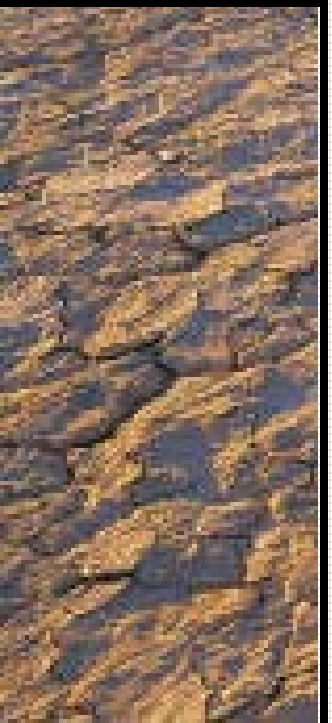

LoCo Diagnostics and LIS-WRF Experimental Design for the 2006-7 Period

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Hydrological Sciences Branch
NASA-GSFC

NEWS Science Team Meeting
2 December 2009

NASA Energy and Water Cycle Study

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NEWS Collaborators: Mike Bosilovich, Randy Koster, Rolf Reichle, Matt Rodell, Xiquan Dong
External Collaborators: Bart vd Hurk (KNMI), Mike Ek (NCEP), Eleanor Blyth (CEH), Cor Jacobs, Obbe Tuinenburg (WUR)

Motivation

- ***Land-atmosphere interactions and coupling*** remain weak links in current land surface and atmospheric prediction models.

- The degree to which the land impacts the atmosphere is difficult to observe, quantify, and simulate given the disparate resolutions and complexities of the ***governing processes and feedbacks***.

Overarching goals of this research:

- To accurately understand, model, and predict the role of **Local Land-Atmosphere Coupling - 'LoCo' -** in water and energy cycle prediction.

- Develop a methodology to study factors controlling **LoCo** using the **LIS-WRF** system, which will serve as the foundation for future pilot experiments to evaluate a range of coupled modeling efforts within the international community.

Outline

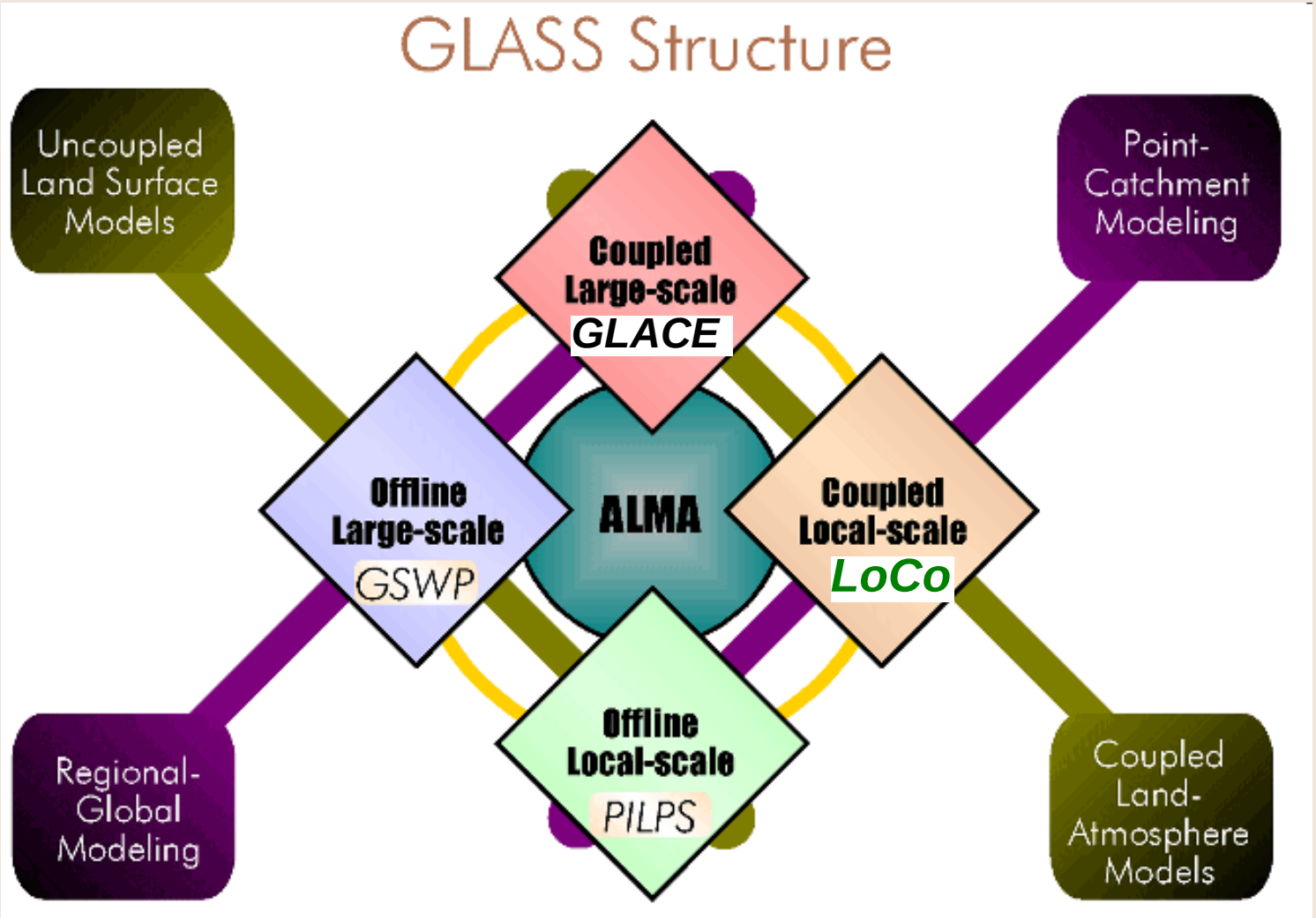
LoCo History and Recent Updates

LoCo Diagnostics

2006-7 Experimental Design

Summary & Future Work

GEWEX
Global Land-Atmosphere System Study



Perspectives on Past Workshops

April 2002: GLASS workshop on land-atmosphere interaction

- **I. Goal**: Inventory conditions where modeled fluxes and state variables are sensitive to the land-atmosphere coupling.
  - **Action**: GLACE – GCM ensembles and identification of 'hotspots' related so SM-precip coupling.

- **II. Goal**: Identify the nature of the land-atmosphere coupling by varying the combinations of land model-PBL model in a systematic way.
  - **Action**: Use a common land-atmosphere coupling framework (LIS-WRF), and start with providing a choice of PBLs, to which a range of LSMs can be connected.

- **III. Goal**: The relation between data assimilation and land-atmosphere feedback will be addressed
  - **Action**: Offline vs. coupled land DA experiments in the works
    - e.g. development of LIS DA module + LIS-WRF

Perspectives on Past Workshops

Sept. 2005: GLASS/GABLS workshop on local L-A coupling

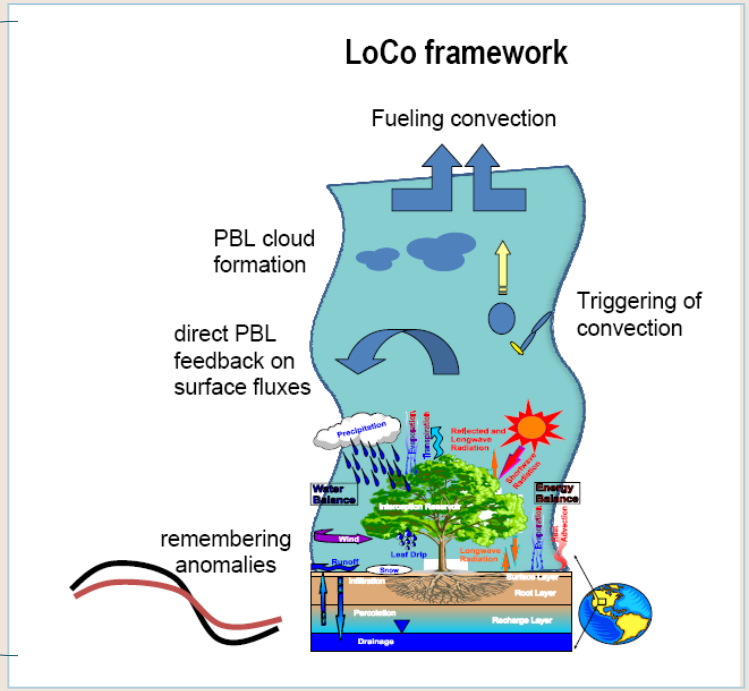
- **Conclusions**
  - It is recommended to carry out simulations in a different number of locations, both within and outside the ***hotspots of L-A coupling***.
  - These integrations should focus on the mechanisms that cause differences in ***coupling strengths among models and observations***.
  - A diagnostic equation like Ek and Holtslag's RH-tendency is a powerful tool to ***stratify the relative contribution of different processes*** to the coupling strength.
  - This should be extended to ***include the relative contribution of advection***. In addition, other diagnostics may be formulated (e.g. residual layer impact, vegetation stress regime).

- **Actions**
  - Using **LIS-WRF** (3D) model at high resolution over **SGP** (3 PBLs+3 LSMs)
  - Mixing diagram approach to diagnosing coupling (explained here)
  - Incorporates much of RH-tendency theory and includes advection

Perspectives on Past Workshops

‘Realm of LoCo’

The temporal and spatial scale of all land-surface related processes that have a direct influence on the state of the PBL



June 2008:
GLASS/EU-WATCH Workshop on Local Land-Atmosphere Coupling

- Direct moistening/drying and heating/cooling of the PBL, and the feedback exerted by this PBL change on the surface fluxes
- Impact of the change of the PBL depth or thermodynamic state on the formation/disappearance of PBL clouds (shallow cumulus) induced by land surface fluxes
- Triggering and fueling of shallow or deep convection
- The accumulation of hydrological anomalies in the soil water or snow reservoir, and the subsequent impacts of these surface states on the surface energy balance.

Outline

LoCo History and Recent Updates

LoCo Diagnostics

- Mixing Diagrams
- RH-tendency
- CTP-HI_{low}

2006-7 Experimental Design

Summary & Future Work

LoCo Diagnostic Connections

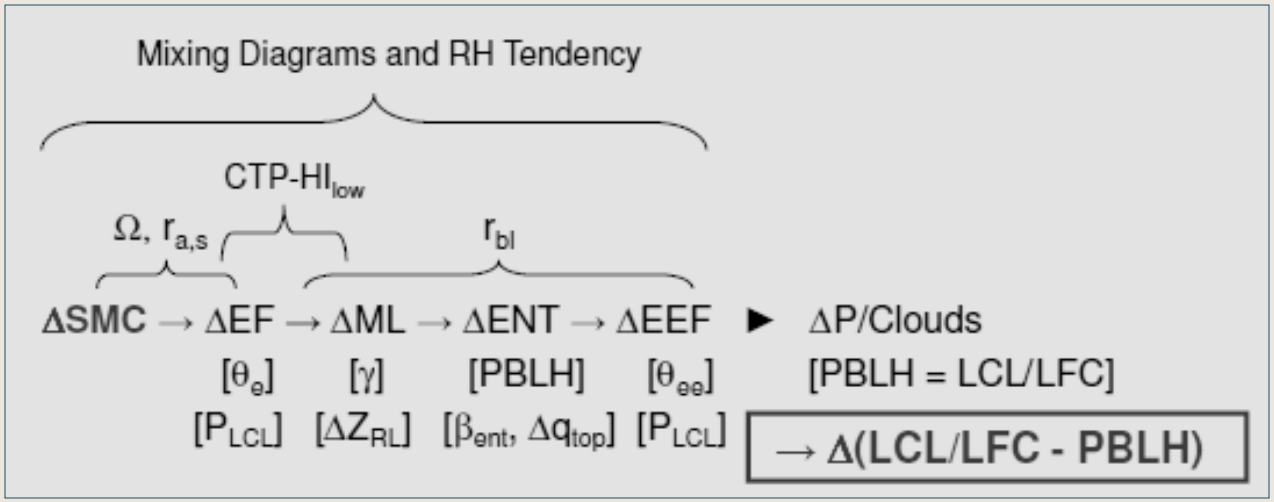
- **<u>2008-9 GLASS (NEWS+WATCH) Collaborations</u>**

  - 'Links in the chain' are being better understood and quantified.

  - Hierarchy approach at the *diurnal process level*:

  d(P)/d(SMC) = **d(EF)/d(SMC) + d(P)/d(EF)** <u>but</u>: **d(EF) = f(ENT feedback on ML equilibrium)**

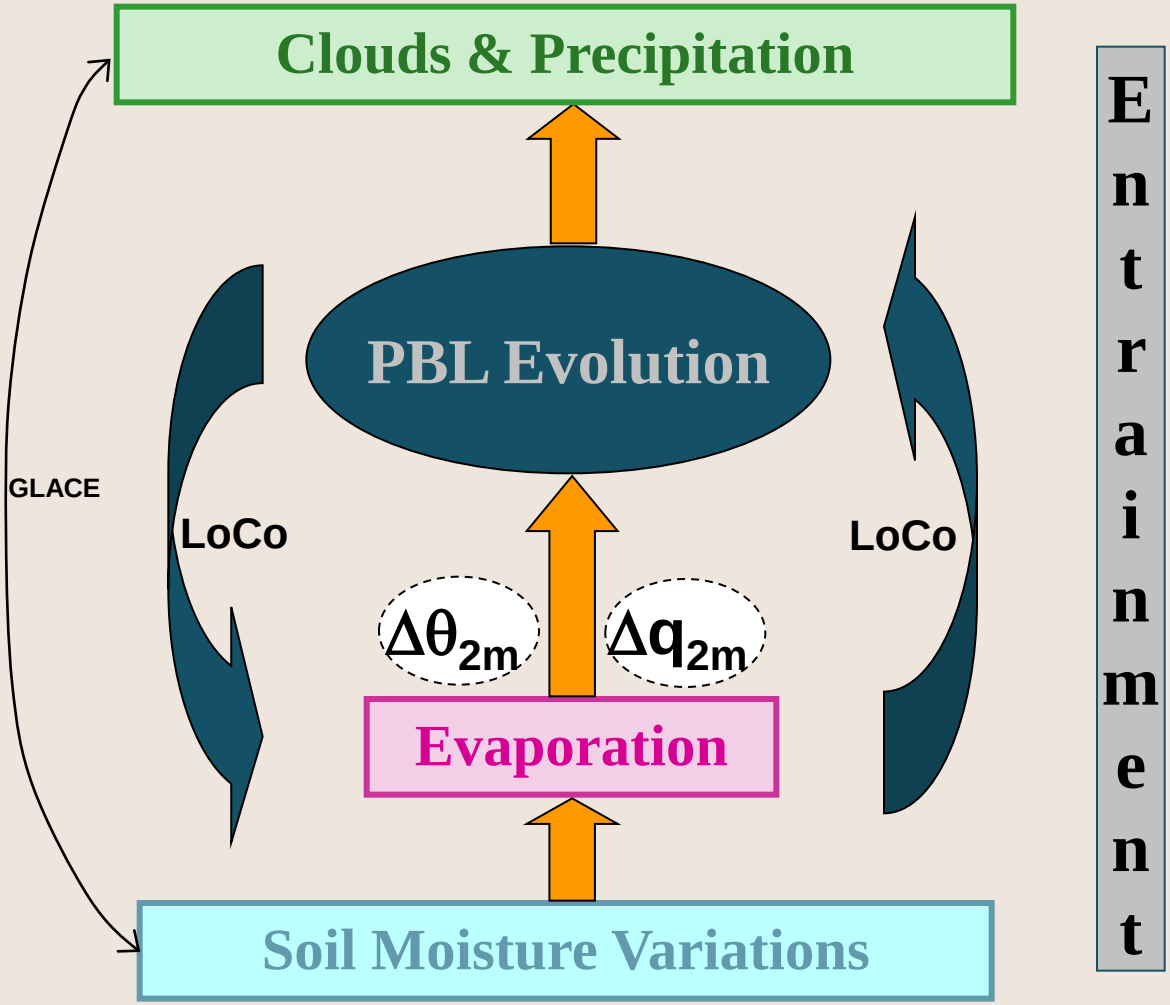
  - <u>Our focus (employing scales and flexibility of **LIS-WRF**):</u> Evaluating the **entrainment feedback** and evolution towards an **equilibrium evaporation fraction (EEF)**.



LoCo Diagnostic Connections

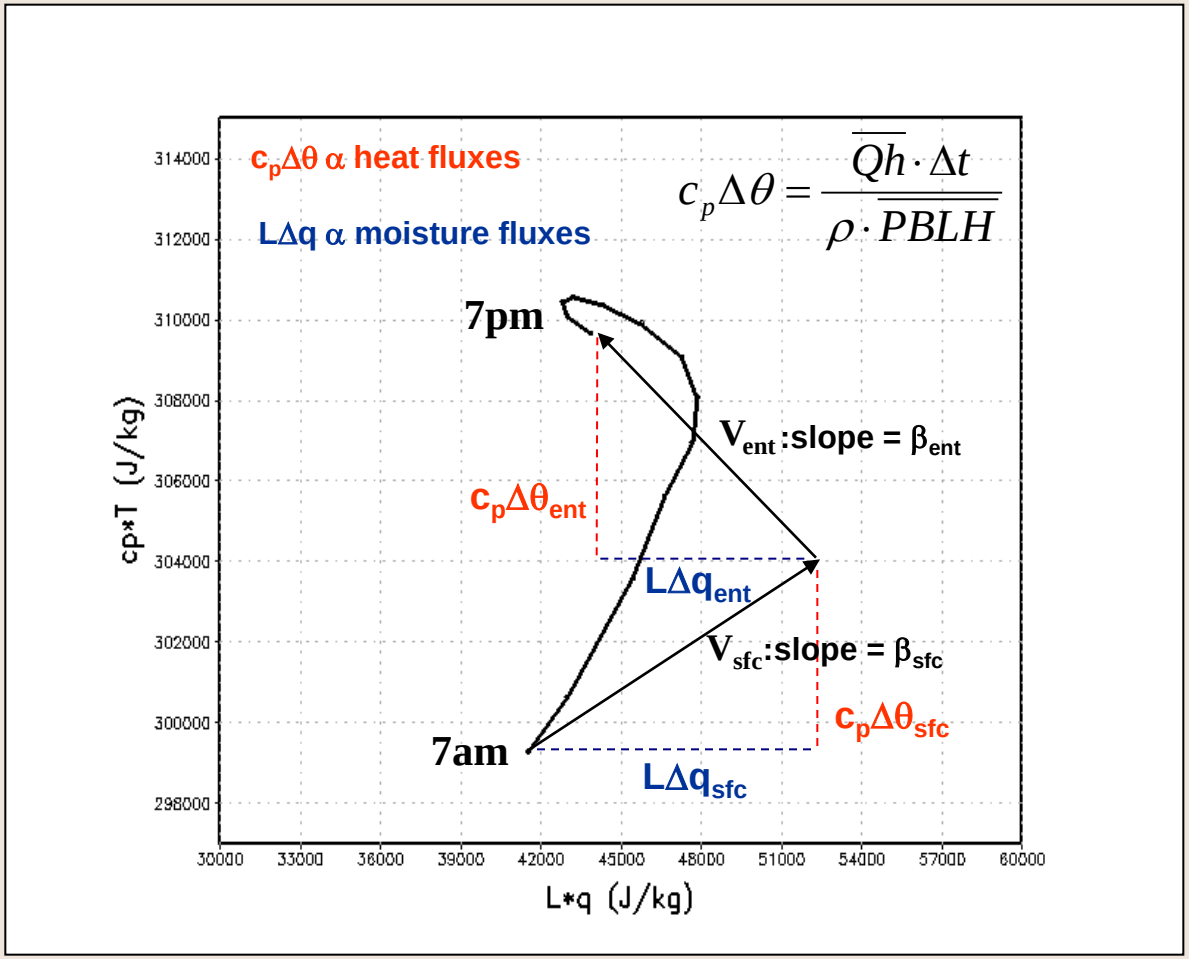
- A ***land surface energy balance and mixed layer equilibrium*** is created each day depends on the nature and degree of PBL-LS interactions in each coupled model.

- The diurnal evolution of: **2m pot. temperature (θ)** **2m humidity (q)** can be used to diagnose the relative contributions of heat and moisture fluxes from the land surface and PBL.



Mixing Diagrams

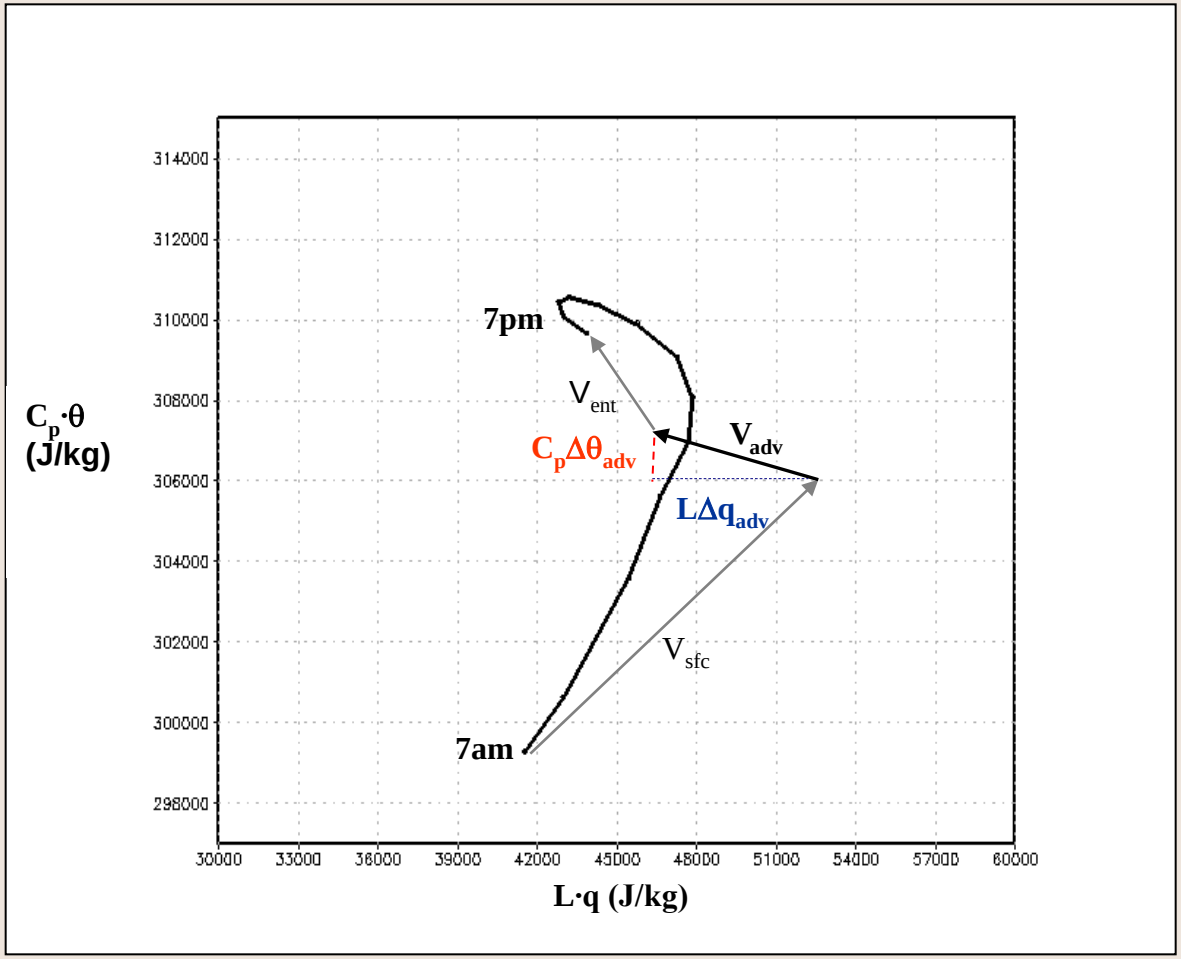
- Based on **Betts (1984, 1992)** mixing diagram (vector) theory evaluated during FIFE.



- "Mixing Diagrams" quantify land-atmosphere fluxes and feedbacks through the evolution of 2m-temperature and humidity.

Diurnal evolution of 2m-specific humidity vs. 2m-potential temperature from a representative day during June 2002 in the U.S. Southern Great Plains.

Mixing Diagrams w/Advection



- Advection vector and fluxes are analogous to sfc and entrainment
- **Example of dry/warm advection**
- Impacts the residual (entrainment) vector only

<u>Heat/Moisture Budget in the PBL</u> = Surface Flux + Entrainment + Advection

Derived Metrics

- **The following metrics can be computed from the mixing diagram approach:**

$A_h = H_{ent}/H_{sfc}$ – General Coupling Statistic

-The entrainment rate produced (PBL) as a consequence of H_{sfc} (LSM).

-Otherwise known as the '**entrainment parameter**'

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

-Quantifies the degree to which dry air entrainment offsets sfc. evaporation.

-If ~ -1 then entrainment balances evaporation and is a negative feedback on surface heating

$\beta_{sfc} = H_{sfc}/LE_{sfc}$ – Surface Bowen Ratio

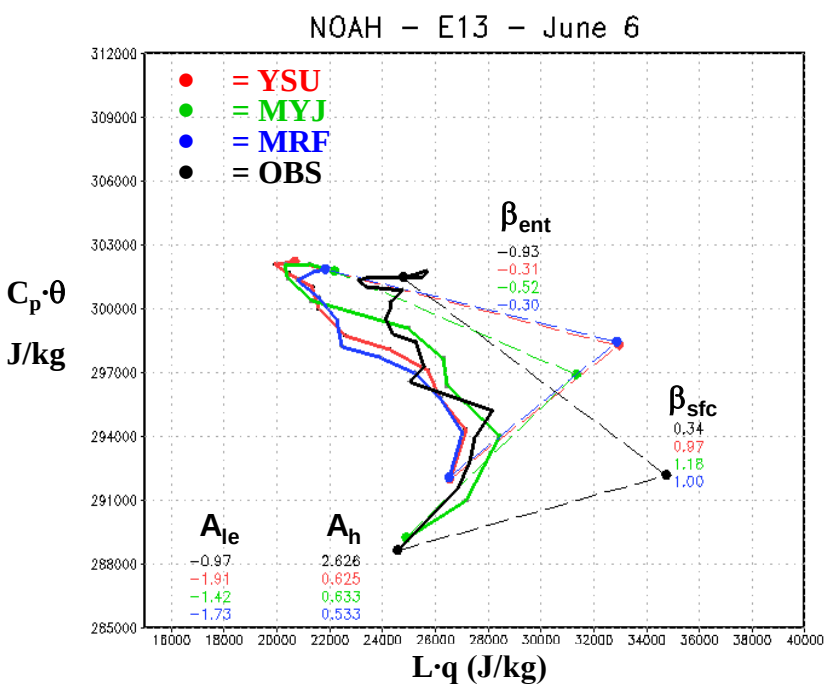
-The partitioning of fluxes at the land surface (strong function of soil moisture).

$\beta_{ent} = H_{ent}/LE_{ent}$ – Entrainment Bowen Ratio

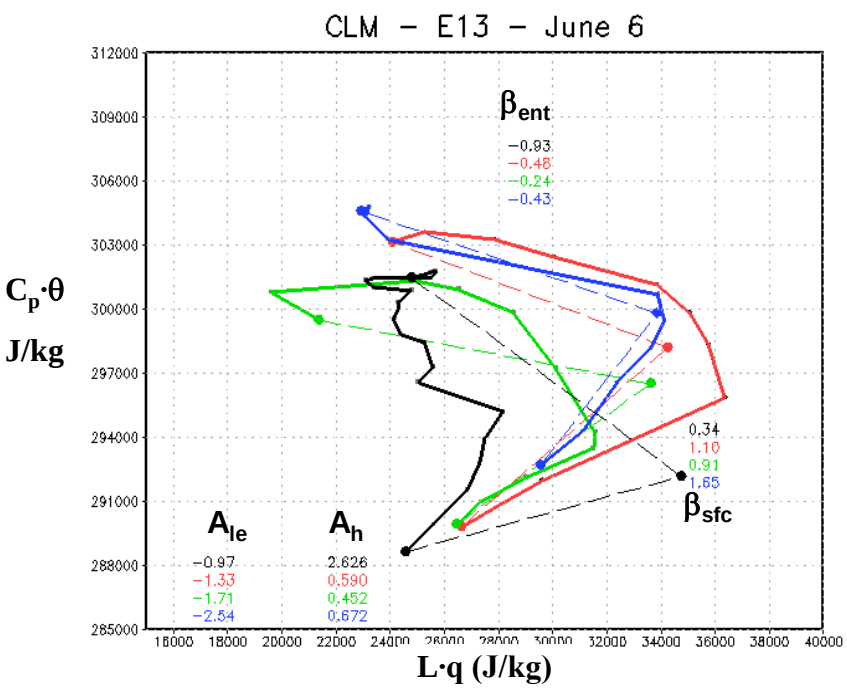
-The amount of heat vs. dry air entrained into the PBL (function of gradient w/ free atmos.)

IHOP 2002 – June 6 – ARM CF

Noah LSM w/ 3 PBLs

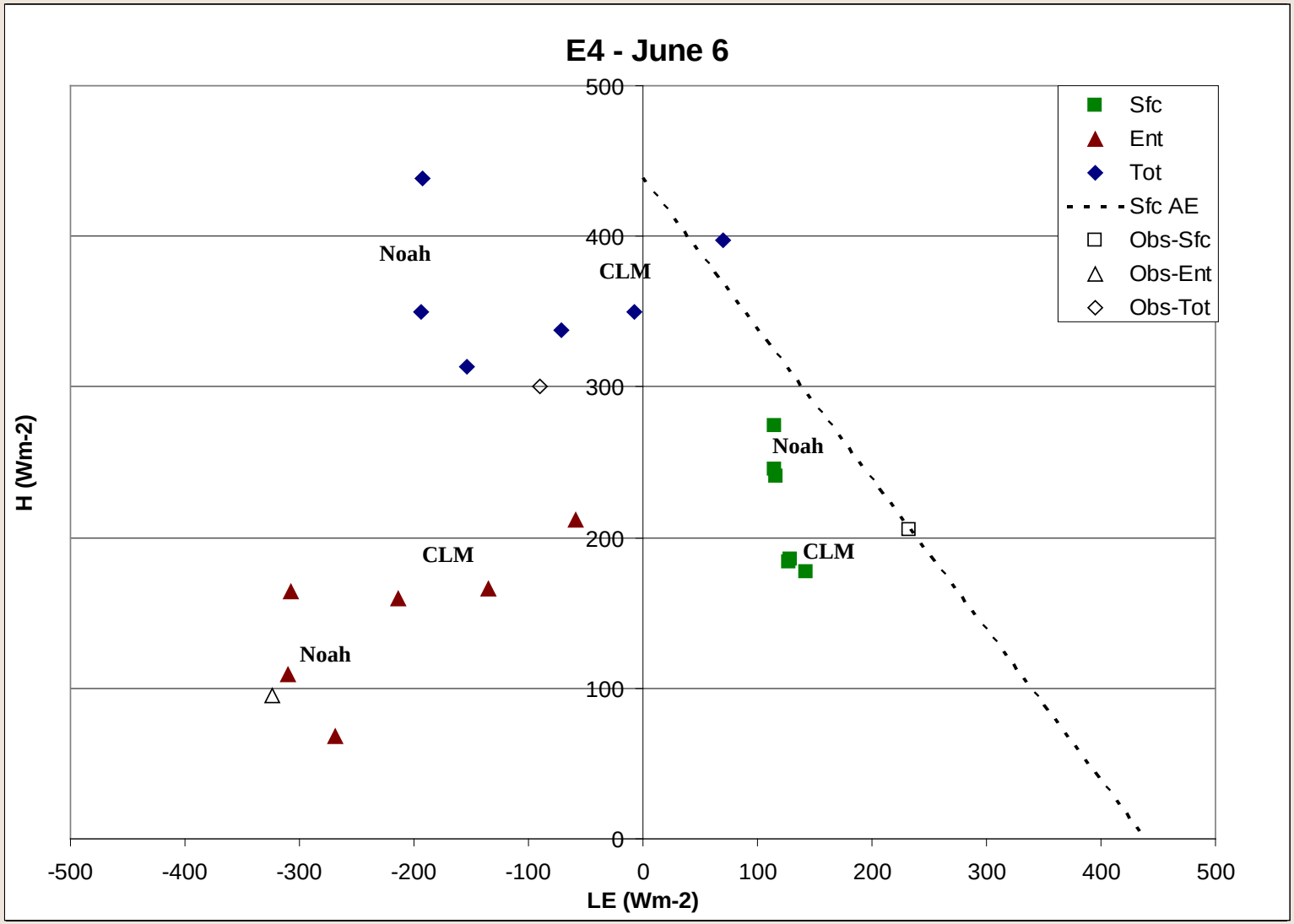


CLM-2 w/ 3 PBLs



- Noah reproduces the observed evolution of θ and q and PBL height
- CLM initially offset; depends on choice of PBL scheme
- CLM overestimates initial moistening of the mixed layer which limits PBL growth

PBL Budgets


E4 - June 6
H (Wm-2)
LE (Wm-2)
500
400
300
200
100
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
Noah
CLM
Noah
CLM
CLM
Noah
Sfc
Ent
Tot
Sfc AE
Obs-Sfc
Obs-Ent
Obs-Tot

IHOP 2002 – June 12 – ARM SGP

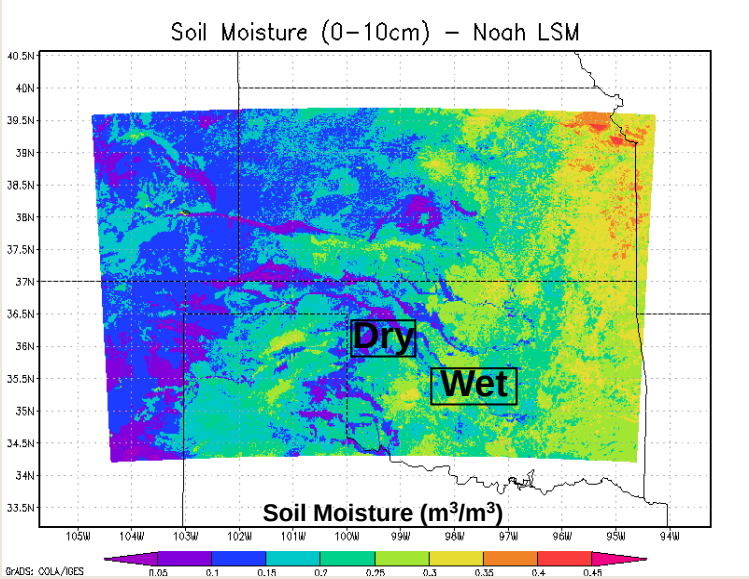


Fig. 1: Near-surface soil moisture map of the Southern Great Plains.

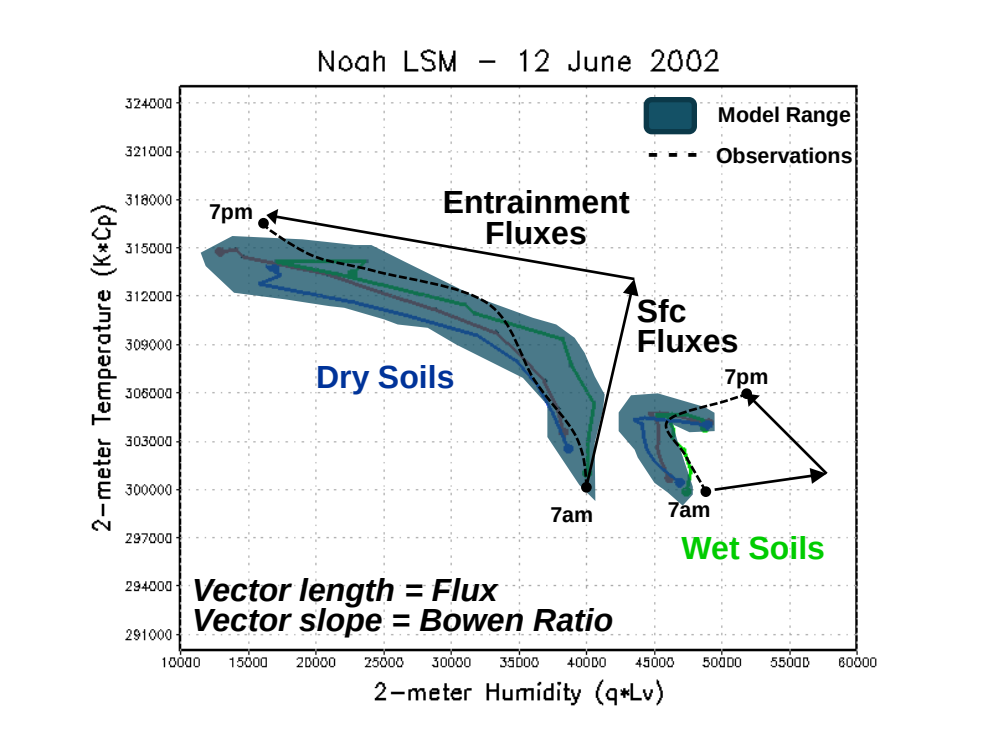


Fig. 2: Daytime evolution of specific humidity vs. potential temperature for the dry and wet soil moisture locations in Fig. 1

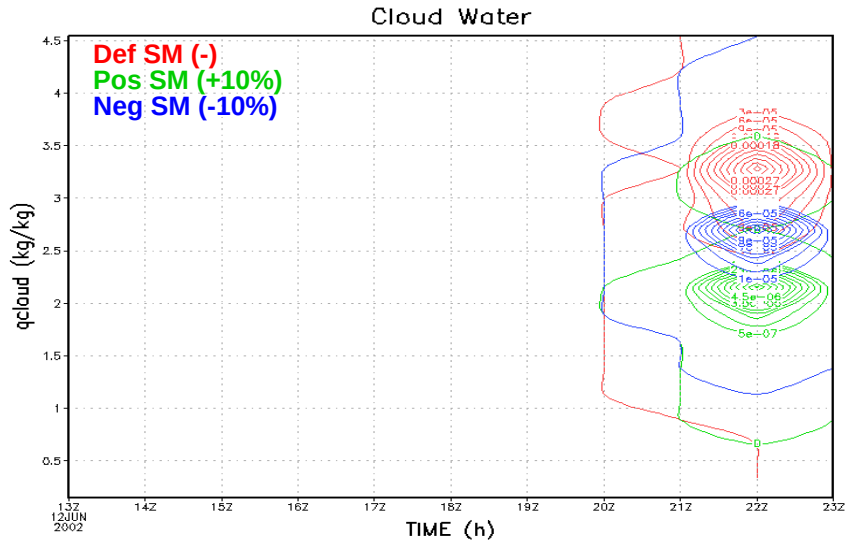
- Soil moisture anomalies lead to significantly different signatures of heat and moisture evolution.

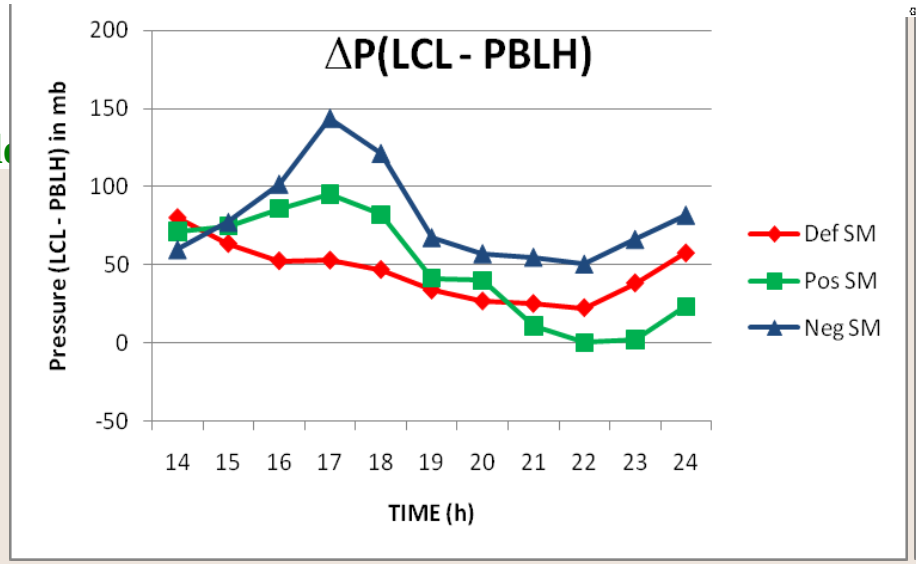
- The sensitivity and strength of the L-A coupling is thus reflected in the balance between PBL and surface fluxes.

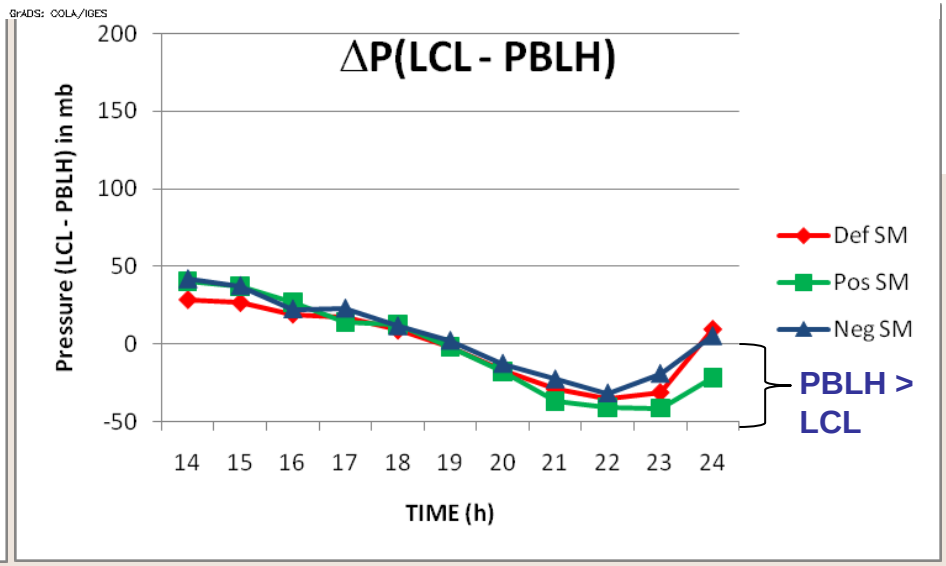
Santanello, J. A., C. Peters-Lidard, and S. Kumar, C. Alonge, and W.-K. Tao, 2009: A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales. *J. Hydrometeor.*, **10**, 577-599.

Soil Moisture Perturbation Experiments

No Clouds







Collaborations w/GLASS-WATCH

- **RH-Tendency Eqn. (Ek and Holtslag 2004)**

The change in RH at the PBL-top is given by:

$$\frac{\partial \mathrm{RH}}{\partial t} = \left(\frac{R_n - G}{\rho L_v h q_s}\right)[e_f + \mathrm{ne}(1 - e_f)], \qquad (1)$$

….and is a function of *evaporative* (EF) and *non-evaporative* (ne) land surface and PBL (i.e. entrainment) processes.

The non-evaporative terms are as follows:

$$\mathrm{ne} = \frac{L_v}{c_p}(1 + C_\theta)\left[\frac{\Delta q}{h\gamma_\theta} + \mathrm{RH}\left(\frac{c_2}{\gamma_\theta} - c_1\right)\right], \qquad (3)$$

Dry-air ↑ entrainment PBL↑ growth ↑ PBL heating

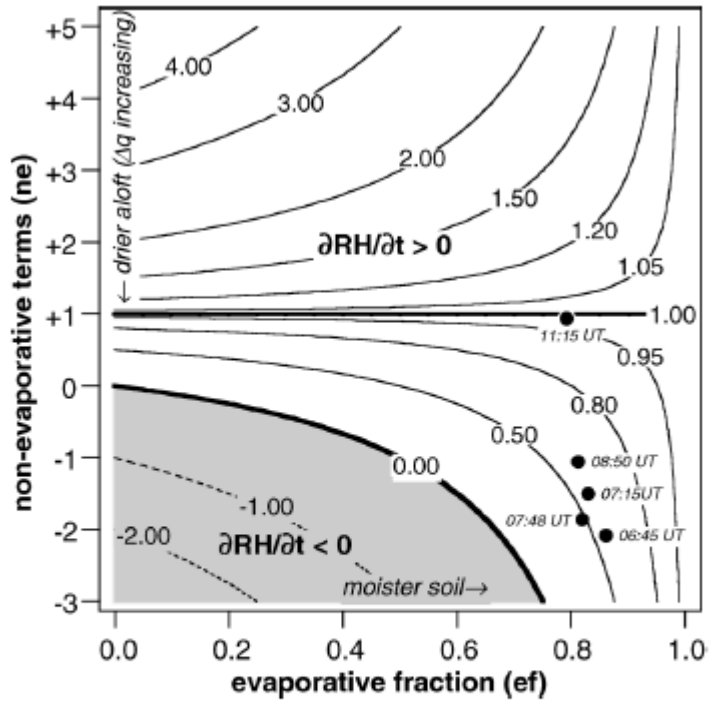
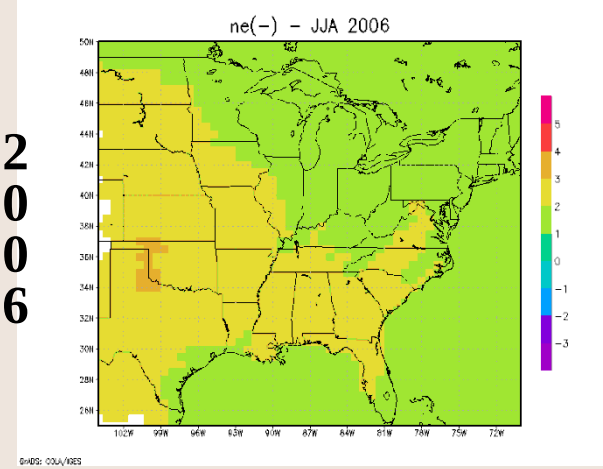


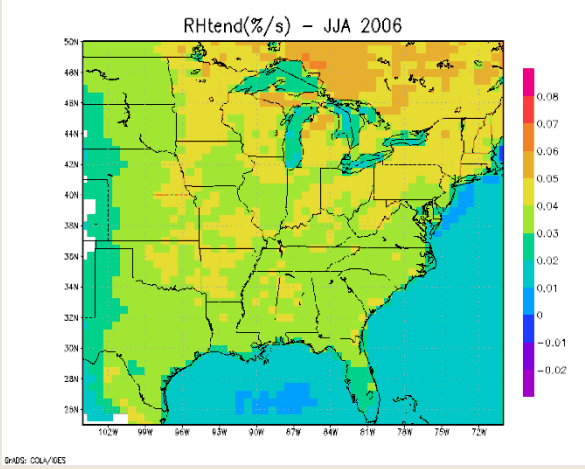
FIG. 10. ABL-top relative humidity tendency equation, $e_f + \mathrm{ne}(1 - e_f)$ (normalized by the available energy term), as a function of evaporative fraction (e_f) vs nonevaporative processes (ne) with Cabauw (Netherlands, 31 May 1978) values and times indicated (dots). See text for details.

NEWS Integration

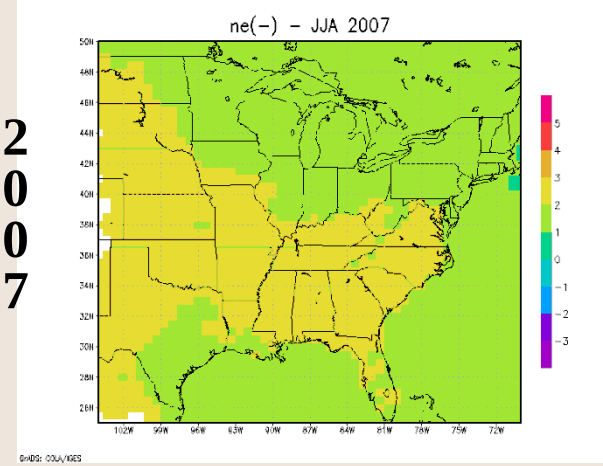
- **RH-Tendency from MERRA for 2006-7 JJA periods (preliminary!)**

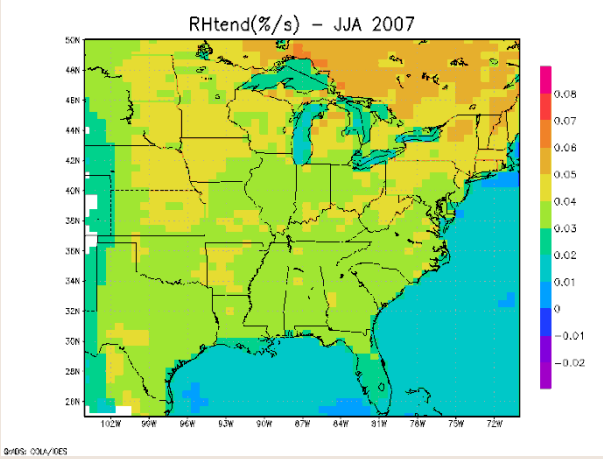
2006





2007





ne **RH-tend**

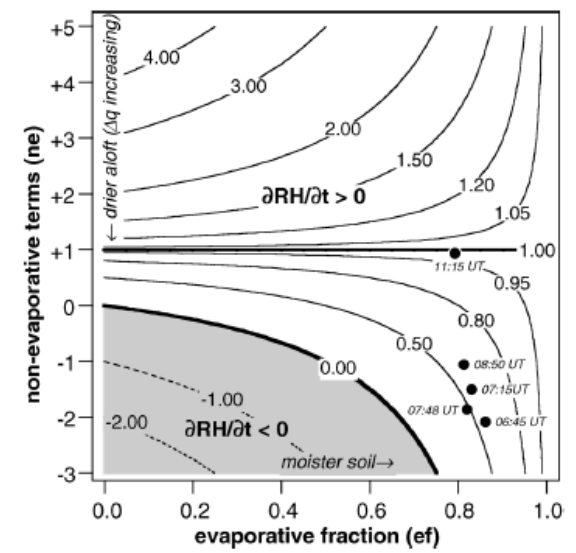


FIG. 10. ABL-top relative humidity tendency equation, e_f + ne(1 − e_f) (normalized by the available energy term), as a function of evaporative fraction (e_f) vs nonevaporative processes (ne) with Cabauw (Netherlands, 31 May 1978) values and times indicated (dots). See text for details.

Collaborations w/GLASS-WATCH

- **<u>Coupling of PBL-top to Land Surface Sensitivities (Jacobs et al. 2009)</u>**

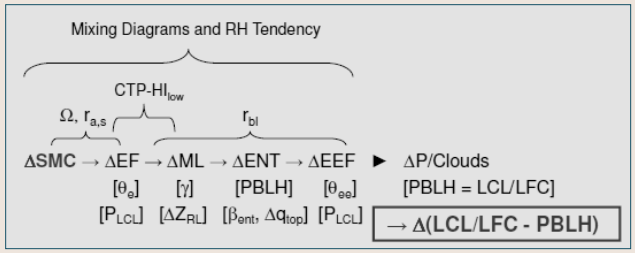
The sensitivity of RH-tend to surface *evaporative fraction* is then expressed as:

$$\frac{\partial RHtend}{\partial EF} = \frac{AE}{\rho L_v h q_s}[1 - ne]$$

…and the corresponding sensitivity to soil moisture can be derived using the decoupling formulation of Jarvis and McNaughton (1986):

$$\frac{\partial RHtend}{\partial SM} = \frac{\frac{E}{L_v h \rho q_s}[1 - ne][1 - \Omega]}{SM - SM_{wilt}}$$

which employs the decoupling coefficient, Ω (ranges from 0-1):

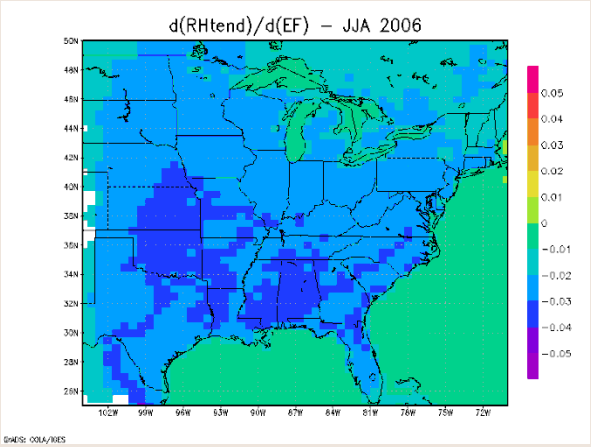


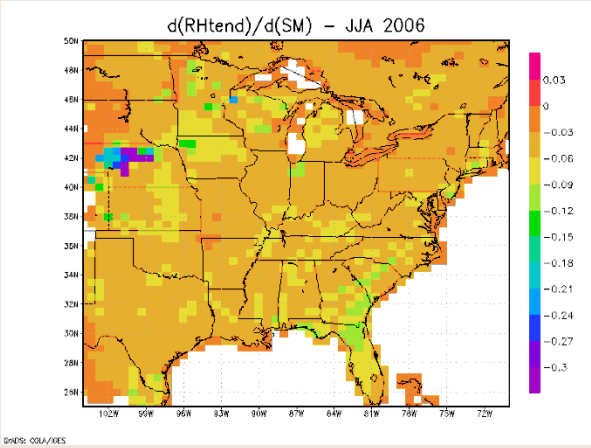
$$\Omega \equiv \left[1 + \frac{\gamma}{\gamma + s}\frac{r_s}{r_a}\right]^{-1}$$

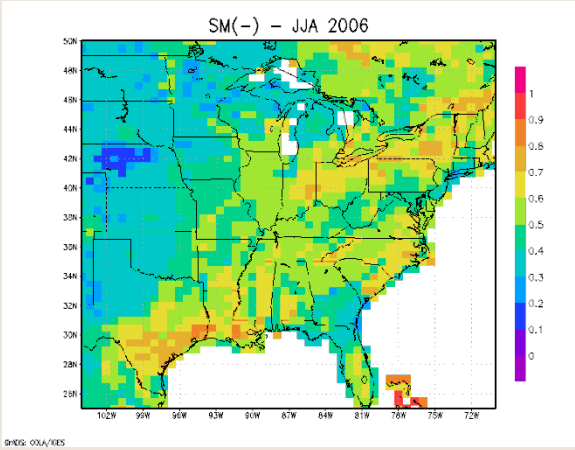
NEWS Integration

- **Sensitivity of RH from MERRA for 2006-7 JJA periods**

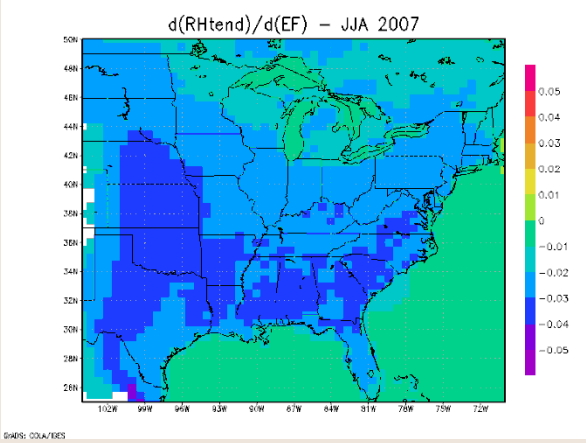
2006

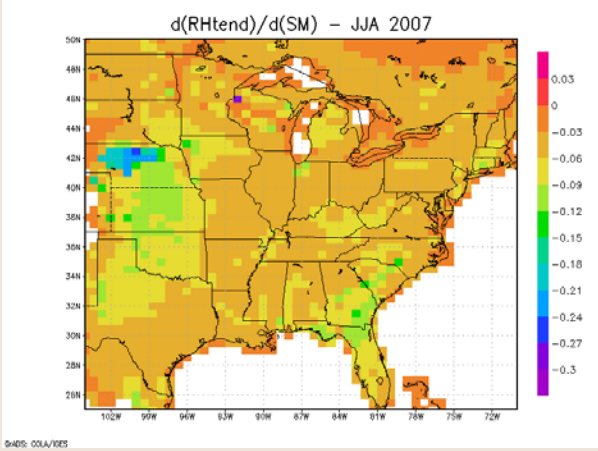


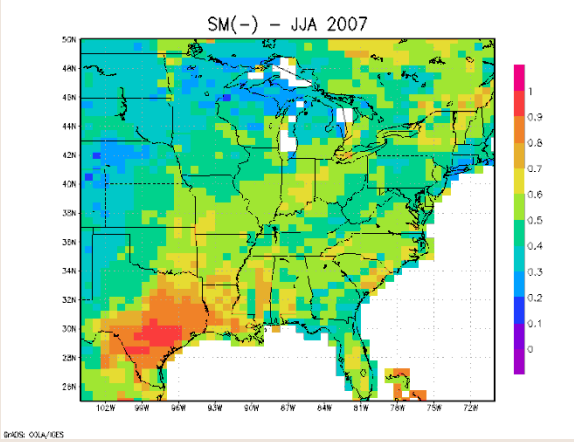




2007





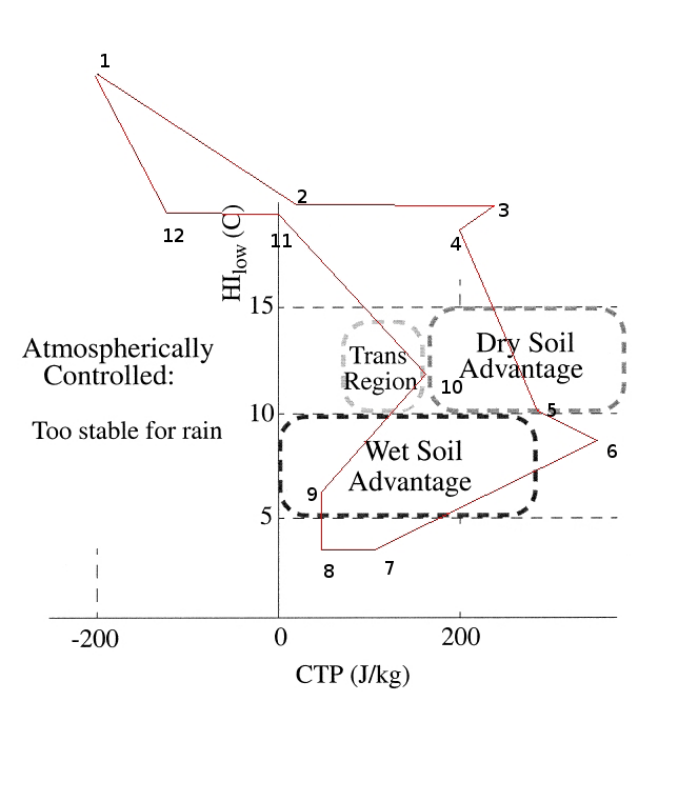


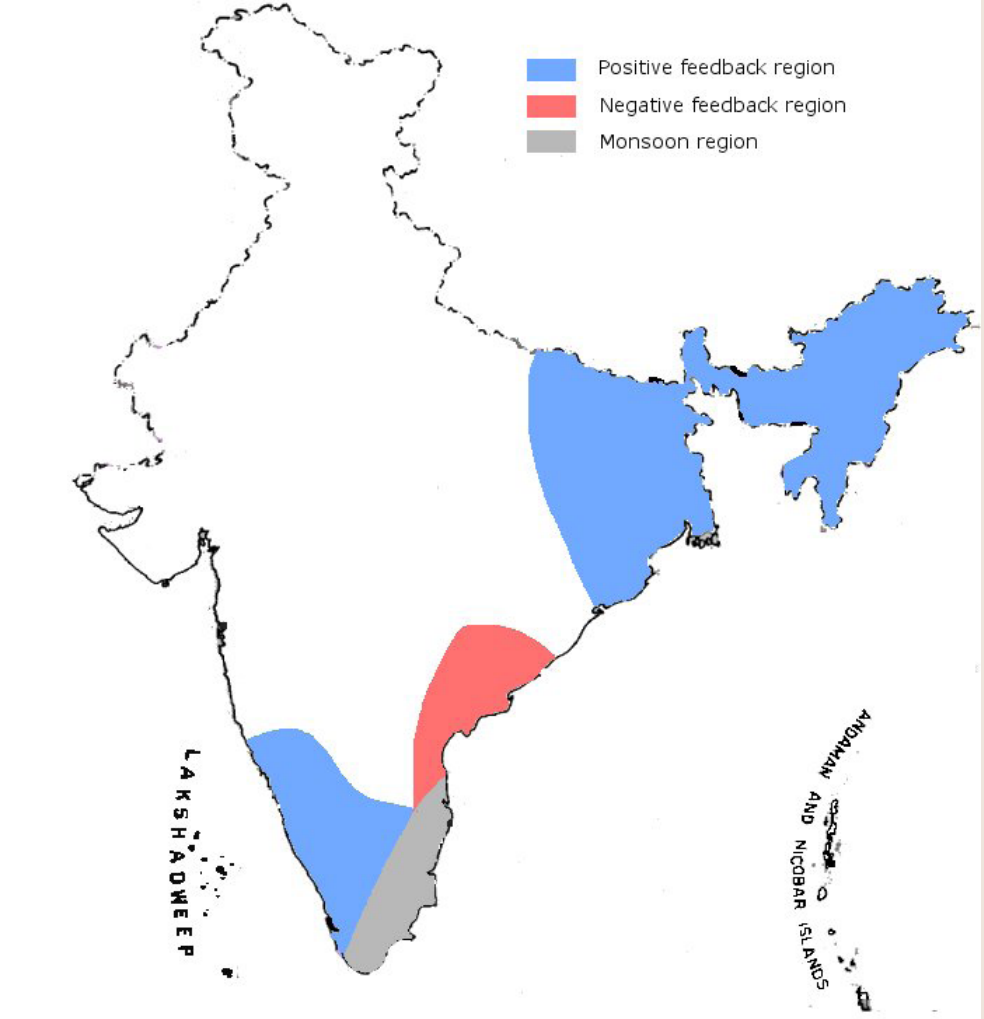
dRH/dEF **dRH/dSM** **Soil Moisture**

Collaborations w/GLASS-WATCH

- **Application of Findell's CTP-HI_{low} framework (Obbe Tuinenburg 2009)**

- Calcutta soundings
- Used 1980-2008 data
- One monthly value
- Numbers are month-numbers





Outline

Role of the CBL in L-A Coupling

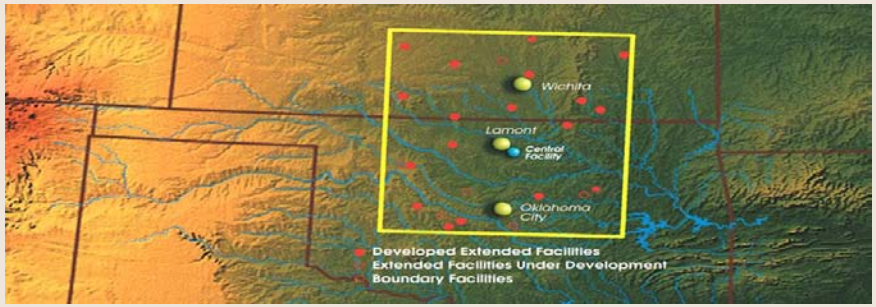
LoCo Diagnostics

2006-7 Experimental Design

- Site and Model Description
- Periods of Interest and Methodology

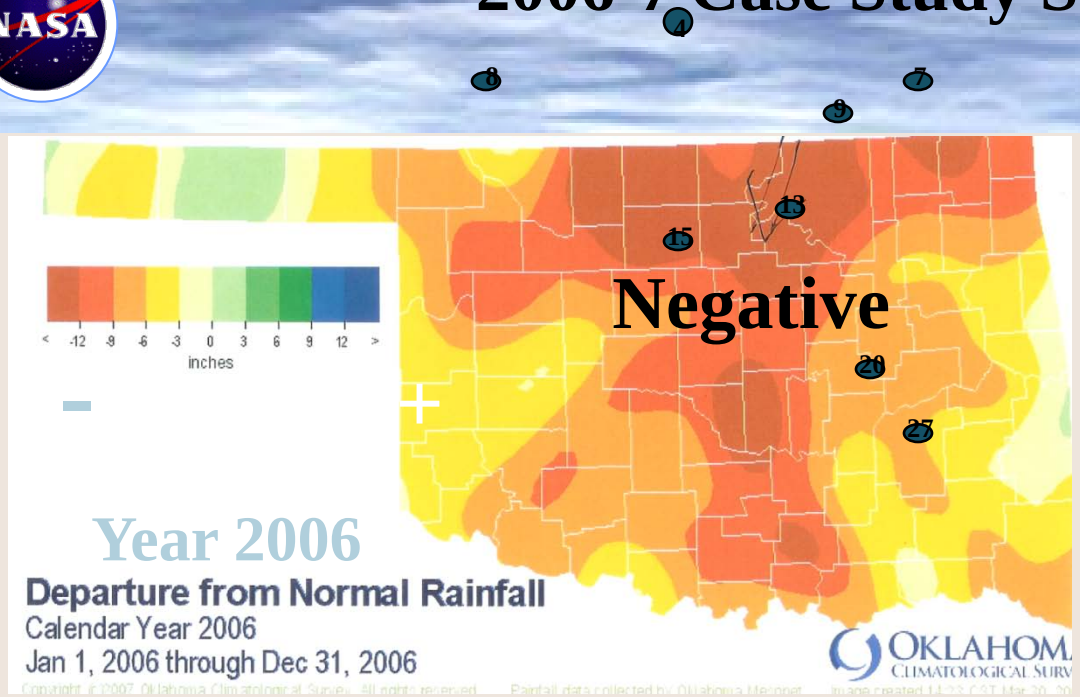
Summary & Future Work

Site Information: ARM-SGP

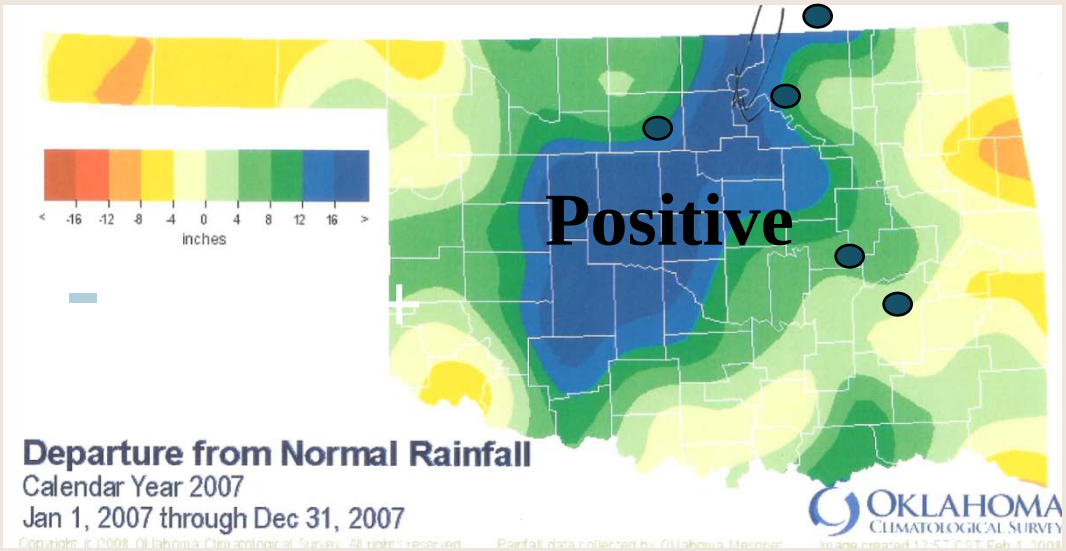


- **Atmospheric data**
  - Radiosonde: 6:30am, 9:30am, 12:30pm, 3:30pm
  - Raman Lidar
  - Profiles of temperature, humidity, pressure, and wind
- **Land Surface data**
  - Bowen ratio flux towers
  - Surface meteorological data
  - 5 soil moisture probes (0-5 cm)
- **IHOP 2002, CASES '99/GABLS2 Experiment**
- **<u>2006-7 Extremes</u>**
  - Standard ARM-SGP data (above)
  - MERRA
  - CLASIC IOP (May-June 2007): met, flux, soil moisture, sonde data

2006-7 Case Study Selection



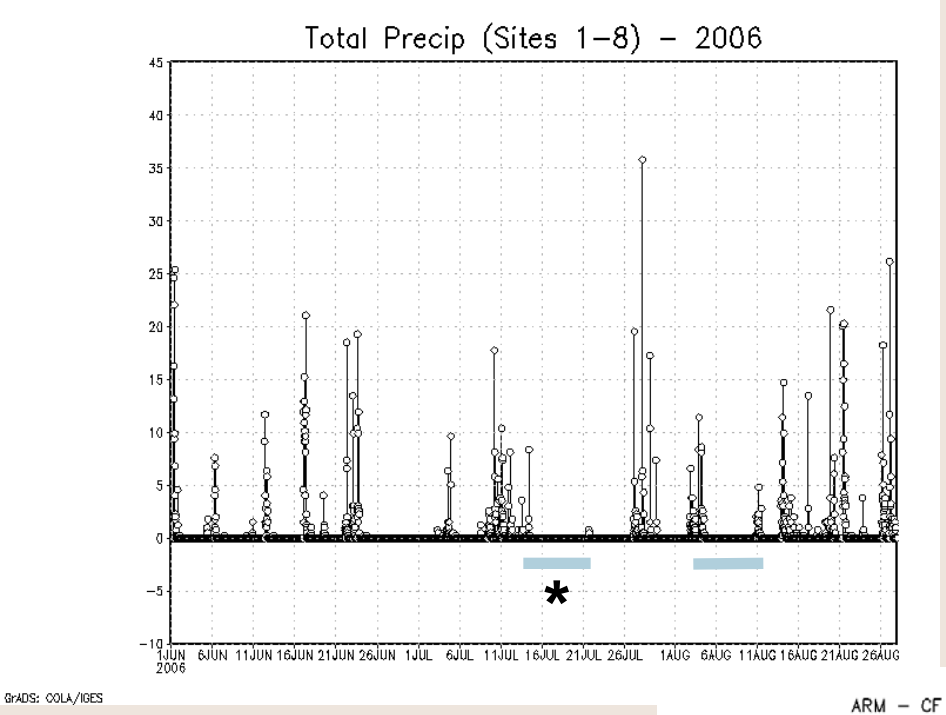
It was state-wide dry event during 2006. The annual rainfall is 18 inches lower than normal.

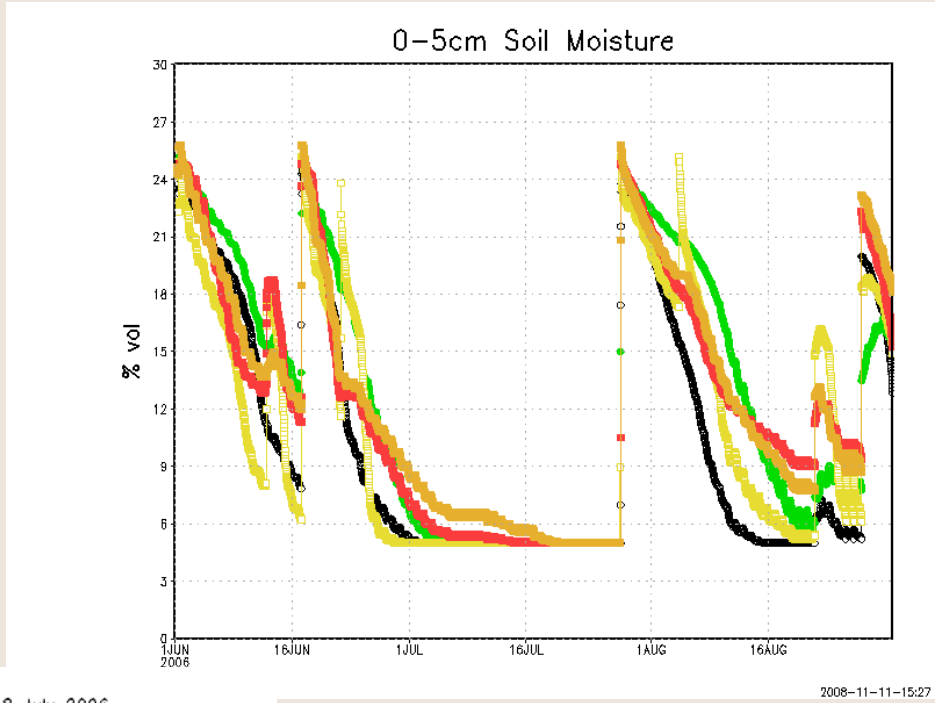


It was on central Oklahoma and summer 2007 with its wettest summer, 14 inches above normal

Courtesy X. Dong

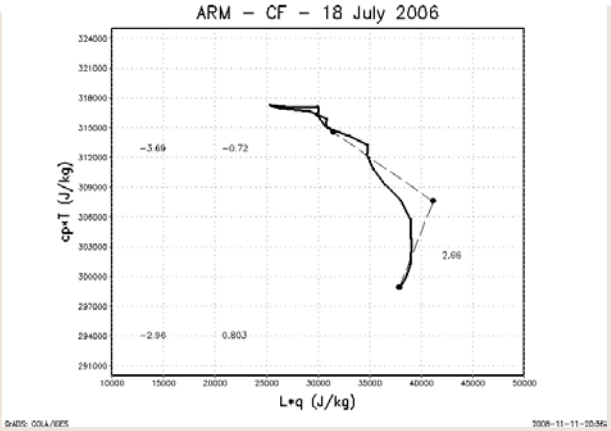
2006 Case Study Selection





*** Case Study**

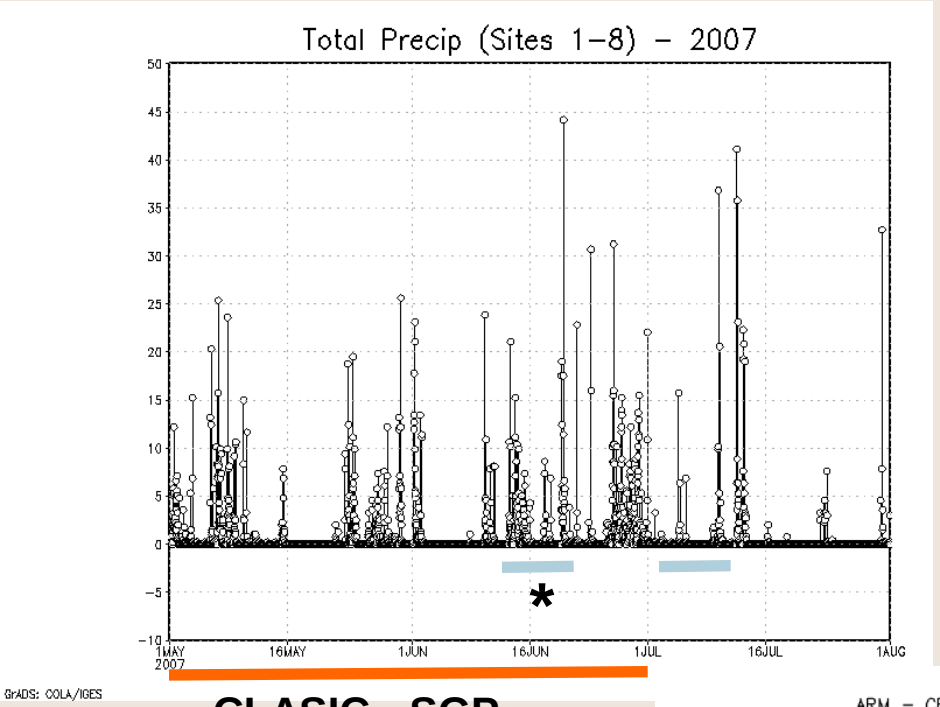
• 7-day LIS-WRF simulations

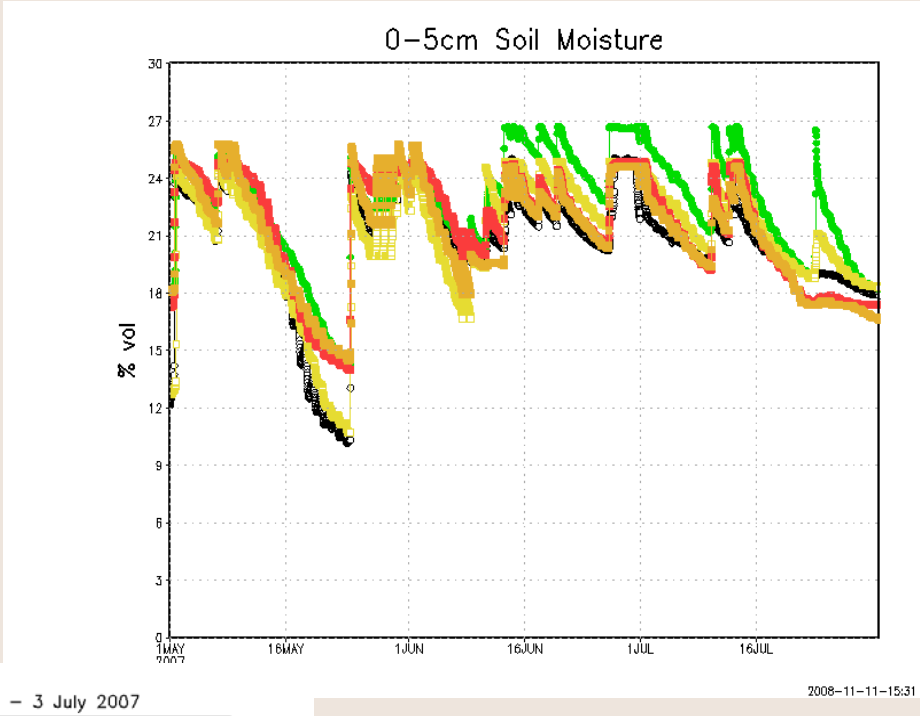


- Fair-weather
- Soil dry-downs

-Capture impact of dry soil anomaly on L-A interactions, PBL development

2007 Case Study Selection

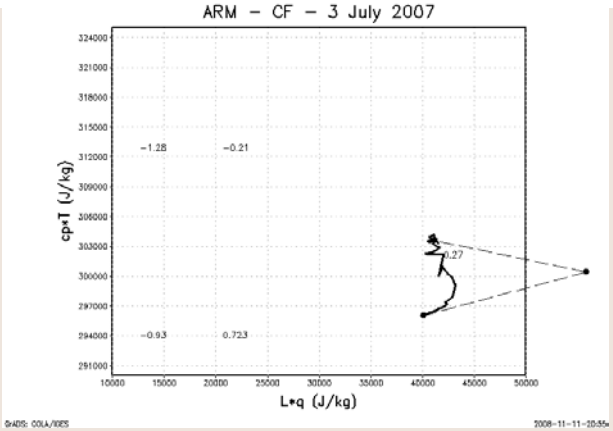




CLASIC - SGP

*** Case Study**

• 7-day LIS-WRF simulations



- Daily, isolated convection
- Wet/saturated soils

-Capture impact of wet soil anomaly on L-A interactions, PBL development, and clouds/precip.

Coupled LIS-WRF System

Weather Research and Forecasting (WRF) Model

- 1-km horizontal resolution
- NARR forcing
- 43 vertical levels (~42m sfc)
- 3 PBL + 3 LSM schemes:
  - → 9 combinations of L-A coupling
- Case studies:
  - → IHOP02, CASES99, Cabauw, NEWS06/07

NASA's Land Information System (LIS)

- Suite of LSMs with flexible resolution, forcing, params
- Provides spinup capability for improved initialization
- Assimilation, uncertainty, and optimization options

Land Surface Models

Noah (v2.7.1)
- 4 soil layers (10 cm upper)
- Derived from the OSU LSM
- Soil moisture and temp; veg, snow

Community Land Model (v2)
- 10 soil layers (2 cm upper)
- Extensive canopy and veg,
- Soil moisture, temp; veg, snow

TESSEL
- ECMWF operational lsm
- HTESSEL – latest version
- Tiled soil, canopy, snow sfc's

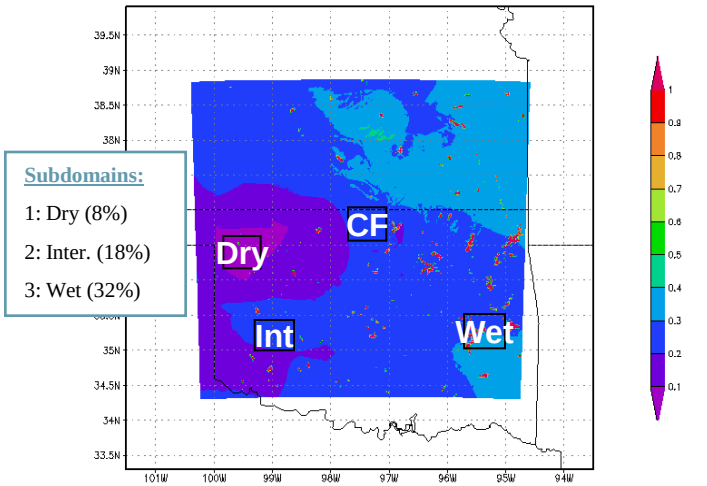
PBL Schemes

YSU (Yonsei University)
- Counter-gradient fluxes; Non-local K theory
- Explicit entrainment at PBL top
- PBL Height from critical Ri number

MYJ (Mellor-Yamada-Janjic)
- Nonsingular M-Y level 2.5 closure
- Length scale limited by TKE, buoyancy, shear
- PBL Height diagnosed based on TKE production

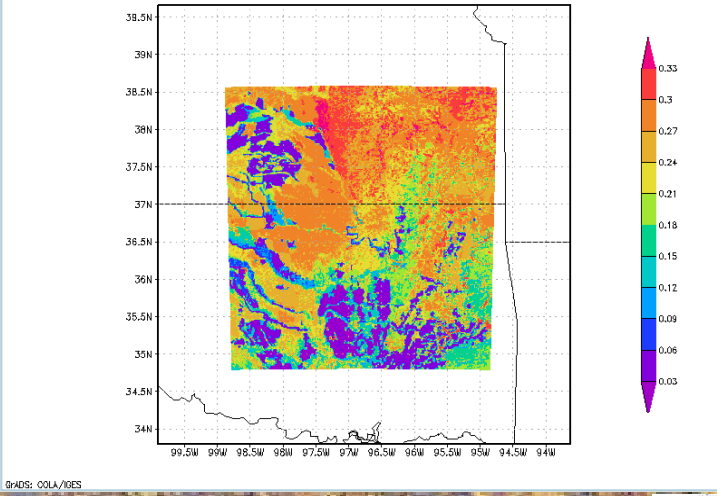
MRF
- Based on YSU scheme
- Implicit (local) vertical diffusion

WRF Initial SWC



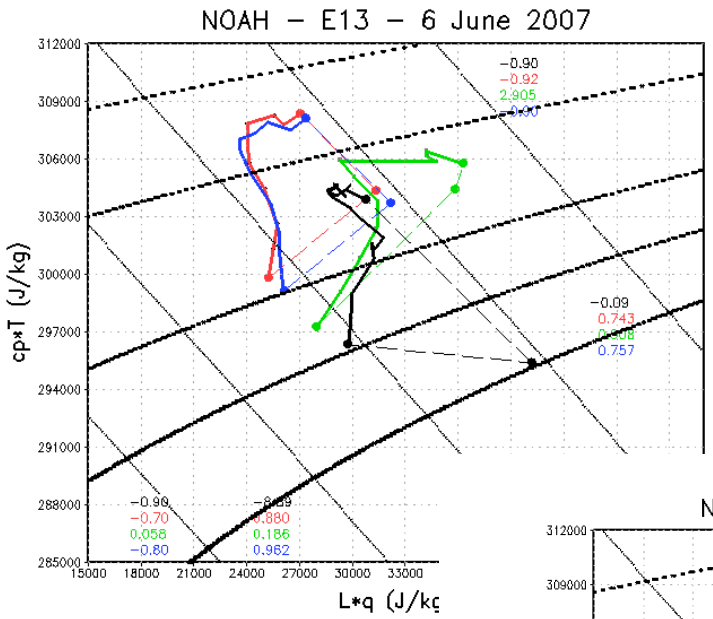
Initial soil moisture for the WRF 1km-domain and locations of the dry, intermediate, and wet analysis regions and ARM-SGP Central Facility.

LIS Spinup – Noah LSM

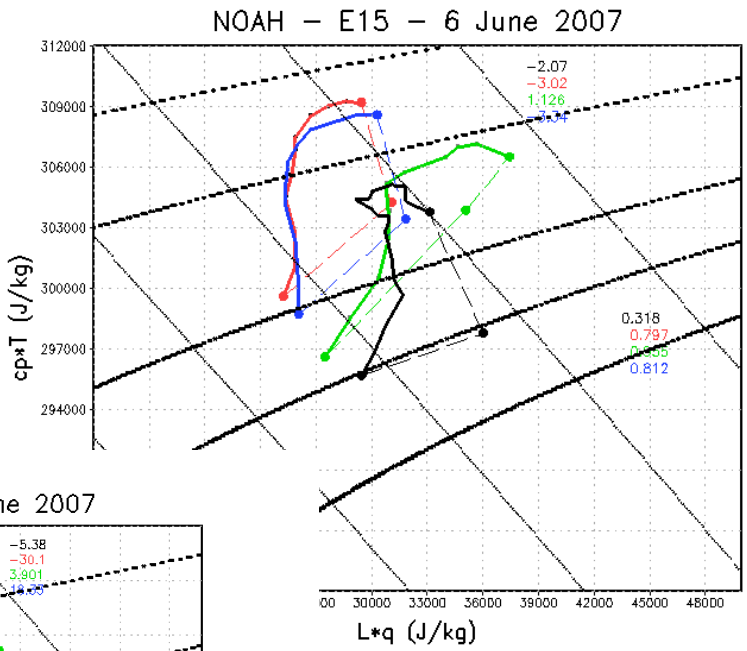


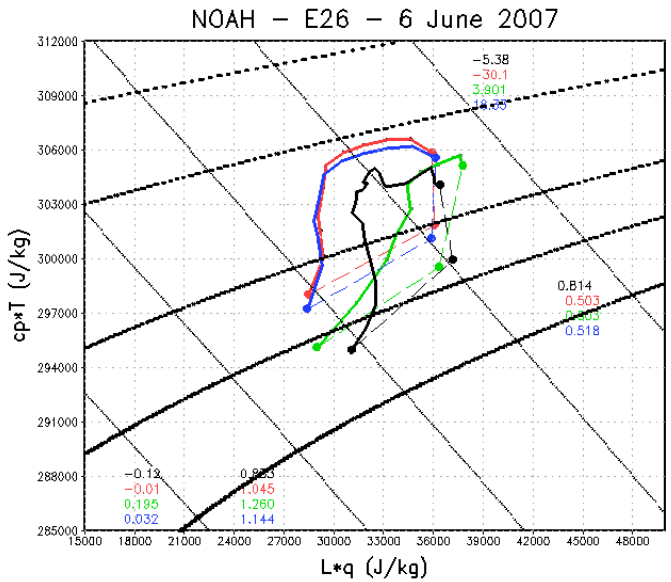
NASA ENERGY AND WATER CYCLE STUDY

Preliminary Results – LIS-WRF 6 June 2007



- = YSU
- = MYJ
- = MRF
- = OBS

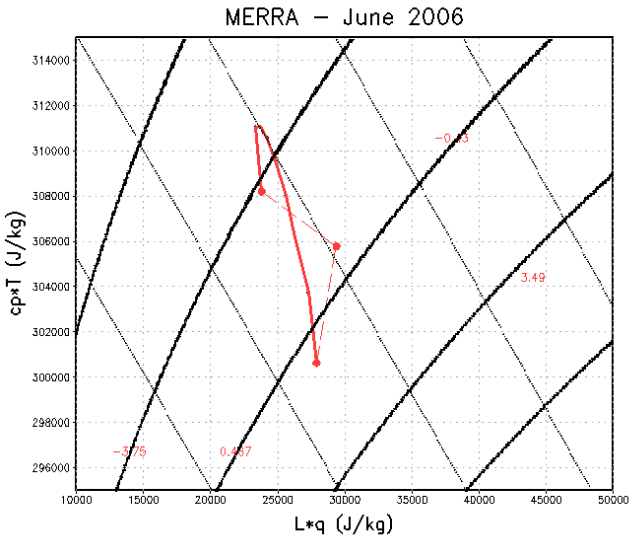


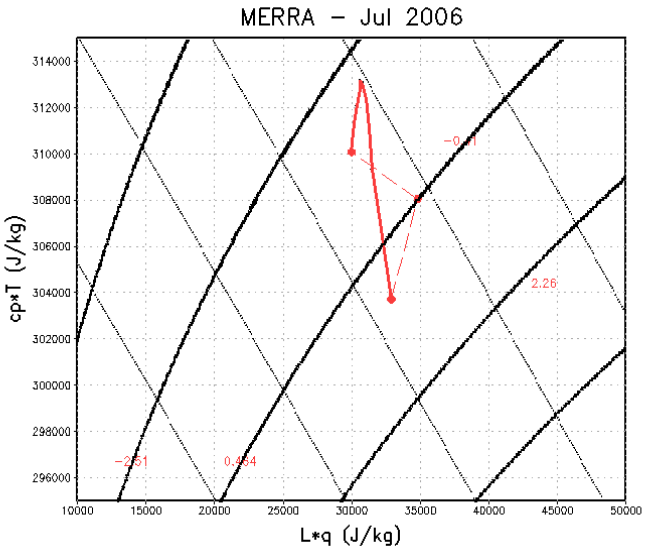


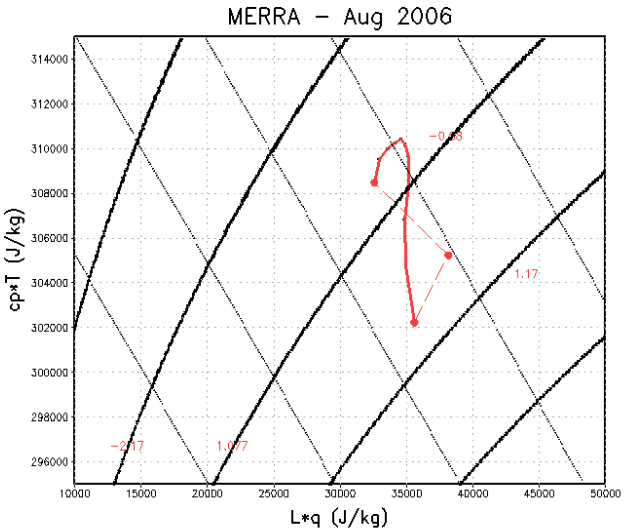
- 6 June 2007
- Noah LSM w/3 PBL schemes
- E13, 15, 26 ARM-SGP sites

- Full 2006&2007 periods to be completed with new version of LIS(v6)-WRF(v3)

MERRA – JJA 2006





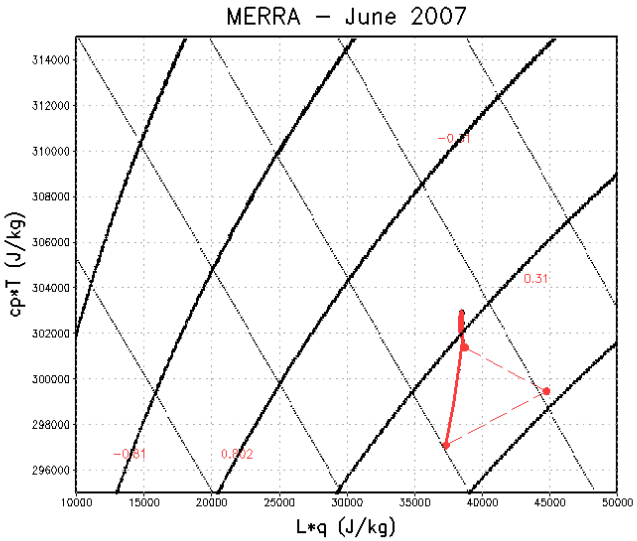


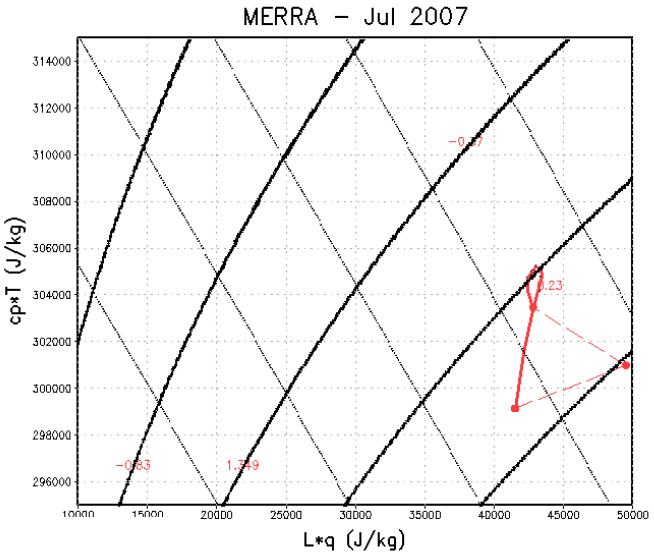
-Valid at ARM Central Facility

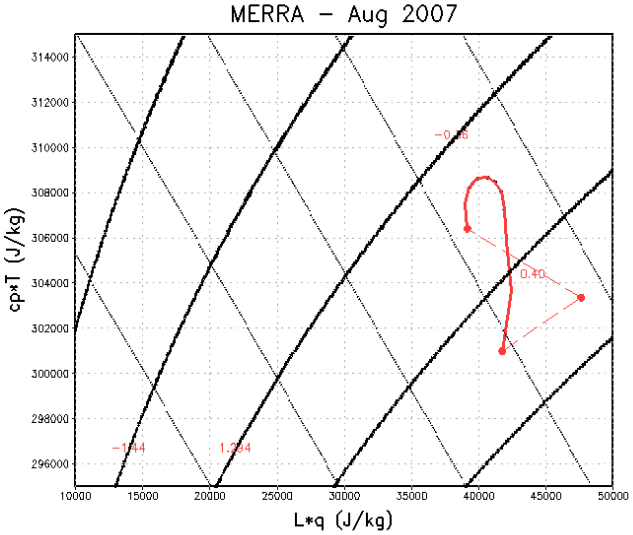
-Monthly mean diurnal cycles

→ To be evaluated against ARM-SGP observations

MERRA – JJA 2007







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Outline

The Role of the CBL in L-A Coupling

LoCo Diagnostics

Results

Summary & Discussion

Discussion

<u>Goal:</u> Use LIS-WRF as a testbed for diagnosing L-A coupling in models and observations during the extreme 2006-7 periods in the SGP.

- **<u>LIS(v6)-WRF(v3.1)</u>**
  - Additional LSM and PBL options – where should the focus be?
- **<u>Process-level Understand</u>**
  - Mixing Diagrams: Quantify errors and sensitivities of fluxes and feedbacks.
  - RH-tendency: Map sensitivities and regimes.
  - Further diagnostic connections (e.g. CTP-HIlow).
- **<u>Issues:</u>**
  - Case study selection and length of model integration.
  - Compositing of high-resolution, short-term LIS-WRF simulations to scales useful for other NEWS investigations and models.
  - Further evaluation of MERRA, ERA-Interim (bridge from LIS-WRF to reanalysis?).
- → How else can LIS-WRF and LoCo studies contribute to NEWS/Extremes studies?

Thank You !

NASA Energy and Water Cycle Study

GEWEX-GLASS, GABLS, and EU-WATCH Communities