Land-Atmosphere Interactions: The LoCo Perspective

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DOE ASR Workshop
L-A-C Interactions Plenary
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Outline

Brief History of LoCo

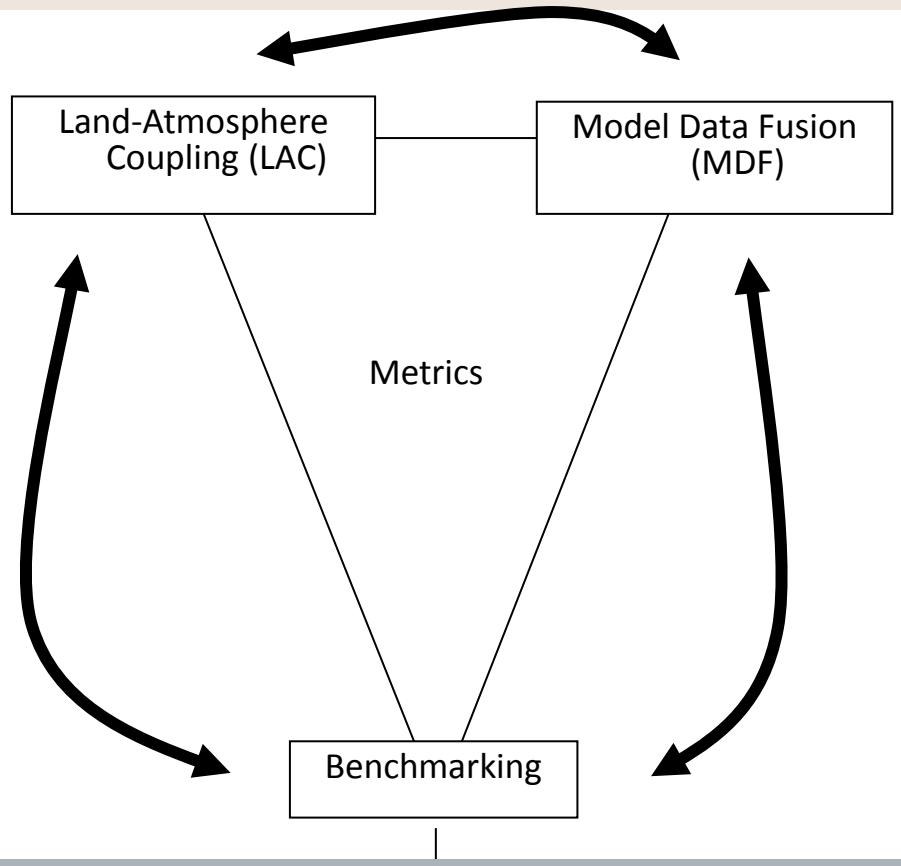
LoCo Diagnostics

Outstanding Issues and Challenges

ASR Science Questions

GEWEX Global Land-Atmosphere System Study

New structure of GLASS (circa 2009)



- **LAC**: Combines the global (GLACE) and local (LoCo) studies
- **MDF**: Incorporates data assimilation and parameter estimation/calibration studies
- **Benchmarking**: Standardized way to evaluate models and their 'goodness'
- **Metrics**: Diagnostics and quantification at the heart of each component

LoCo History

April 2002: 1st GLASS workshop on L-A Interactions

Sept. 2005: GLASS/GABLS workshop on Local L-A Coupling

June 2008: GLASS-WATCH Workshop on L-A Coupling

Overarching Goals of LoCo:

- Are the results of PILPS, GSWP, or data assimilation experiments affected by the lack of L-A coupling?
- Can we explain the physical mechanisms leading to the coupling strength differences found in GLACE or other coupled NWP/climate experiments?
- Is there an observable diagnostic that quantifies the role of local land-atmosphere coupling?

LoCo History

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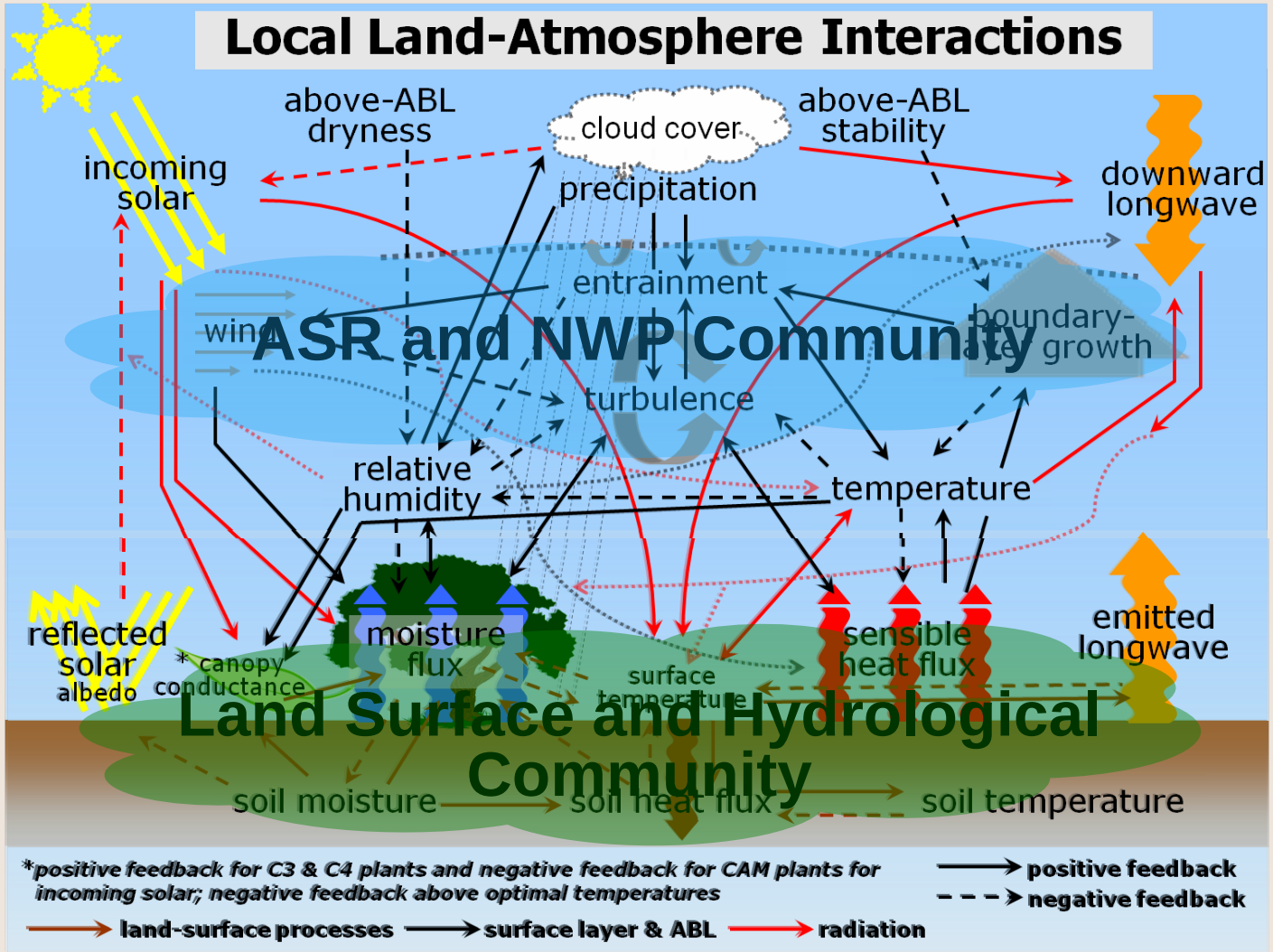
Challenges of LoCo:

- Land-atmosphere coupling takes place at many different spatial and temporal scale and involves many physical processes simultaneously.

- These *multi-scale* and *multi-process* phenomenon makes a proper definition of "local" land-atmosphere coupling not easy.

- Defining the 'Realm of LoCo' is certainly useful for:
  - identifying where L-A interaction has a significant impact on the local climate
  - defining proper diagnostics expressing the strength of coupling
  - designing model intercomparison experiments in order to evaluate the coupling

Complexity of L-A Interactions



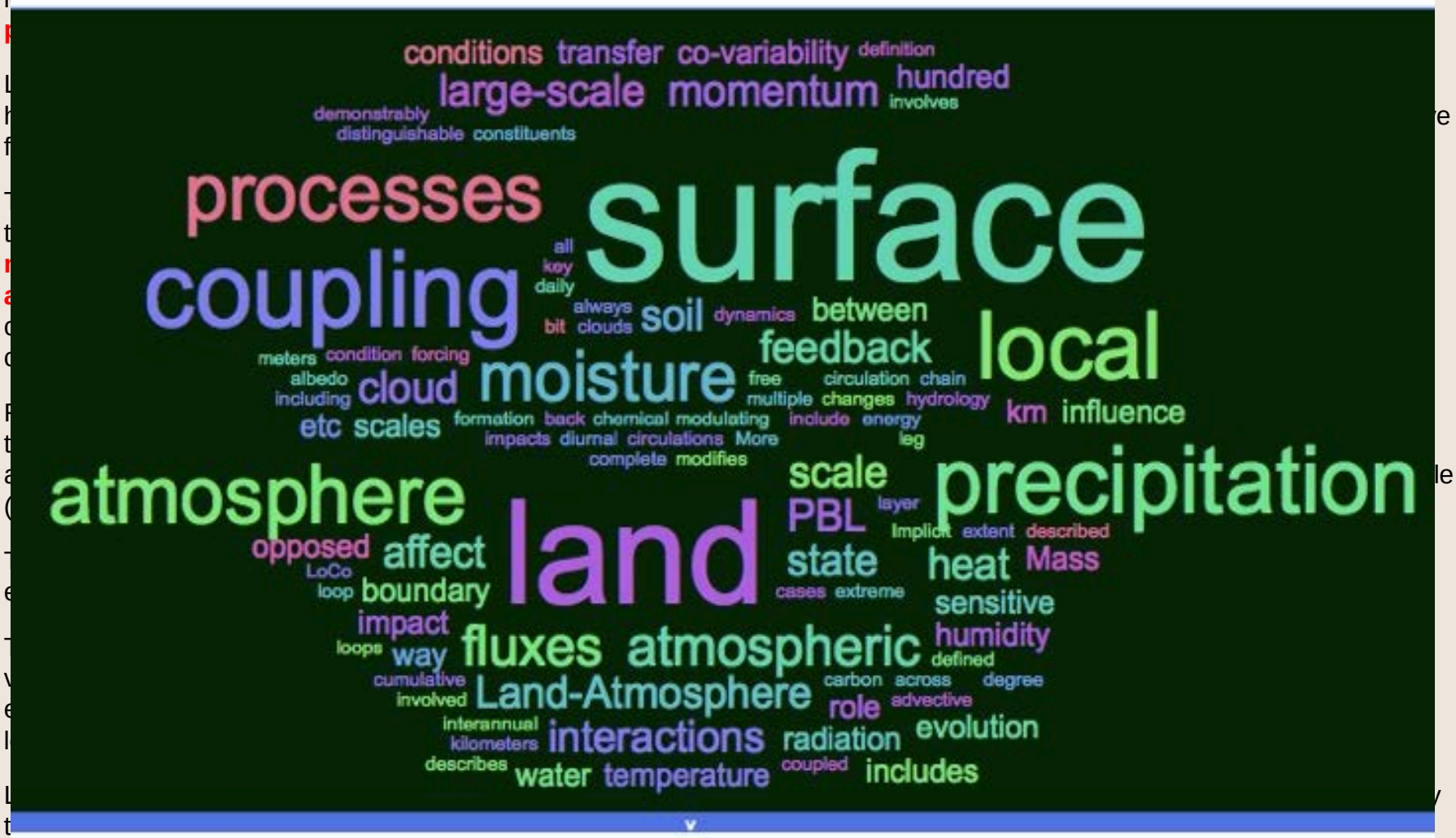
Ek, M. B., and A. A. M. Holtslag, 2004: Influence of Soil Moisture on Boundary Layer Cloud Development. *J Hydrometeorol.*, **5**, 86-99.

LoCo and Land Surface/Hydrology Expertise

- Geological Sciences
- Geosciences/Geophysics
- Environmental Science
- Civil and Environmental Engineering
- Mathematics
- Meteorology
- Atmospheric Sciences
- Physical Geography
- Natural and Earth Resources
- Computer Engineering
- Hydrology and Water Resources

What is 'LoCo'?

- The strength of coupling or degree with which changes in land states (e.g. soil moisture) affect surface fluxes ("near-surface local" coupling), surface fluxes affect PBL evolution ("local" coupling), and **coupled surface/PBL processes affect**



and precipitation formation.

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LoCo Motivation

Motivation:

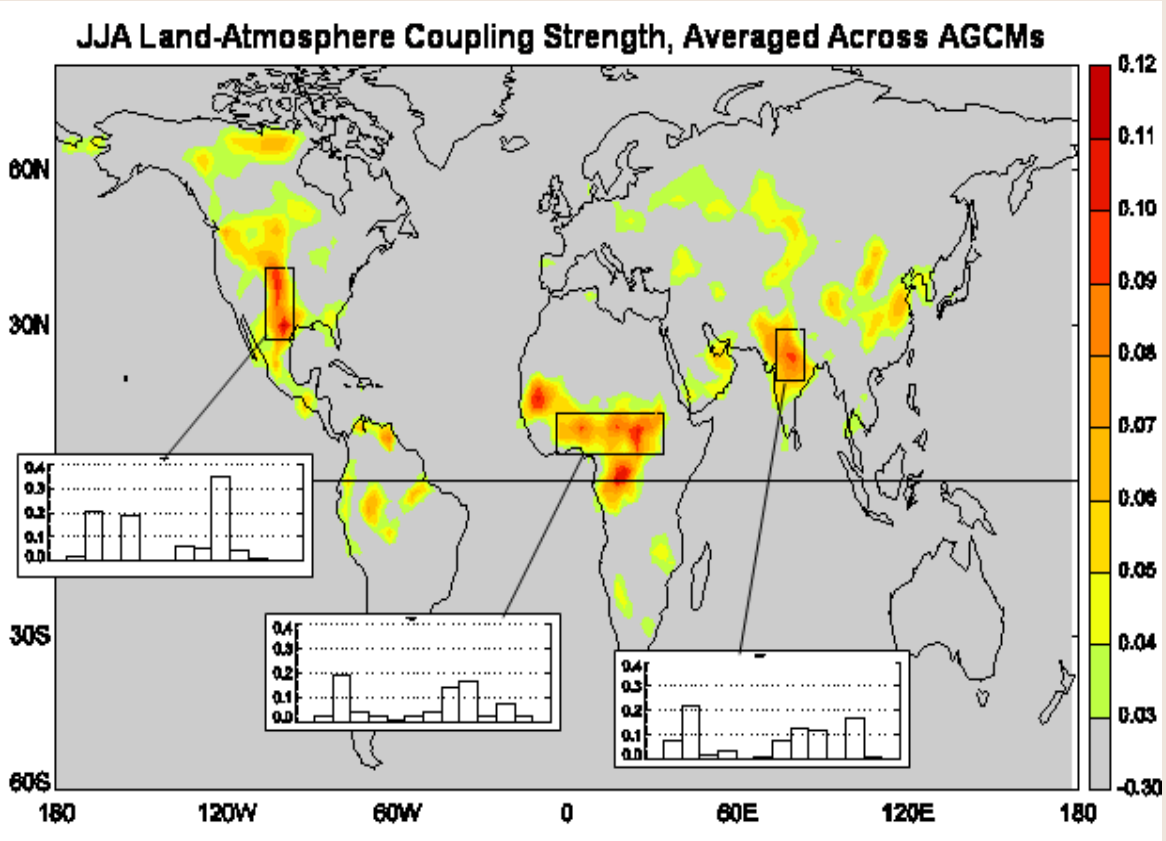
- ***Land-atmosphere interactions (L-A)*** play a critical role in supporting and modulating extreme dry and wet regimes, and must therefore be quantified and simulated correctly in coupled models.

Deliverables:

- **Diagnostics** that can be applied to any model, scale, or observation (in-situ or satellite).
- **Assessment** of coupled model components and their integration through the land-PBL 'process-chain' linking the soil to precipitation.
- Provide a **diagnostic and observational testbed** for GEWEX-GLASS directed studies of LoCo and model intercomparisons.

Global Land-Atmosphere Coupling Experiment (GLACE)

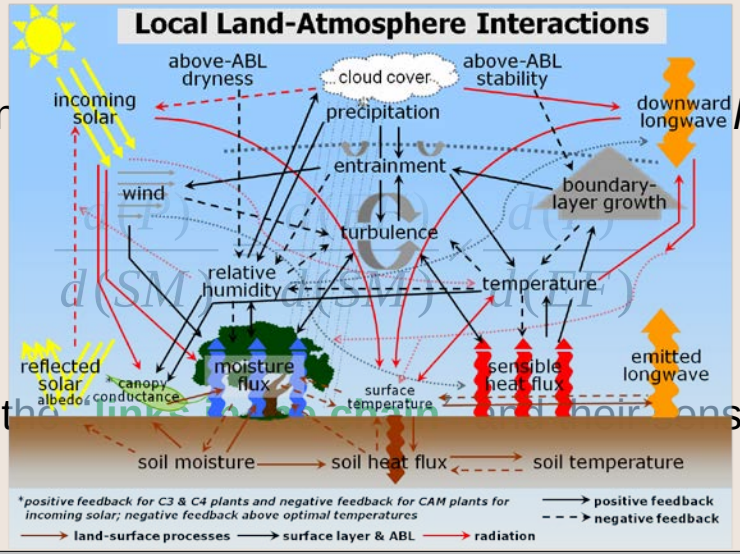
- 'Omega' diagnostic determined by ensembles of GCMs indicates the connection between soil moisture and precipitation
- Well-known "Hot Spots" of L-A coupling strength, in particular over the SGP of the U.S.
- These results have steered L-A investigations over the last decade more than any other study to date.



Courtesy of Koster et al. (2004)

LoCo Diagnostic Approach

- Diagnose the compor *level*:



- Our focus: Evaluate t sitivities to land and PBL perturbations:

$$\Delta SM \rightarrow \Delta EF_{sm} \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta EF_{pbl} \blacktriangleright \Delta P/Clouds$$

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

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

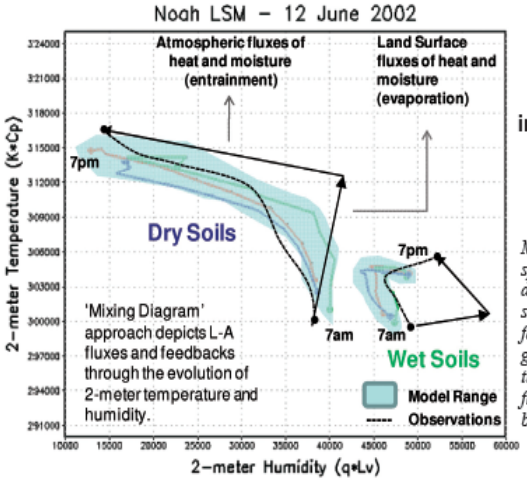
'LoCo Process-Chain' defined by non-linear series of interactions and feedbacks

Motivation

GEWEX WCRP Global Energy and Water Cycle Experiment NEWS

Vol. 21, No. 4 November 2011

Results from Local Land-Atmosphere Coupling (LoCo) Project



GEWEX LoCo Project results on wet/dry extremes show that the choice of LSM is critical for dry regimes, and that the PBL and LSM are comparable influences on coupled behavior during wet regimes.

See article by J. Santanello et al. on page 7.

Mixing diagram showing the diurnal co-evolution (7AM–7PM) of 2-meter specific humidity and 2 meter-potential temperature on 12 June 2002 at a dry and wet soil location as simulated by a coupled mesoscale model. The shaded regions for each indicate the model range for different land-surface model (LSM)-planetary boundary layer (PBL) scheme couplings (red, green, and blue) versus what was observed (dashed black). Also shown for the dry site are the vectors that represent the fluxes of heat and moisture from the land surface versus those from the atmosphere due to entrainment, both of which are quantified using this approach.

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LoCo Diagnostics

- Condensed list of LoCo metrics
- Each attempts to quantify particular links in the process-chain

$$\Delta SM \rightarrow \Delta EF_{sm} \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta EF_{pbl} \blacktriangleright \Delta P/Clouds$$

- Range from simple correlations to multi-variate space to preconditioning assessment
- Wide ranging input requirements (temporally, spatially) and model application (SCM, MM, GCM)
- Ultimate impact of land/near-surface variables on the PBL, clouds, precip

LoCo Metrics

3-D atmospheric (instantaneous)	**2-D surface (correlation over time)**
Convective triggering potential (**CTP**; Findell and Eltahir 2003b,c)	Root-zone soil moisture - surface evaporative fraction (**SM-EF**; Ferguson et al., 2012)
Humidity index, low-level (**HI_{low}**; Findell and Eltahir 2003b,c)	Surface evaporative fraction - lifting condensation level (**EF-LCL**; Ferguson et al., 2012)
Convective available potential energy (**CAPE**)	Surface soil moisture - lifting condensation level (**SM-LCL**; Ferguson et al., 2012)
Convective inhibition (**CIN**)	Surface soil moisture - 2m air temperature (**SM-T2m**; Koster et al., 2006)
Moist static energy (**MSE**; Gentine et al. 2013)	Latent heat - 2m air temperature (**LH-T2m**; Seneviratne et al. 2006a)
Low-level (850-700 hPa) **lapse rate** (Frye and Mote, 2010)	Two-legged terrestrial coupling index (**$I_{SM,LH}$, $I_{SM,SH}$**; Dirmeyer, 2011)
Lifting condensation level (**LCL**; Betts 2004)*also derivable from screen level*	
Lifting condensation level deficit (**LCL deficit**; PBL height minus LCL height; Santanello et al., 2011, 2013)	
Buoyant condensation level (**BCL**; Tawfik and Dirmeyer, 2014)	
Buoyant mixing potential temperature (**θ_{BM}**; Tawfik and Dirmeyer, 2014)	
Potential mixed layer moisture deficit (**q_{def}**; Tawfik and Dirmeyer, 2014)	
PBL saturation deficit (**q^*_{sat}**; Santanello et al., 2013)	
3-D atmospheric (diurnal cycle)	
Mixing diagrams/PBL heat and moisture budgets (Santanello et al., 2009, 2011, 2013)	

Courtesy C. Ferguson

LoCo Diagnostics in 60 seconds (or less)……

Mixing Diagram Analysis

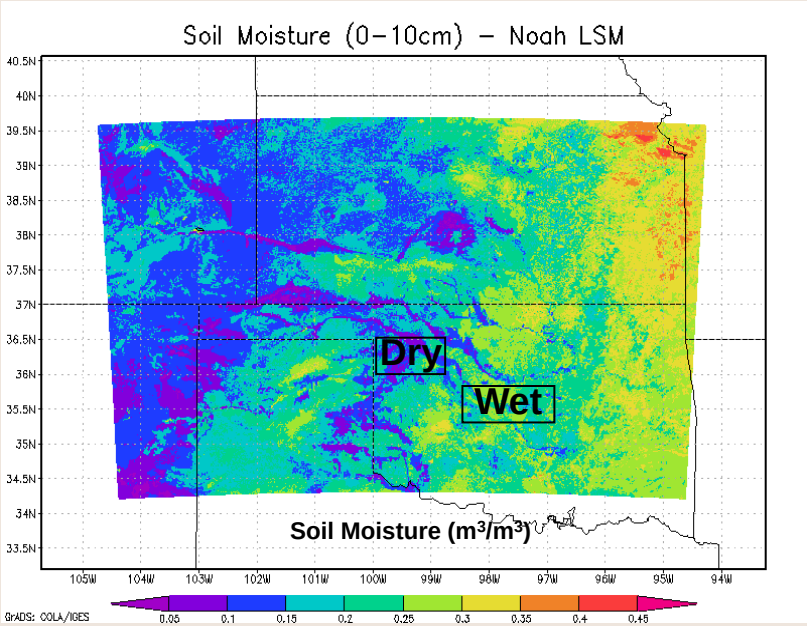


Fig. 1: Near-surface soil moisture map of the Southern Great Plains as simulated by LIS-WRF.

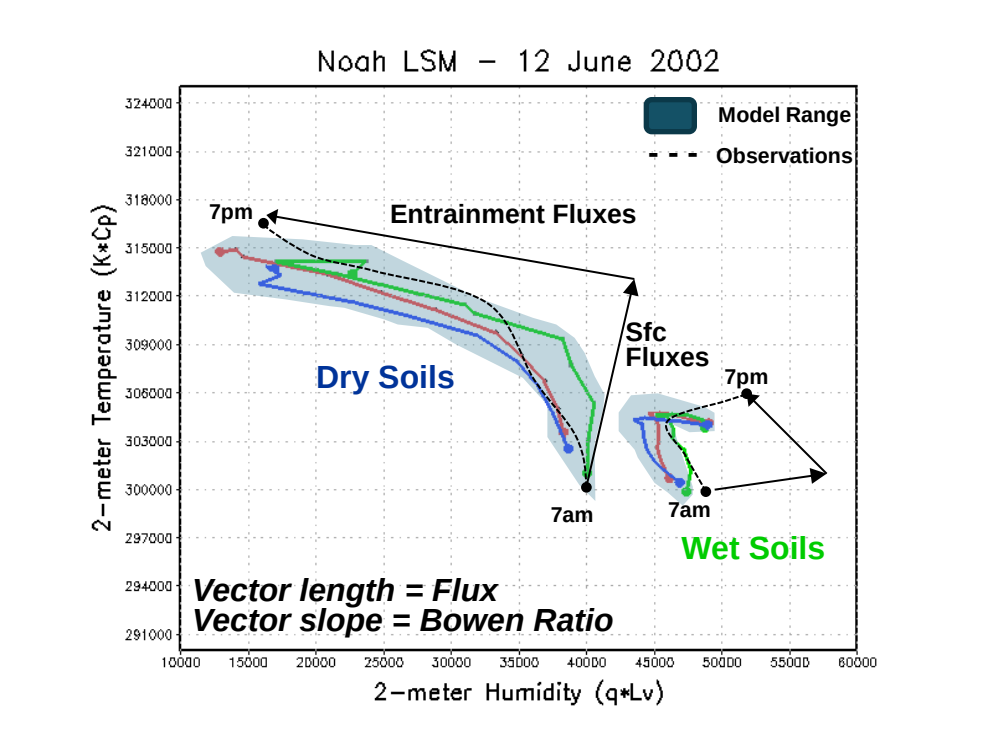


Fig. 2: Daytime evolution of specific humidity vs. potential temperature for the dry and wet soil moisture locations in Fig. 1

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

- The sensitivity 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.

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 surface evaporation.

-If ~ -1 then entrainment balances evaporation.

$\beta_{sfc} = H_{sfc}/LE_{sfc}$ – 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.)

Thermodynamic Overlays

Relative Humidity:

$$RH = \frac{q}{q_s}$$

Equivalent Potential Temperature:

$$\theta_e = \left(T + \frac{L}{c_p} r \right) \cdot \left(\frac{p_0}{p} \right)^{\frac{R_d}{C_p}}$$

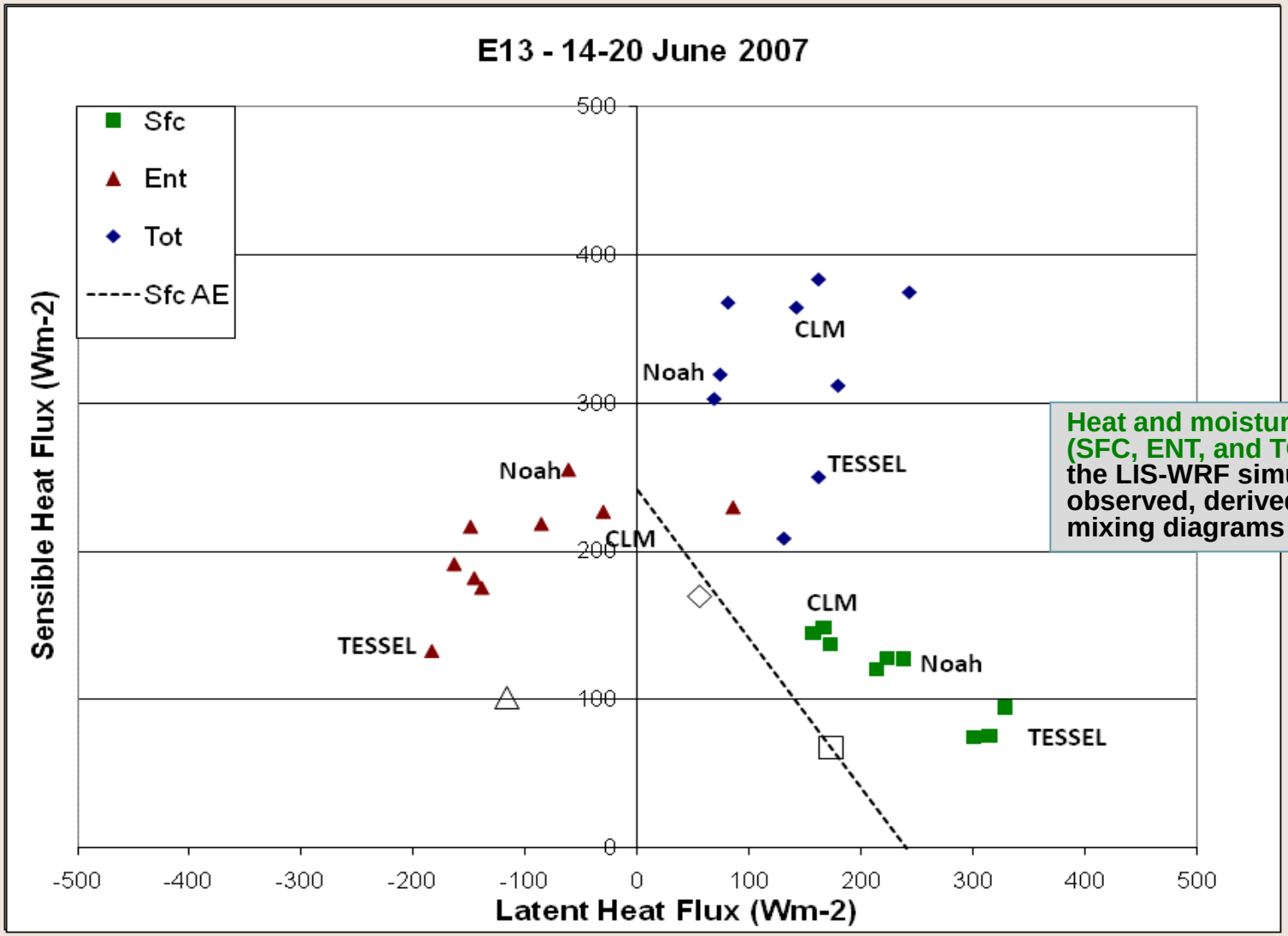
Pressure of the Lifting Condensation Level:

$$P_{lcl} = \frac{1}{\left(\frac{T - Td}{223.15} \right) + 1} \cdot p_0$$

Potential Saturation Humidity Deficit:

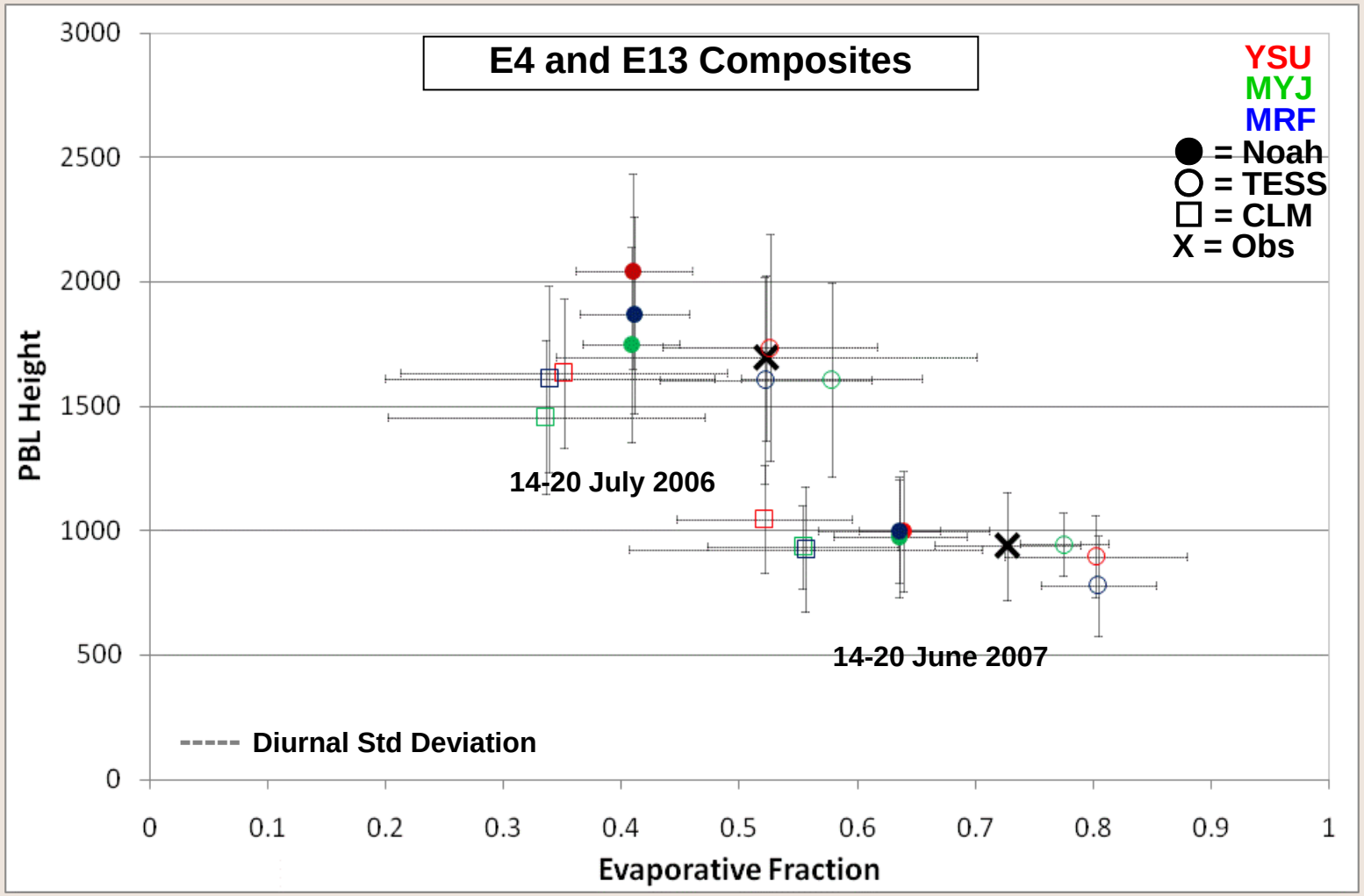
$$\Delta q^* = q_s(\theta) - q$$

PBL Heat and Moisture Budgets



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

EF vs. PBL Height

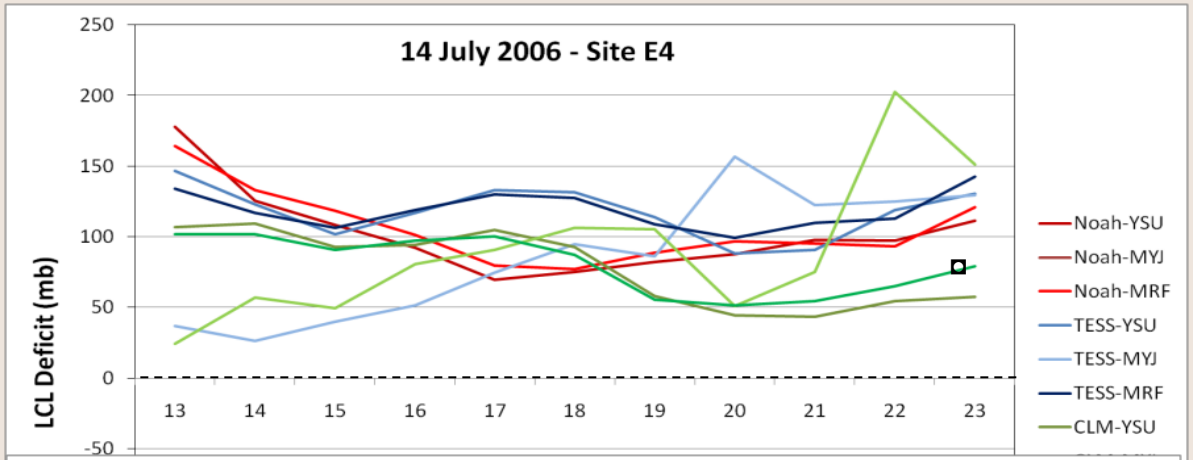


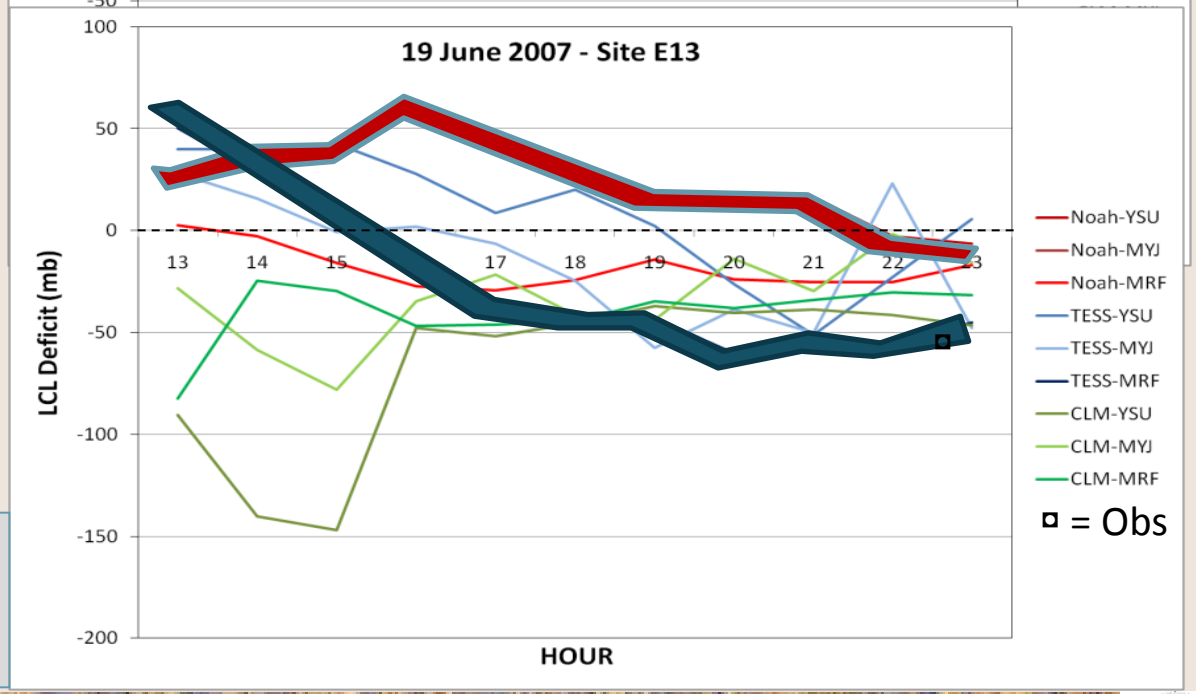
Evaporative Fraction vs. PBL Height for each simulation vs. observed, along with the diurnal standard deviation through the 7-day period

LCL Deficit

LCL Deficit = P(pbl) - P(lcl)
+ = LCL not reached
- = LCL reached

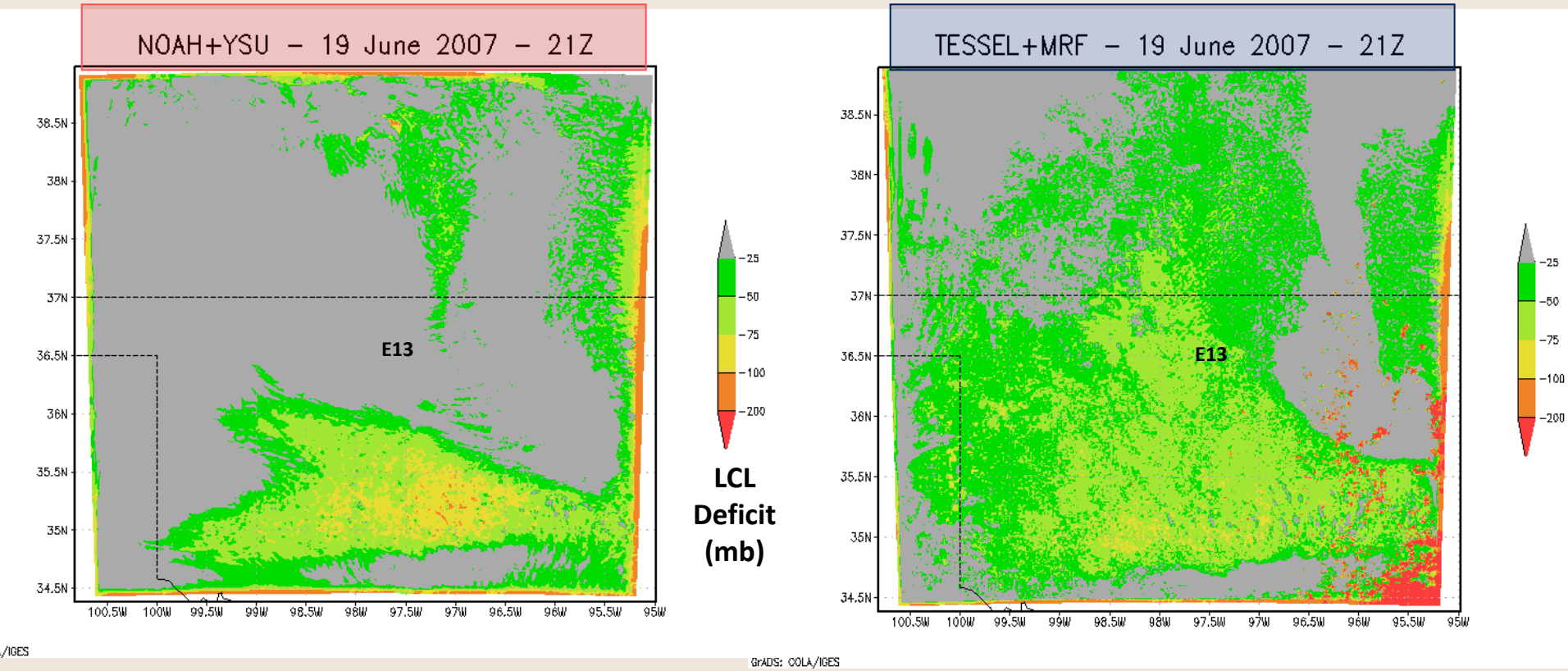
- Measure of how close the PBL gets to Clouds/Precip
- Larger positive (+) indicates drying regime
- Integrated measure of the diurnal land-PBL coupling





LCL Deficit time series from each LIS-WRF run at the E4 and E13 sites.

LCL Deficit



LCL Deficit calculated spatially at 21Z on 19 June 2007 for the Noah-YSU and TESSEL-MRF simulations.

M. Ek and C. Jacobs

Local near-surface land-atmos. coupling: soil moisture – transpiration relationship

Evaporative fraction for transpiration:

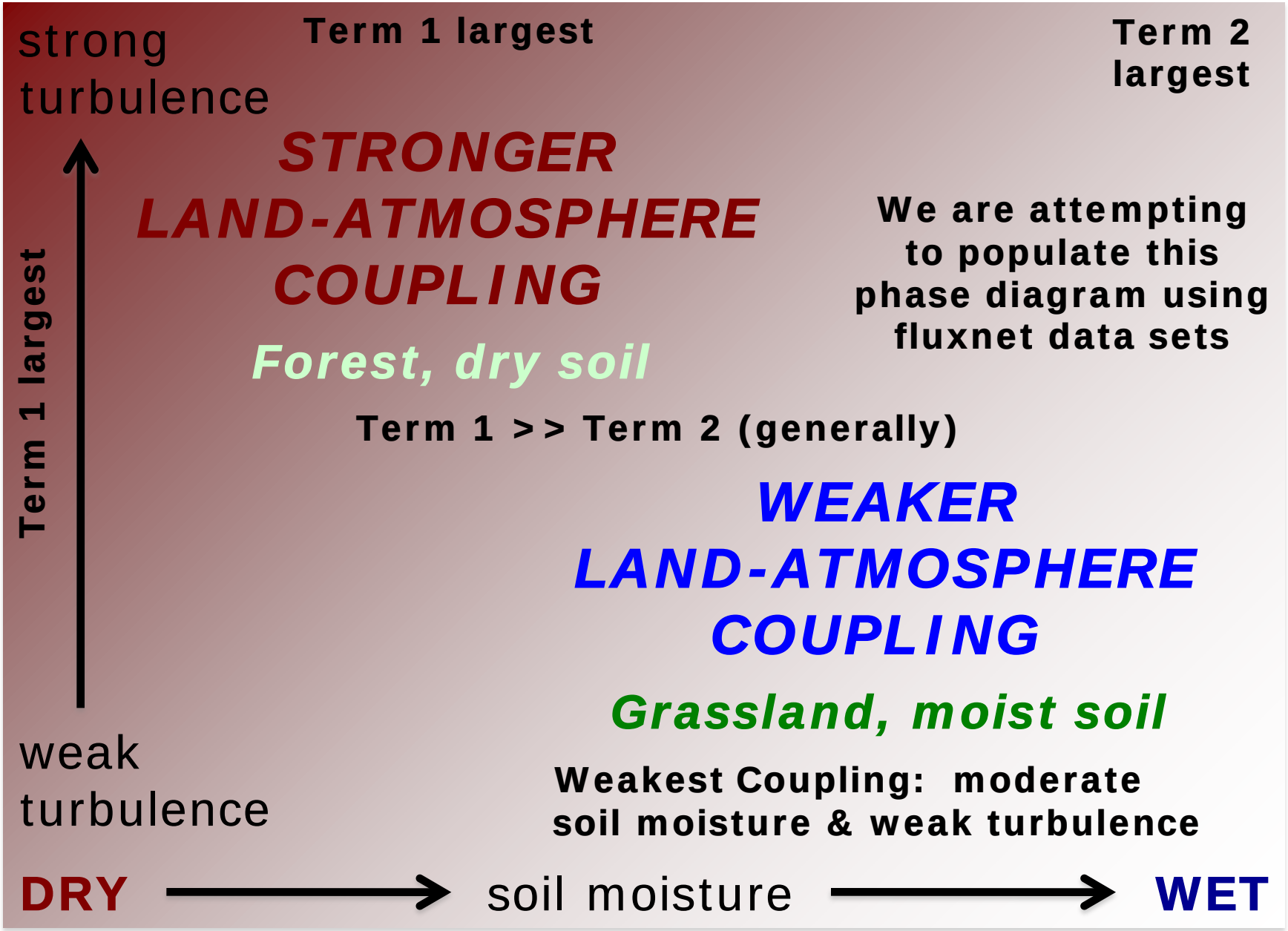
$$ef_t = \frac{s + \frac{\rho c_p g_a \delta e}{R_n - G}}{s + \gamma\left(1 + \frac{g_a}{g_c}\right)},$$

Evap. fraction change with soil moisture change:

$$\frac{\partial \ln ef_t}{\partial \Theta} = \frac{1}{\delta\Theta_{rz}}\left\{\left[\left(\frac{s+\gamma}{\gamma}\right)\frac{g_c}{g_a} + 1\right]^{-1} + \left[\frac{s(R_n - G)}{\rho c_p g_a \delta e} + 1\right]^{-1}\frac{\delta\Theta_{rz}}{\Theta_{ns}}\frac{b\beta G}{(R_n - G)}\right\}$$

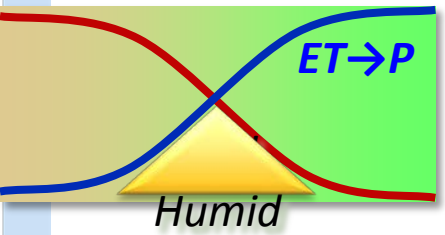
	Term 1: stomatal control vs surface-layer turbulence, range: 0-1	**Term 2: soil heat flux contribution, 0 to O(1)**
Stronger Coupling:	***Strong stomatal control, strong turbulence, e.g. forest with dry soil***	***Strong turbulence, dry air, small Rn, large soil heat flux, wet soil***
Weaker Coupling:	***Weak stomatal control, weak turbulence, e.g. grassland with wet soil***	***Weak turbulence, moist air, large Rn, small soil heat flux, dry soil***

M. Ek and C. Jacobs



For the land-atmosphere feedback loop to be complete, we need:

- **ΔET → ΔP** (atmosphere sensitivity)
- **ΔSM → ΔET** (land sensitivity)



*The **conceptual model** from GLACE: ET sensitivity to soil moisture strongest where the* $\mathrm{d}ET/\mathrm{d}SM$ *response curve is steep (arid); precip responds to ET where convectively unstable (humid) – transition zone has some of both.*

Terrestrial Coupling Index: $I = \frac{\partial ET}{\partial SM}\sigma_{SM} = r(SM, ET)\sigma_{ET}$

The surface component from the "Mixing Diagram" approach: $\frac{\overline{LH} \cdot \Delta t}{\overline{\rho_{PBL}}\,\overline{H_{PBL}}}$

We can replace LH with the Terrestrial Index and produce a "2-Legged Metric":

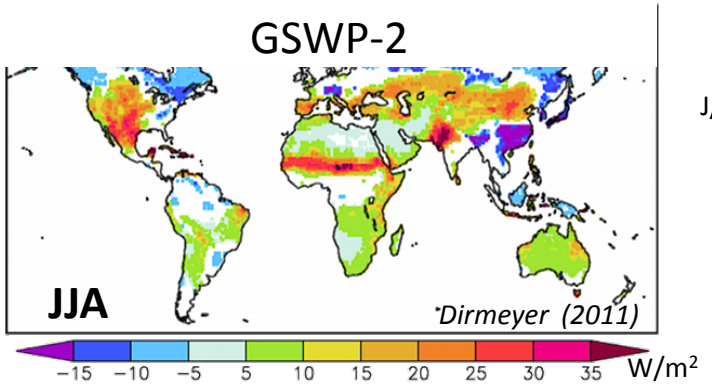
$$\frac{I_{LH} \cdot \Delta t}{\overline{\rho_{PBL}}\,\overline{H_{PBL}}}$$

GCM PBL Net Moistening (all terms)

JJA

a la Santanello et al. (2009; 2011)

Terrestrial Index based on GSWP-2



J/kg

"2-Legged" Coupling Metric

JJA

Dirmeyer et al. (2012)

J/kg

Paul Dirmeyer

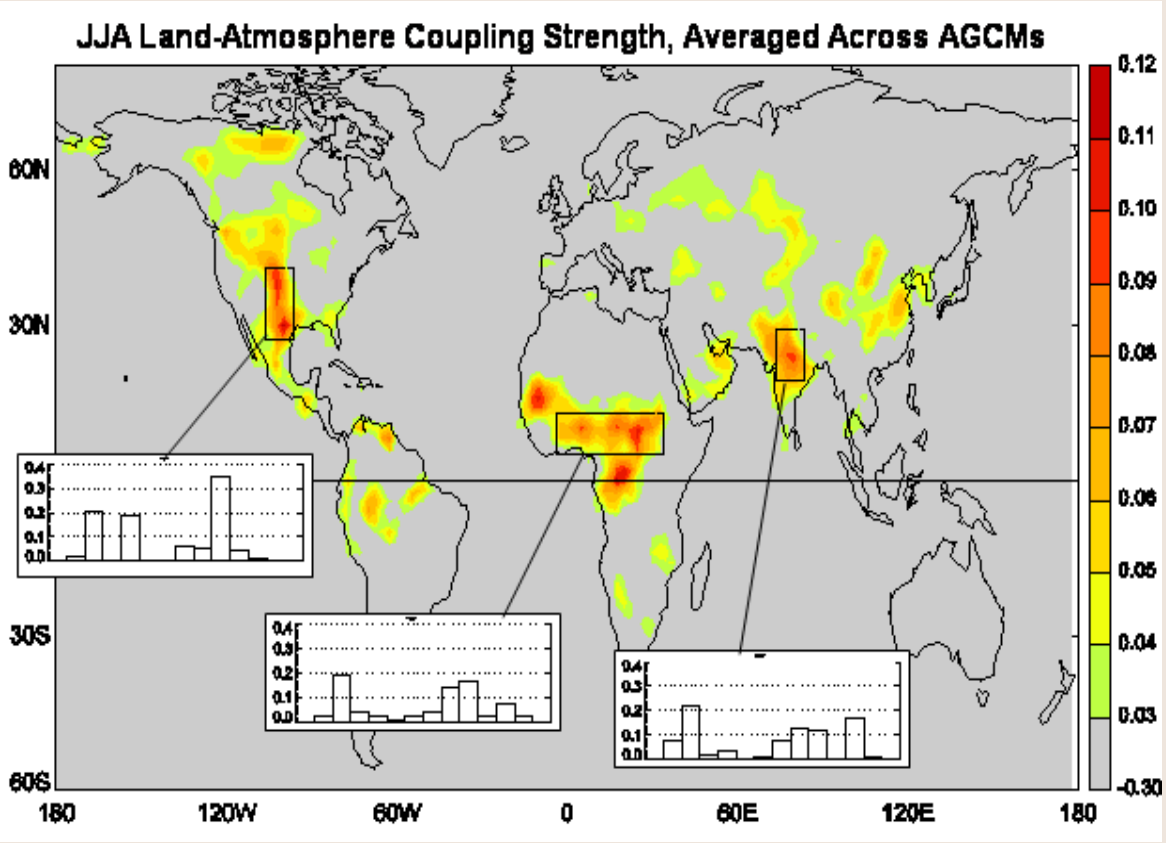
COLA Center for Ocean-Land-Atmosphere Studies

GEORGE MASON UNIVERSITY

Global Land-Atmosphere Coupling Experiment (GLACE)

- 'Omega' diagnostic determined by ensembles of GCMs indicates the **connection between soil moisture and precipitation**

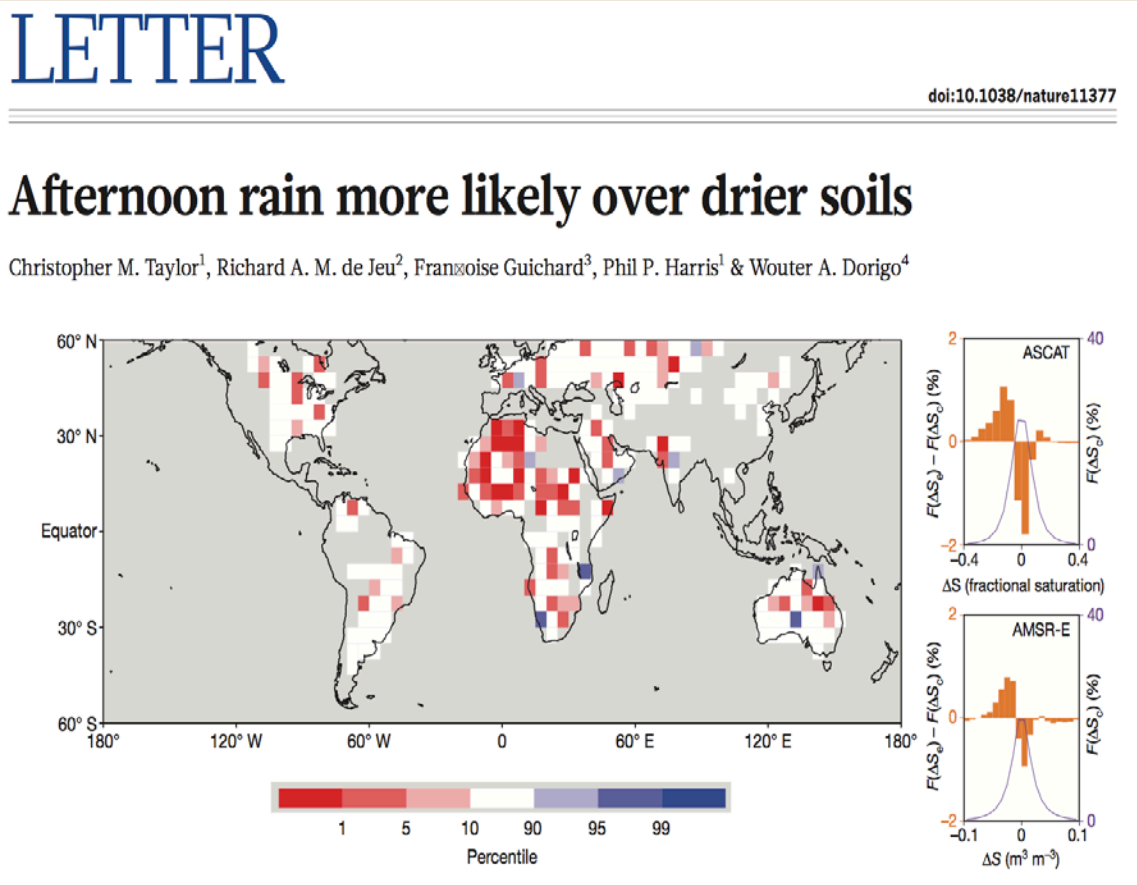
- Focuses on **positive feedbacks** of soil moisture on precipitation (e.g. higher SM > more P)



Courtesy of Koster et al. (2004)

SM-P Feedbacks

- Other studies and metrics have focused on global scales and sign of SM-P feedbacks.
- **Negative feedbacks** due to surface heterogeneity (Taylor et al. 2012).
- Spatial patterns of 'coupling' differ based on scales, models, observations and metrics.



LETTER

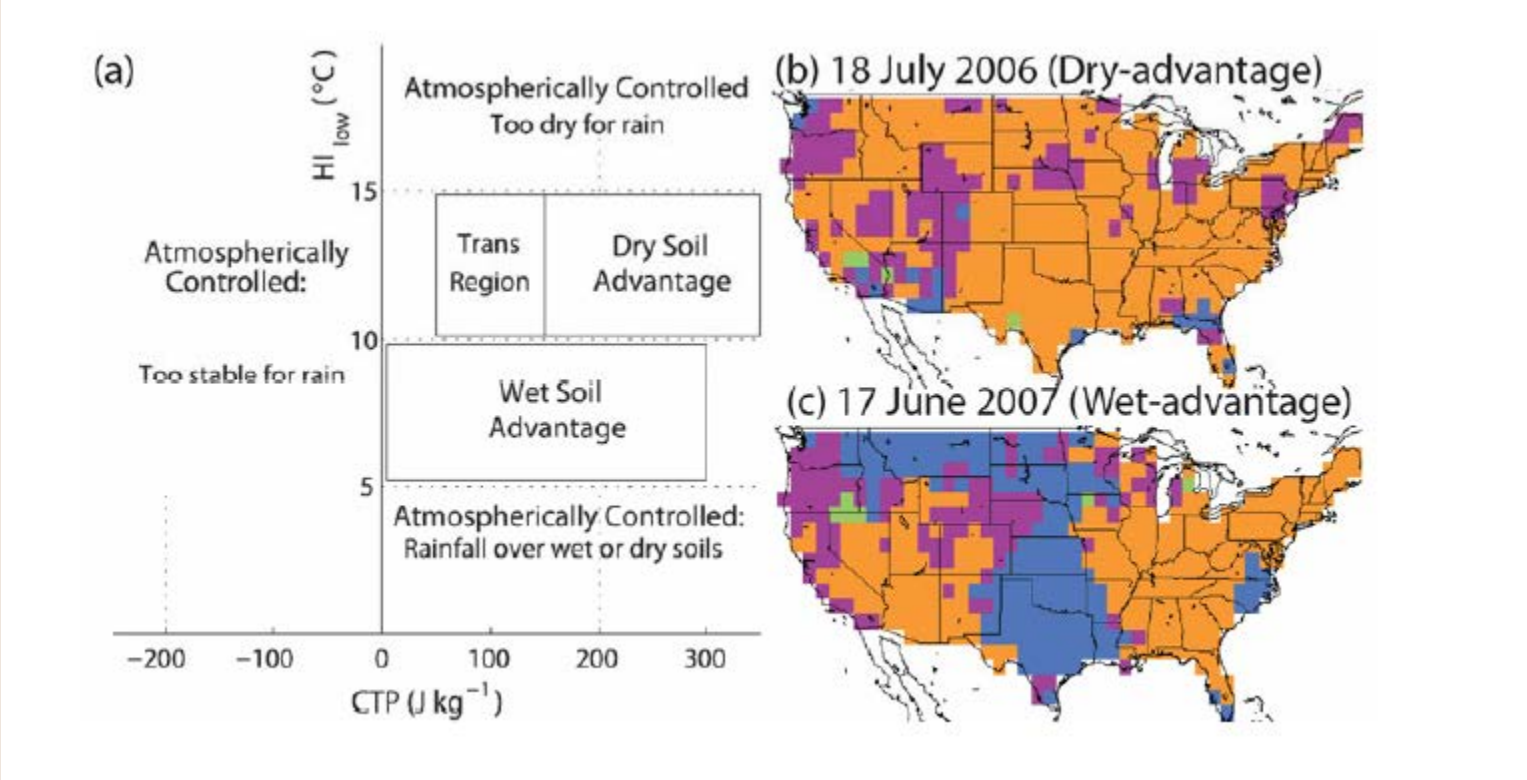
doi:10.1038/nature11377

Afternoon rain more likely over drier soils

Christopher M. Taylor[1], Richard A. M. de Jeu[2], Franxoise Guichard[3], Phil P. Harris[1] & Wouter A. Dorigo[4]

Courtesy of Taylor et al. (2012)

CTP-HI_{low} Framework



- Findell and Eltahir (2003) established the **CTP-HI_{low} framework** for assessing coupling regimes.
- Based on stability (CTP) and humidity (HI) state of the morning profile and likelihood of afternoon precipitation for a given soil moisture anomaly.
- Identifies positive (rain over wet soils) and negative (rain over dry soils) feedbacks

Heated Condensation Framework

HCF contains a suite of variables

Threshold Variables:

BCL = Buoyant Condensation Level [m]
θ_{BM} = Buoyant mixing temperature [K]

Necessary inputs to achieve threshold:

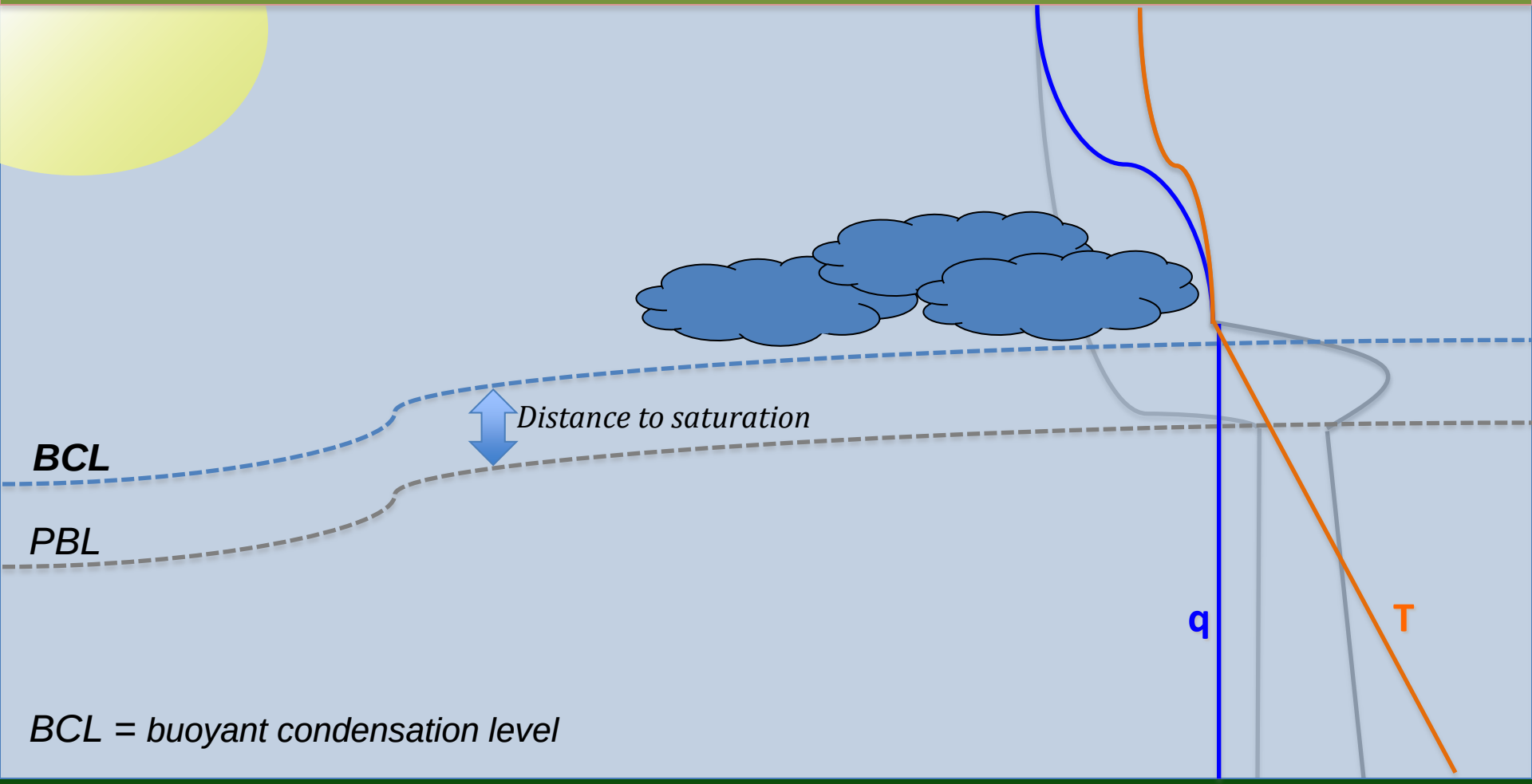
q_{def} = Moisture input required [kg/kg]
θ_{def} = Temperature input required [K]

Convection is initiated when:

PBL *intersects* **BCL**
θ_{2m} *reaches* **θ_{BM}**

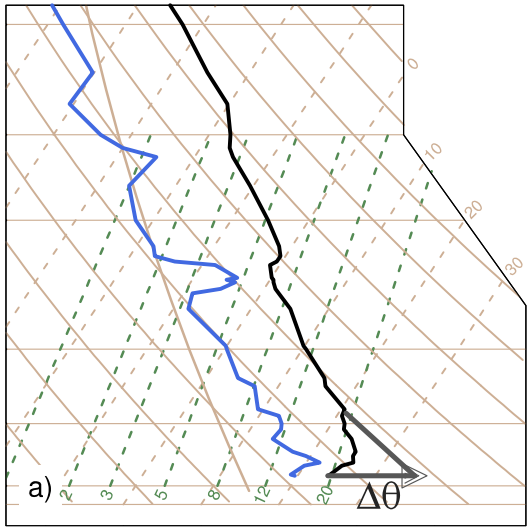
(Tawfik and Dirmeyer 2014 *GRL*)

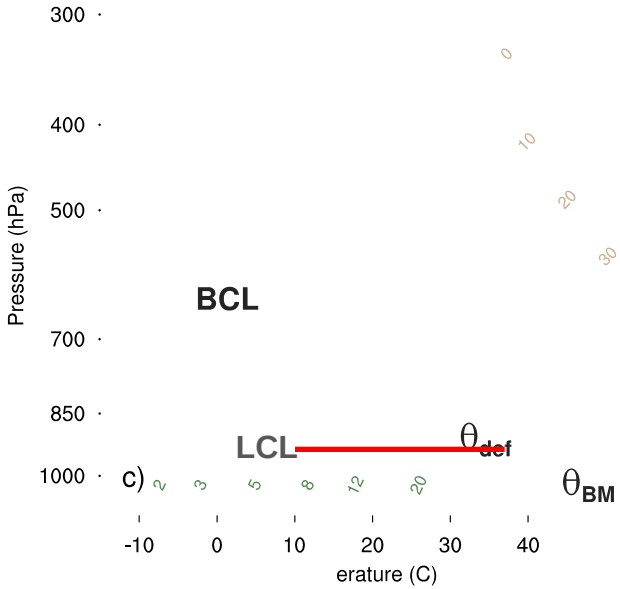
Heated Condensation Framework



BCL = buoyant condensation level

Calculating Convective Threshold



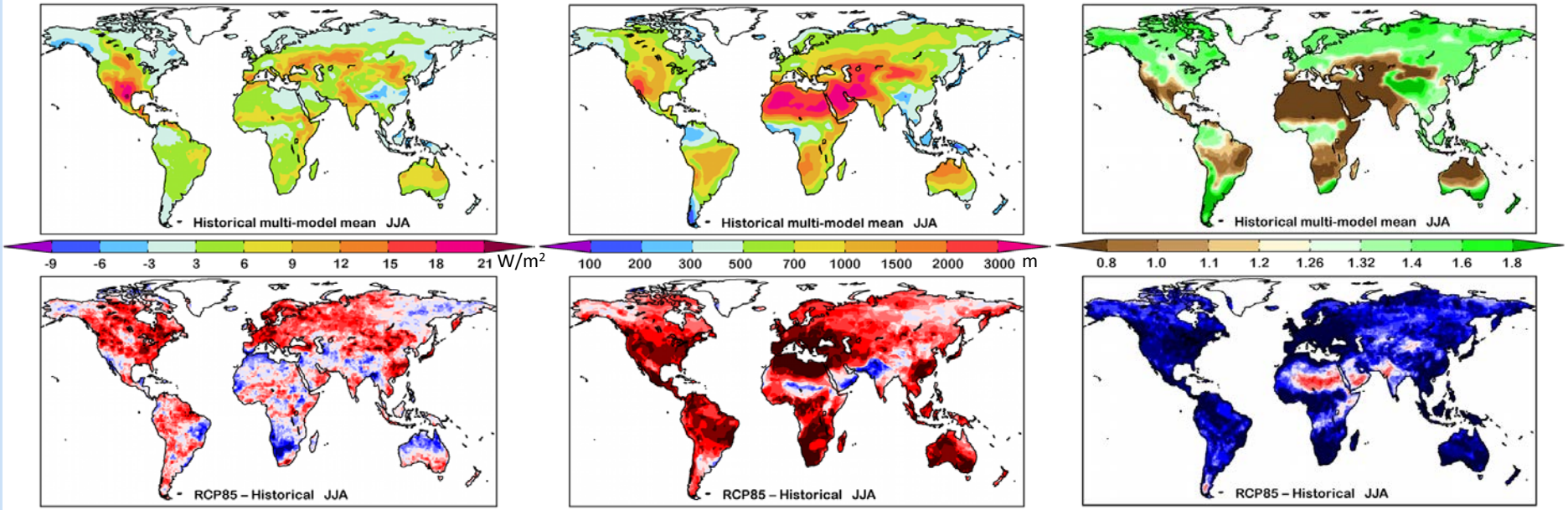


(Tawfik and Dirmeyer 2014 *GRL*)

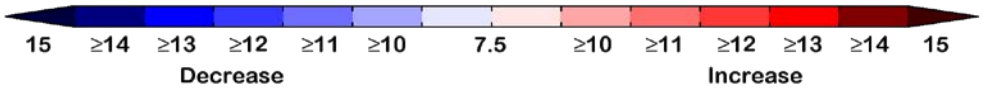
Assessment of changing L-A interactions from CMIP5:

- Current climate (top) and consensus <u>sign</u> of future changes for the extreme RCP8.5 case (bottom).
- Soil moisture control on surface fluxes onset is earlier, expands aggressively into today's cooler and wetter climates.
- Deeper LCL/PBL, reduced gradients across entrainment zone mean less impact of free atmosphere on PBL properties.
- **Land impacts on atmosphere increase in both relative and absolute senses**.

Terrestrial Coupling Index | LCL Height | Priestley-Taylor Coefficient



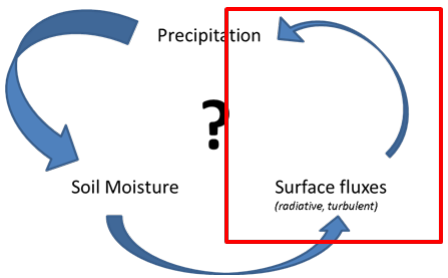
Number of models agreeing:

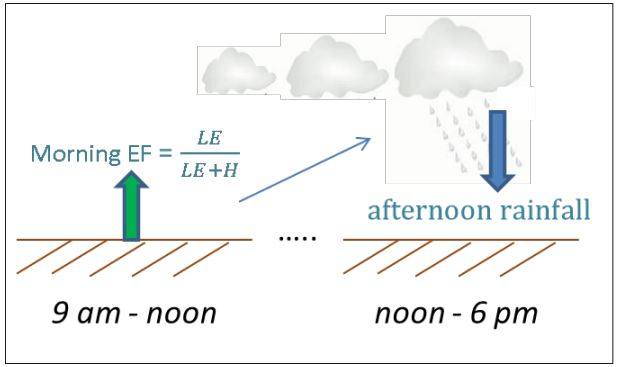


Paul Dirmeyer, Yan Jin, Bohar Singh & Xiaoqin Yan

Efforts to extend the TFS/AFS approach to GFDL's current suite of models

- **TFS/AFS approach: new metrics that assesses the impact of morning surface evaporative fraction (EF) on the *probability* and *intensity* of afternoon convective rainfall**





Triggering Feedback Strength

TFS σ_{EF}

Γ = Probability

Amplification Feedback Strength

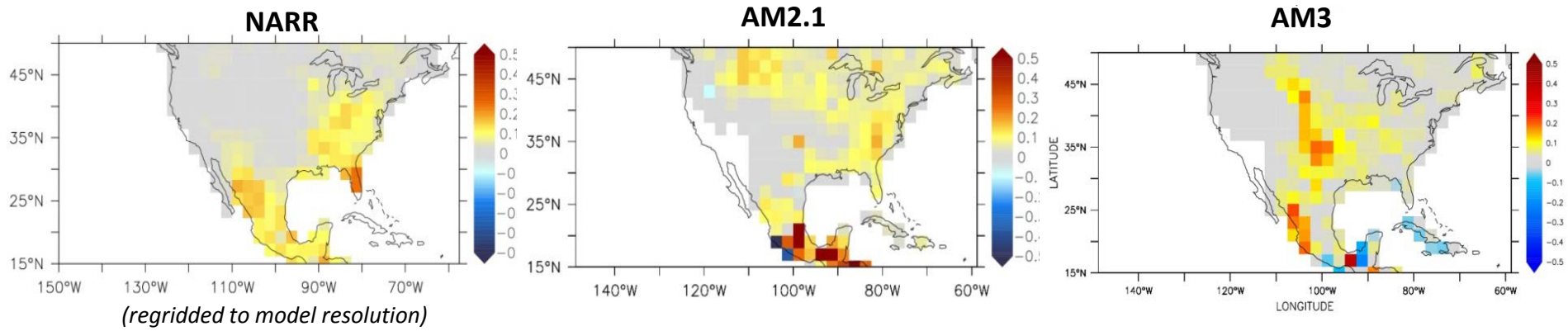
AFS σ_{EF} , on rainy days only

E = expected value

- **Findell et al. 2011 : applied this metric to the NARR dataset (North American Regional Reanalysis) over North America ⟶ *"observational" assessment***

  How do these results hold in GFDL's climate models ?

TFS, 1979-2003, JJA



(regridded to model resolution)

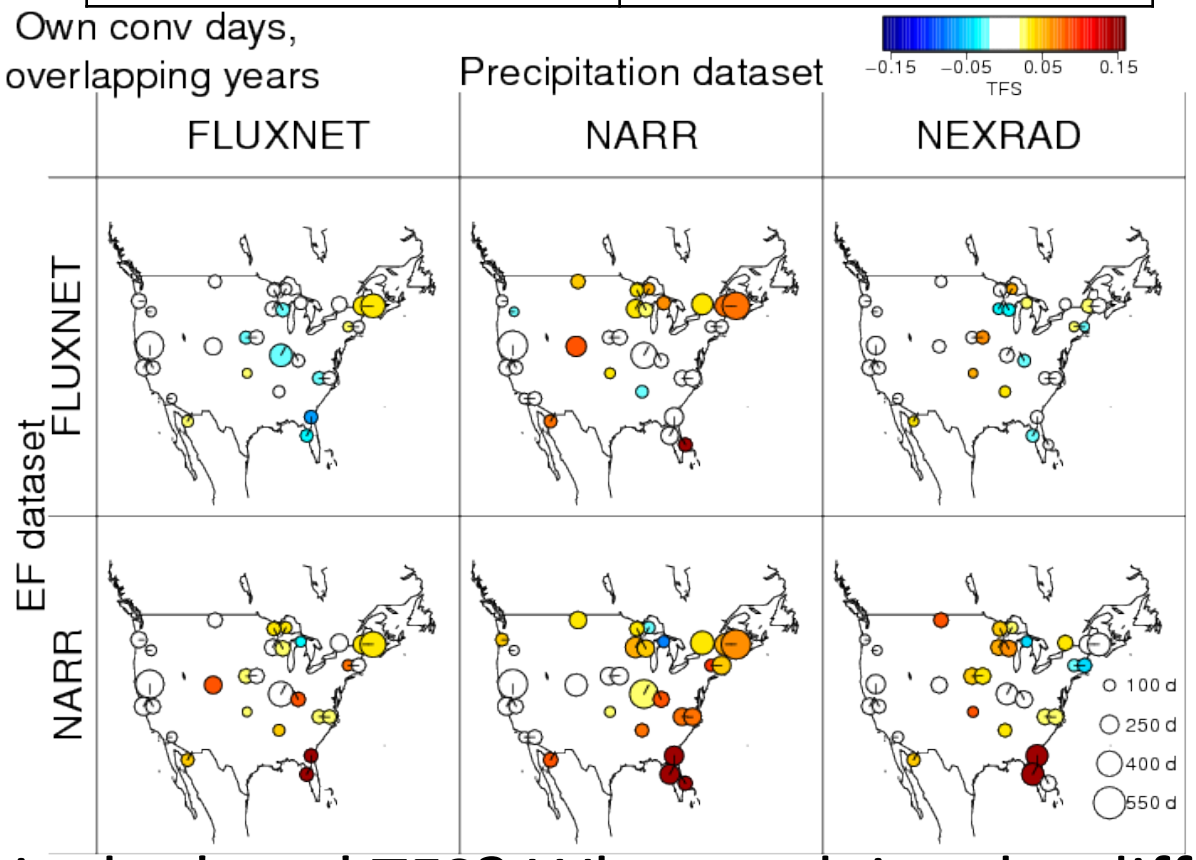
⟶ What explains these differences ?

Thanks to B. Guillod

Efforts to extend the TFS approach to observational data

Datasets

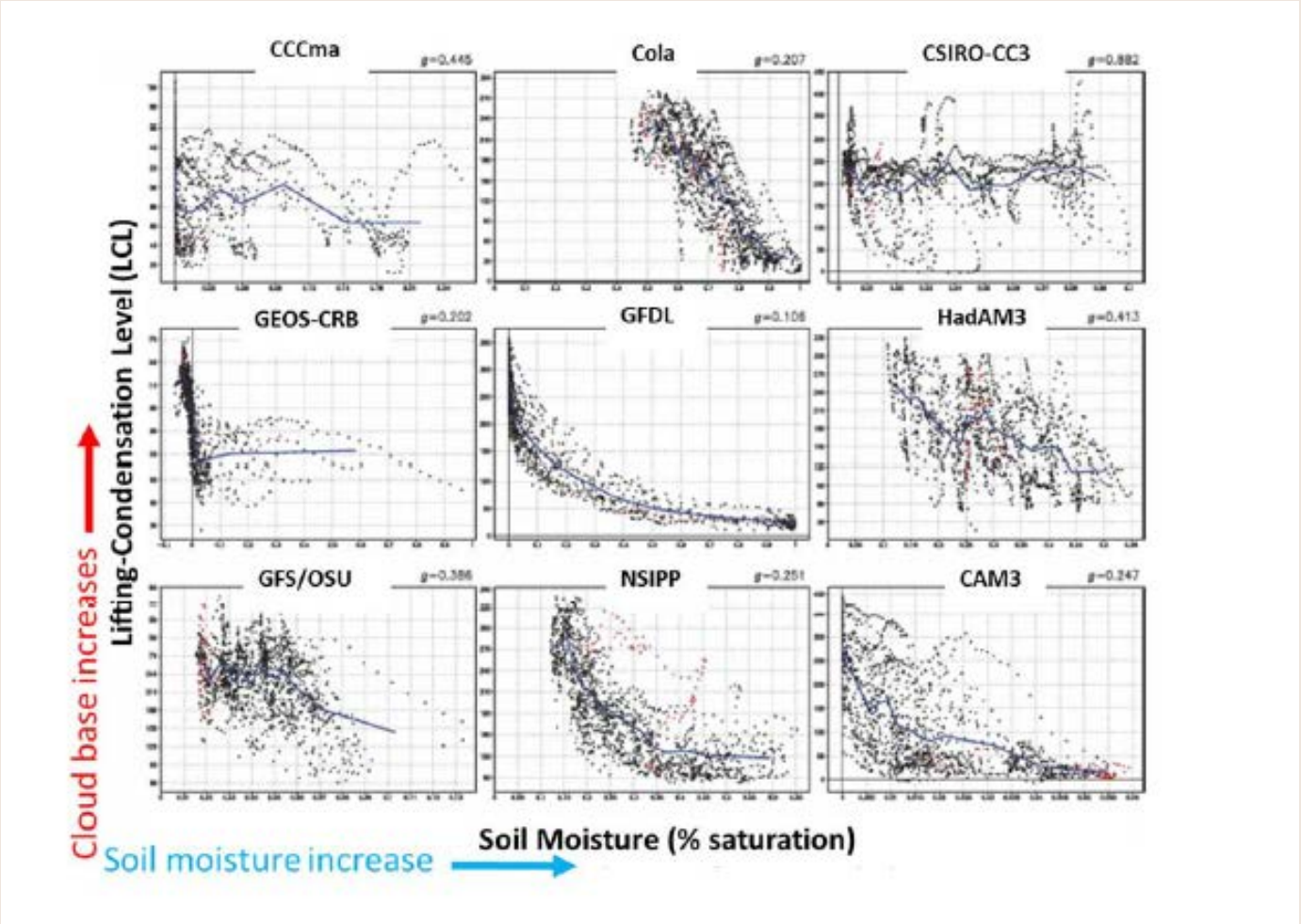
Precipitation	EF
FLUXNET	FLUXNET
NARR	NARR
NEXRAD (radar)	



Thanks to B. Guillod

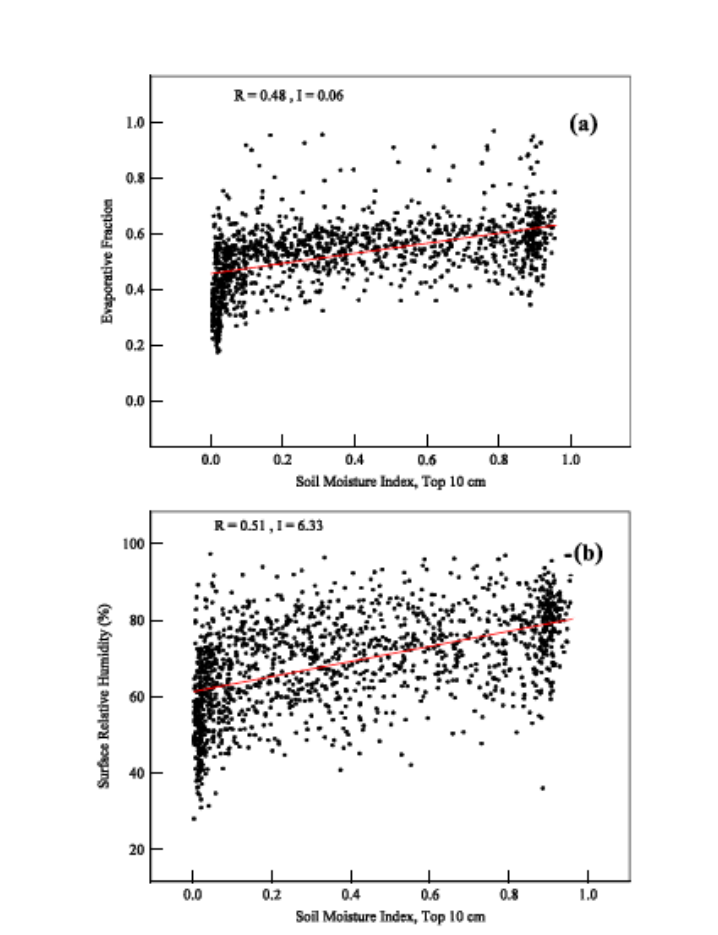
What is the 'true' TFS? What explains the differences?

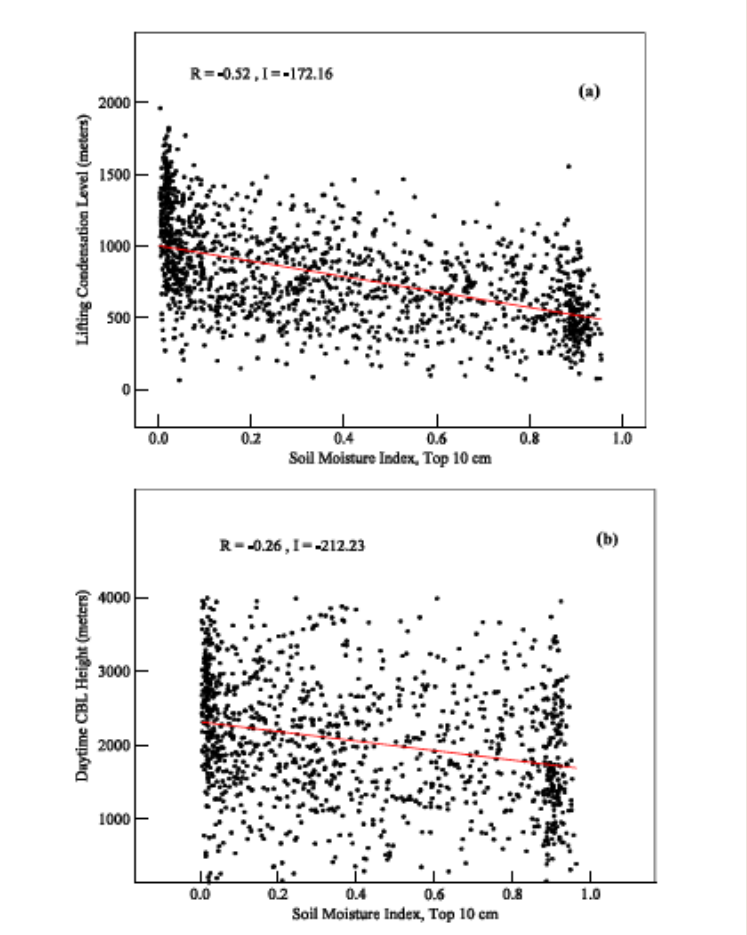
GCM Representation of L-A Interactions



Dirmeyer et al. (2006): Relationship between soil moisture and cloud base (LCL as a proxy) from 9 GCM's over the ARM-SGP CF.

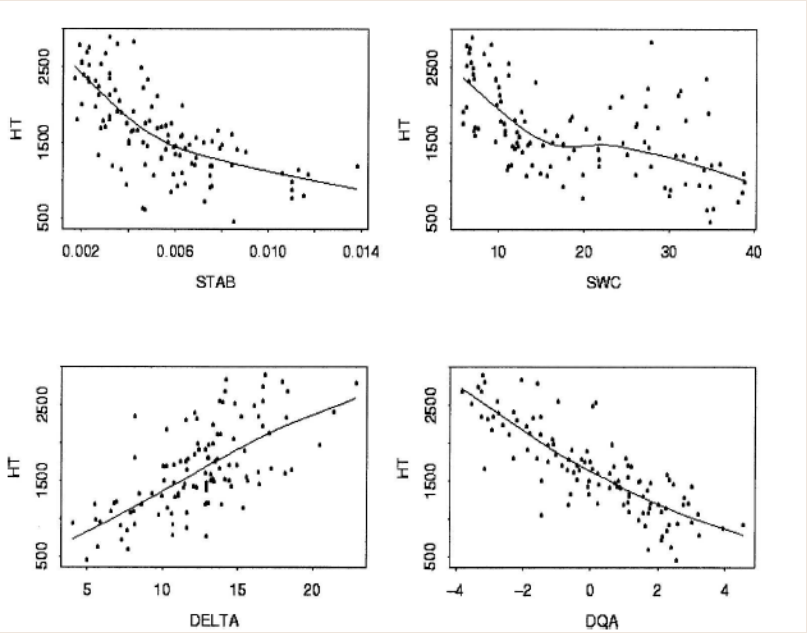
Observed Relationships at ARM-SGP

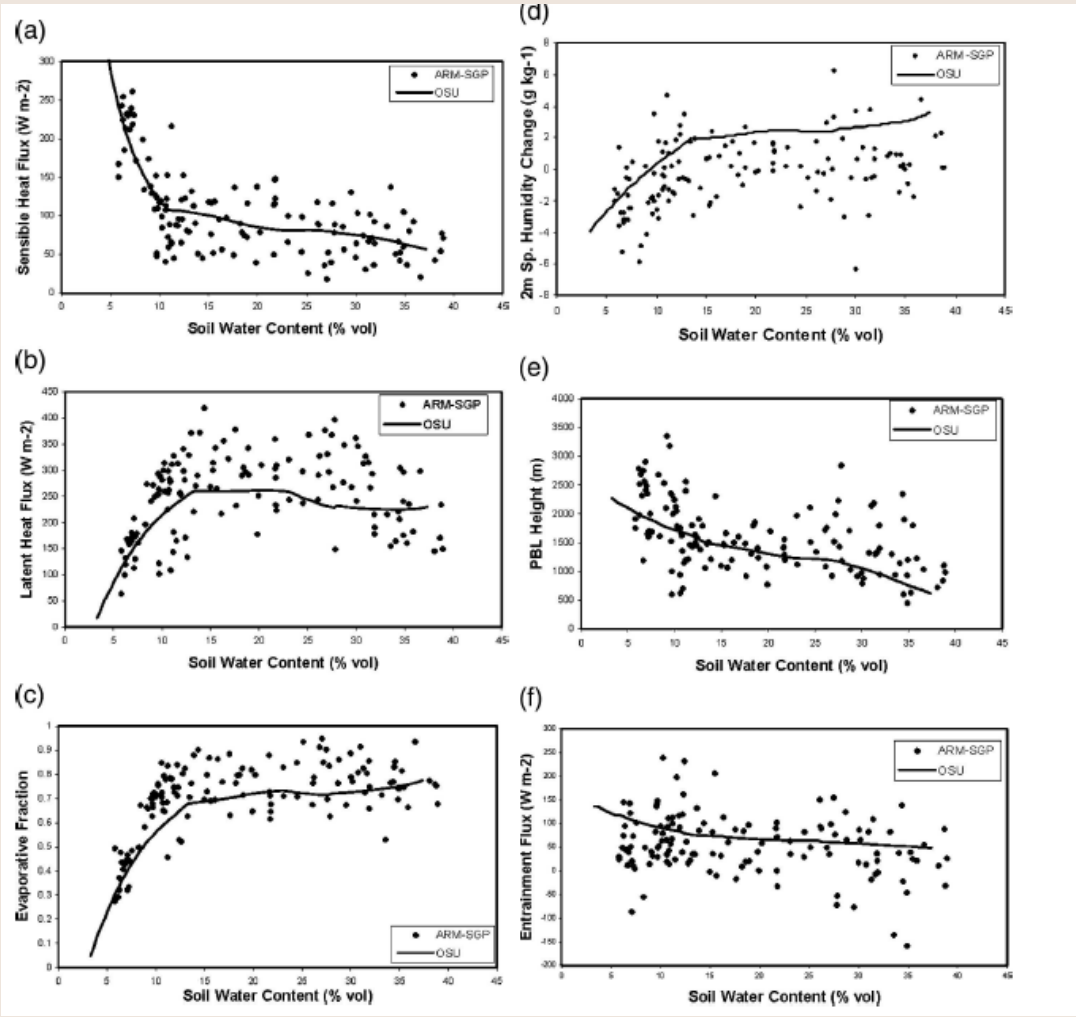




Phillips and Klein (2013): Land-atmosphere coupling manifested in warm-season observations on the U.S. southern great plains.

Observed Relationships at ARM-SGP





Santanello and Friedl (2005, 2007): Empirical investigation of CBL-Land interactions on diurnal timescales.

Motivation

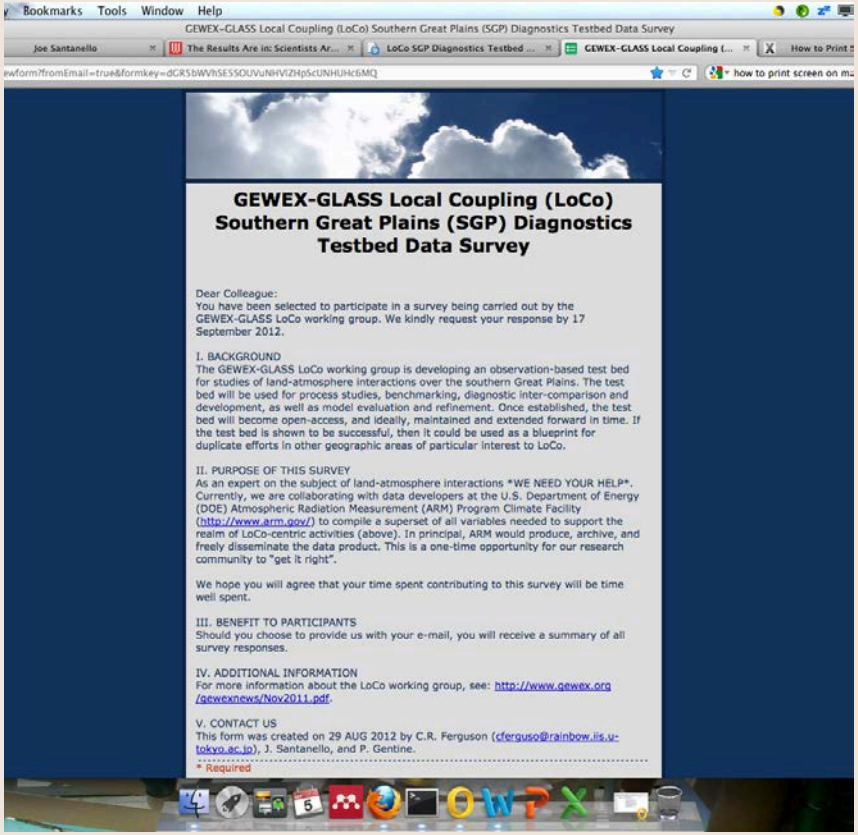
- **Now the question is:** ***'What as a community should we do with these methods, models, and datasets to propel our understanding and quantification through metrics of land-atmosphere interactions?'***
  - 'Holy Grail' of a single observable LoCo diagnostic has proven to be elusive
  - No community-wide LoCo experiments (e.g. PILPS, GSWP and GLACE)
  - Challenge: Difficult to converge on scope, metrics, and DOF
  - SCM and 1st order experiments underway in GLASS (Diurnal Cycle Coupling Experiments; DICE)
  - How do we best leverage off existing/future projects and programs?

LoCo-SGP Testbed

To this end, the ARM-SGP was identified as testbed for LoCo studies and datasets:

- Provide a multi-year observational and modeled data test bed for the evaluation and inter-comparison of diagnostics.
- Provide a hierarchy of diagnostic tests to identify and subsequently classify coupling.
- Determine the information content source for L-A coupling in terms of temporal and spatial scale, modeled quantities, and observation type.
- Quantify the sensitivity of coupling classification to metric applied.

LoCo/SGP Data Survey



GEWEX-GLASS Local Coupling (LoCo) Southern Great Plains (SGP) Diagnostics Testbed Data Survey

Dear Colleague:
You have been selected to participate in a survey being carried out by the GEWEX-GLASS LoCo working group. We kindly request your response by 17 September 2012.

I. BACKGROUND
The GEWEX-GLASS LoCo working group is developing an observation-based test bed for studies of land-atmosphere interactions over the southern Great Plains. The test bed will be used for process studies, benchmarking, diagnostic inter-comparison and development, as well as model evaluation and refinement. Once established, the test bed will become open-access, and ideally, maintained and extended forward in time. If the test bed is shown to be successful, then it could be used as a blueprint for duplicate efforts in other geographic areas of particular interest to LoCo.

II. PURPOSE OF THIS SURVEY
As an expert on the subject of land-atmosphere interactions *WE NEED YOUR HELP*. Currently, we are collaborating with data developers at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program Climate Facility (http://www.arm.gov/) to compile a superset of all variables needed to support the realm of LoCo-centric activities (above). In principal, ARM would produce, archive, and freely disseminate the data product. This is a one-time opportunity for our research community to "get it right".

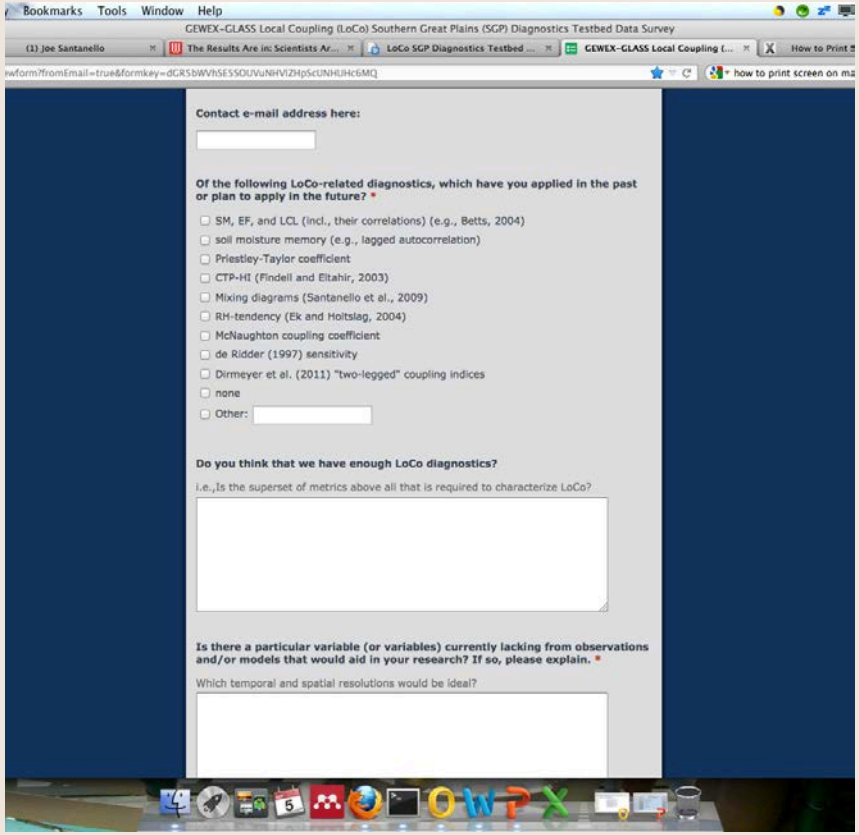
We hope you will agree that your time spent contributing to this survey will be time well spent.

III. BENEFIT TO PARTICIPANTS
Should you choose to provide us with your e-mail, you will receive a summary of all survey responses.

IV. ADDITIONAL INFORMATION
For more information about the LoCo working group, see: http://www.gewex.org/gewexnews/Nov2011.pdf.

V. CONTACT US
This form was created on 29 AUG 2012 by C.R. Ferguson (cferguso@rainbow.iis.u-tokyo.ac.jp), J. Santanello, and P. Gentine.

* Required



Contact e-mail address here:

Of the following LoCo-related diagnostics, which have you applied in the past or plan to apply in the future? *

- SM, EF, and LCL (incl., their correlations) (e.g., Betts, 2004)
- soil moisture memory (e.g., lagged autocorrelation)
- Priestley-Taylor coefficient
- CTP-HI (Findell and Eltahir, 2003)
- Mixing diagrams (Santanello et al., 2009)
- RH-tendency (Ek and Holtslag, 2004)
- McNaughton coupling coefficient
- de Ridder (1997) sensitivity
- Dirmeyer et al. (2011) "two-legged" coupling indices
- none
- Other:

Do you think that we have enough LoCo diagnostics?

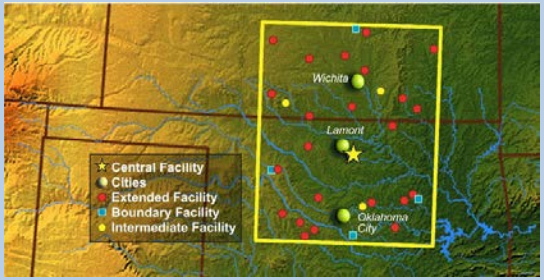
i.e.,Is the superset of metrics above all that is required to characterize LoCo?

Is there a particular variable (or variables) currently lacking from observations and/or models that would aid in your research? If so, please explain. *

Which temporal and spatial resolutions would be ideal?

https://docs.google.com/spreadsheet/viewform?fromEmail=true&formkey=dGR5bWVhSE5SOUVuNHVlZHpScUNHUHc6MQ

- Based on feedback and through collaboration between LoCo, ARM, and the NASA NEWS program, a new data product called **ARM Best Estimate (ARMBE) - Land** has been produced for the SGP Central Facility (Lamont, OK).



- PI: Shaocheng Xie, Lawrence Livermore National Laboratory
- Data Product Name: ARMBELAND - Critical soil quantities for describing land properties Product Type: ARM Evaluation Products
- **Date Range of Product: 01/01/1994 - 12/31/2012**
- Data Directory Location: http://iop.archive.arm.gov/arm-iop/0eval-data/xie/armbe-eval/armbeland/
- General Description: The ARMBELAND is a subset of the ARM Best Estimate (ARMBE) products for supporting community land-atmospheric research and land model developments. It contains several critical soil quantities that ARM has been measuring for many years for describing land properties. The quantities in ARMBE-Land are averaged over one hour time interval, consistent with other ARMBE datasets. It is recommended to use with other ARMBE data products such as **ARMBECLDRAD** (cloud and radiative fluxes) and **ARMBEATM** (surface precipitation, surface sensible and latent heat fluxes and other atmospheric state variables) to get a more complete description of the land condition and its associated large-scale environment. The ARMBE-land data are currently available for the ARM SGP central facility site: SGP.C1 (Lamont, OK) for the period when these data are available.
- Currently, the ARMBE-Land contains the following quantities:
  - **Soil temperature measured from CO2FLX, EBBR, and SWATS**
  - **Soil moisture content measured from CO2FLX, EBBR and SWATS**
  - **Soil heat flux from CO2FLX, EBBR**
  - **CO2 flux from CO2FLX**
  - **CO2 density from CO2FLX**
  - **Friction velocity from CO2FX**
  - **Photosynthetic photon flux density (PAR) from CO2FX**

Data availability:

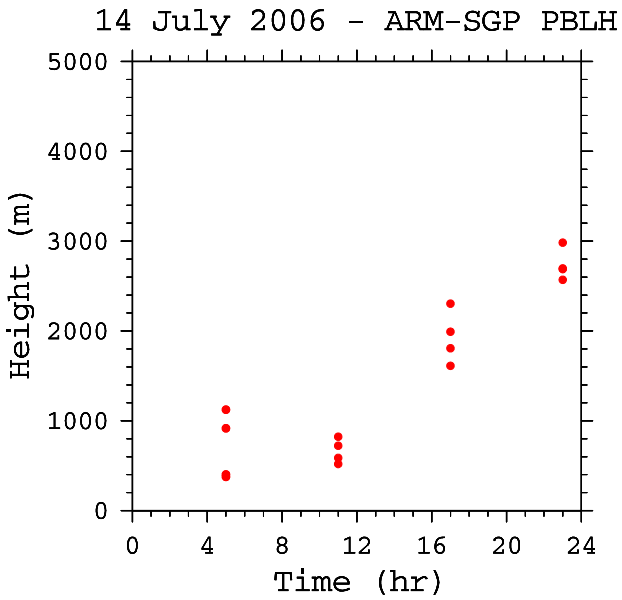
- Quantities from CO2FLX : 2003-2012
- Quantities from EBBR: 1994-2012
- Quantities from SWATS: 1996-2012

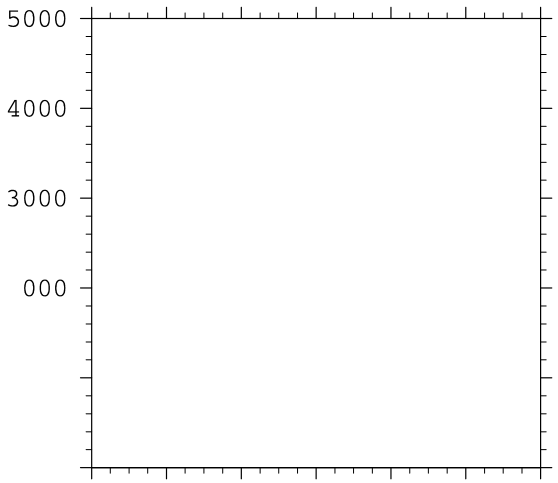
- Work has begun on a 2-D gridded product over the broader ARM SGP network, which will include all the fields relevant for land-atmosphere coupling studies as well as sub-grid scale variability. Delivery of this product is expected by early 2014.

PBL/Profile Observations

- ARM-SGP Value Added Product (*PBLH)
  - SGP sonde data (4x daily) over period of record 1996-present
  - 4 method intercomparison of PBLH detection
    - Heffter (gradient), Liu-Liang (parcel), Bulk Richardson 0.5 and 0.25 (stability/shear)
- ARM-SGP PBLH Product (*PBLH)
  - AERI + Raman Lidar to construct temperature profile in lower troposphere
  - 2009-2012 hourly dataset
- Li-Sawyer Method (*PBLH)
  - Combines gradient/wavelet detection
  - Employs sonde, AERI, and MPL (lidar) @ SGP
  - To be released soon
- ARM-SGP Merge Sonde VAP (*profs)
  - Sonde+MWR+Met+ECMWF data
  - 1996-present @ hourly resolution and 266 vertical levels
  - Artifacts in lower 1km at times, makes automated (Ri) difficult – waiting for email reply
- AERIoe Produce (*profs)
  - NEW ARM highlight, profiles based on AERI for clear and cloudy – focused on PBL
  - http://www.arm.gov/science/highlights/RNTQ2/view
- COSMIC – GPS Radio Occultation (*prof/PBLH)
  - India Dept. of Space
  - Vertical profiles of refractivity (N)
  - PBLH from wavelet analysis
  - Irregular, global coverage depending on land/sea and latitude
  - SGP 2006-12, +/- 2 degrees saw 1136 profiles available (~1 every 2 days)
- ECMWF (ERA-Interim) Climatology Product (*PBLH)
  - Teixeira and von Englen
  - Monthly gridded PBLH @ 0, 6, 12, 18 UTC
  - 5 gradient methods – RH most robust
- AIRS (*prof)
  - NEWS proposal (2012-2014)
  - L2 profiles limited in lower troposphere
  - AIRS radiances as a proxy for L-A conditions
- Gadanki, India Site (*prof)
  - Met station, tower, soil moisture/temperature, and fluxes (installed recently)
  - 3-hourly Radiosonde (2006-present)
  - Monsoon studies

ARM PBLH Value-Added Product





Outline

Brief History of LoCo

LoCo Diagnostics

Outstanding Issues and Challenges

ASR Science Questions

Current Challenges

- **Spatial Scale**
  - Heterogeneity and Representativeness (inc. soils, vegetation)
  - Local vs. Non-local Coupling
  - Advection/Large-Scale Processes
- **Temporal Scale**
  - Metric requirements vary significantly
  - Model applications range from local/point/diurnal to global/climate
- **Models & Diagnostics**
  - True coupling 'strength' is elusive and transient
  - Disparate scales, but should be complimentary approaches
    - E.g. GLACE & TFS results (GCM world) could be explained by Terrestrial and PBL 'links in the chain' metrics.
- **Satellite Data**
  - Not benchmark quality (fluxes (ET), soil moisture, PBL all limited)
  - Treat as a 'model' and determine future requirements

Satellite Monitoring of L-A Interactions

- Diagnostics and models, including the land and PBL schemes within, ultimately need to be *evaluated and applied at both the local and global scales.*

<u>Global Monitoring of LoCo Variables from Satellite:</u>

- Land Surface (well-established)
  - Soil Moisture: Microwave (AMSR-E, SMOS, SMAP)
  - Evaporative Fraction: IR Sounders (AIRS, IASI), MODIS, Microwave
    - – Global ET efforts underway (e.g. Landflux)
    - – Includes LST, Veg, Soils

- PBL (under established)
  - Mixed-layer T/q profiles and evolution: IR Sounders (AIRS, IASI)
  - LCL: GOES, IR Sounders (AIRS, IASI)
  - PBL Height: AIRS, CALIPSO, GPS, others….?

Outline

Brief History of LoCo

LoCo Diagnostics

Outstanding Issues and Challenges

ASR Science Questions

Current Challenges

- **Perspective**
  - Atmosphere, PBL, Clouds, and Precipitation are often boundary conditions for land surface community.
  - In particular, clouds/precip are the 'end points' of many LoCo diagnostics and cloud processes are not dealt with by LSM community. (GASS vs. GLASS)
  - Likewise, ASR (including LES, CRMs) has not dealt with issues at core of land/hydrology model development (e.g. heterogeneity, soil moisture, groundwater, snow, vegetation).
  - Driving questions from land surface often differ from atmosphere, e.g. 'How do surface anomalies (e.g. drought) translate into atmos/climate impacts?'

- **Expertise**
  - Many science questions can be posed, some of which can only be answered with certain expertise, models, scales, datasets.
  - How to determine first-order impact questions (i.e. complexity in LSMs required to answer specific questions)?

- **Programmatic**
  - Funding for LACI is limited and often sporadic across agencies
  - NASA (no core program support); L-A/PBL viewed as a current 'gap'

Motivational Summary

- **Model biases** in precipitation, temperature and humidity (particularly over the SGP) have led to closer inspection of of the role of L-A interactions.
- Results over the last decade have demonstrated the potential of **land surface contribution to predictability** and prediction skill (e.g. GLACE) and the connection of soil moisture to precipitation.
- Supports the need for model development to concentrate on **coupled processes** between land and atmosphere.
- In **LoCo**, hope to point specifically to **where the weaknesses lie** and where model development should be focused.

Proposed Science Questions (1 of 3)

How important is the influence of the land surface on the boundary-layer turbulence and structure, cloud life cycle, and precipitation?

- ***Diurnal Cycle of LACI***
  - How do land surface process impact the diurnal cycle of the boundary layer structure, and the occurrence and spatial extent of clouds and precipitation?
  - What is the effect of soil moisture anomaly (dry or wet) on the surface flux partition, boundary layer turbulence structure and cloud occurrence? What is the role of ground water, irrigation, and phenology? Which soil moisture is most important at ARM sites: root zone layer or ground water?
- ***Surface Heterogeneity***
  - How large is the flux-foot print of clouds seen at the ARM sites? What does that tell us about the relevant spatial scales?
  - What is the impact of land-surface heterogeneity on the PDFs of thermodynamic variables and vertical velocity, and their relationship with clouds and precipitation? Are our representations in models consistent with observations?
  - How is land-surface heterogeneity represented in models and how does it impact the PDFs of variables in the PBL?
- ***Boundary Layer/Turbulence***
  - What are the long-term boundary layer turbulence statistics at ARM sites? How do they compare to the representations in models? What is the impact of entrainment at the PBL top on the thermodynamic properties, trace gases, and aerosol in the PBL?
  - What is the role of longwave flux divergence on the surface energy balance and its impact/coupling with the boundary-layer turbulence
- ***Regime***
  - What is the impact of the surface on cloud pool dynamics and the life cycle of convection?
  - How can we define local vs. non-local (including wave dynamics) effect of LACI?

Proposed Science Questions (2 of 3)

What boundary layer and land processes contribute to the diversity of soil moisture-precipitation feedbacks observed in nature and simulated in models [LES, CRMs, Mesoscale Models (MMs), GCMs]?

- ***Scale dependence of feedback pathways***
  - What are the proper linkages between soil moisture, boundary-layer, clouds, and precipitation in nature and how are they simulated in models? How do they change as a function of scale?
  - How do those linkages change in different flow and hydrological regimes? How does the change in PBL state (shallow/deep, dry/humid…) define the feedback sign between surface fluxes and clouds?
- ***Regional and local scale transport***
  - How do we quantify relative roles of local moisture sources and regional-scale transport over a range of spatial and temporal scales
  - Can we use high-resolution models coupled with land models to improve the representation in large-scale models (e.g. MMs and GCMs)?
- ***Impact of Clouds***
  - How does radiative cloud forcing (shading and enhanced diffuse radiation) impact the surface sensible and latent heat flux, CO_2 flux, and biogenic emissions, as well as their spatial structure?

Phillips and Klein (2013)

-Weak support of SM-P connections

-Cloud albedo and surface radiation is strong

-Large component of SM range that isn't strongly correlated with other variables, PBL, clouds (*except when dry-downs occurring in time; clustering and regimes also useful)

-Prescribe P for accurate SM initialization in GCMs

-Diagnose processes and parameterization deficiencies in LS and PBL

-LoCo metrics useful framework

-GLACE hotspot might not be reality based on obs – if so the models show too strong of coupling

Proposed Science Questions (3 of 3)

How do feedbacks between biogenic emissions, SOA, boundary layer, and clouds influence the cloud lifecycle?

- ***Surface processes***
  - What are the important links between land use, soil moisture, biogenic emissions, and clouds over a range of landscapes (from the Amazon to the Artic)?
  - How well do our models represent these links?
  - How do changes in the land use influence changes in biogenic emissions?
  - What are the uncertainties in biogenic emissions and SOA formation? How do we quantifying them?
- ***Boundary-layer processes***
  - How does vertical mixing (with alternating cycles of high and low RH) change SOA?

- In terms of BVOC and the SOA out of it, the current NU-WRF employs a simple parameterization to **convert BVOC to SOA**. Apparently this simplification does not allow us to answer many important scientific questions, e.g.,
  - How does RH/vertical mixing change SOA?
  - How does environment elements (e.g., temperature, humidity, homo/heterogeneous reactions, etc.) affect gas-particle partition that is important to SOA formation? Solving these problems need resources to improve the representation of SOA in NU-WRF.
  - On the other side, how the L-A-C interaction induced changes in soil moisture, PBLH, near-surface temperature, surface flux etc., impact BVOC emissions.

- The other issue is **how SOA affects cloud and precipitation**.
  - What is the SOA's role on cloud formation at the local-to-regional scale?
  - Is there any observational evidence to show its role?
  - What is the relationship between SOA and CCN/IN (cloud condensation nuclei and ice nuclei), and what, hydrophobic or hydrophilic, SOA is more important in CCN/IN?
  - Will SOA invigorate or dissipate precipitation and under which conditions?

- The difficulty of aerosol-cloud interaction is that it is hard to have any **direct observational data** to prove and improve the processes. The current NU-WRF has the capability to separate aerosol species (e.g., anthropogenic vs. biogenic vs. dust, etc.) which allows the investigation of aerosol-cloud interaction at individual source level theoretically.

- BVOC emissions are closely tied to **land usage.** For example, the MEGAN embedded in NU-WRF takes the plant-function-type (PFT) approach, of which the **emissions factors (EFs)** associated with each PFT are prescribed based on limited field/lab experiments. In the real world, the EFs display large range for the same PFT in different regions. The uncertainty associated with the EFs is large. The solution could be a global database of EFs as a function of both PFT and location.

- The other interesting scientific question about BVOC is what is the fundamental physiological mechanism that regulates **BVOC emissions**. What are the within-canopy processes that determine actual BVOC emissions and how it can be implemented in the regional/global models like NU-WRF? What is the linkage between within-canopy and over-canopy (into the PBL) BVOC emissions?

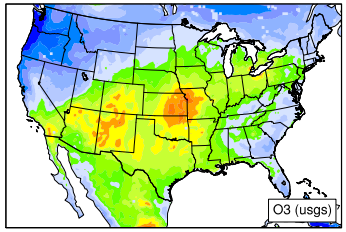
Land Cover-Chemistry Interactions

Effect of Land Cover on Atmospheric Processes and Air Quality over the Continental United States

- The NU-WRF team conducted coupled **chemistry-atmosphere-land simulations** with MODIS, UMD, and USGS land cover data. NASA's MODIS dataset estimates a **doubling** of urban area relative to the standard WRF USGS dataset circa 1993 (115,600 vs. 42,400 km2).
- As a result, the average surface NO_2 concentration decreases by 13% while 8-hour-average ozone concentration increases by 3%.
- Overall, increased urban land cover tends to produce lower surface NO_2 concentrations due to deeper PBLs but generates more frequent high surface ozone events as a result of higher temperatures.

Surface O_3(ppbv)

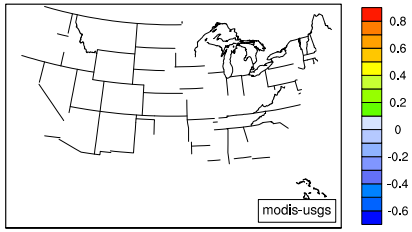
[USGS]



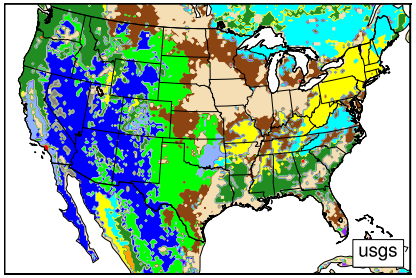
Surface NO_2(ppbv)

[UMD-USGS]

[MODIS-USGS]

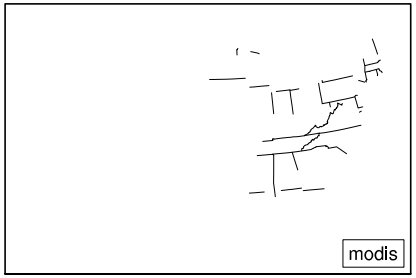


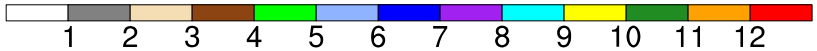
USGS



UMD

MODIS



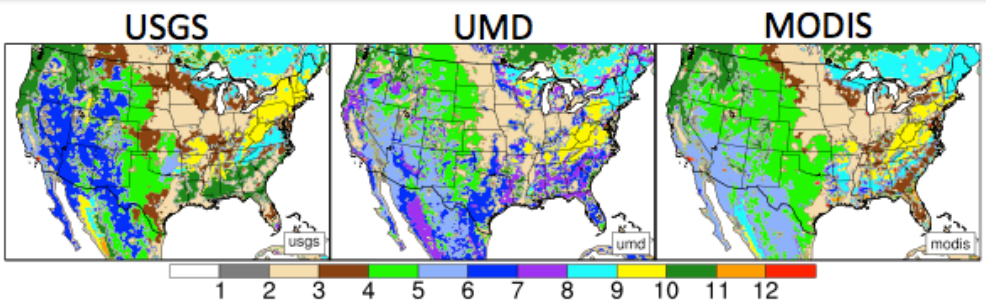


1 = barren land; 2 = cropland;
3 = cropland/natural land mosaic;
4 = grassland; 5 = open shrubland;
6 = closed shrubland; 7 = woodland;
8 = mixed forest; 9 = deciduous BL forest; 10 = evergreen NL forest;
11 = evergreen BL forest; 12 = urban

Tao, Z., Santanello, J. A., Chin, M., Zhou, S., Tan, Q., Kemp, E. M., and Peters-Lidard, C. D.: Effect of land cover on atmospheric processes and air quality over the continental United States – a NASA Unified WRF (NU-WRF) model study, Atmos. Chem. Phys., 13, 6207-6226, doi:10.5194/acp-13-6207-2013, 2013.

Land Cover-Chemistry Interactions

Effect of Land Cover on Atmospheric Processes and Air Quality over the Continental United States – A NASA Unified WRF (NU-WRF) Model Study



1 = barren land; 2 = cropland;
3 = cropland/natural land mosaic;
4 = grassland; 5 = open shrubland;
6 = closed shrubland; 7 = woodland;
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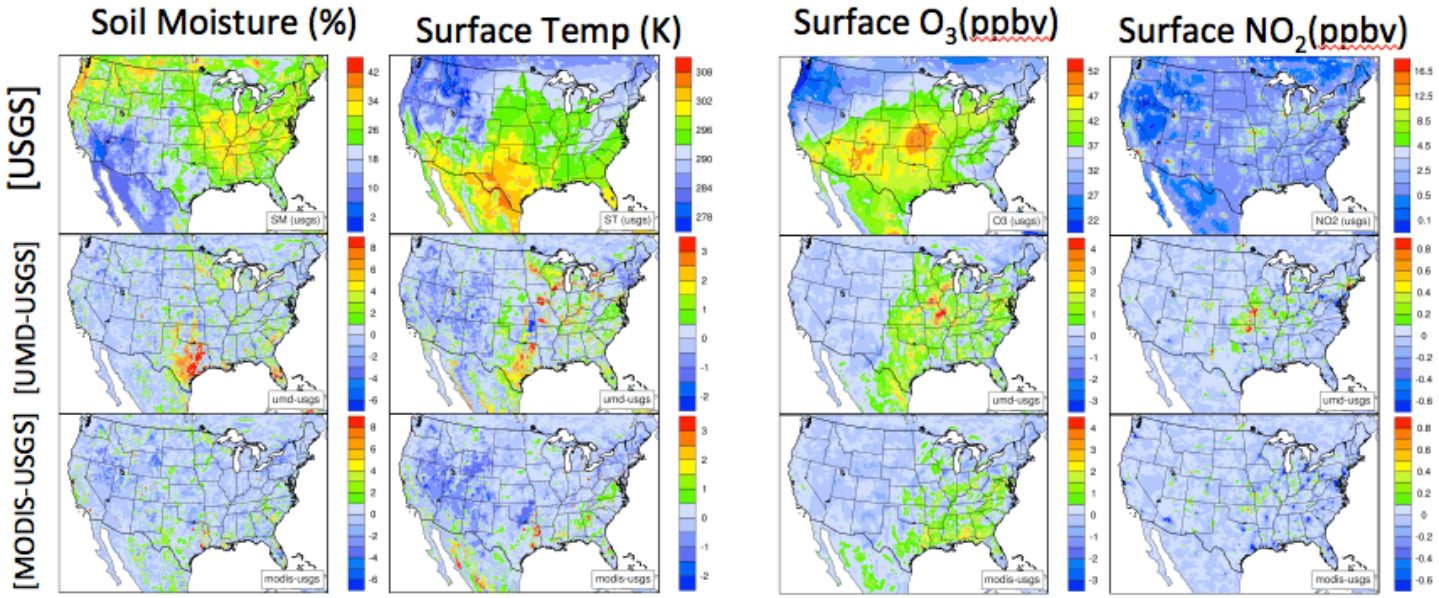
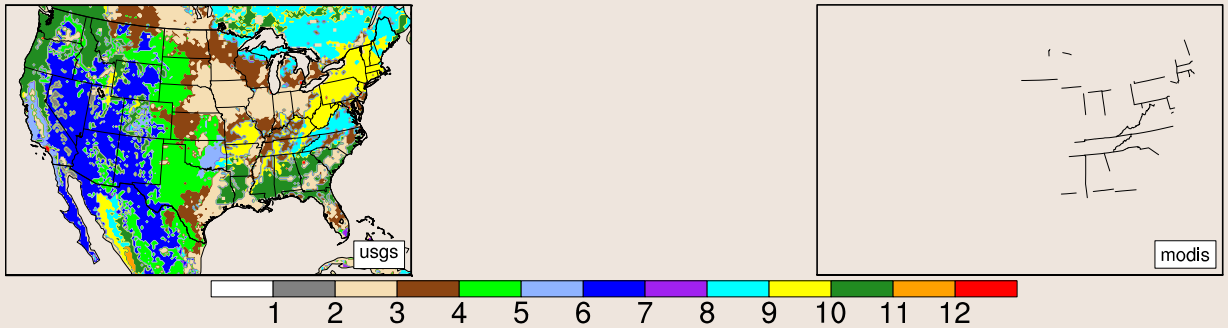


Z. Tao et al., ACP (2013)

Land Cover-Chemistry Interactions

USGS UMD MODIS



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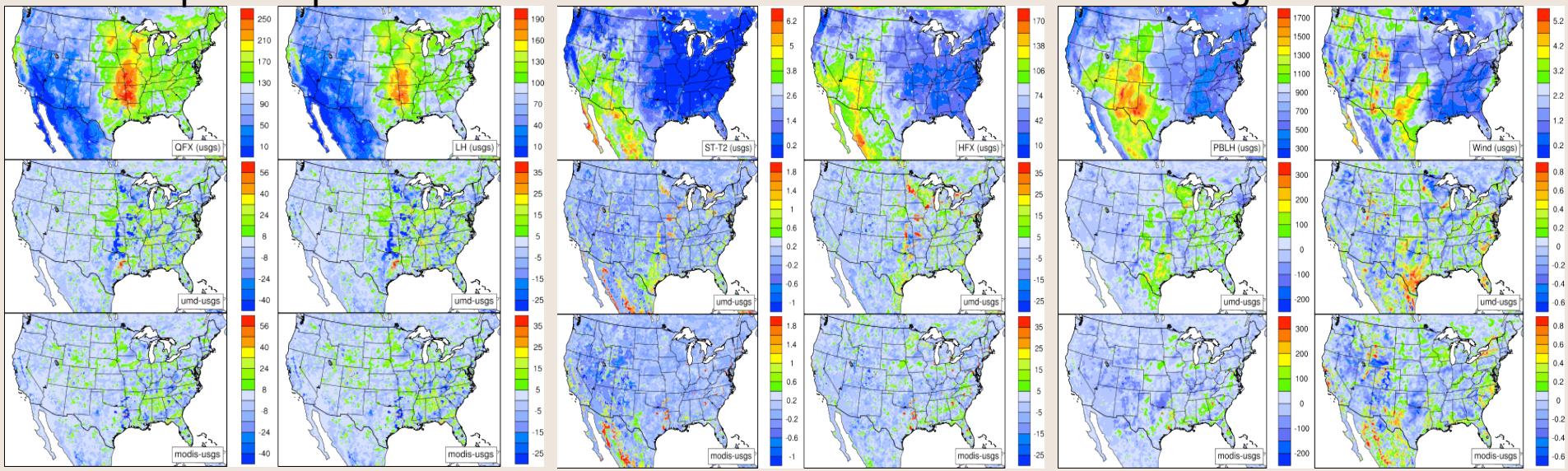
Evapotranspiration T2m SHF PBL Height Wind



- Links between land (soil moisture, vegetation) and O3/NO2 connected via soil moisture, evaporation, PBL, and temperature.