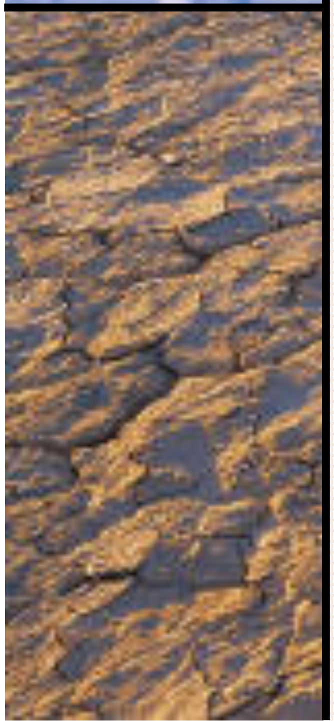

Impact of Calibrated LSM Parameters on the Accuracy of Land-Atmosphere Coupling in WRF Simulations

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NASA-GSFC
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13th Annual WRF Users' Workshop
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NASA's Advanced Information System Technology (AIST) Program

LIS Team: Christa Peters-Lidard, Sujay Kumar, and Ken Harrison

Motivation & LoCo

- Objective: Examine the impact of 'optimal' land surface fluxes and improved model and initial conditions on coupled prediction.

- Case Study: Extremes in the U.S. Southern Great Plains: Summer 2006 (dry), 2007(wet), 2008(avg)

- Methodology:

  a) Estimate parameters in Noah LSM to better fit observations of surface fluxes using **LIS-OPT**

  b) Quantify the impact of improved surface fluxes on prediction of land and atmospheric variables (**LIS-WRF**) using recently developed diagnostics of Local Land-Atmosphere Coupling ('LoCo')

Motivation & LoCo

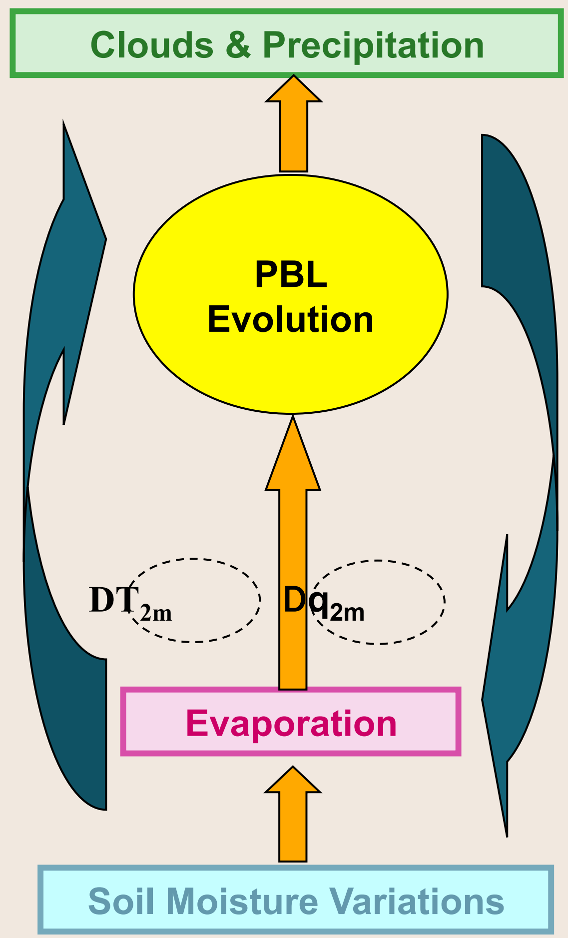
- **Land-atmosphere (L-A) interactions** play a critical role in supporting and modulating extreme dry and wet regimes, and must therefore be quantified and simulated correctly in coupled models.

- Recent efforts to quantify the strength of Local L-A Coupling ('LoCo') in prediction models have produced diagnostics that integrate across both the land and PBL components of the system.

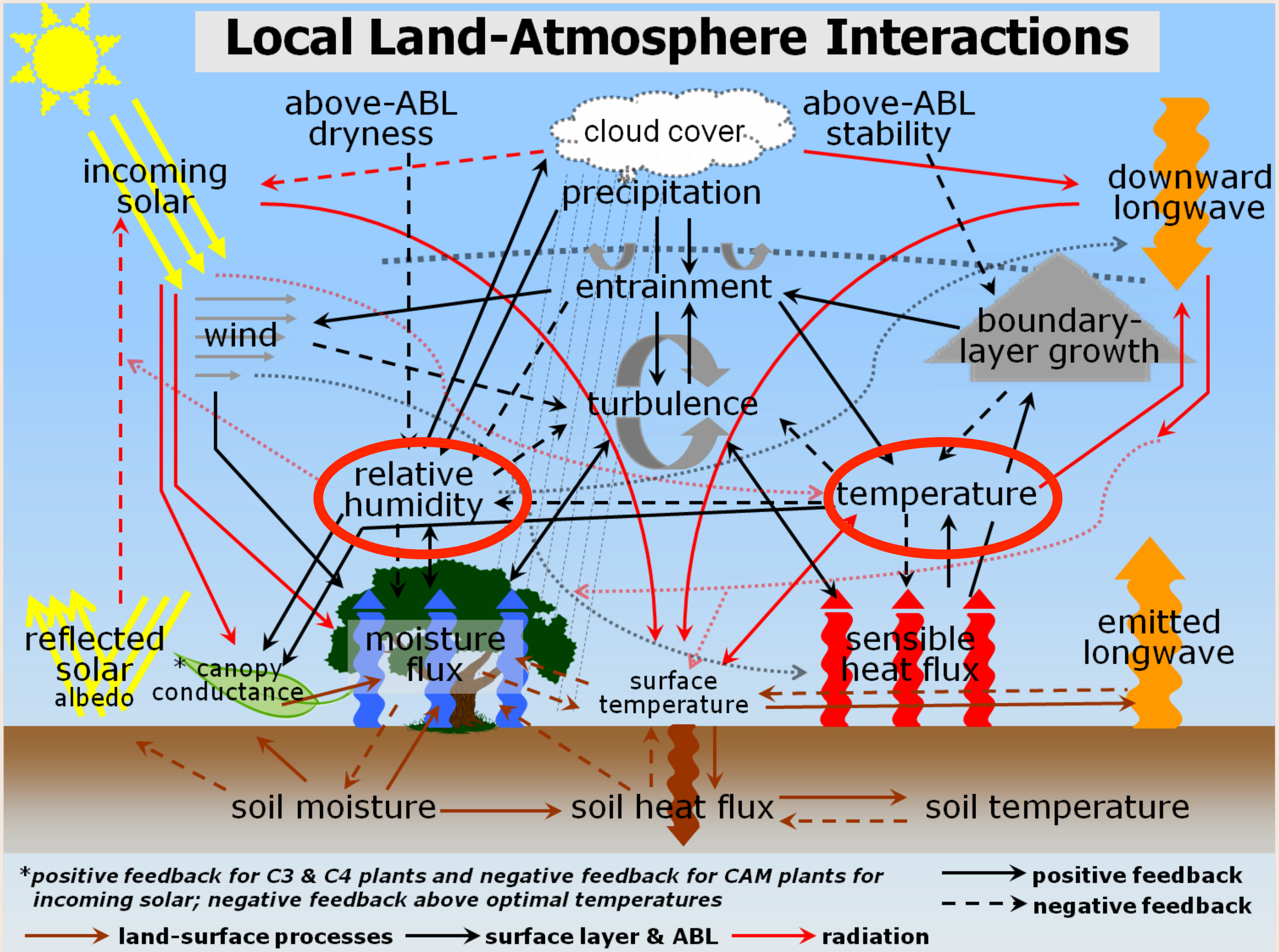
DSM* → *DEF* → *DPBL* → *DENT* → *DEF* ► *DPrecip/Clouds
(a) (b) (c) (d)

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

- LoCo diagnostics provide simultaneous assessment of the land-PBL states, fluxes, and interactions, highlighting the accuracies and potential deficiencies in components of the modeling system.



Motivation & LoCo



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

Motivation & LoCo

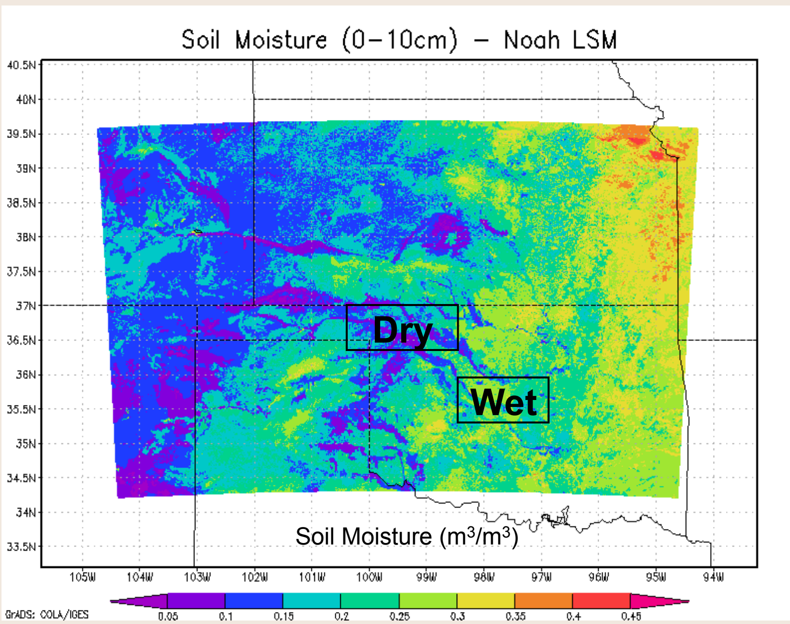


Fig. 1: Near-surface soil moisture map of the Southern Great Plains as simulated by LIS-WRF.

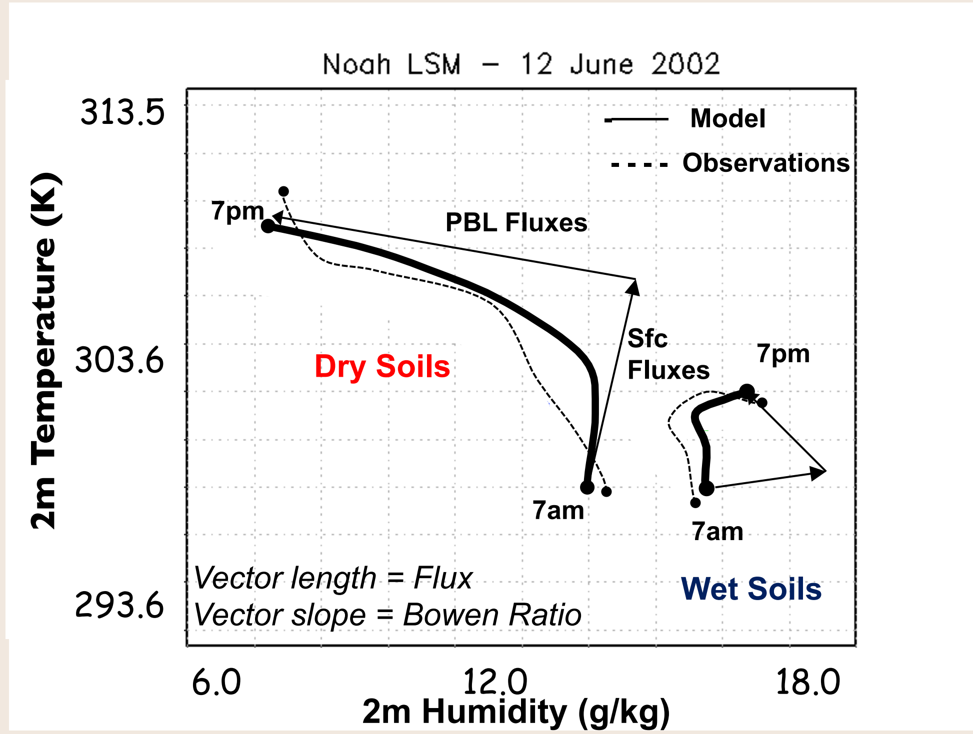


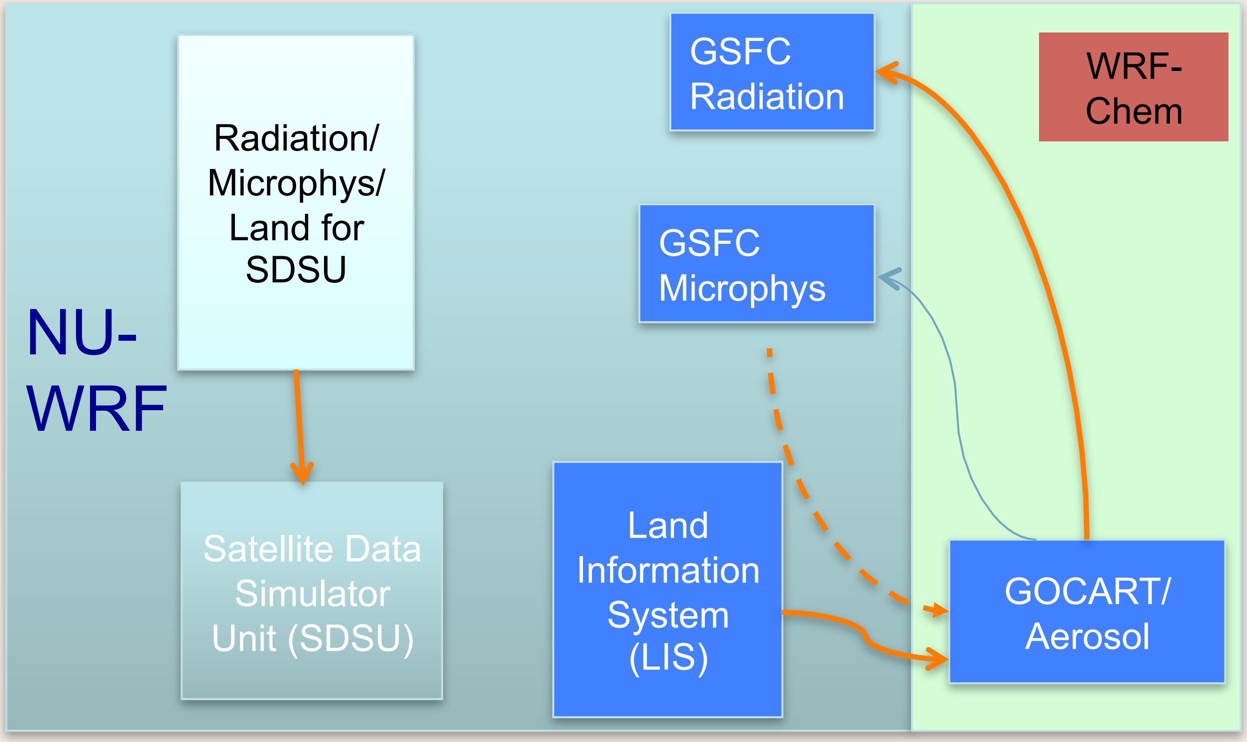
Fig. 2: Daytime evolution of specific humidity vs. potential temperature for the dry and wet soil moisture locations in Fig. 1

- Soil moisture leads to significantly different signatures of heat and moisture.

- Provides a robust methodology to simultaneously evaluate the coupled L-A states and fluxes of the system versus observations.

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.

NASA-Unified WRF (NU-WRF)



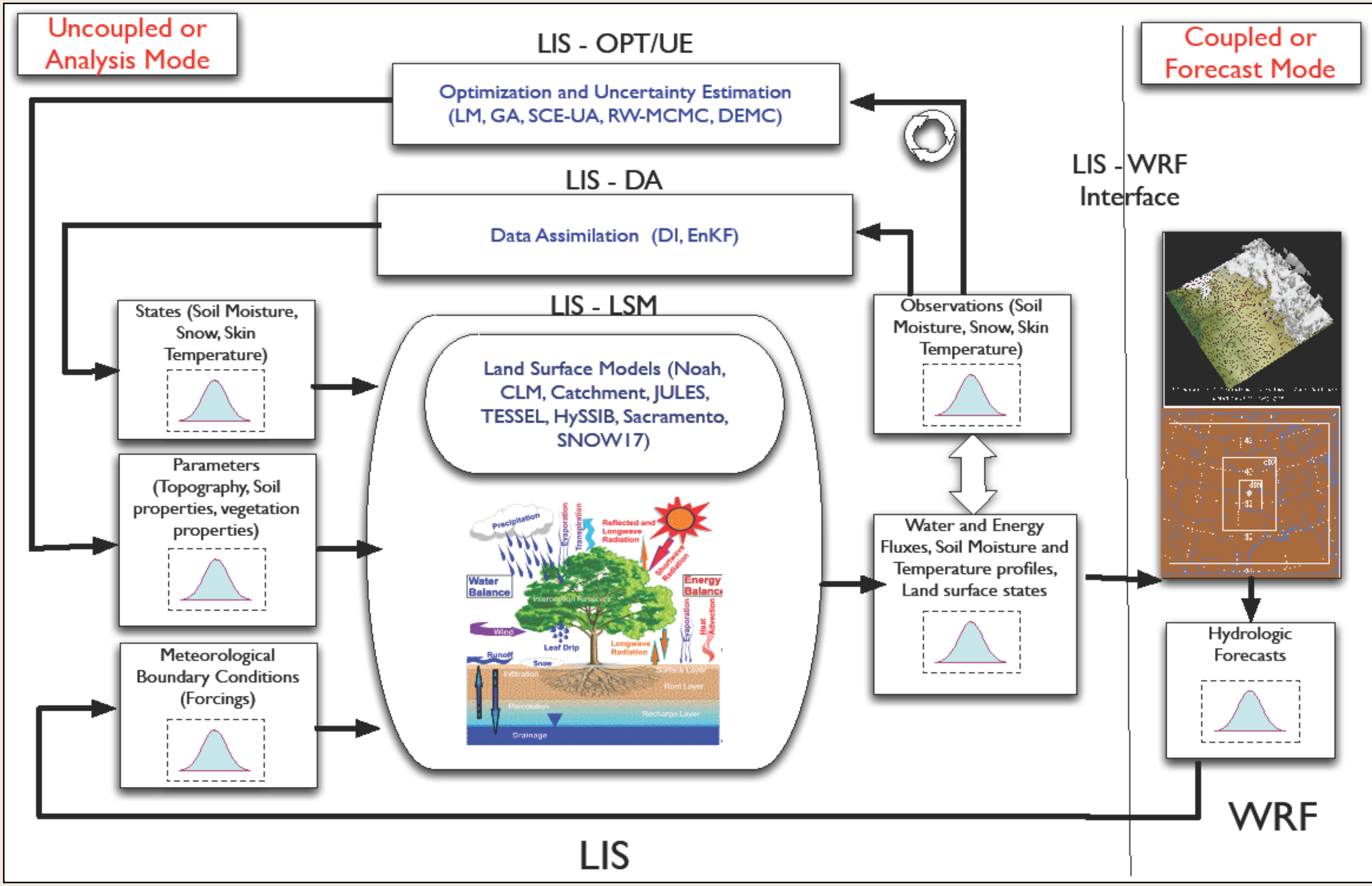
Integrates NASA-oriented capabilities into WRF-ARW:

- Land Information System (**LIS**)
- GOddard Chemistry Aerosols Radiation Transport (**GOCART**)
- Goddard Satellite Data Simulator Unit (**SDSU**)
- Goddard microphysics
- Goddard **radiation** (w/ explicit interaction between clouds radiation)
- Land **data assimilation** system
- GOCART global transport
- Real-time forecasting system using **GEOS and MERRA** global analyses as init/bdy conditions

Overarching Goal:

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

LIS-WRF Coupling and Calibration



Experimental Design

- **2006-7 Dry/Wet Extremes**
  - Domain: U. S. Southern Great Plains (SGP; 500x500 @ 1km resolution)
  - **LIS-Noah (v3.2) LSM** + Yonsei University (YSU) PBL scheme

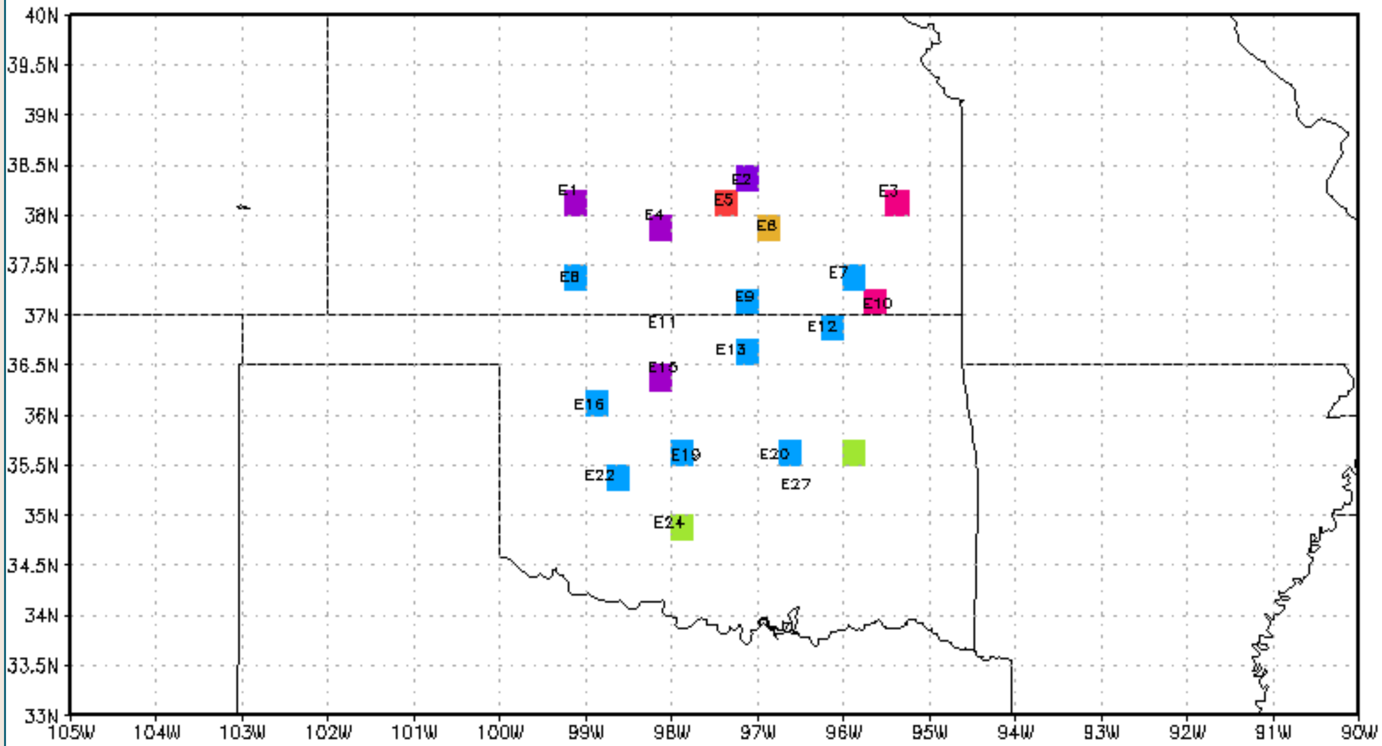
- **Optimization Runs**
  - Algorithm: GA
  - Calibration Periods: 1 May – 1 Sept of 2006, 2007, & 2008
  - Parameter set: 32 soil, vegetation, and general (Noah) parameters
  - Observations: 20 EBBR (Energy Balance Bowen Ratio) and ECOR (Eddy CORrelation) flux tower sites
  - Objective Function: Cumulative RMSE of sensible (Qh), latent (Qle), and soil (Qg) heat flux

- **Parameter Classification**
  - The parameters are estimated individually at each station and then are grouped and averaged by vegetation type and soil type across the 20 sites
  - Parameters then assigned to full domain based on veg/soil classification.

- **4 Case Studies:**
  - 14 July 2006 (dry; LIS-WRF test case)
  - 18-19 July 2006 (dry; peak of dry-down)
  - 16-17 June 2007 (wet; little precip)
  - 19-20 June 2007 (wet; scattered precip)

Experimental Design

Locations of the Atmospheric Radiation Measurement-Southern Great Plains (ARM-SGP) flux towers



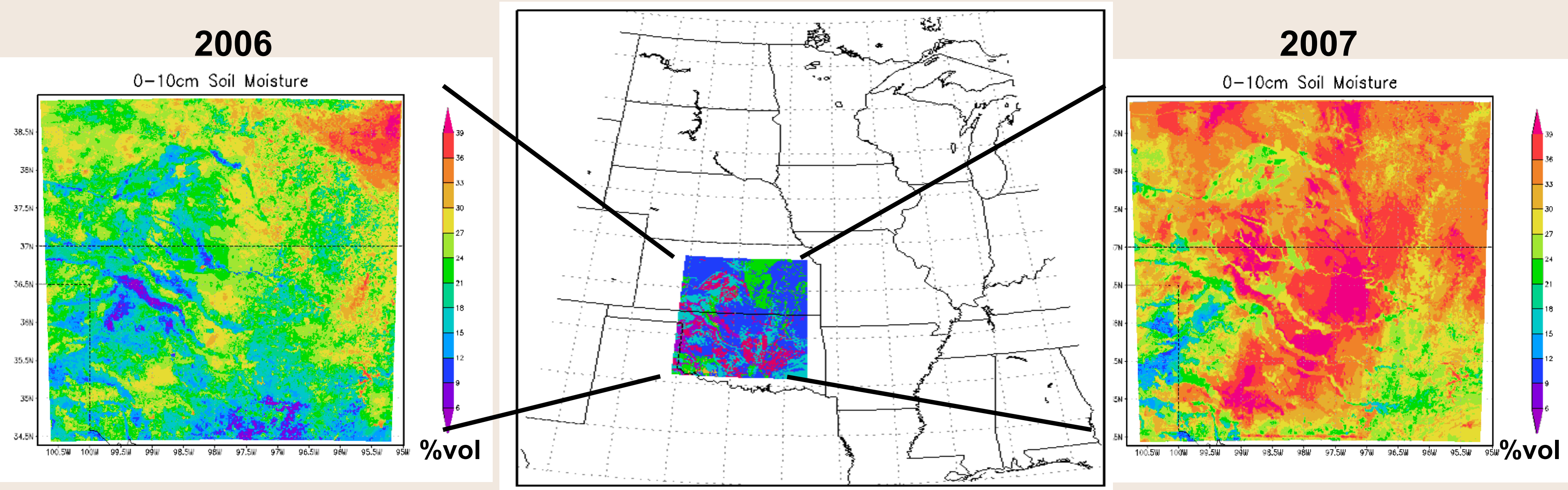
Experimental Design

Methodology

1. Use **LIS-OPT** to calibrate LSM parameter sets in each year and use Land surface Verification Toolkit (LVT) to evaluate results.
2. Generate **new lookup tables** of soil, vegetation, and general parameters based on optimization results
3. Run a suite of **offline LSM spinups** with both default and calibrated parameters.
4. Run **coupled LIS-WRF** initialized w/spinups for each case study and different parameter set.

	Exp.	Description	Spinup Parameters	Coupled Parameters
1	**DEF**	Default run w/lookup table params in LIS & LIS-WRF	**Default**	**Default**
2	**CPL**	Impact of calibrating coupled LIS-WRF ONLY	Default	Calibrated
3	**SPN**	Impact of calibrating LIS spinup (ICs) ONLY	Calibrated	Default
4	**SCP**	Impact of full calibration (LIS and LIS-WRF)	**Calibrated**	**Calibrated**

Experimental Design



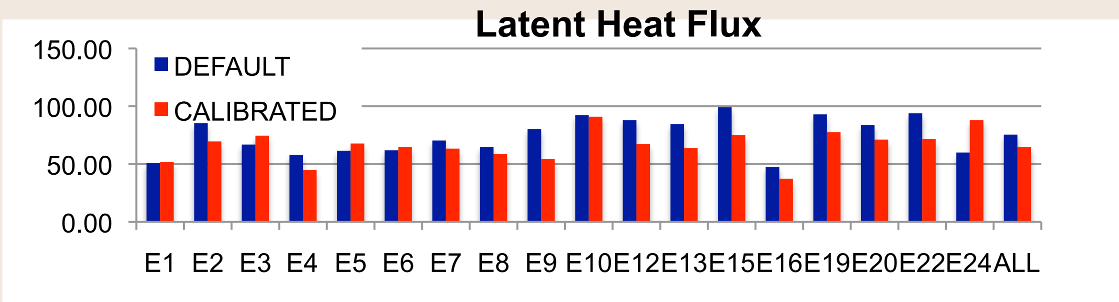
Research Questions:

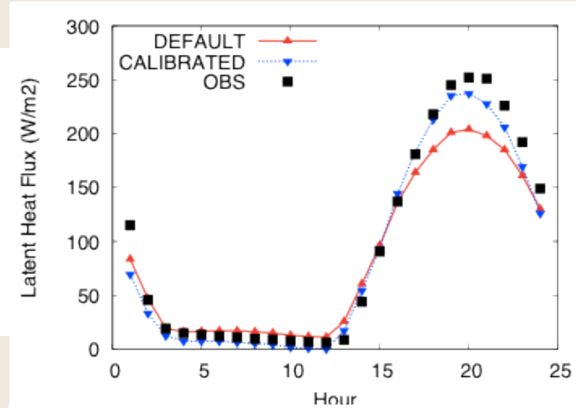
1) Employ LIS-OPT to calibrate surface fluxes in an offline LSM using a mesoscale observing network and averaging across veg/ soil characteristics.

2) Quantify impact of 'optimal' surface fluxes on coupled forecasts using an array of LoCo diagnostics.

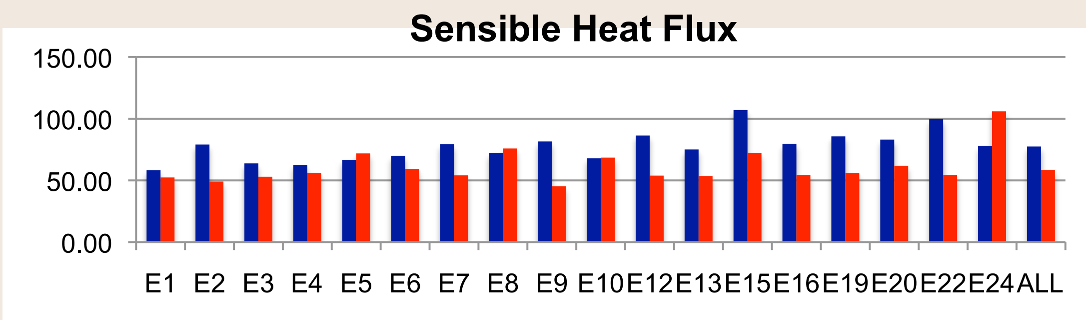
Offline Calibration - 2006

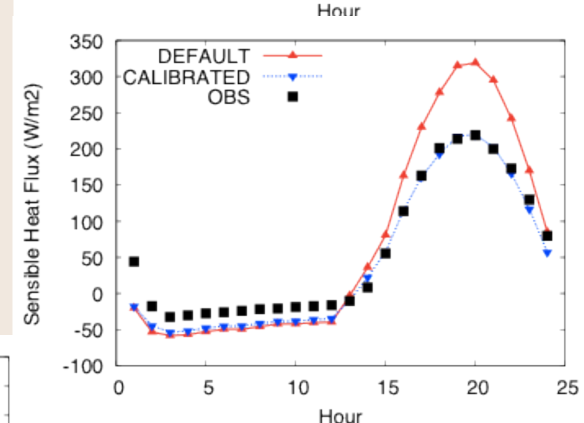
Qle



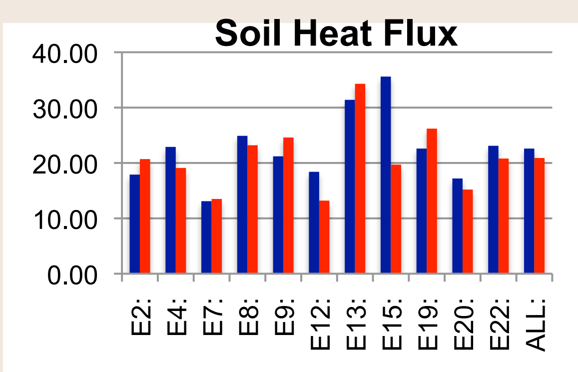


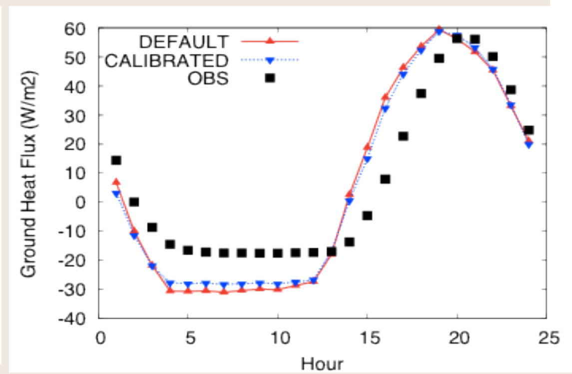
Qh





Qg





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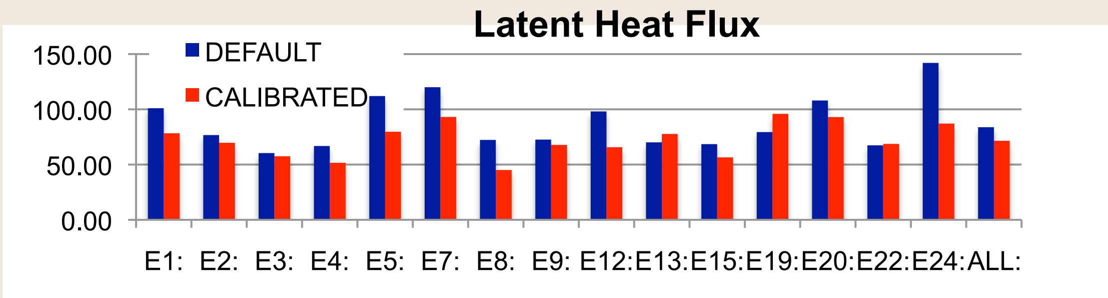
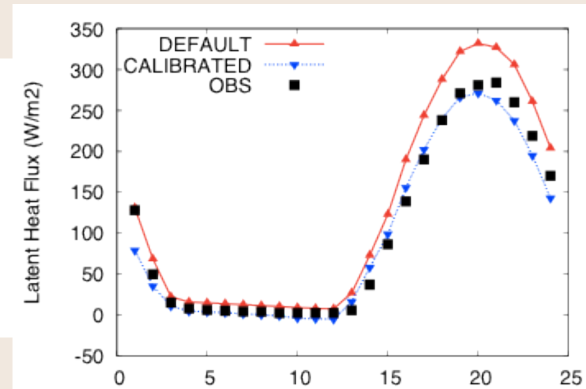
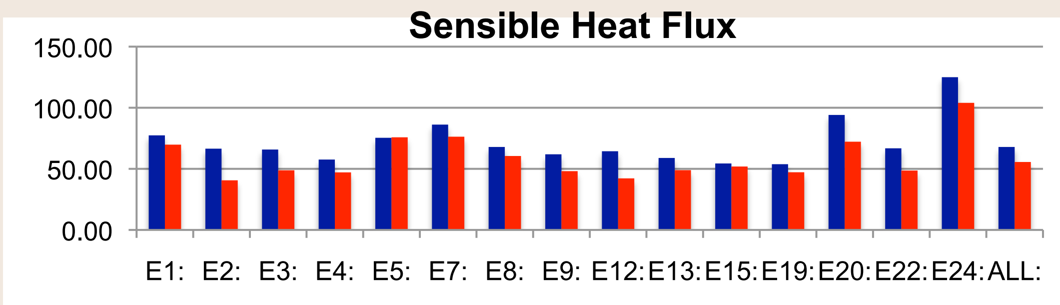
Offline Calibration - 2007

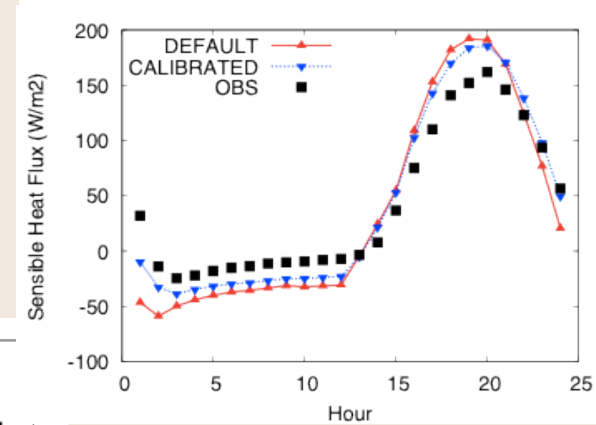
Qle





Qh





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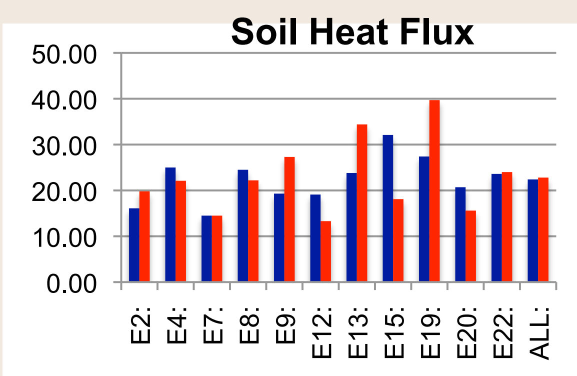
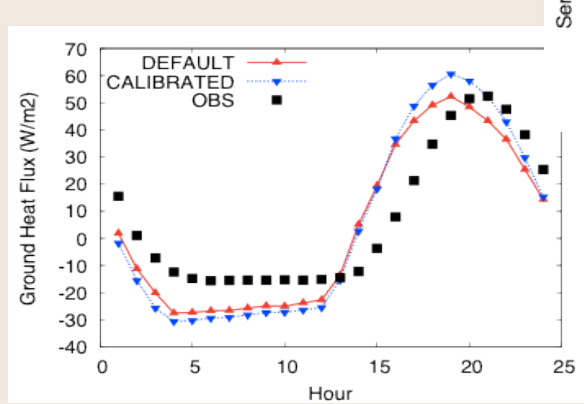




Offline Calibration: Summary

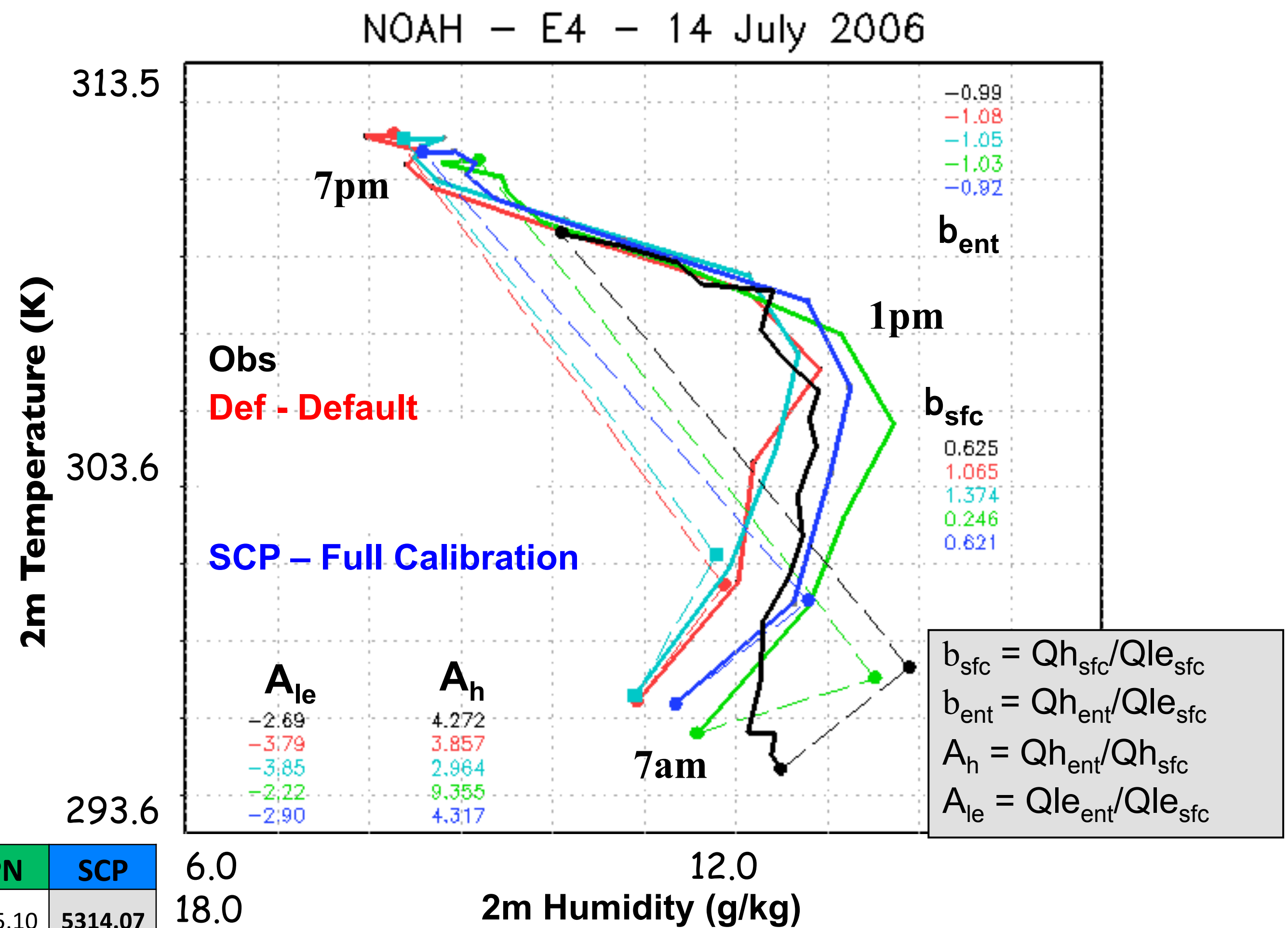
- **Sensible (Qh) and Latent (Qle) Heat Fluxes** are improved at nearly all individual sites and over the full domain.
- **Mean diurnal cycles** of Qh and Qle are improved in both regimes.
- Largest improvement is seen in Qh for the dry and Qle for the wet regime.
- Little change in Qg during dry regime, and degrades during the wet regime with no improvement in phase.

LIS-OPT Coupled Experiments

Impact of Calibration

• **Default** (DEF) parameters lead to largest errors in T, q, fluxes and PBL

• **Calibration** (SCP) improves all components of L-A coupling and reduces cumulative RMSE by 15-26% and T and Q biases by 8-30%.

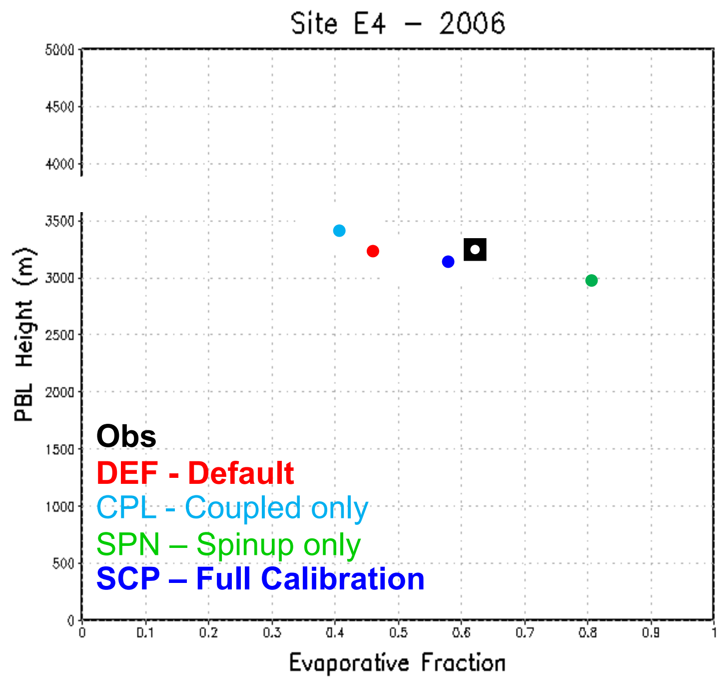


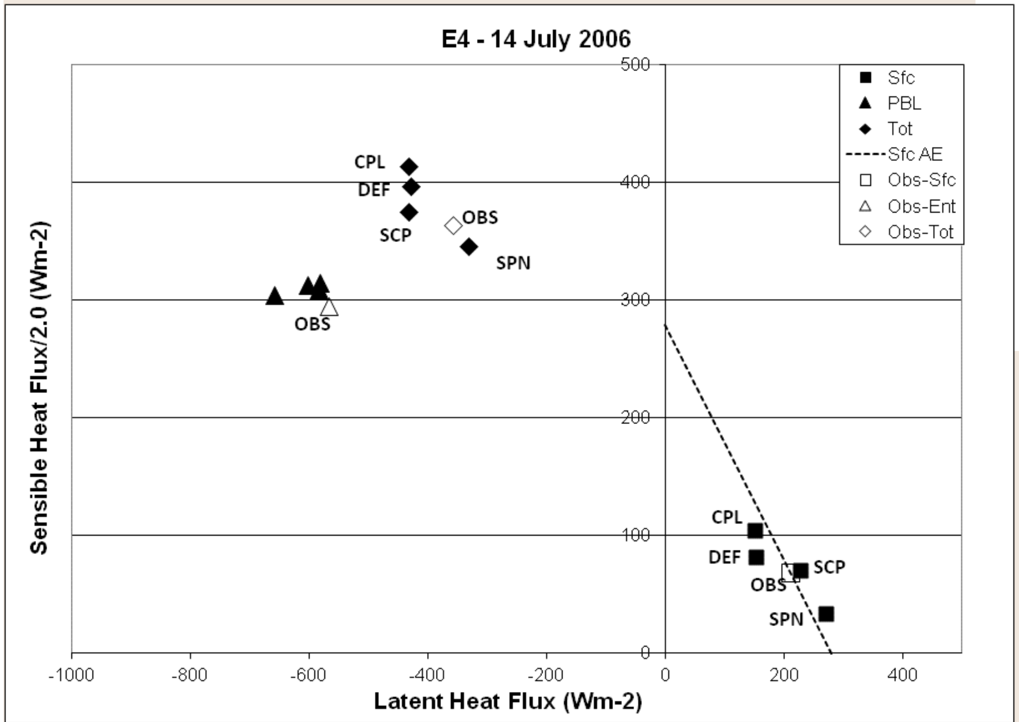
		DEF	CPL	SPN	SCP
Cum RMSE		6288.60	6161.24	4665.10	**5314.07**
Cum MAE		5231.25	5181.39	4044.50	**4541.69**
BIAS	Q2	-6022.76	-5743.49	-3159.91	**-4196.35**
BIAS	T2	4244.72	4458.54	3336.54	**3919.27**
N-S Efficiency		-1.78	-1.67	-0.53	**-0.98**

LIS-OPT Coupled Experiments

Impact of Calibration

• Calibration of both the offline and coupled parameters (SCP) produces the best coupling of the land surface forcing (Evaporative Fraction) and atmospheric response (PBL Height) in LIS-WRF.





Offline vs. Coupled Calibration

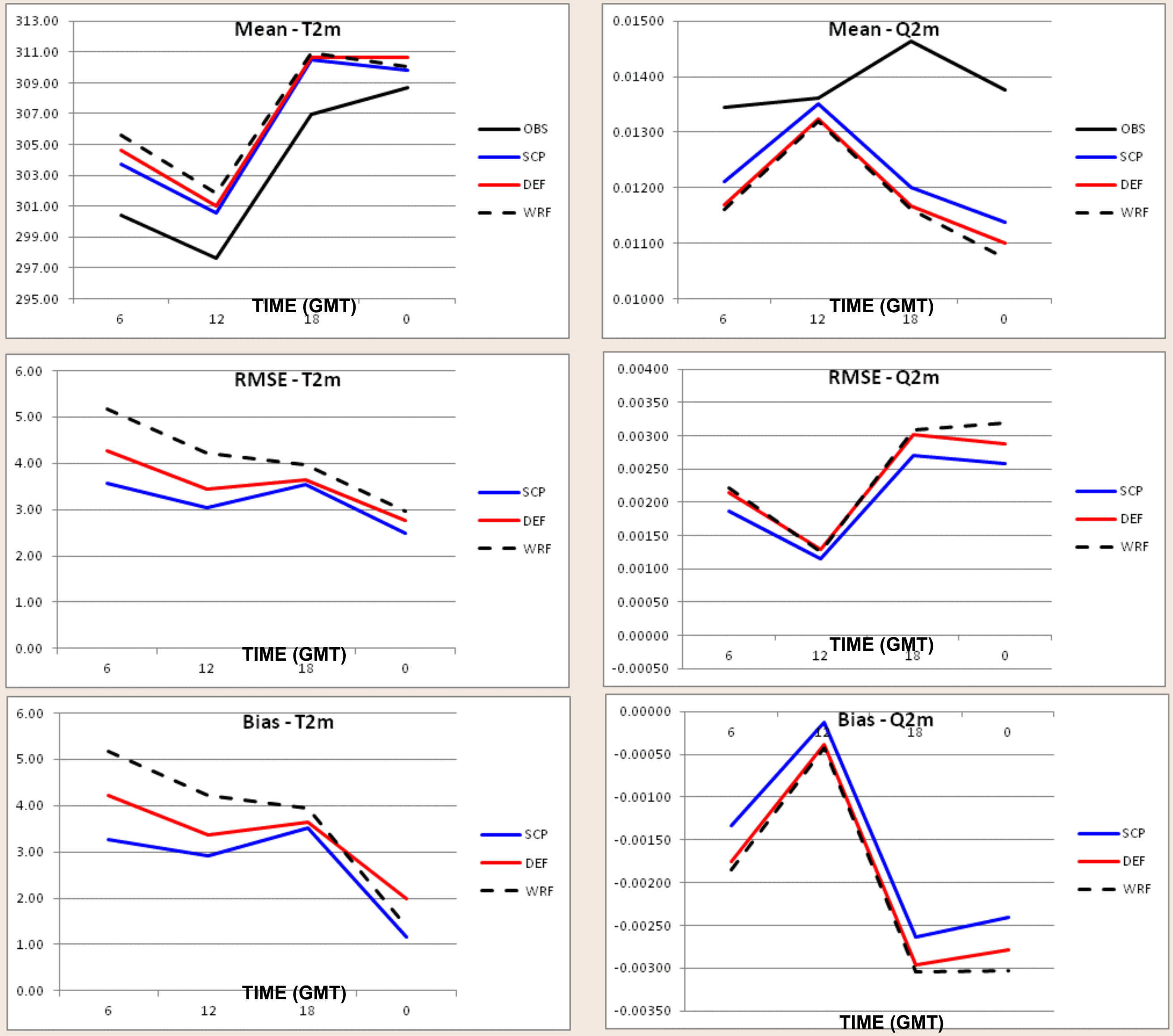
• Mismatch in offline vs. coupled parameter sets leads to surface net radiation and flux imbalance.

Impact on Ambient Weather Forecasts

<u>**14 July 2006**</u>
-Domain average stats
-Processed using Model Evaluation Toolkit (MET)
-**214 site observations** at each analysis time (6h)

- Calibration (**SCP**) improves the 2m Temperature and Humidity forecasts across the full domain

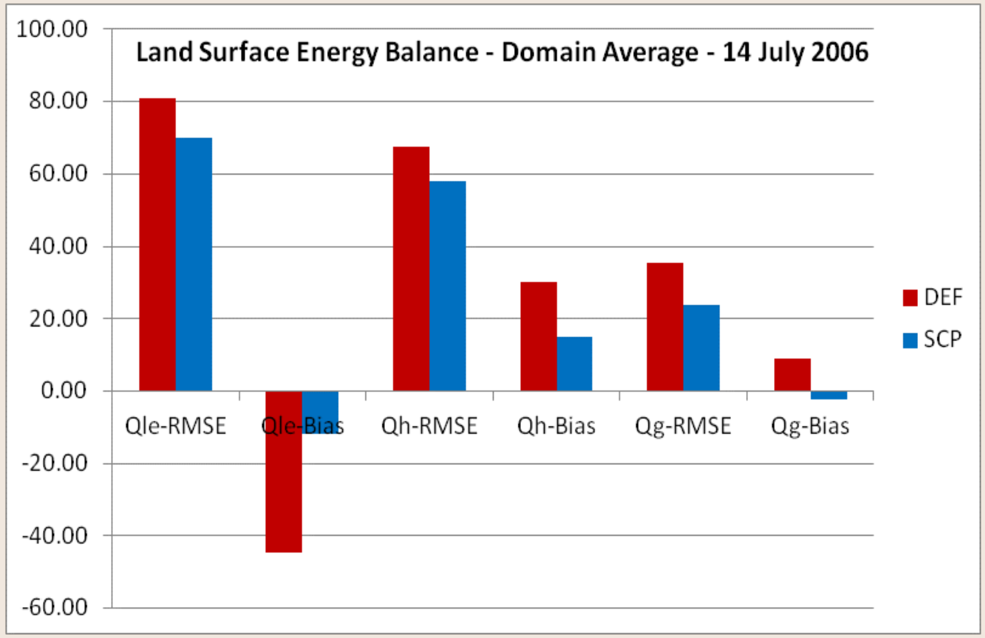
- LIS Spinup (**DEF**) and Calibration (**SCP**) improves over default WRF

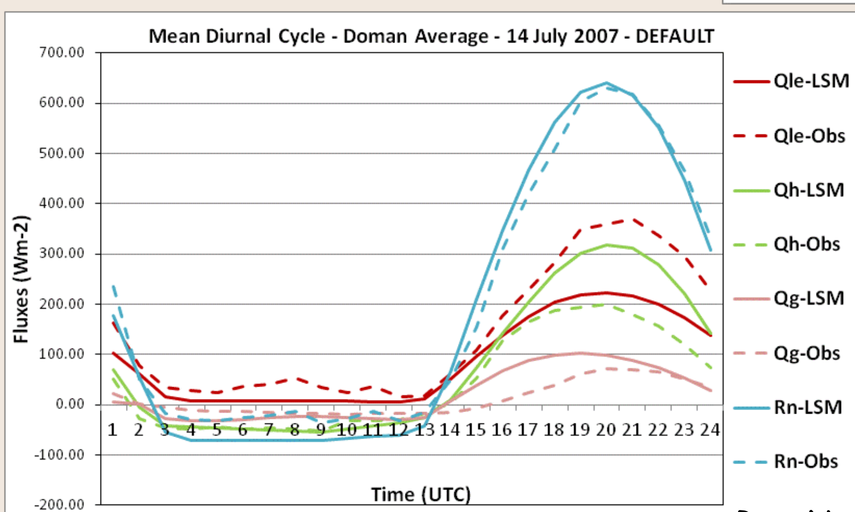


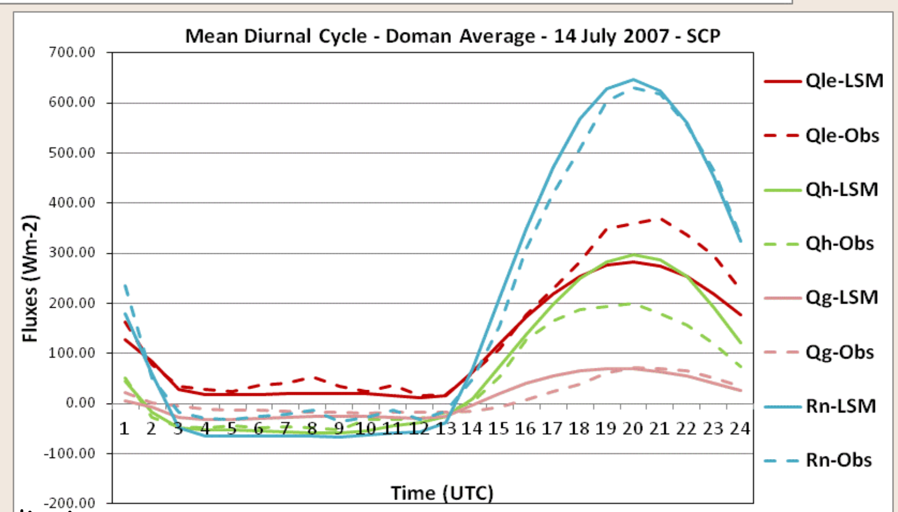
Impact on Land Surface Energy Balance

<u>**14 July 2006**</u>
-Domain average stats
-Processed using LVT
-19 ARM-SGP site observations at each analysis time (1h)

• Calibration (SCP) improves the Sensible, Latent, and Soil Heat Flux forecasts across the WRF domain

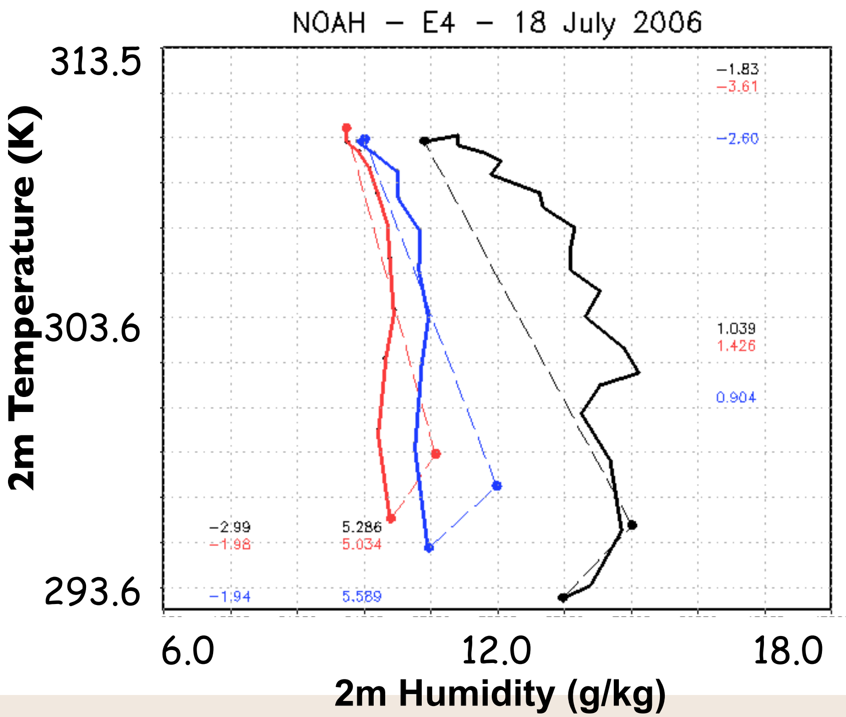


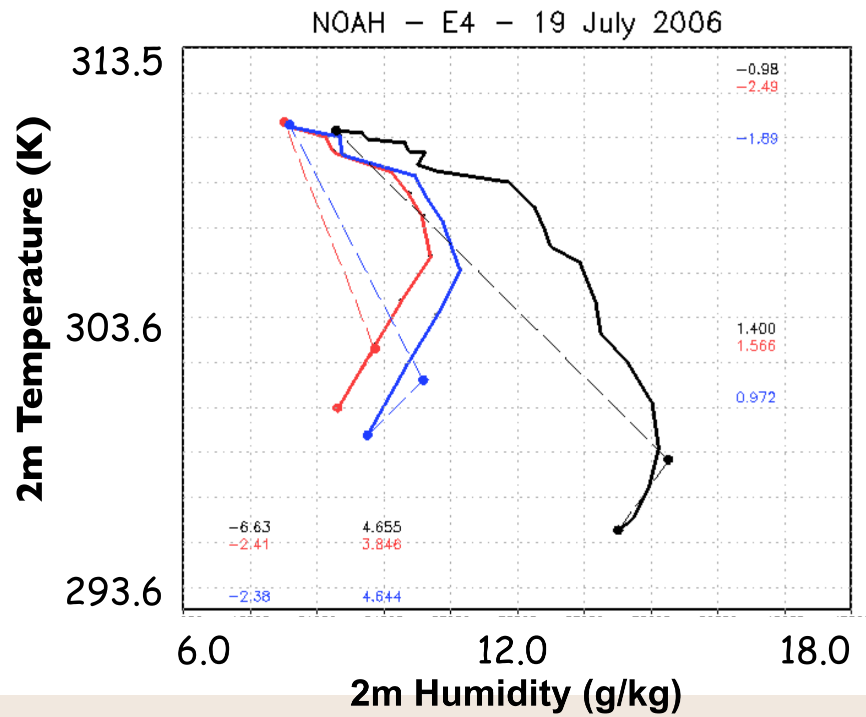




Rn = Net Radiation

18-19 July 2006





		DEF	CPL	SPN	SCP
Cum RMSE		6018.59	5992.34	3977.58	**5086.32**
Cum MAE		4921.32	4992.19	3050.16	**4129.53**
BIAS	Q2	-7889.19	-7859.74	-5002.86	**-6663.78**
BIAS	T2	1953.45	2124.63	818.18	**1595.27**
N-S Efficiency		-0.385	-0.373	0.394	**0.011**

		DEF	CPL	SPN	SCP
Cum RMSE		5916.36	5464.83	4031.29	**5116.14**
Cum MAE		4638.54	4450.96	2475.01	**3970.43**
BIAS	Q2	-6905.71	-6541.11	-3709.10	**-5976.76**
BIAS	T2	2371.36	2360.82	416.55	**1964.09**
N-S Efficiency		-0.128	0.038	0.476	**0.157**

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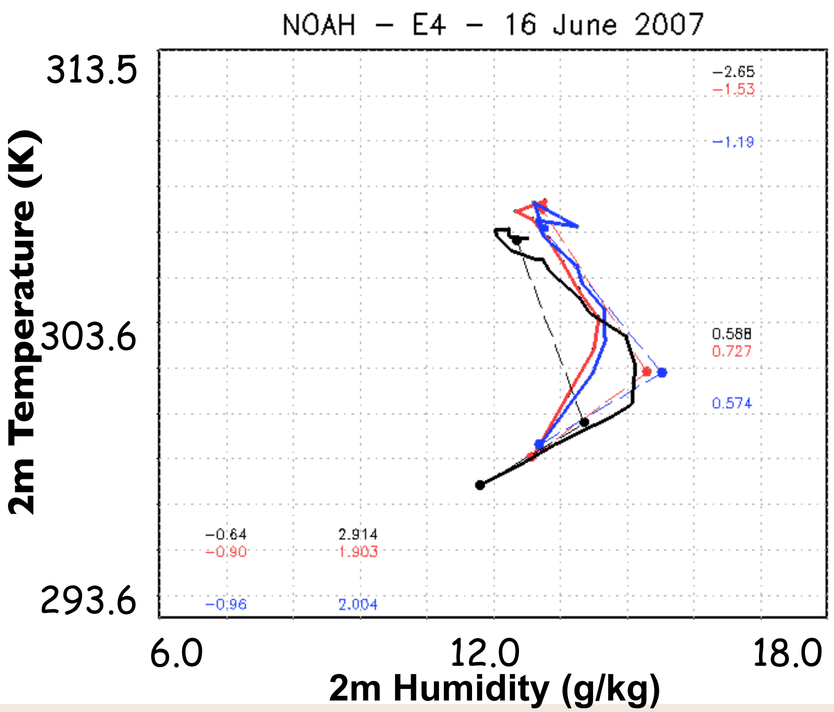
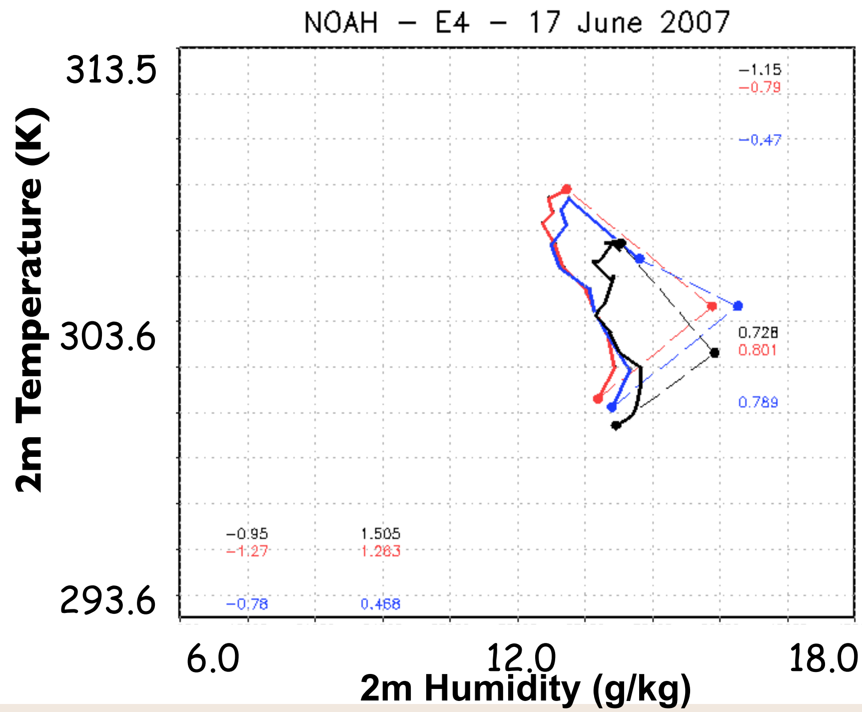
16-17 June 2007

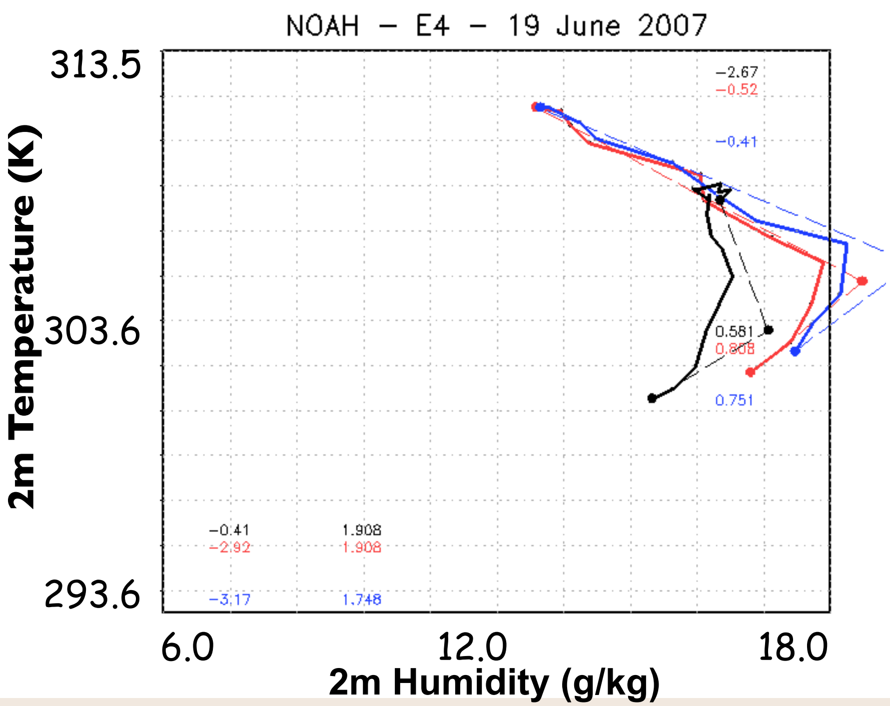


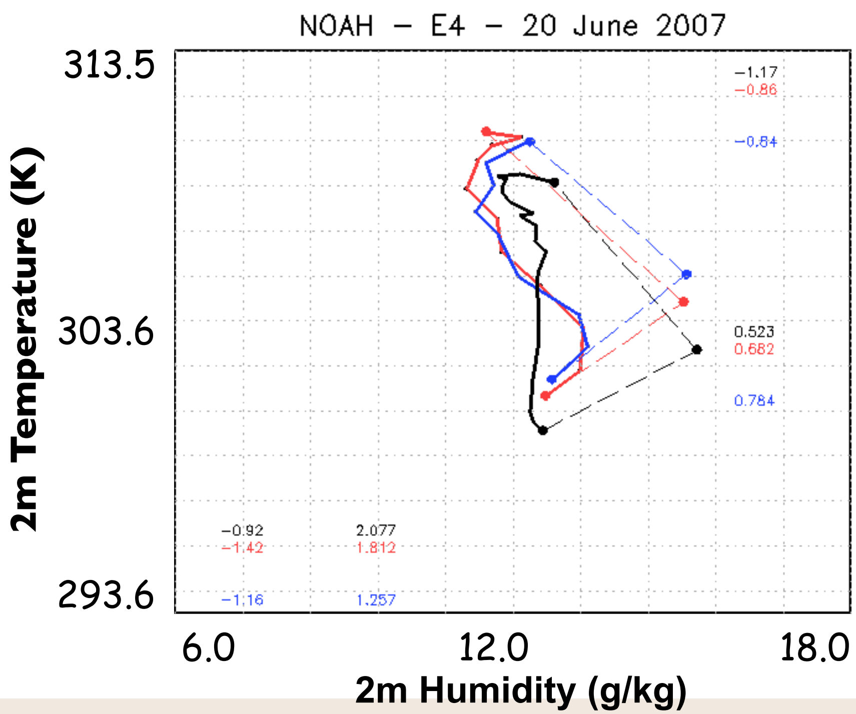


		DEF	CPL	SPN	SCP
Cum RMSE		**1380.69**	1731.27	1539.36	1718.66
Cum MAE		**1190.26**	1421.29	1280.70	1386.36
BIAS	Q2	**436.17**	-478.81	1283.31	938.37
BIAS	T2	**1412.82**	1920.64	1155.18	1485.82
N-S Efficiency		**0.809**	0.699	0.762	0.704

		DEF	CPL	SPN	SCP
Cum RMSE		1788.06	2480.89	1240.10	**1498.29**
Cum MAE		1644.65	2280.67	1119.14	**1338.25**
BIAS	Q2	-1761.03	-2627.25	-977.38	**-1164.02**
BIAS	T2	1528.27	1934.09	1237.55	**1240.91**
N-S Efficiency		0.183	-0.573	0.607	**0.426**

19-20 June 2007





		DEF	CPL	SPN	SCP
Cum RMSE		**4177.31**	4963.27	4263.40	4611.42
Cum MAE		**3501.51**	4383.16	3576.48	3987.41
BIAS	**Q2**	-257.51	-1412.37	1159.99	**142.81**
BIAS	**T2**	**2361.73**	3213.09	2043.18	2811.18
N-S Efficiency		**-1.193**	-2.096	-1.285	-1.673

		DEF	CPL	SPN	SCP
Cum RMSE		**1598.93**	1898.51	2301.55	1632.62
Cum MAE		**1412.15**	1708.75	2026.01	1497.77
BIAS	**Q2**	-467.35	-1119.43	2471.04	**-195.45**
BIAS	**T2**	**1373.55**	1948.36	1144.36	1639.91
N-S Efficiency		**0.672**	0.538	0.321	0.658

LIS-OPT Coupled Simulations: Summary

- Calibrated parameters improve fluxes (Sfc and PBL) and states (T2m and Q2m) during both regimes.
- Near-perfect surface fluxes (b_{sfc}) often translate into better coupled components (b_{ent}, $A_{h,}$ A_{le}), and are reflected in better Total RMSE/MAE, PBL Budgets and EF/PBLH.
- Largest improvement and impact of the land model and parameters is seen during the dry regime.
- Improvement due to calibrated parameters diminishes as regimes become more extreme (e.g. end of dry-down and during high-freq precipitation).

Implications for Improved Coupled Prediction

- Calibrated parameter sets are compensatory in terms of:
  A) Water and energy states (e.g. higher soil moisture)
  B) Water and energy fluxes (e.g. lower evaporation rate)

- As a result, the proper:
  a) land surface initial conditions AND
  b) evaporative physics

  are both required (**SCP**) to maximize calibration in coupled simulations.

- A calibrated LSM spinup (**SPN**) by itself can produce more accurate **temperature and humidity forecasts**, regardless of the parameter sets used in the coupled simulation.

Experimental Design: Part II

Methodology

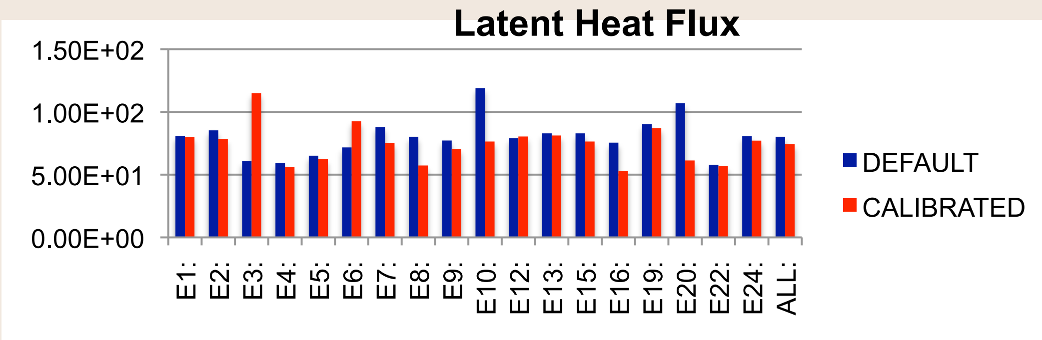
1. Use **LIS-OPT** to calibrate LSM parameter sets in 2008 and 2006-7-8 combined (May-Sept in each).

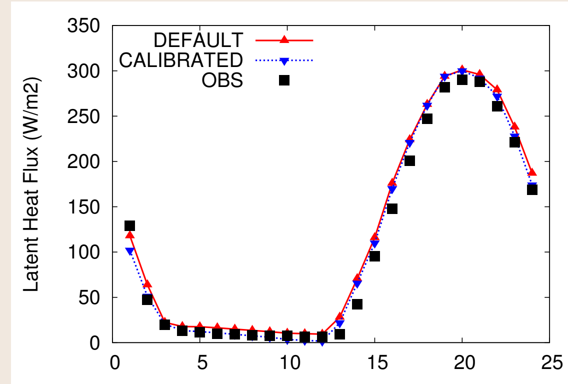
2. Evaluate the offline calibration in each year and the impact on coupled **LIS-WRF forecasts** from calibrating during different periods (dry, wet, normal, combined).

	Exp.	Description	Spinup Parameters	Coupled Parameters
1	DEF	Default run w/lookup table params in LIS & LIS-WRF	Default	Default
2	C07	Impact of calibrating during 2007 only	2007	2007
3	C08	Impact of calibrating during 2008 only	2008	2008
4	C06	Impact of calibrating during 2006 only	2006	2006
5	C678	Impact of calibrating to all three years combined	2006-7-8	2006-7-8

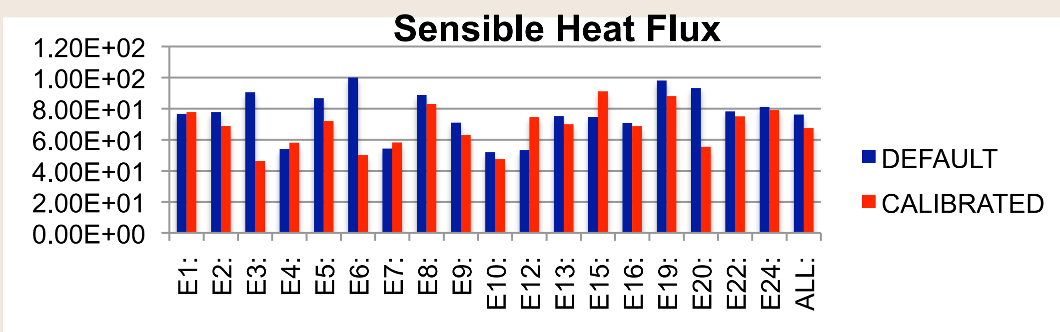
2008 Calibration

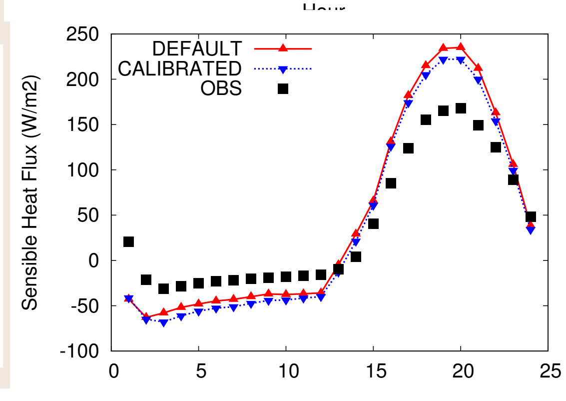
Qle



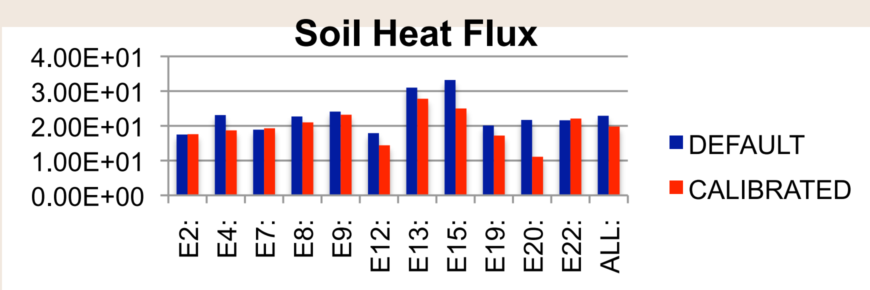


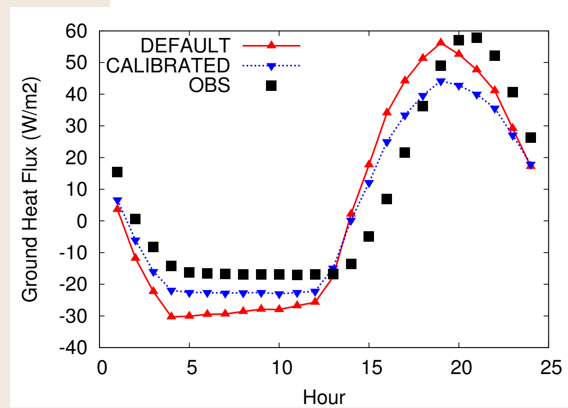
Qh





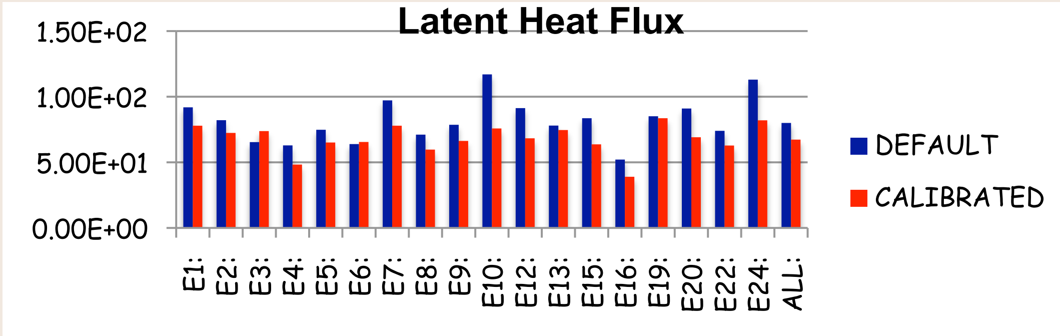
Qg

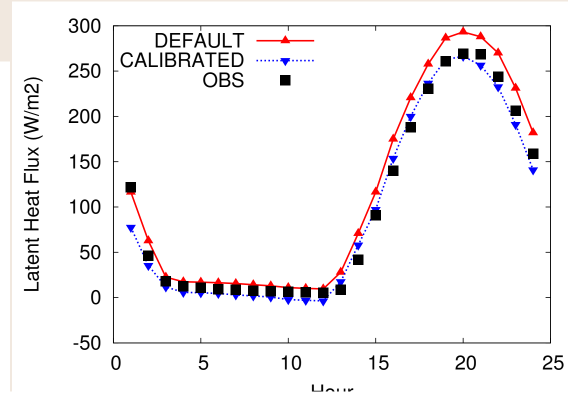




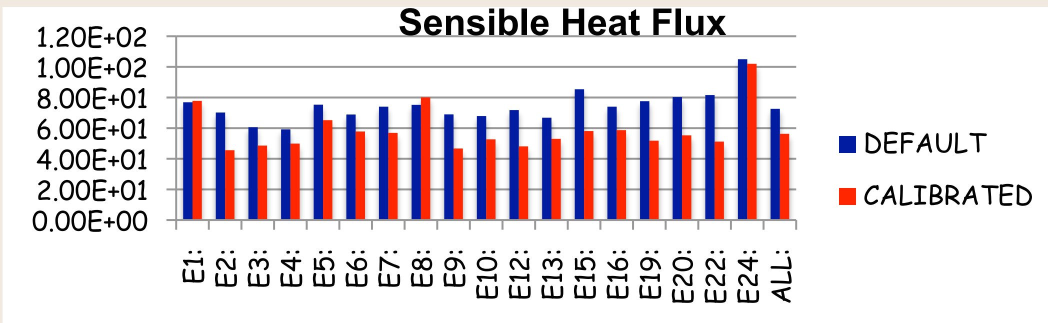
2006-7-8 Calibration

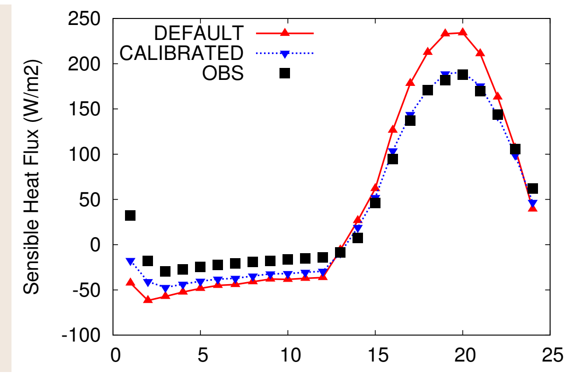
Qle



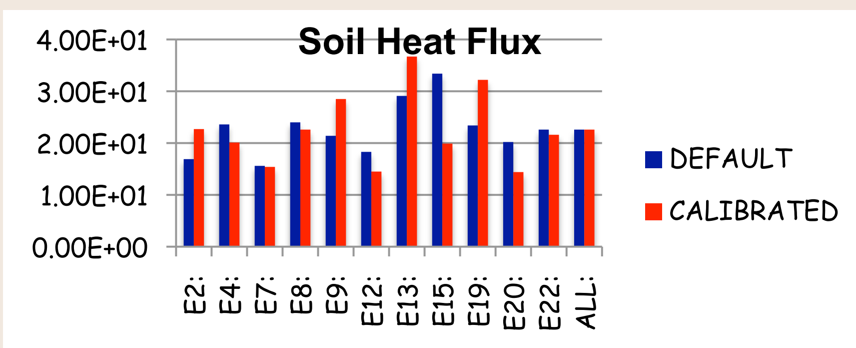


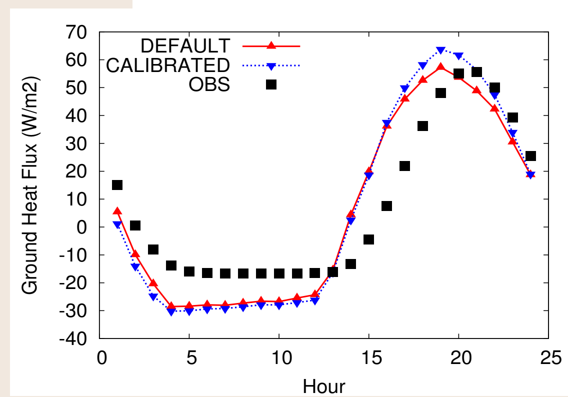
Qh





Qg





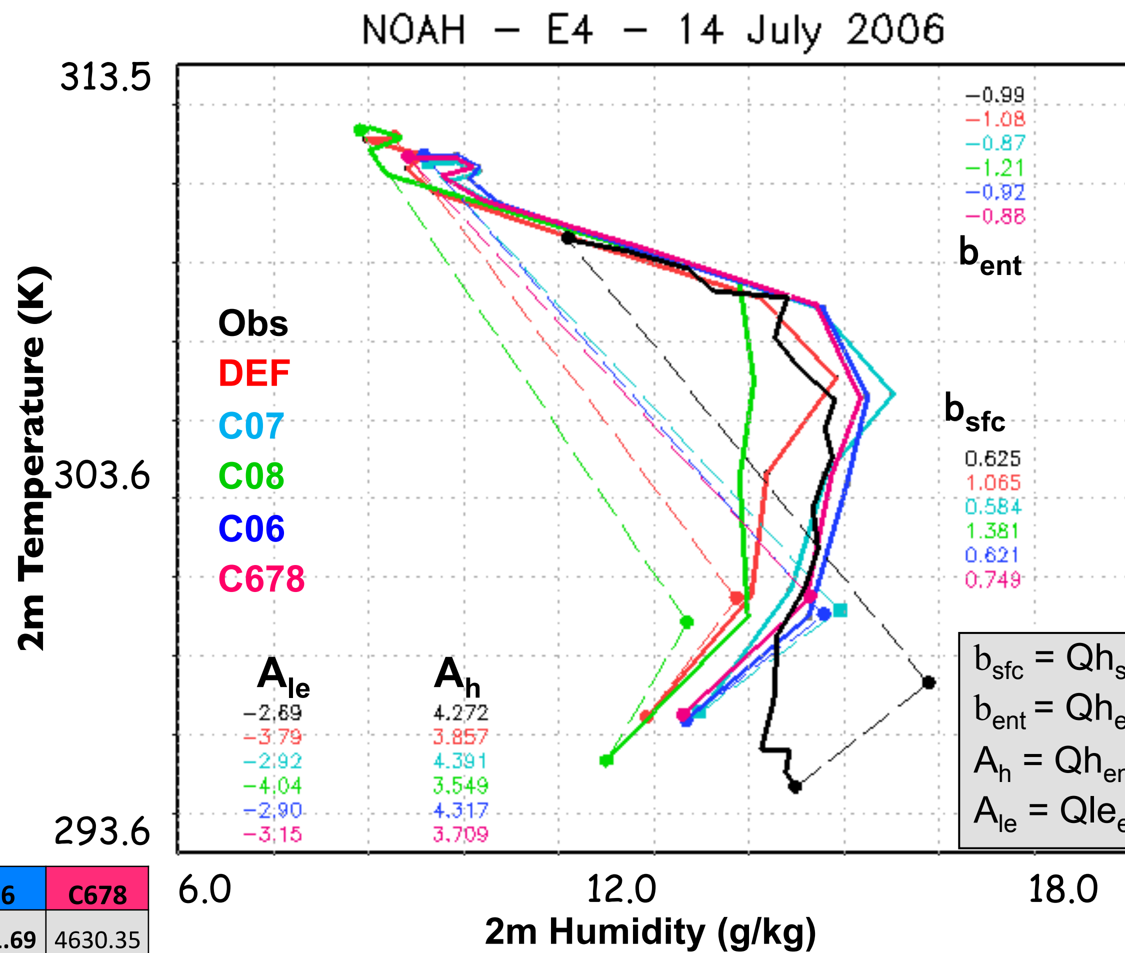
NASA ENERGY AND WATER CYCLE STUDY NEWS

GLASS

LIS-OPT Coupled Experiments

Impact of Calibration Period:

- Default (DEF) and 2008-calibrated (C08) parameters lead to largest errors in T, q, fluxes and PBL evolution.
- Calibration in either the dry or wet year (C06,C07) improves all components of L-A coupling and produce very similar fluxes & states.
- Calibration using all available data (C678) improves prediction, but less than during extremes.



$b_{sfc} = Qh_{sfc}/Qle_{sfc}$

$b_{ent} = Qh_{ent}/Qle_{sfc}$

$A_h = Qh_{ent}/Qh_{sfc}$

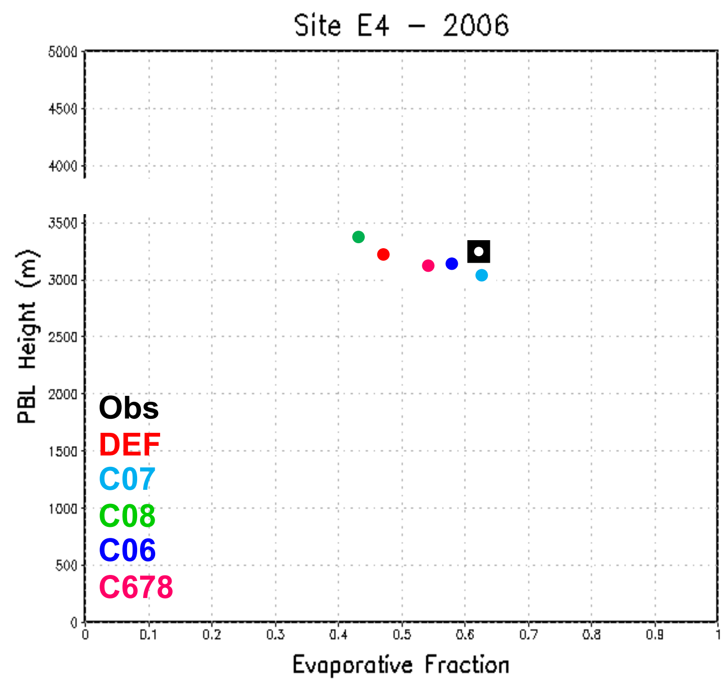
$A_{le} = Qle_{ent}/Qle_{sfc}$

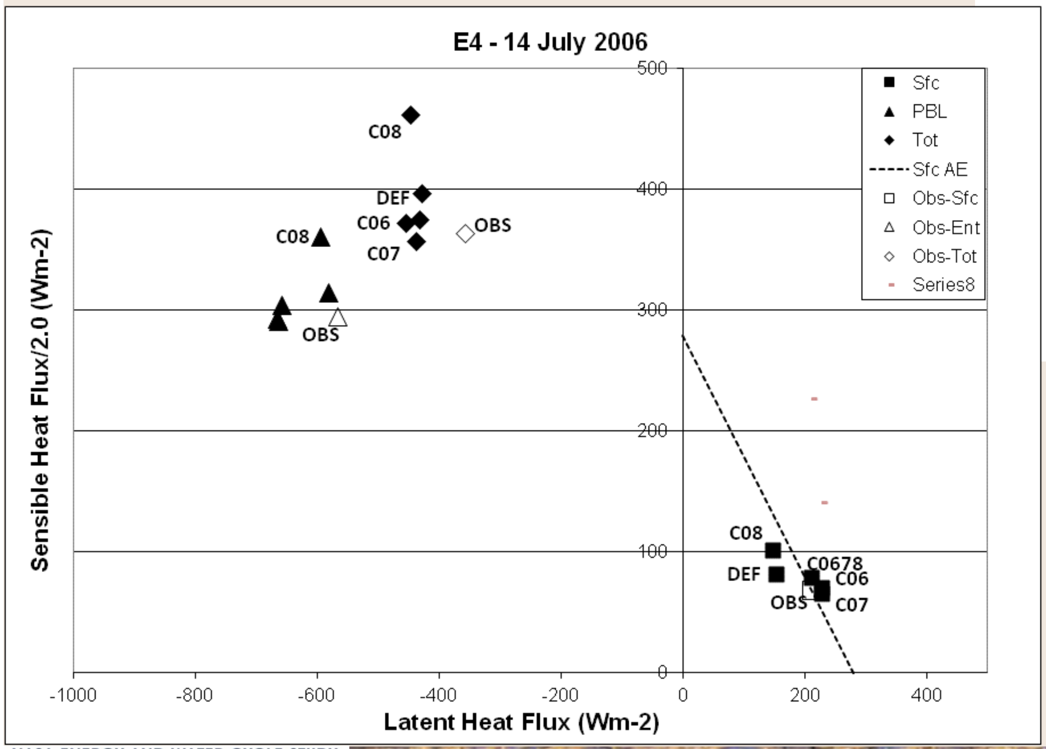
	DEF	C07	C08	C06	C678
Cum MAE	5231.25	**4538.32**	5707.05	**4541.69**	4630.35
Cum RMSE	6288.60	**5371.56**	6851.72	**5314.07**	5490.36
Q2 BIAS	-6022.76	**-4249.04**	-7044.01	**-4196.35**	-4492.11
T2 BIAS	4244.73	**3977.18**	4370.09	**3919.27**	3998.27
N-S Efficiency	-1.782	**-1.030**	-2.303	**-0.987**	-1.121

LIS-OPT Coupled Experiments

Impact of Calibration Period:

• Calibration of the dry year during either of the extreme regimes (C06 and C07) produces the best coupling of the land surface forcing (Evaporative Fraction) and atmospheric response (PBL Height) in LIS-WRF.





Impact of Calibration Period:

• Calibration during either extreme period acts to **correct a dry bias** in the Noah LSM.

• During a 'normal' regime (C08), the calibration produces a slightly drier and less evaporative Noah.

Consistency in Calibrated Parameters

C06	C07	C08	DEF
General	General	General	General
SBETA_DATA	SBETA_DATA	SBETA_DATA	SBETA_DATA
-3.06	-2.83	-2.93	-2
FXEXP_DATA	FXEXP_DATA	FXEXP_DATA	FXEXP_DATA
1.06	1.34	[illegible]	[illegible]
CSOIL_DATA	CSOIL_DATA	CSOIL_	[illegible]
2.44E+06	2.43E+06	2	[illegible]
REFDK_DATA	REFDK_DATA	REFDK	[illegible]
1.50E-05	1.40E-05	1	[illegible]
REFKDT_DATA	REFKDT_DATA	REFKD	[illegible]
4.9	5.15	[illegible]	[illegible]
FRZK_DATA	FRZK_DATA	FRZK_	[illegible]
0.18	0.17	0.169	0.15
CZIL_DATA	CZIL_DATA	CZIL_DATA	CZIL_DATA
0.6	0.6	0.1	0.1

	DEF	C06	C07	C08	C678
FXEXP	2	1.06	1.34	0.969	1.19
CZIL	0.1	0.6	0.6	0.1	0.6

CZIL_DATA

CZIL: Zilitinkevich coefficient relating surface fluxes to the roughness length for heat (Z_{oh}) and exchange coefficient (C_h)

- Higher values decrease Z_{oh} and C_h
- Consistent with results from NCAR/NCEP

FXEXP_DATA

FXEXP: Exponent for bare soil evaporation calculation as fn(SM, Veg)

- Lower values increase $ET_{bare\ soil}$
- Consistent with results of Santanello et al. (2007) and Peters-Lidard et al. (2008)

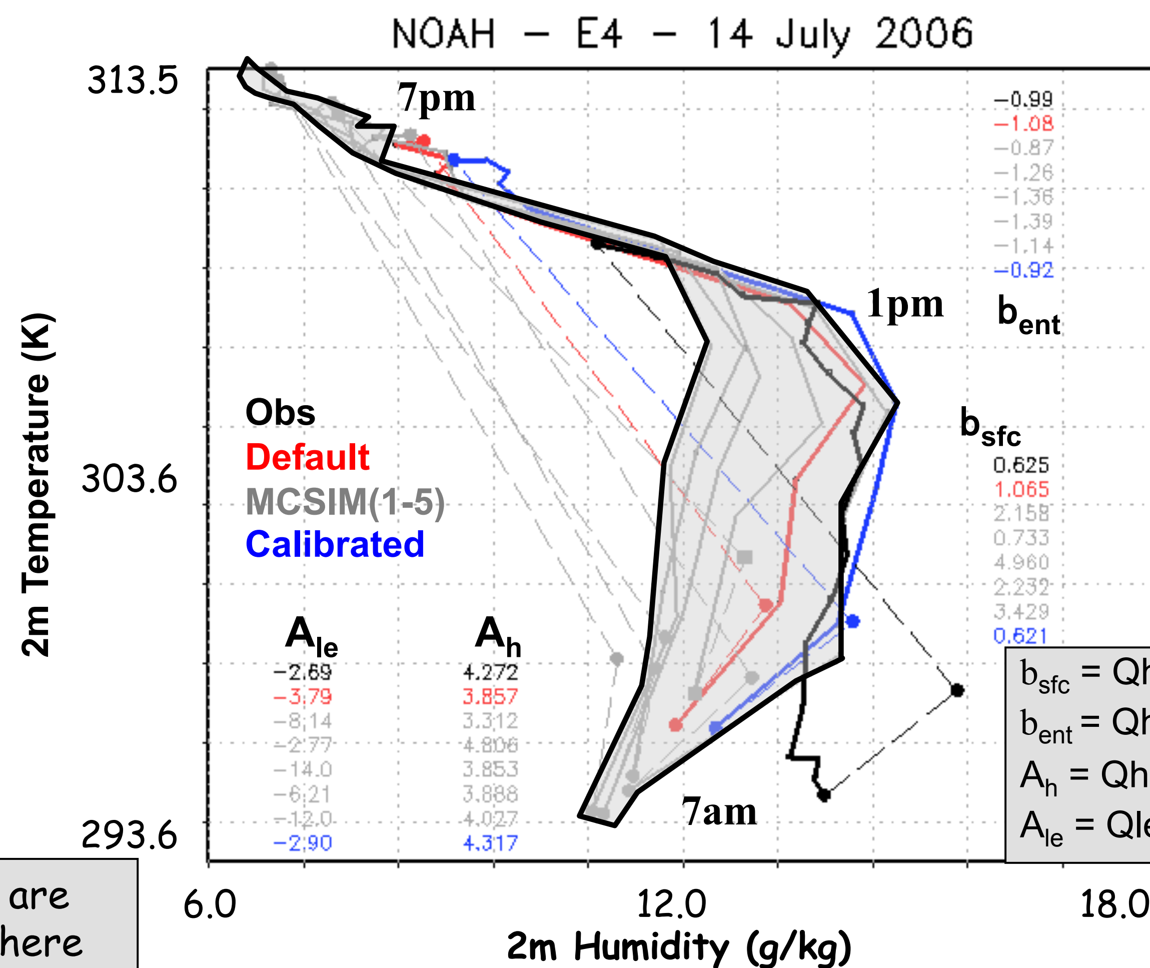
Uncertainty in Coupled Forecasts

Impact of MCSIM:

- **Default** (DEF) based run
- **Fully Calibrated** (SCP)

- Five additional runs conducted using the parameter values sampled from a uniform prior distribution (MCSIM)

- The results indicate significant spread in hydrometeorological prediction resulting from land surface parameter uncertainty.



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$A_h = Qh_{ent}/Qh_{sfc}$
$A_{le} = Qle_{ent}/Qle_{sfc}$

► A similar set of simulations are being conducted with DEMC where the parameter values are revised using ARM-SGP surface flux data

Implications for Coupled Calibration

For improvements in coupled prediction using LSM calibration, the following must be considered:

What to calibrate?

- Fluxes most important for atmospheric/climate models
- Soil states are a by-product in this approach (hard to measure and validate)
- Near-future missions – focus on measuring soil states rather than fluxes
- Ultimately, *both states and fluxes* measured and used for calibration will inform on LSM performance and improvement in translating e.g. SM to Evap

How to calibrate?

- *Averaging* across soil and veg classes and categorizing soil-soil & veg-veg parameters appears to work overall (isolated sites where degrades)

When to calibrate?

- Seasonally to capture wings of the distribution (dry-downs and wet-ups) and model biases
- Not a one-size-fits-all approach: extremes (06/07) vs. normal conditions (08)

Summary

- This experiment was designed as a **prototype OSSE** for future missions (e.g. SMAP).

- Using LIS-OPT/UE, we can quantify the **tradeoffs of data availability** vs. accuracy in prediction:
  - Space: Categorical estimation
  - Time: Period of calibration
  - Variables: Fluxes vs. States

- In the future, simultaneous development of Earth Science **technologies** (e.g. microwave soil moisture sensors) **and methodologies** (e.g. thermal evapotranspiration retrievals) will warrant the LIS-OPT/UE approach.

  ► With the NU-WRF and LIS-OPT/UE system, we can now jointly calibrate and assimilate land & atmosphere states and fluxes.