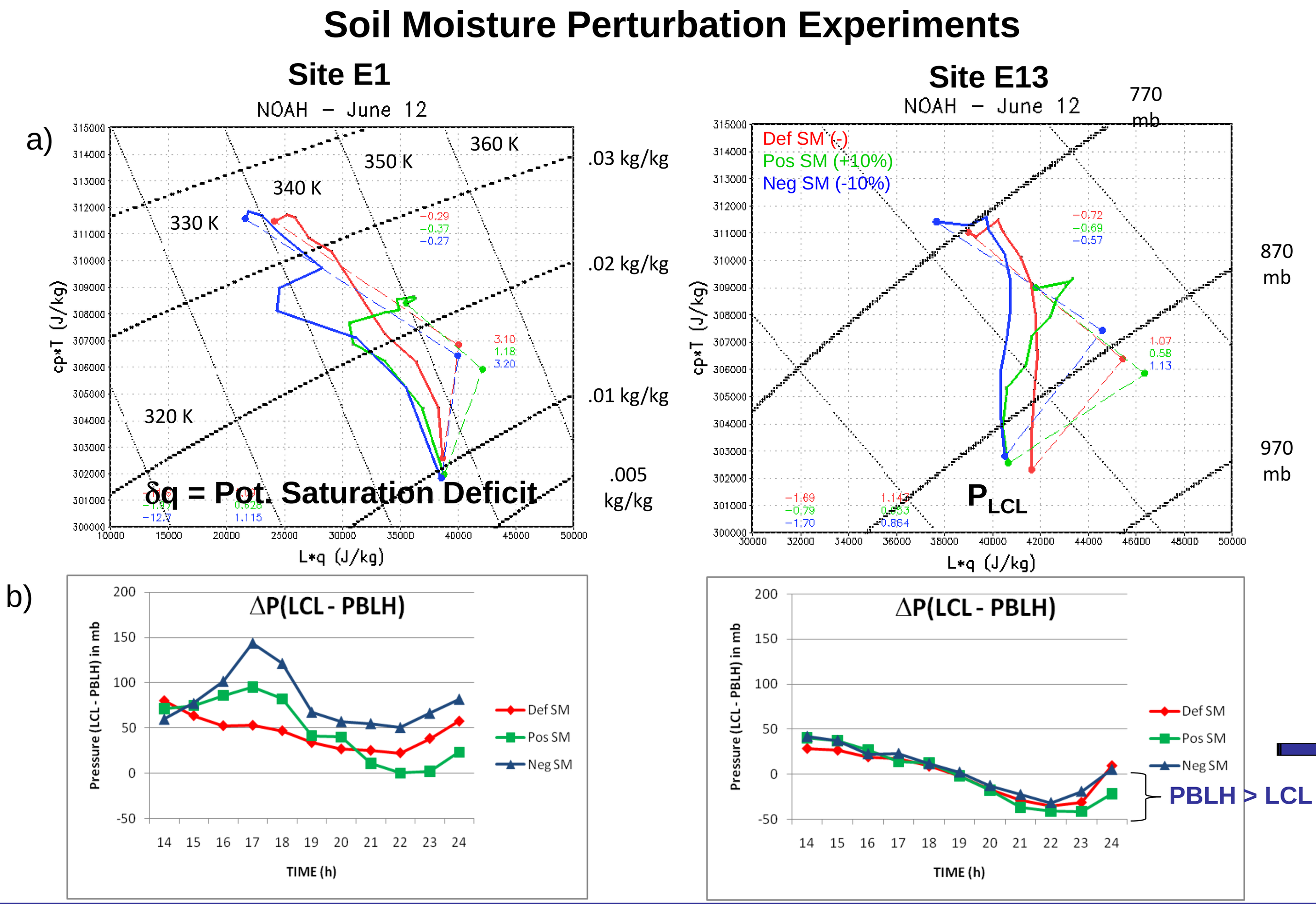




- These plots show the variability in land *and* atmospheric fluxes caused by **different PBL-LSM couplings,** and the relative sensitivity of the simulations to a particular LSM or PBL choice.

Figure 5: Relationship between latent (LE) and sensible (H) heat fluxes from the surface (■), entrainment (▲), and their sums (◊) derived from Fig. 4 along with observations (□).

Soil Moisture Perturbation Experiments



- The PBL-LSM couplings have varying responses to a **perturbed soil moisture conditions** indicating the strength of LoCo.
- The sensitivity of LoCo can be evaluated in terms of the diurnal evolution of the following as overlays on mixing diagrams: P_{LCL}, **Theta-e**, **δq**, and **RH**.
- Following along lines of constant **δq** indicates **equilibrium evaporation** in the PBL where the surface moisture flux is balanced by dry air entrainment.
- Each exhibits different sensitivities of **cloud formation,** as calculated from the diagrams as the **difference between PBL height and the LCL**, and supported by cloud formation in the WRF model.

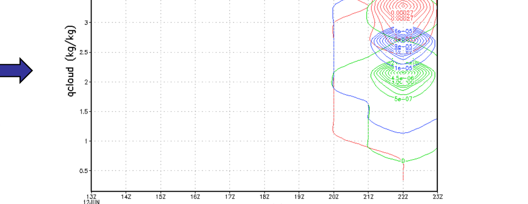


Figure 7: a) Mixing diagrams for **Noah** + **YSU** simulations with **default**, **positive**, and **negative** soil moisture content (+/-10%) overlain by δq and P_{LCL}. b) The temporal evolution of the difference between the LCL and the PBL height at each site. c) Vertical profile of cloud water content evolution at E13 (note: E1 has zero cloud water).

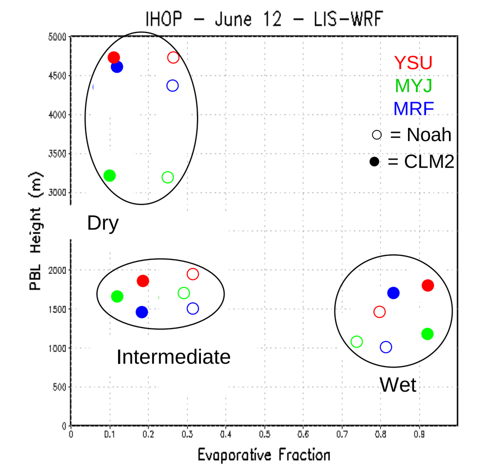
- The evolution of each q vs. θ curve reflects the balance between **surface fluxes** and the **entrainment rate** of the growing PBL.
- Dry air entrainment dominates at the dry soil site, while a noticeable shift towards a moistening regime is evident at the intermediate and wet soil sites (**Fig. 3**).
- The accuracy of each **PBL-LSM coupling** can be quantified using observations (**Fig. 4**).

Bowen Ratios
- $\beta_{sfc} = H_{sfc}/LE_{sfc}$
- $\beta_{ent} = H_{ent}/LE_{ent}$

Entrainment Ratio
- $A_h = H_{ent}/H_{sfc}$

Dry Air Entrainment Ratio
- $A_{le} = LE_{ent}/LE_{sfc}$

Evaporative Fraction vs. PBL Height



- This relationship highlights the overall **sensitivity of the L-A system** to the choice of LSM and PBL scheme, and when compared with observations indicates the accuracy of each.
- When combined with the mixing diagrams and PBL budget analyses, **deficiencies in components of PBLs and LSMs** can be pinpointed to improve simulations and proper representation of LoCo.

Figure 6: Relationship of EF to maximum PBL height as simulated by **Noah** (○) and **CLM** (●) coupled with the **YSU**, **MYJ**, and **MRF** PBLs at the E13 and E4 sites (Figs. 4-5)

Future Work

Diagnostic approach:

- Soil moisture perturbation experiments
- LIS-WRF to serve as testbed for GLASS/LoCo-directed experiments
- ► NEWS 2006/7 extremes
- Single-column model testbed (WRF 1-D)

Extend methodologies:

- Convective initiation, clouds, precipitation & heterogeneity
- Mass-flux treatment
- Larger scales and models (MERRA, GEOS-5, MMF)

NASA observations:

- Incorporate satellite remote sensing of PBL and LS properties into diagnostics
- How does LoCo impact data assimilation in offline, single-column, and coupled models?
- EnKF in LIS-WRF: surface temperature, soil moisture, & snow cover

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