A Modeling Study of Irrigation Effects on Surface Fluxes and Land–Atmosphere–Cloud Interactions (LACI) in the Southern Great Plains

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Irrigation change in SGP (Data source: NASS)

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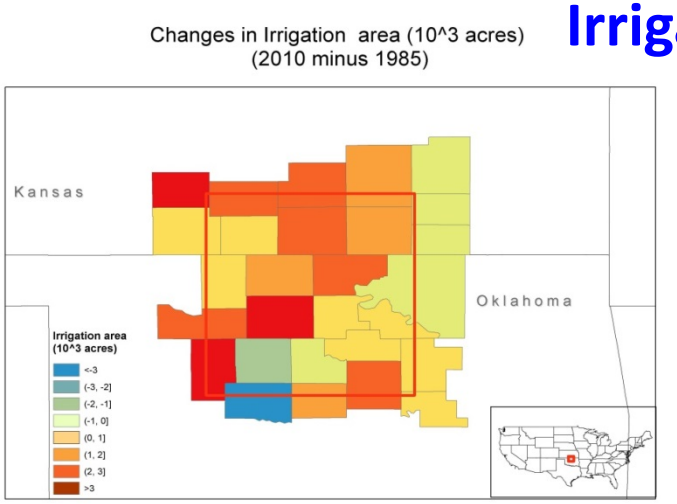
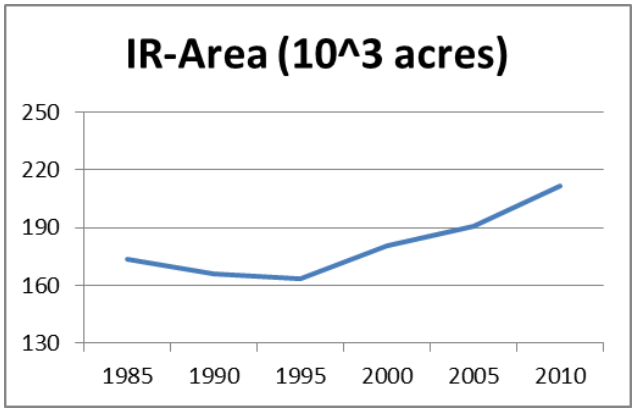
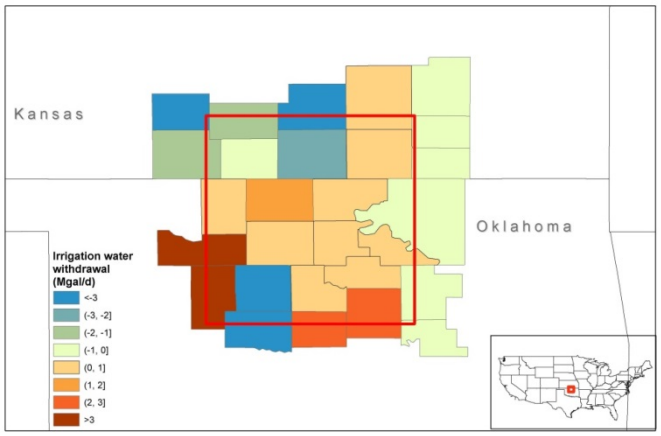
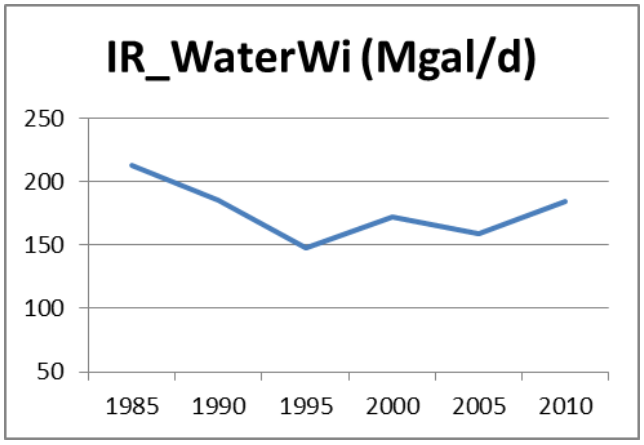
Irrigation Area





Irrigation Water Withdraw





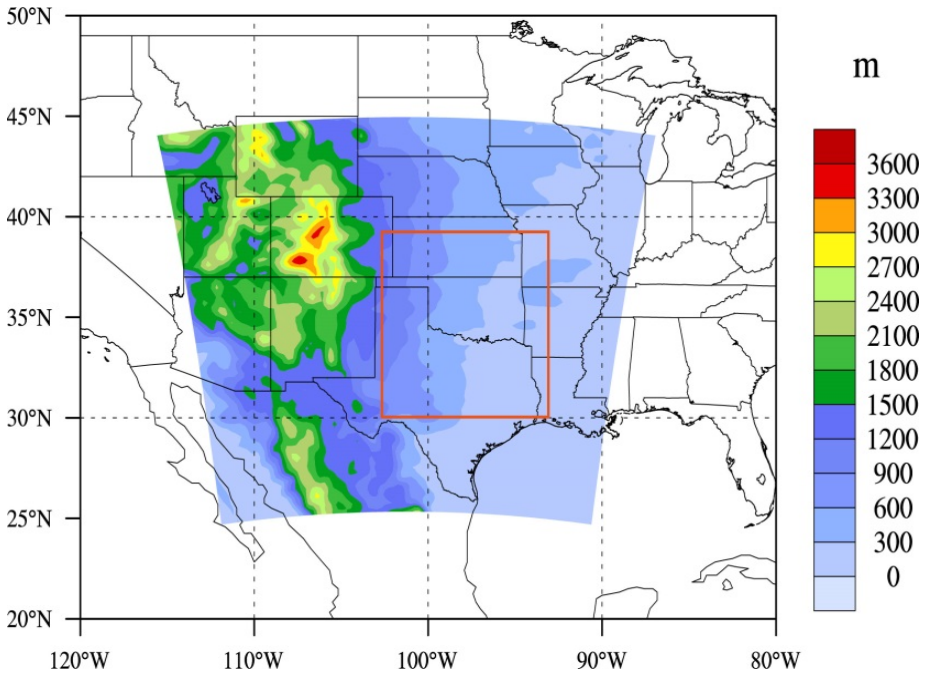
Irrigation accounts for about 70% of the global freshwater withdrawals and 90% of consumptive water uses (Siebert et al. 2010).

The National Agricultural Statistics Service (NASS) provides timely, accurate, and useful statistics in service to U.S. agriculture.

Objectives

- To improve the representations of irrigation and the interaction with land and air in a regional modeling framework.
- To evaluate the WRF performance in simulating the surface water and energy budgets and land-atmosphere-cloud interactions (LACI) over the SGP region and whether the use of a more realistic irrigation scheme will improve the simulation.
- To investigate the impact of irrigation on land surface fluxes, boundary layer structure, initiation of convective clouds and local climate.
- To better understand the role of soil moisture changes induced by human activities (e.g. irrigation) in affecting cumulus clouds, land-atmosphere interaction and water recycling.

Model



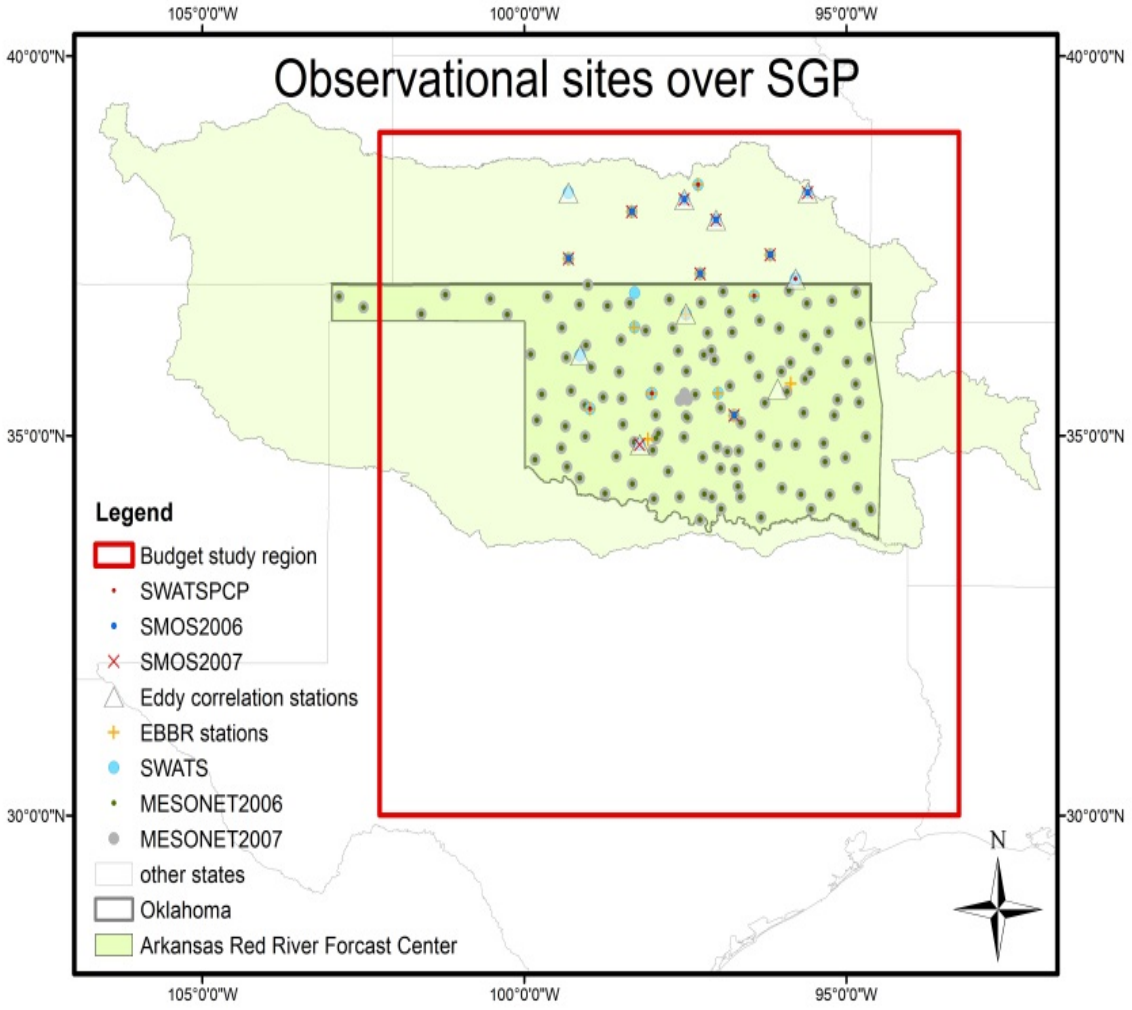
Configuration

Version: WRF 3.2
Microphysics: Morrison
Radiation: RRTMG Scheme
PBL: Mellor-Yamada-Janjic
Land-Surface: NOAH
Cumulus: Kain-Fritsch
Horizontal Resolution: 12 km
Simulation periods:
May 1 – Oct 1, 2006 (dry)
May 1 – Oct 1, 2007 (wet)

Simulations:

Control (2006, 2007)
Irrigation (2006, 2007)

Observations



ARM:

EC: Eddy Correlation

EBBR: Energy Balance Bowen Ratio (LH, SH)

SWATS: Soil Water and Temperature System (SM, T)

SMOS: Surface Meteorological Observation System

Others:

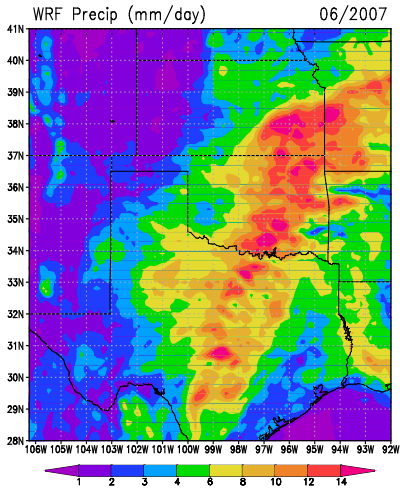
OKM: Oklahoma Mesonet

ABRFC: Arkansas–Red Basin River Center

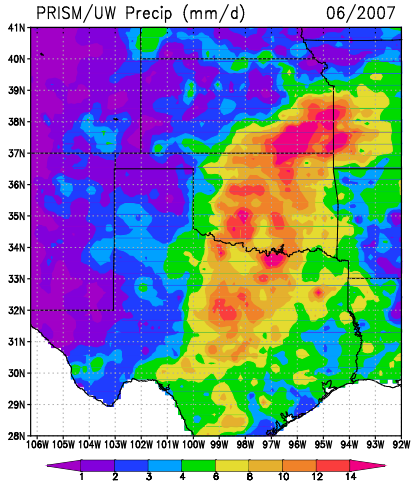
NLDAS2: North American Land Data Assimilation System

Evaluation of Precipitation (left) an Surface Flux (right)

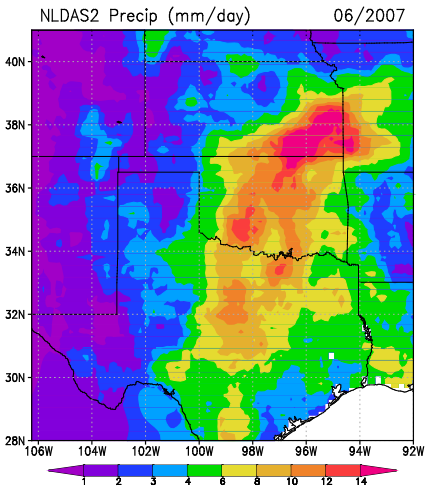
WRF (12km)



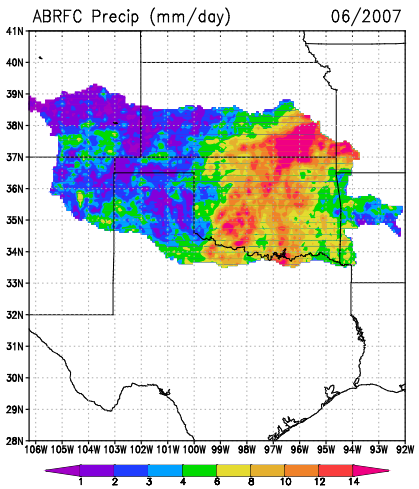
UW 1/8 degree

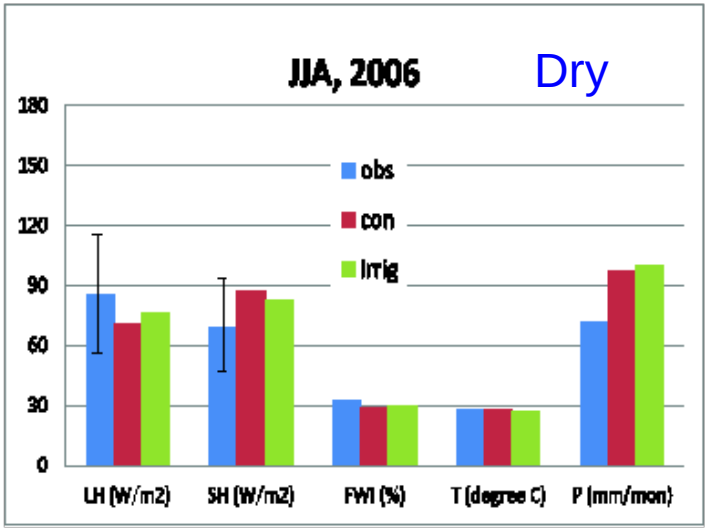


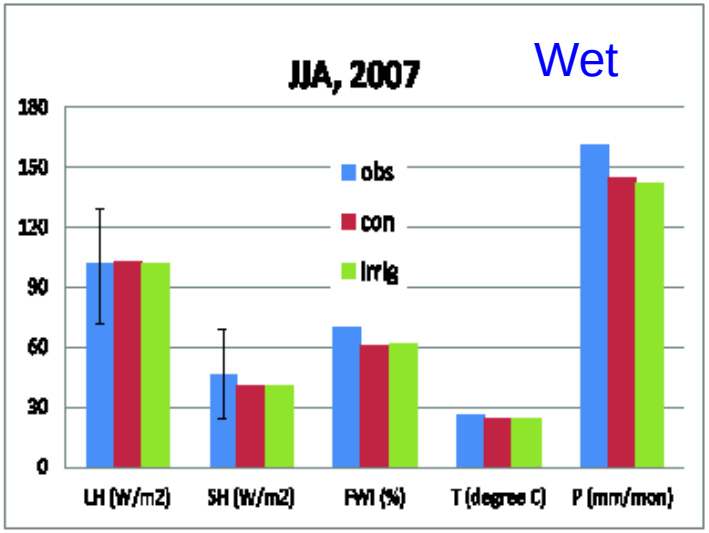
NLDAS2



ABRFC (4km)



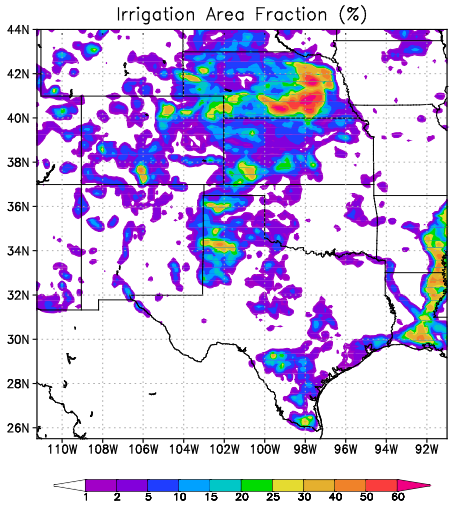




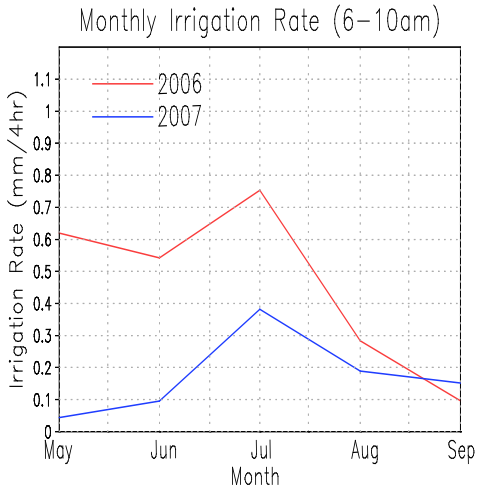
JJA 2007 (Wet)

Irrigation Scheme

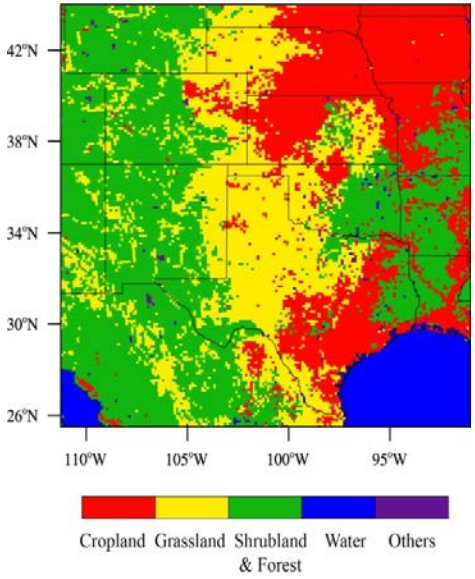
MODIS Potential Irrigation Area Fraction (%)



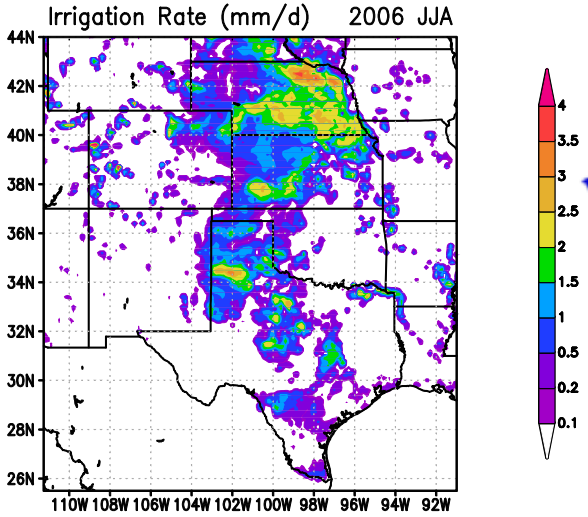
Irrigation Rate



Noah land cover



Irrigation Rate



- ✓ Incorporated an irrigation scheme into the Noah land surface model as part of WRF.
- ✓ Integrated the satellite-measured potentially irrigation area data into our model.
- ✓ Irrigation is triggered when root-zone soil moisture availability (MA) is below a specific threshold (e.g. 50%) over croplands or pastures during the growing season (Apr – Oct).
- ✓ $$MA = \frac{SM - SM_{WP}}{SM_{FC} - SM_{WP}}$$

where SM is current root-zone soil moisture, SM_{WP} and SM_{FC} are soil wilting point and field capacity, respectively

Irrigation-induced changes (JJA 2006)

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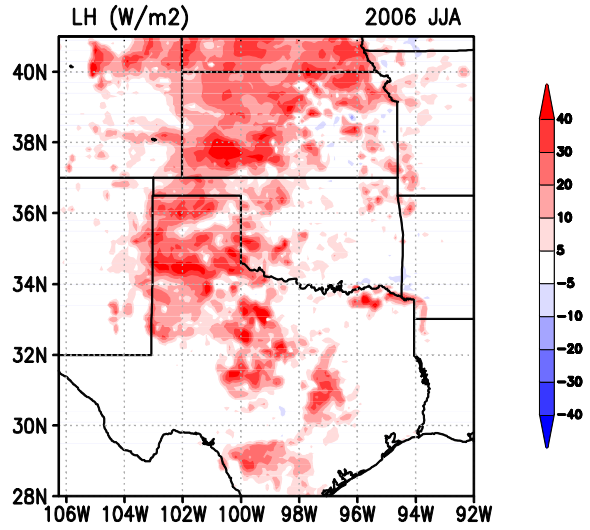
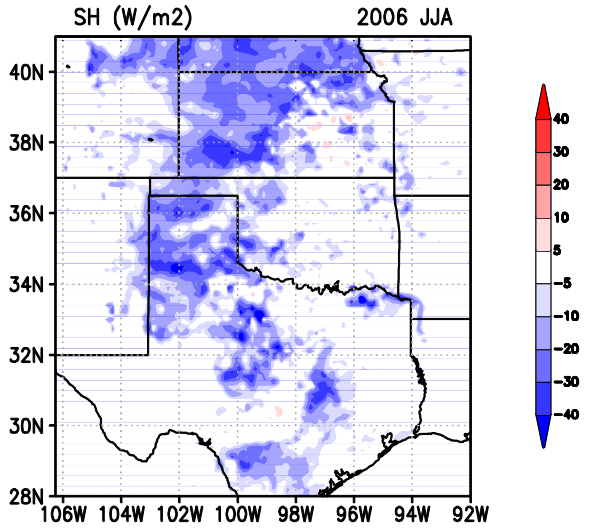
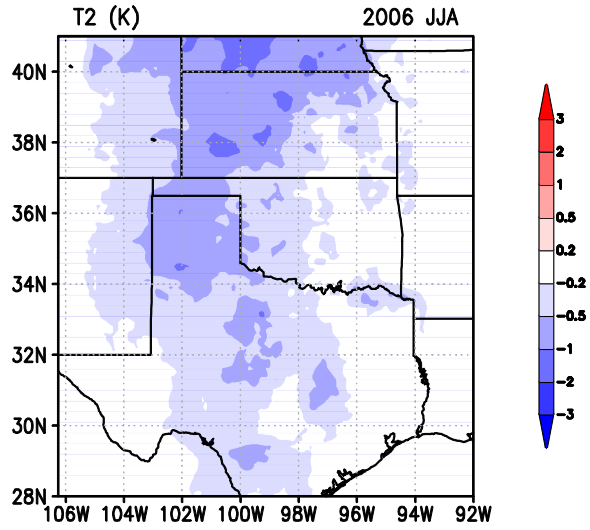
LH



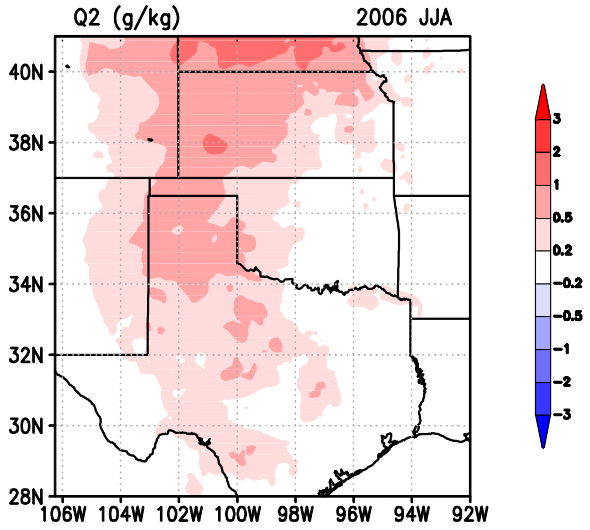
SH



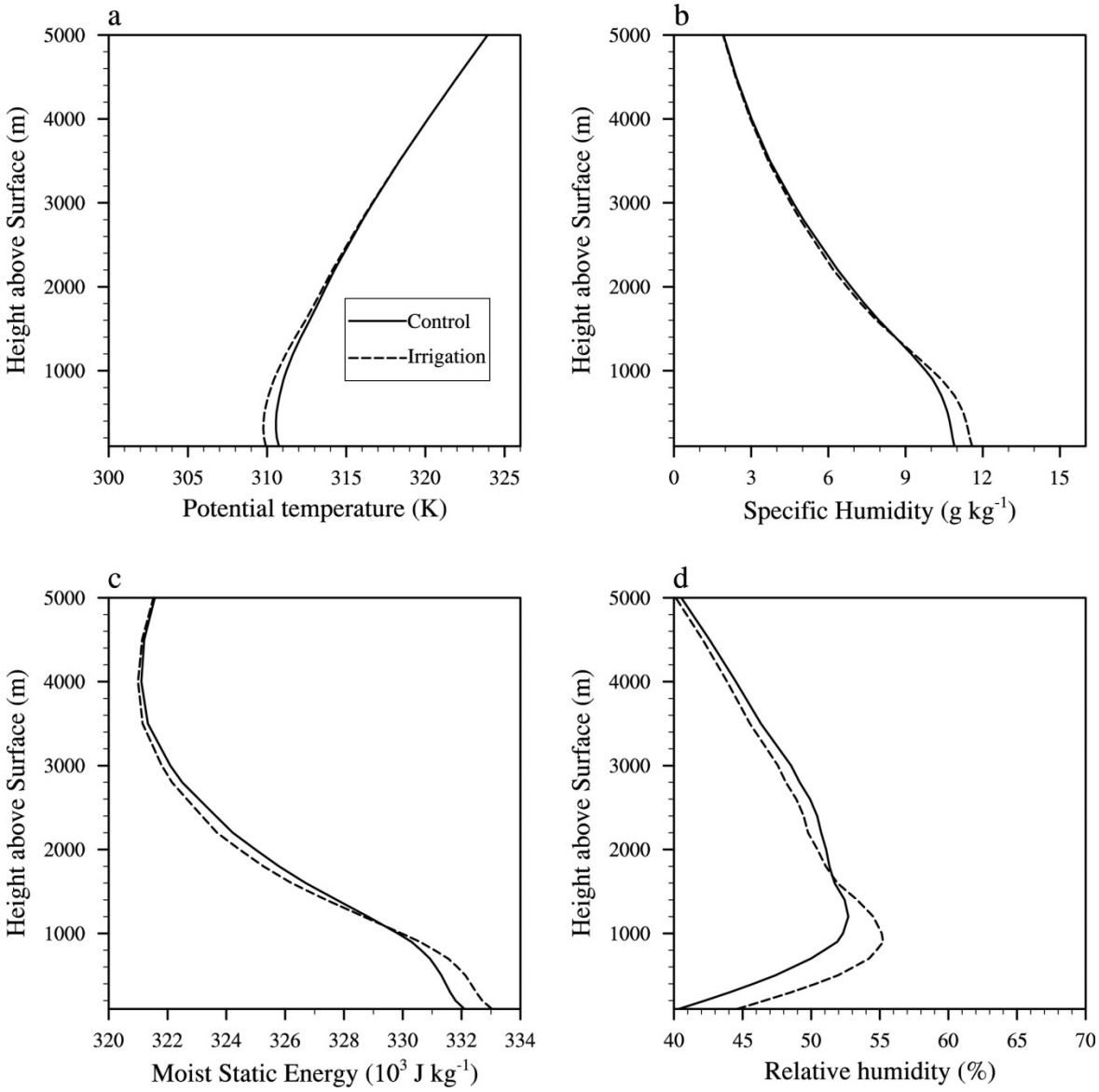
2m Air Temperature



2m Air Moisture

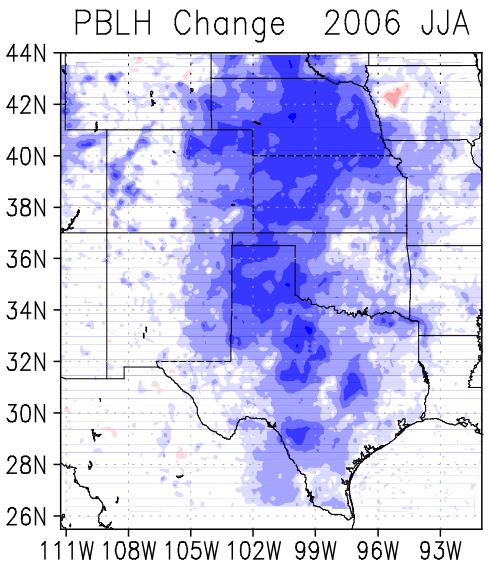


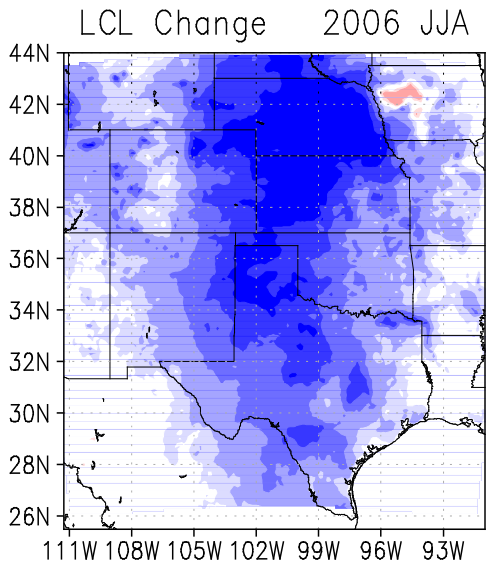
Vertical Profiles (1300-1500LST)



Decrease in both Lifting Condensation Level (LCL) and Planetary Boundary Layer Height (PBLH)

dPBLH



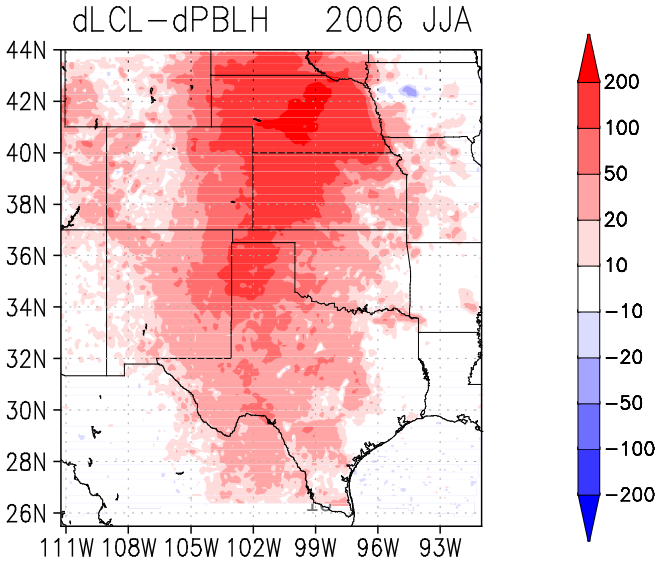


dLCL

Clouds form if LCL<PBLH, so positive of values of

|dLCL|-|dPBLH|

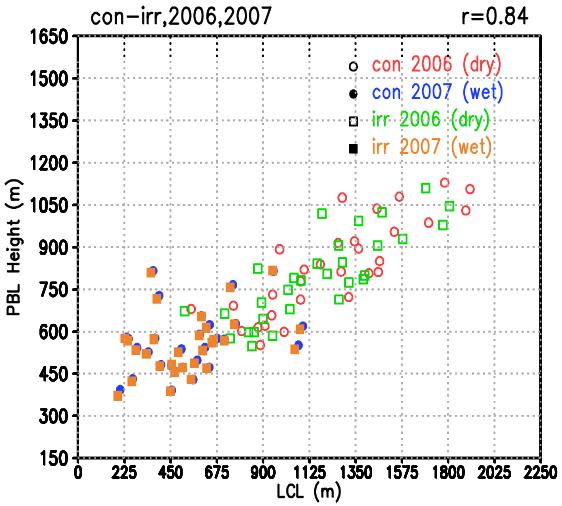
indicate a more likely cloud formation.



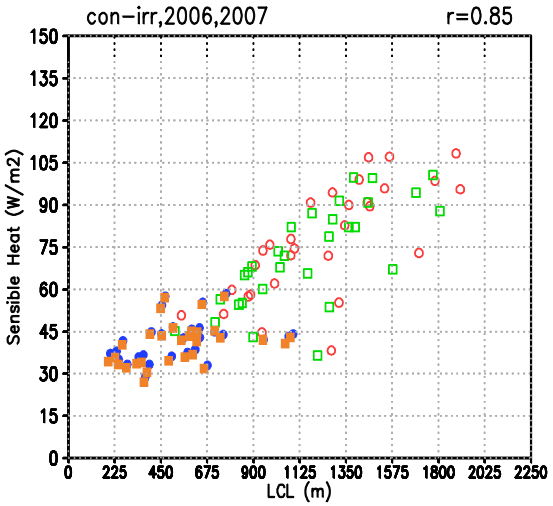
|dLCL|-|dPBLH|

5-day mean Lifting Condensation Level LCL and surface fluxes

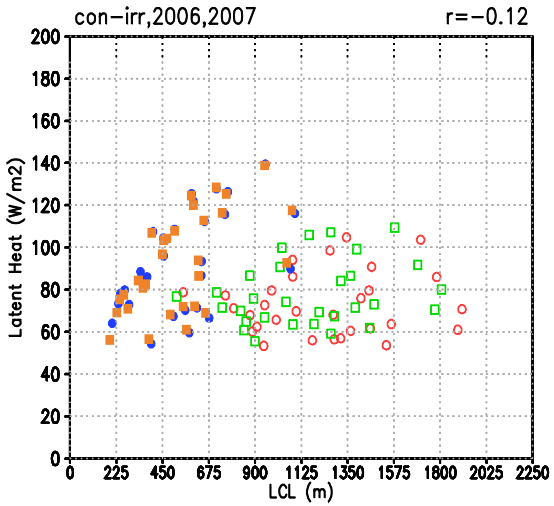
PBLH



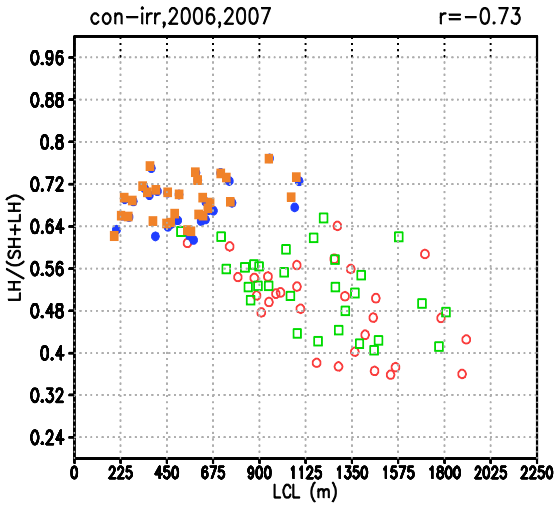
SH



LH



LH/(SH+LH)



LCL

5-day mean soil moisture and surface fluxes

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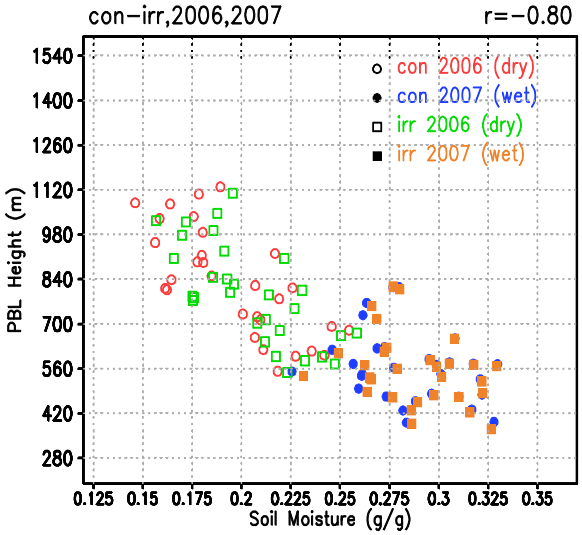
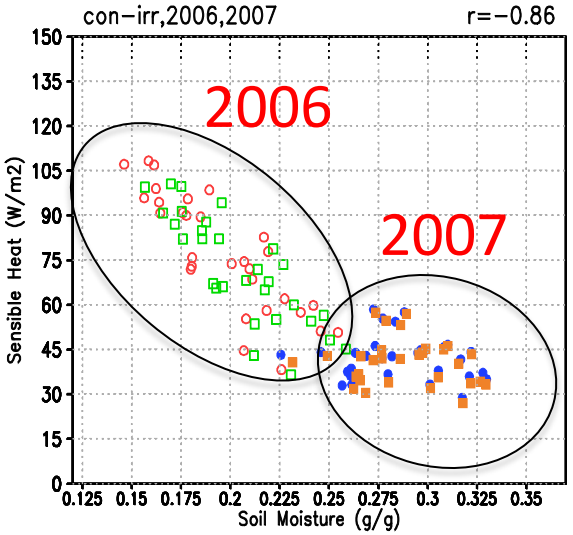
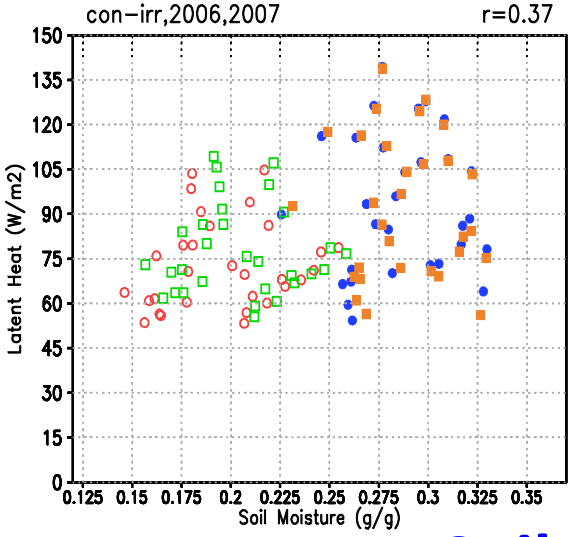
PBLH



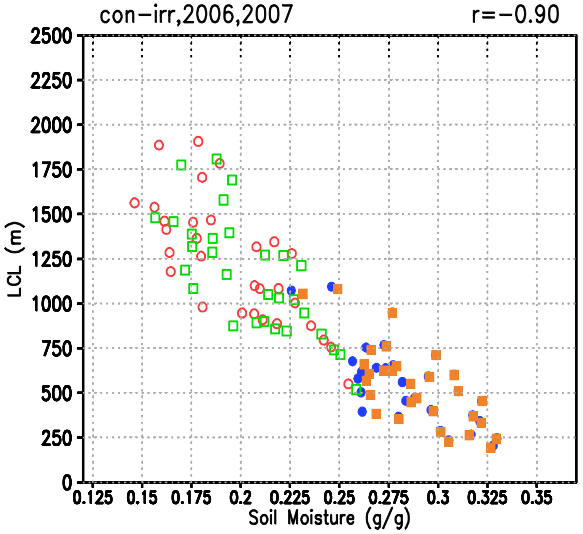
SH



LH



LCL



Soil Moisture

Summary

- An operational-like irrigation scheme is incorporated into the Noah-WRF model to enable the investigation of the irrigation effects on cumulus cloud and land-air interactions. Including irrigation reduces the model bias in LH, SH and soil moisture in a dry summer.
- Irrigation adds additional water to the surface, leading to the increase in soil moisture (SM) and evapotranspiration (EV). The near surface air is cooled because of the decreased SH, which is compensated with the increased LH.
- Irrigation-induced decrease in lifting condensation level is larger than the decrease in mixed layer depth, suggesting an increasing probability of shallow cloud formation, which is linked closely to the partitioning of the surface fluxes and soil moisture.
- The land-atmosphere interactions behave differently under wet and dry conditions. In the dry year, the land-atmosphere interactions likely play a more important role in the regional water cycle. In the wet year when the EV is not constrained by the SM, however, we find weaker correlations between SM and surface fluxes.

Irrigation-induced changes

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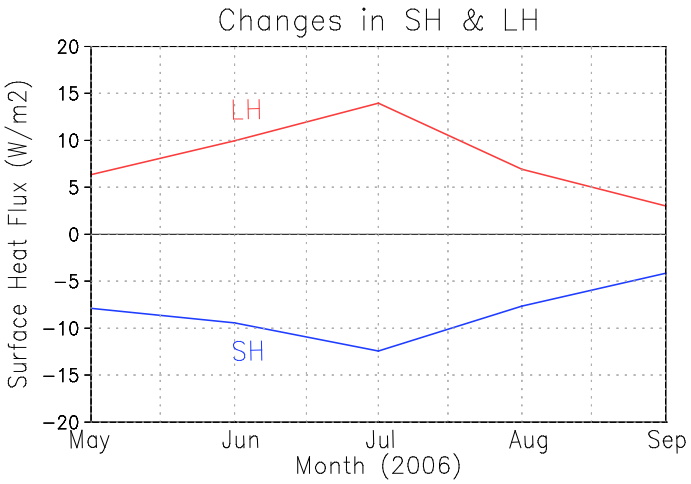
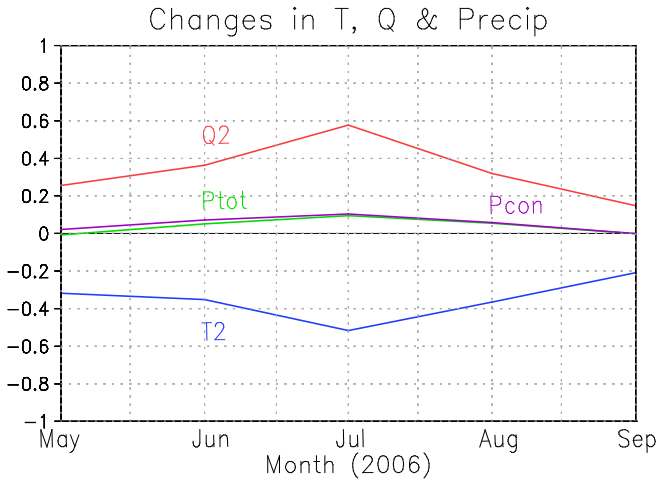
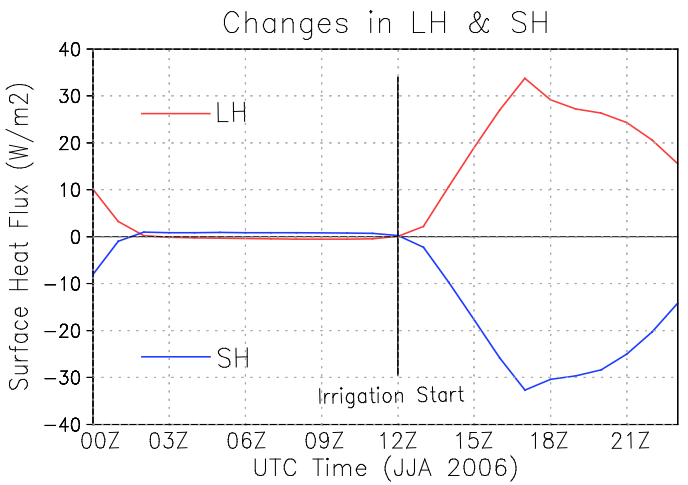
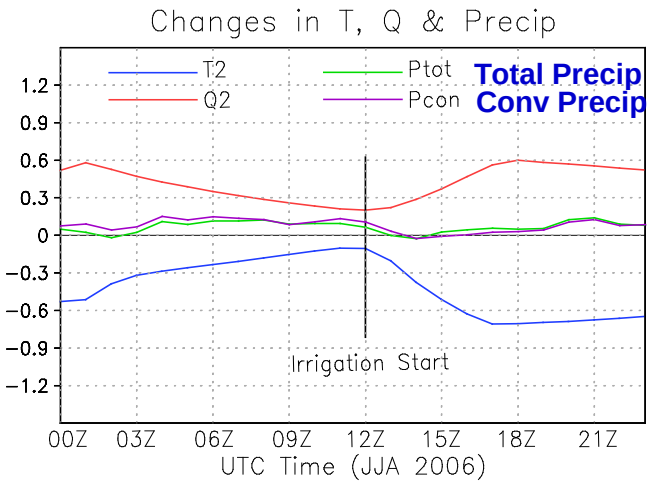
Monthly Change





Diurnal cycle





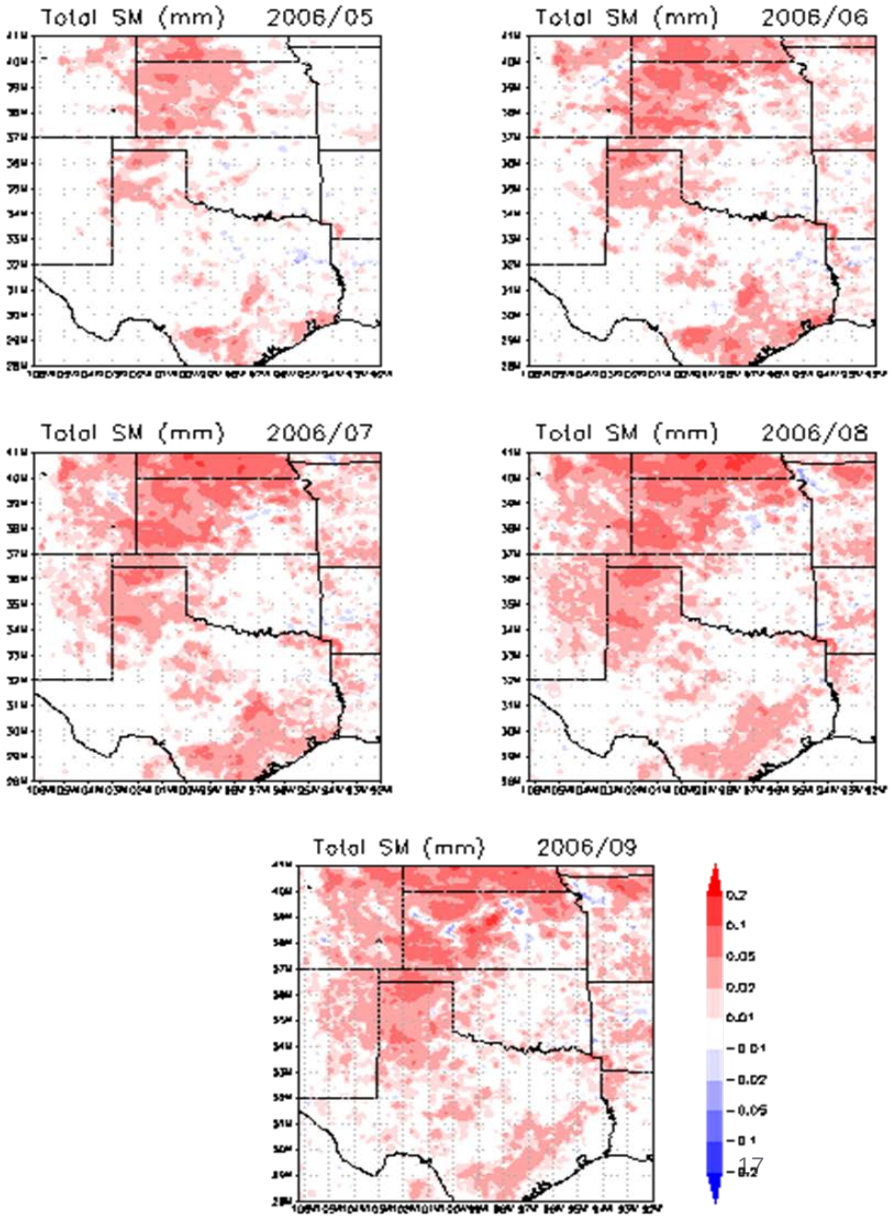
Time scale of land-air interaction

Table 1 Correlation Coefficients between soil moisture (LCL) and surface flux as a function of Average time. LCL=Lifting Condensation Level.

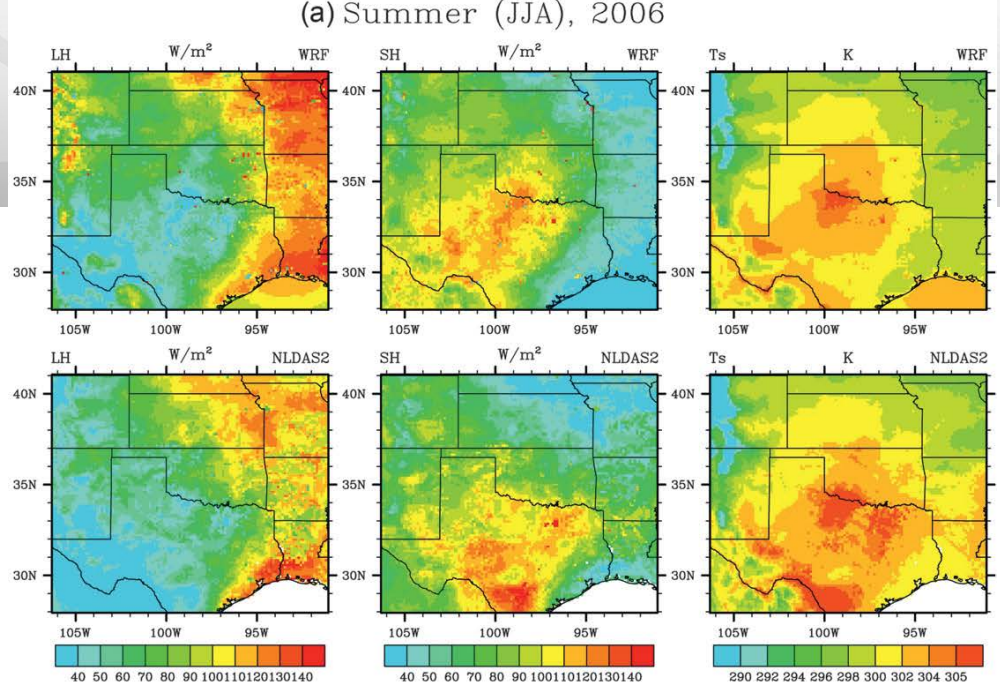
		PBL	SH	LH	LCL
	5-day	-0.80	-0.86	0.37	-0.90
Soil Moisture	10-day	-0.85	-0.88	0.41	-0.93
	30-day	-0.90	-0.90	0.66	-0.98

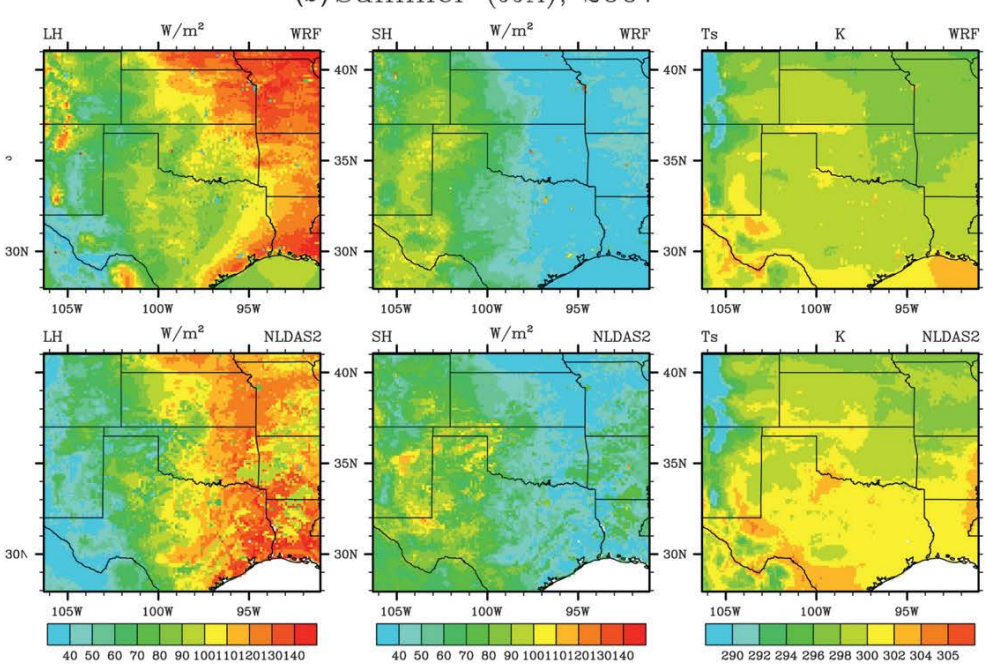
		PBL	SH	LH	LH/(SH+LH)
	5-day	0.84	0.85	-0.12	-0.73
LCL	10-day	0.87	0.88	-0.19	-0.81
	30-day	0.92	0.94	-0.58	-0.94

Soil moisture change



- **The irrigation-induced soil memory and resulted wetter and cooler surface from the previous period can last for a few weeks to months, implying a lagging effect of irrigation at the scale potentially from intraseasonal to seasonal.**


(a) Summer (JJA), 2006
LH W/m² WRF
SH W/m² WRF
Ts K WRF
LH W/m² NLDAS2
SH W/m² NLDAS2
Ts K NLDAS2
40N
35N
30N
105W
100W
95W
40 50 60 70 80 90 100 110 120 130 140
290 292 294 296 298 300 302 304 305


(b) Summer (JJA), 2007
LH W/m² WRF
SH W/m² WRF
Ts K WRF
LH W/m² NLDAS2
SH W/m² NLDAS2
Ts K NLDAS2
40N
35N
30N
105W
100W
95W
40 50 60 70 80 90 100 110 120 130 140
290 292 294 296 298 300 302 304 305