Integrating Remote Sensing Products to Improve the Representation of Vegetation and Transpiration Processes in the Noah LSM Model

Fei Chen[1], Anil Kumar[1,2], Dev Niyogi[2], Mike Barlage[1]
Mike Ek[3], Kenneth Mitchell[3]

[1]National Center for Atmospheric Research (NCAR), Boulder
[2]Purdue University, West Lafayette, IN
[3]National Center for Environment Prediction (NCEP)

Supported by the NOAA/JCSDA Land-Component Program

NCAR

PURDUE UNIVERSITY

Outline

- Motivation.
- Impact of canopy resistance and new satellite data (offline Noah and coupled WRF/Noah results).
- Impact of canopy resistance on deposition velocity.
- Future work.

Motivations

- Data assimilation approach is largely determined by inherent model physics.
- Evapotranspiration is the most effective and sustainable way to transport water vapor from land to the atmosphere.
- Jarvis-type canopy resistance (Rc) formulation still widely used in coupled NWP/LSM models (e.g., WRF/Noah).

Jarvis scheme

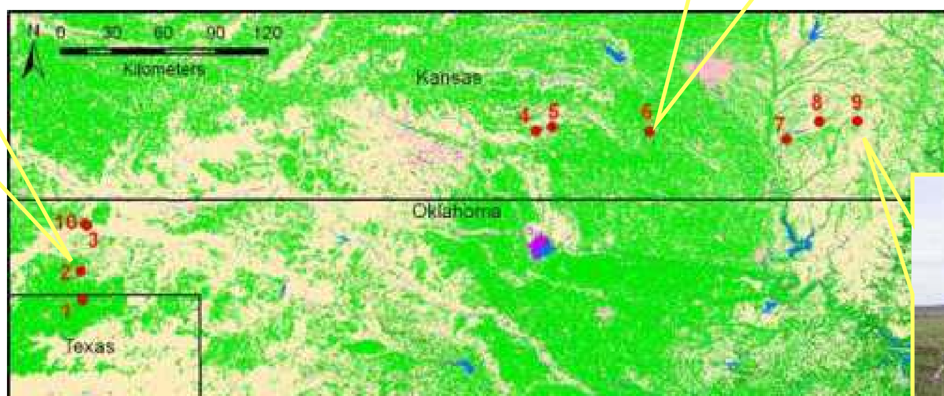
$$Rc = \frac{Rc\_\min}{LAI\, F_1\, F_2\, F_3\, F_4}$$

LAI – Leaf Area Index,
F1 ~ f (amount of PAR)
F2 ~ f(air temperature: heat stress)
F3 ~ f(air humidity: dry air stress)
F4 ~ f(soil moisture: dry soil stress)

  – Jarvis-type scheme relies on minimum stomatal resistance, Rc_min, which is a constant specified as function of land-cover type.

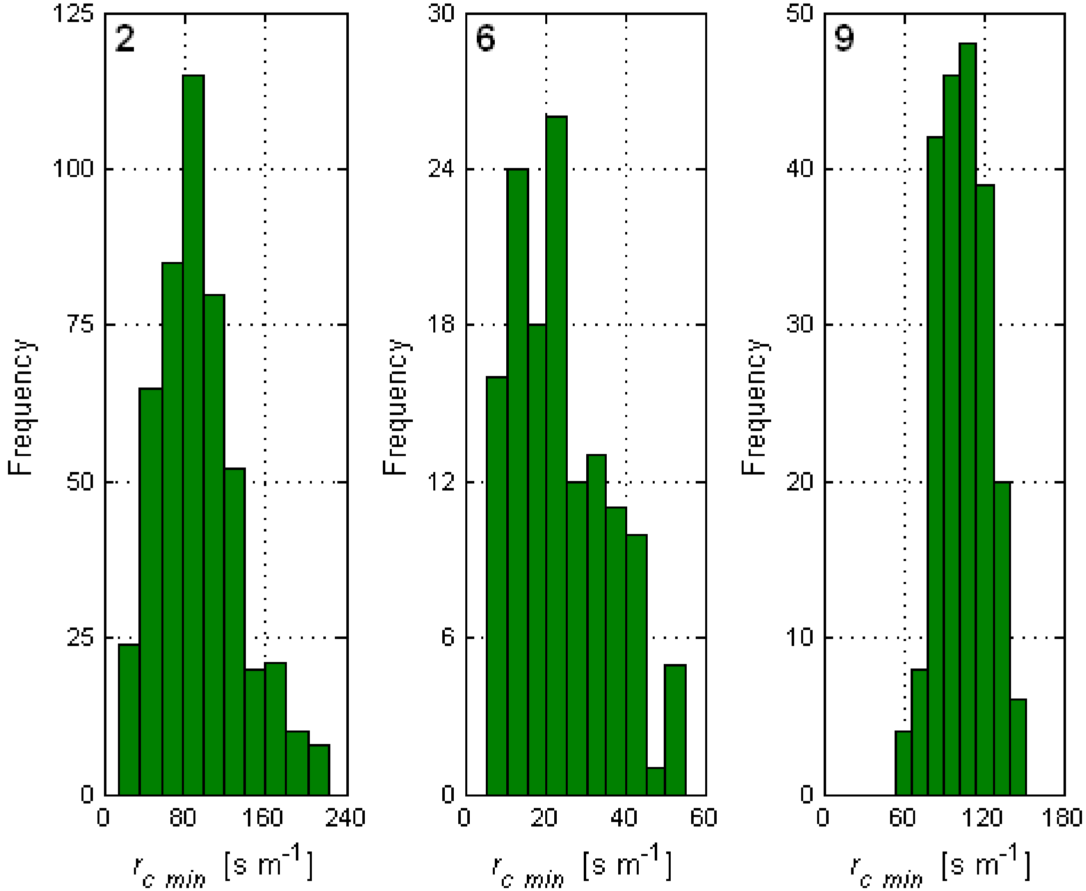
Estimate Rc_min from 2002 International H_2O Project Data

- IHOP_2002 was a multi-agency field campaign conducted in the Southern Great Plains during May and June 2002.
- Micrometeorological, surface tower, and properties data were collected at 10 sites representing the surface characteristics typical of the region.



Spatiotemporal Variability of Rc_min

Site 2: Sparse grass | Site 6: Winter wheat | Site 9: Tall grass



- Rc_min highly variable spatially and temporally.
- The mean Rc_min ranging from 24 s m^{-1} at the Site 6 to 107 s m^{-1} at Site 8.
- Standard deviations ranging from 8 s m^{-1} to 41 s m^{-1} at Sites 5 and 8, respectively.

Alfieri, Niyogi, Chen, LeMone, Mitchell, Ek, and Kumar, 2008, *Mon. Wea. Rev.*, in press.

Objectives

- Integrate recent remotely-sensed and *in-situ* datasets and products to systematically evaluate vegetation and transpiration processes in the Noah LSM.
- Improve the capacity of Noah to simulate
  – Water vapor fluxes in WRF/Noah
  – Deposition velocity in WRF-Chem/Noah.
- Study conducted in
  – Long-term uncoupled runs
  – Coupled WRF/Noah runs
  – With the legacy USGS and new MODIS LULC dataset, MODIS vegetation phenology data.

Jarvis Scheme vs Ball-Berry Scheme

Jarvis scheme

$$R_c = \frac{R_c\_\min}{LAI \times F1 \times F2 \times F3 \times F4}$$

LAI – Leaf Area Index,
F1 ~ f (amount of PAR)
F2 ~ f(air temperature: heat stress)
F3 ~ f(air humidity: dry air stress)
F4 ~ f(soil moisture: dry soil stress)

Fundamental difference: evapotranspiration as an ‘inevitable cost’ the foliage incurs during photosynthesis or carbon assimilation

A_n: three potentially limiting factors:

1. efficiency of the photosynthetic enzyme system
2. amount of PAR absorbed by leaf chlorophyll
3. capacity of the C3 and C4 vegetation to utilize the photosynthesis products

Ball-Berry scheme in GEM (Gas Exchange Model)

$$g_s = m\frac{A_n}{C_s}h_s p_s + b \qquad R_c = \frac{1}{g_s}$$

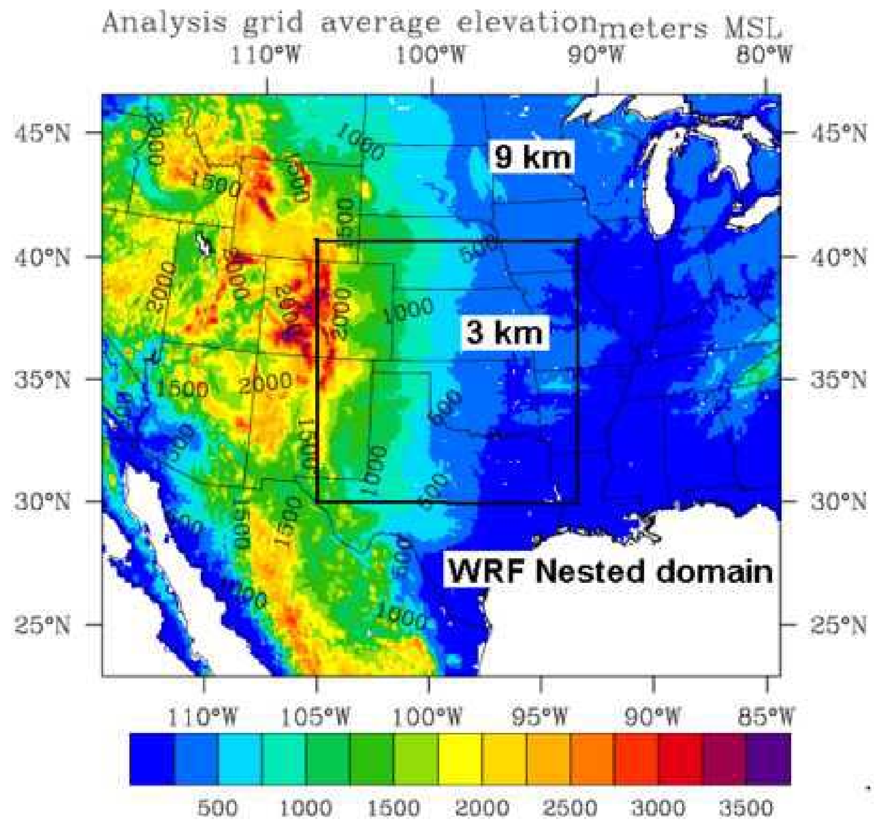
hs – relative humidity at leaf surface
ps – Surface atmospheric pressure
An – net CO2 assimilation or photosynthesis rate
Cs – CO2 concentration at leaf surface
m and b are linear coeff based on gas exchange consideration

GEM model reference: Niyogi, Alapaty, Raman, Chen, 2007: JAMC, in revision.

NCAR High-resolution Land Data Assimilation System:

Capturing Small-Scale Surface Variability

- Input:
  - **4-km hourly NCEP Stage-II rainfall**
  - **1-km landuse type and soil texture maps**
  - 0.5 degree hourly GOES downward solar radiation
  - 0.15 degree AVHRR vegetation fraction
  - T, q, u, v, from model based analysis
- Output: long term evolution of multi-layer soil moisture and temperature, surface fluxes, and runoff

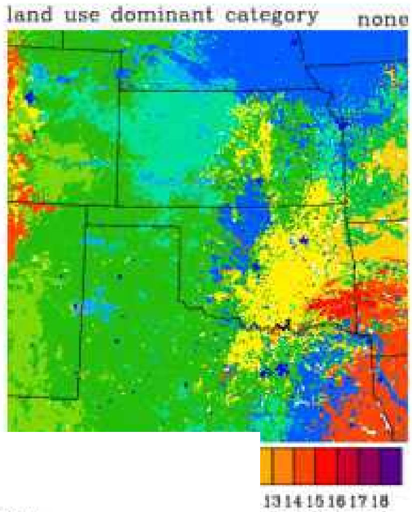


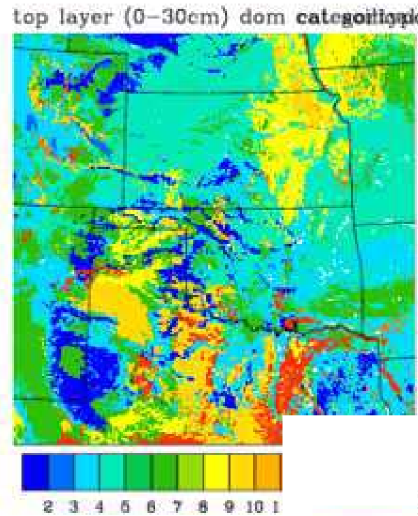
HRLDAS executed from January 2001 - July 2002

HRLDAS reference: Chen et al., 2007 (JAMC)

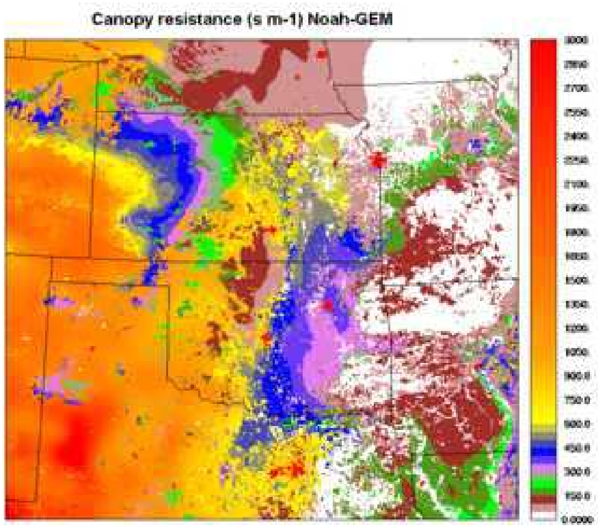
HRLDAS results valid at 1900 UTC June 1, 2002 after 18-month spin-up

Land-use





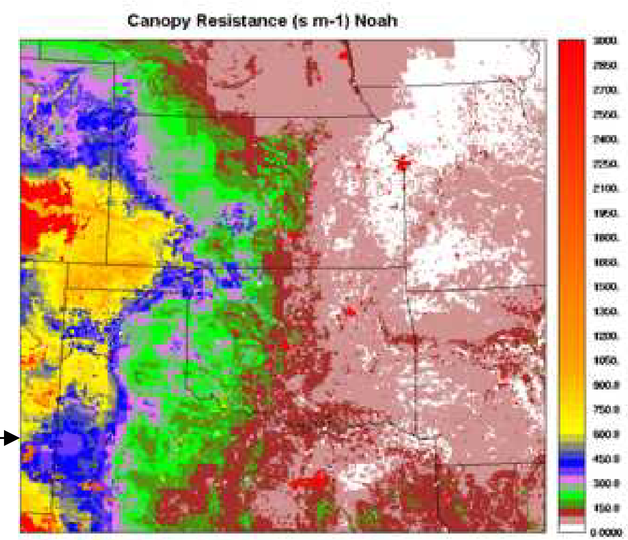
Soil texture



Canopy resistance

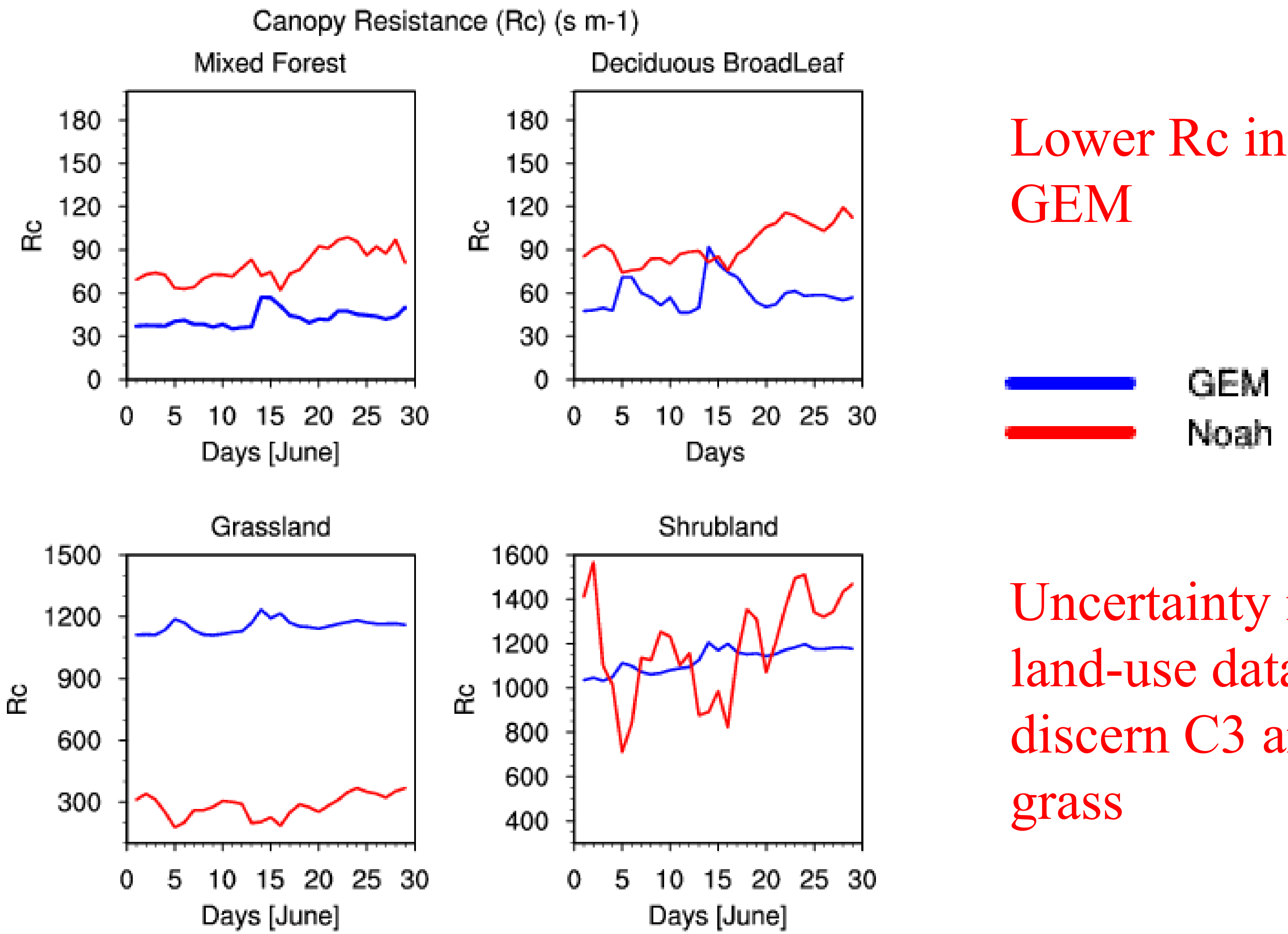
← Noah-GEM

Noah-Jarvis →



Rc Differences simulated by Noah-Jarvis and Noah-Gem

midday-mean and averaged for the same land-use types for June 2002



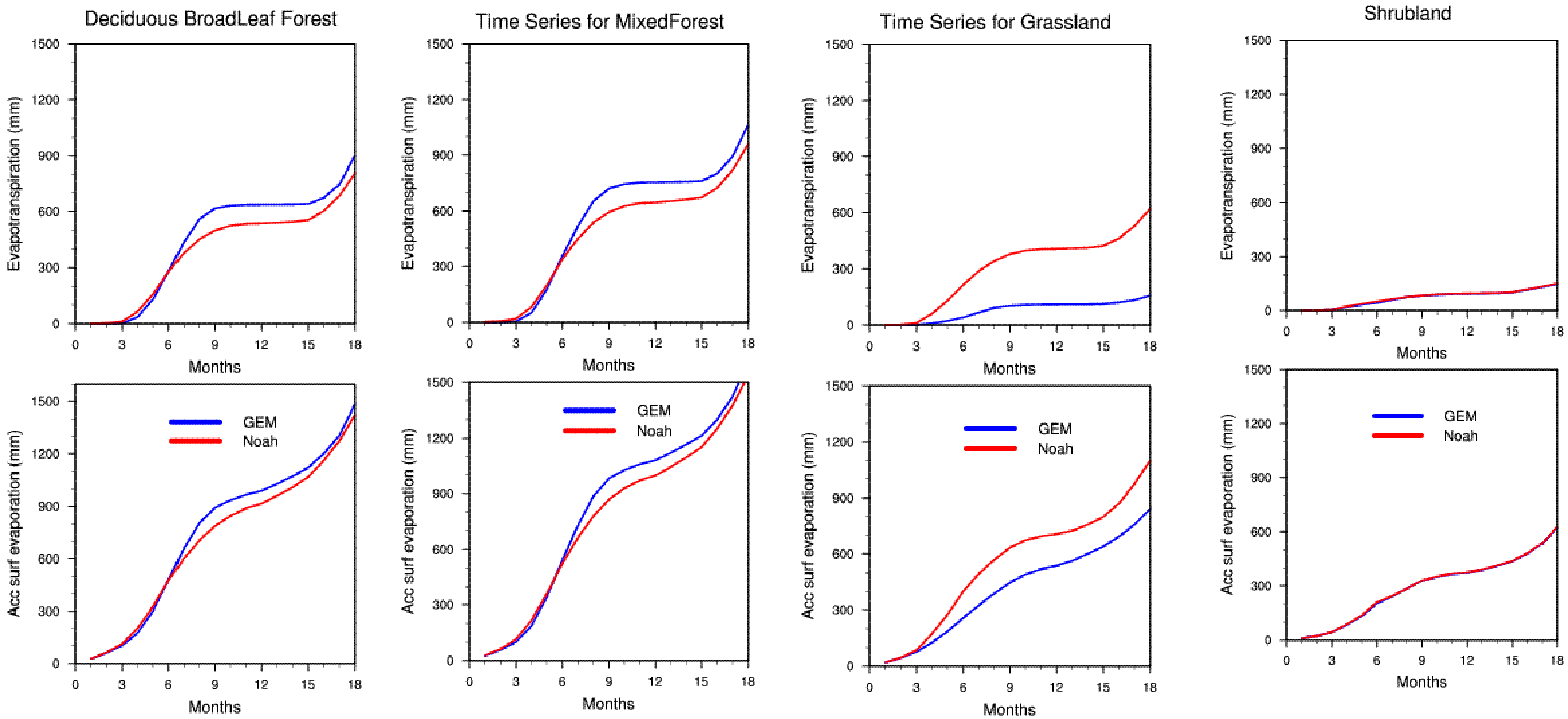
Lower Rc in Noah-GEM

Uncertainty in current land-use data to discern C3 and C4 grass

NCAR

PURDUE UNIVERSITY

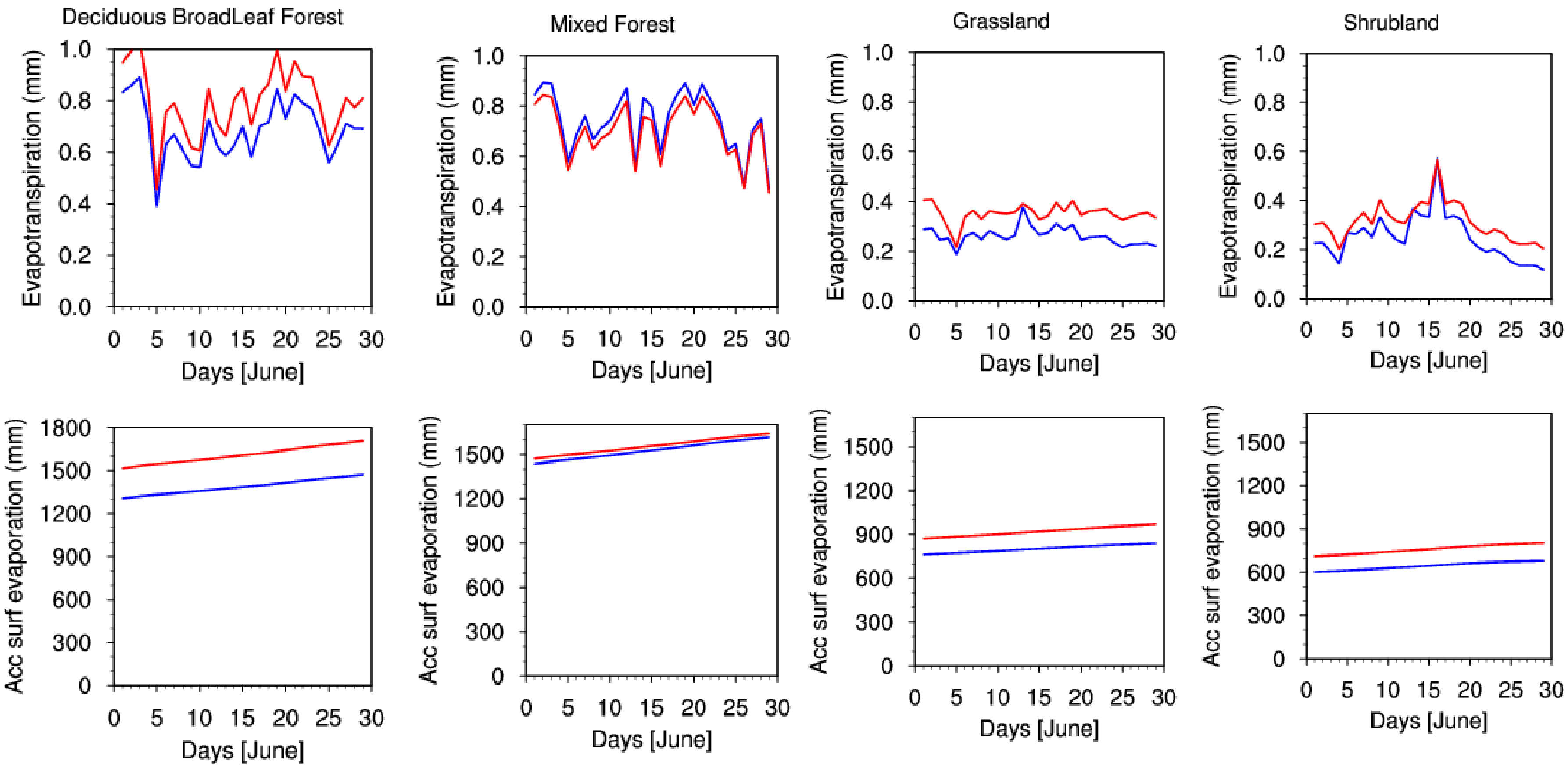
Differences in HRLDAS Long-Term Evapotranspiration and Total Evaporation



Differences in surface evaporation is offset by evapotranspiration.

Uncertainty Introduced by Treating Vegetation Phenology
midday-mean evapotranspiration and accumulated total evaporation

Red: Noah-GEM with constant LAI, Blue: Noah-GEM with time-varying LAI



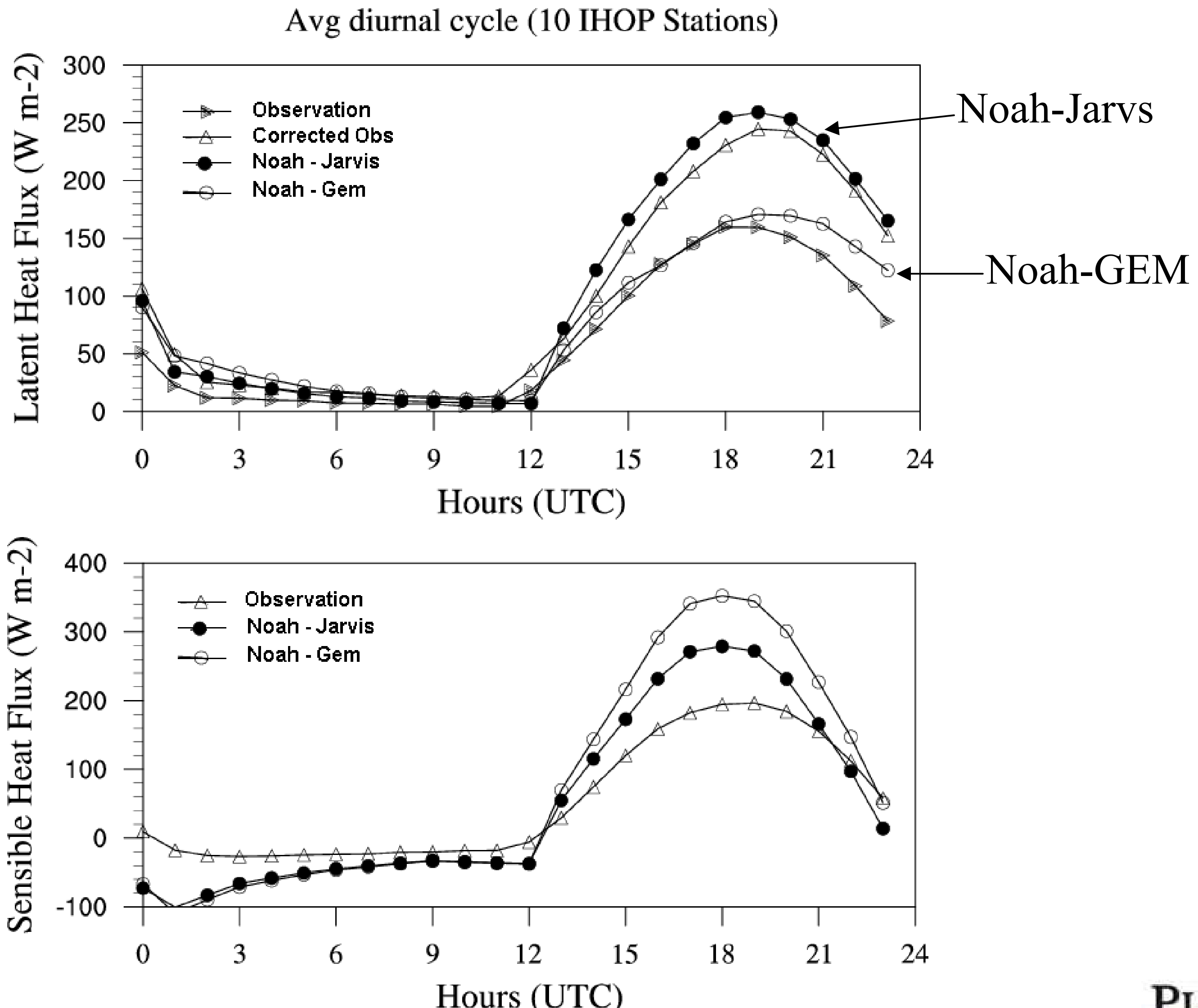
Different LAI can cause difference in total evaporation ranging from 50 mm to 150 mm for the month of June

NCAR

PURDUE UNIVERSITY

Evaluation of Noah-GEM

Averaged over nine IHOP 02 sites and for June

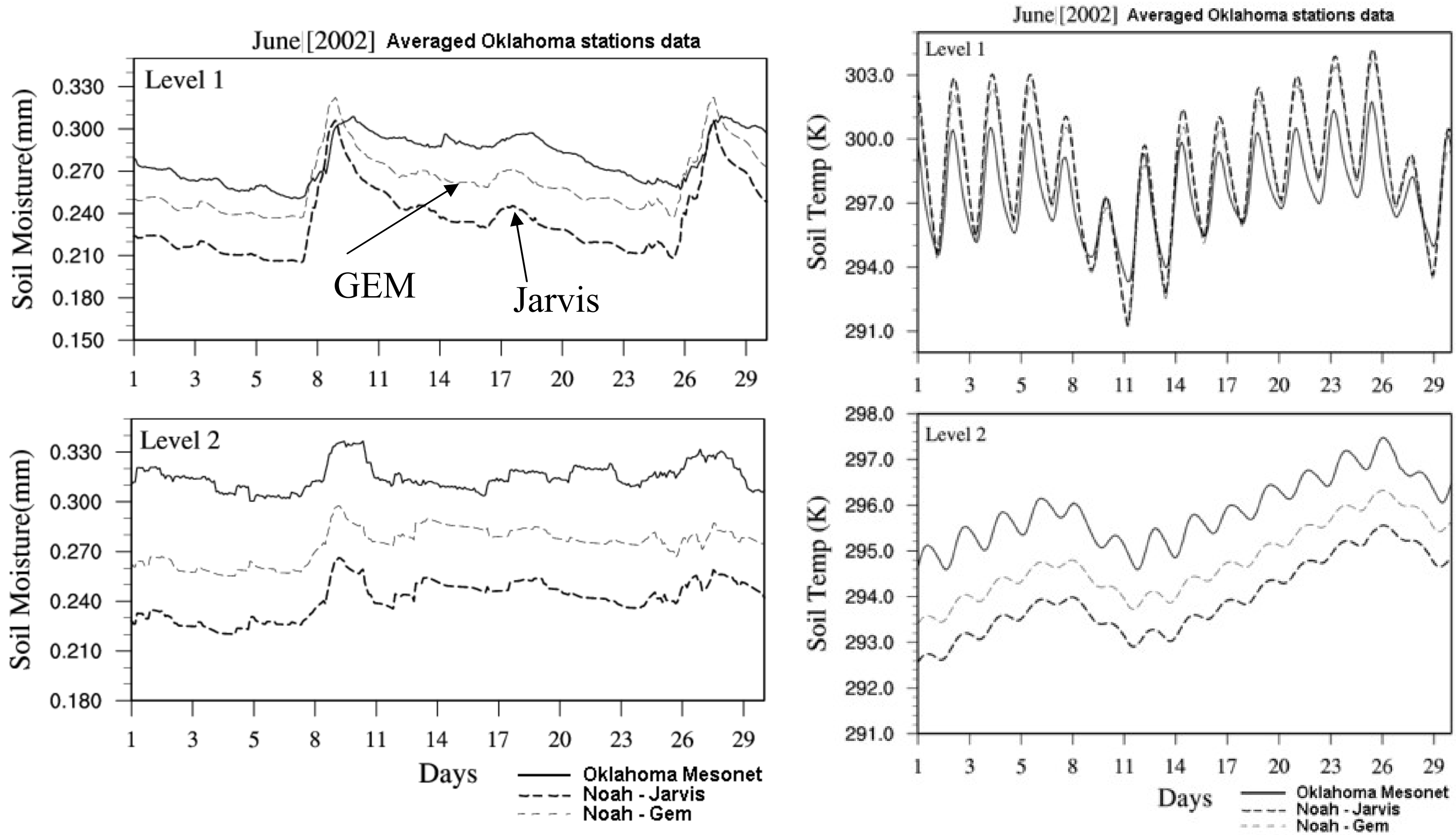


NCAR

PURDUE UNIVERSITY

Evaluation of Noah-GEM

soil moisture averaged over ~80 Oklahoma Mesonet Stations



GEM improve simulation of soil moisture at both 5-cm and 25-cm depths

Dry Deposition velocity (Ozone) estimation from GEM-model

Objectives

1. Dry deposition modeling approach that includes photosynthesis/carbon assimilation relationship.
2. Evaluated over Niwot Ridge (CO) Ameriflux site (coniferous subalpine forest) in Roosevelt national Forest, Colorado.
3. Photosynthesis based approach will be used in WRF-Chem/Noah for Air-Quality modeling and forecast.

Photosynthesis-Based Dry Deposition Velocity formulation Gas-Exchange Model (GEM)

Deposition flux is given by $F_d = V_d C$

Vd is deposition velocity and C is mean gas concentration.

$$V_d = \left(R_a + R_b + R_c\right)^{-1}$$

1. The aerodynamic resistance can be parameterized as (Baldocchi 1998)

$$R_a = \Pr\left(\ln\frac{z}{z_0} - \psi_h\right)\left(ku_*\right)^{-1}$$

2. Quasi-laminar sublayer/boundary layer resistance (Rb)

$$\frac{1}{R_{bfc}} = cT^{0.56}\left[\left(T+120\right)\frac{u}{dp}\right]^{0.5}$$

Forced convection

$$\frac{1}{R_{bfr}} = cT_s^{0.56}\left\{\frac{T_s + 120.0}{P}\right\}^{0.5}\left\{\frac{T_{vs} - T_{va}}{d}\right\}^{0.25}$$

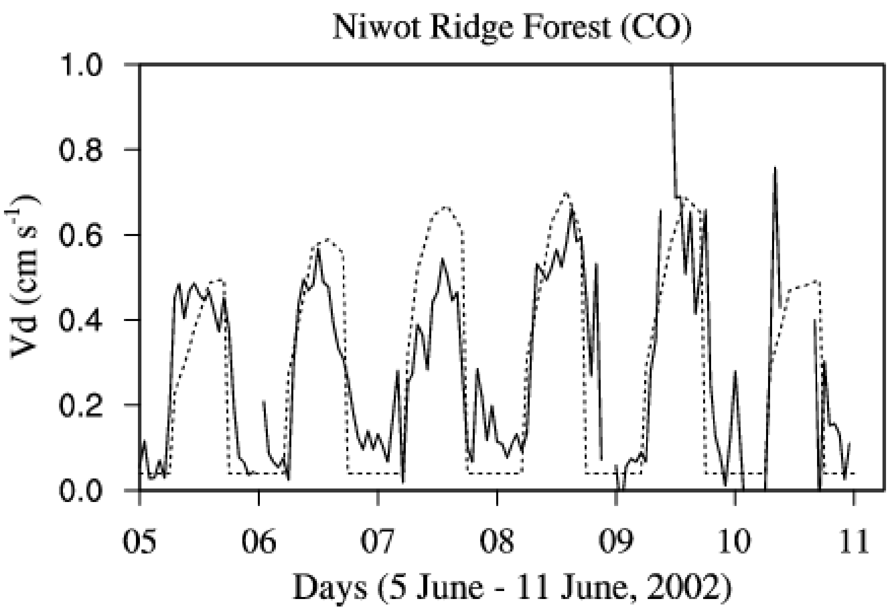
Free convection:

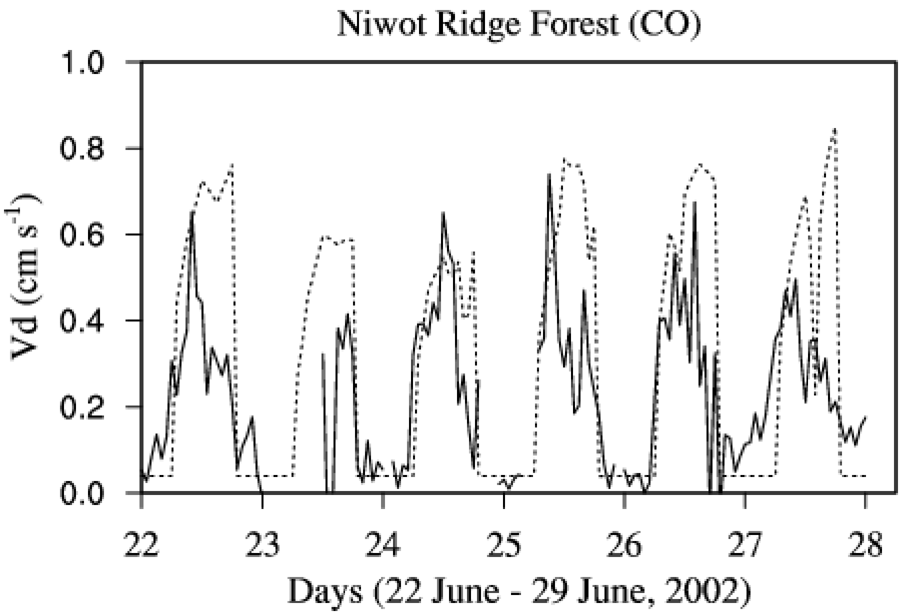
3. Canopy resistance (Rc) from GEM

$$g_s = m\frac{A_n}{C_s}h_s p_s + b$$

$$R_c = \frac{1}{g_s}$$

Dry Deposition Velocity (cm s-1) Estimated by Noah/GEM for the Niwot Ridge Forest, CO, site

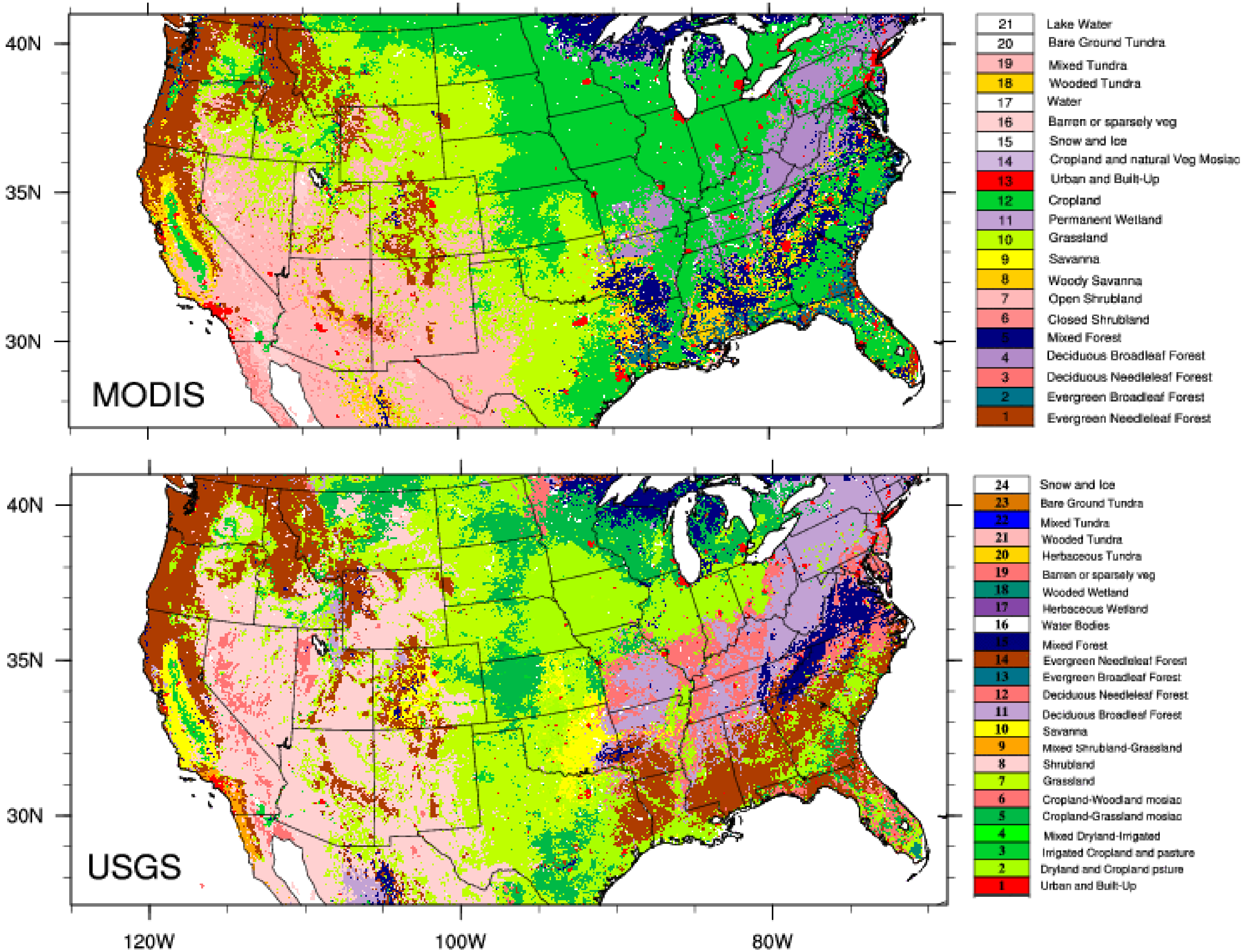




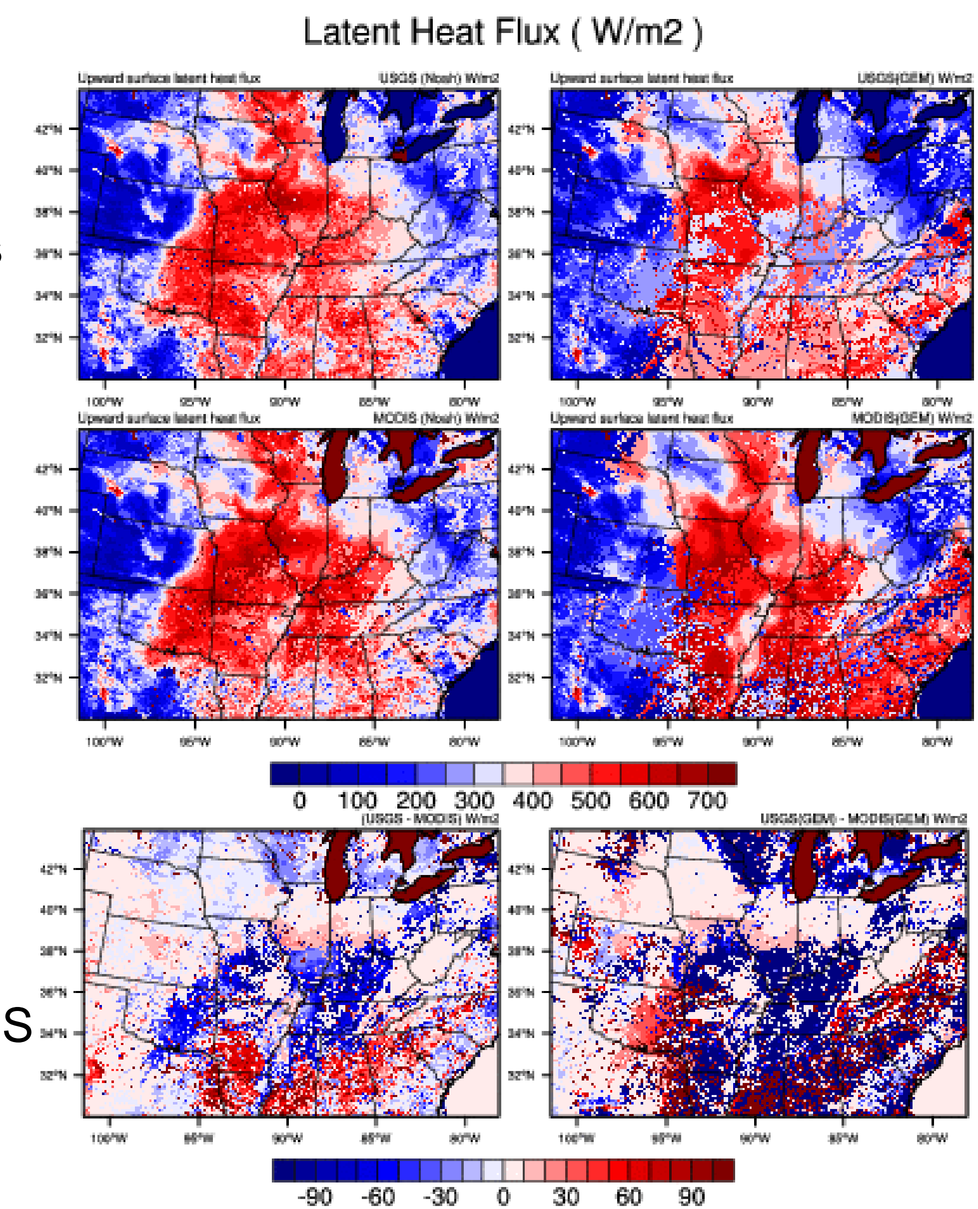
Dotted Line: Noah-GEM

Solid Line: Observed

MODIS and USGS LANDUSE MAP



Latent flux comparison (19 UTC 15 June)



USGS+Jarvis

USGS+GEM

MODIS+Jarvis

MODIS+GEM

Difference
USGS - MODIS

USGS(GEM) -
MODIS (GEM)

Land-use difference between USGS and MODIS over US

Vegetation Type	USGS	MODIS	Diff	% Diff	Vegetation change in USGS and MODIS (grid points)
Savanna	13947	1964	11983	- 85.91%	**Savanna change to** Grass(5837), crop(2081), ENLF(1384), Shrubland(1073) **Mixed Forest change to** DBLF(3460), EBLF(74), ENLF(4926), Dry crop(1271), cropland/woodland mosaic(1221) **Urban change to** Urban change(3545) Grass(517), crop(1012), shrubland(442) **Cropland change to** Grass(7292), dry cropland(68045), MF(2428), Savanna(2081), DBLF(12664), ENLF(3763), crop/grass mosaic (41349), crop/wood mosaic (23480)
Grassland	86357	109938	23581	+ 27.30%	
Deciduous Braodleaf Forest	47336	30048	17288	- 36.72%	
Evergreen Broadleaf Forest	451	7188	6737	--	
Evergreen Needleleaf Forest	92019	56238	35781	- 38.88%	
Deciduous Needleleaf Forest	0	12	12	-	
Mixed Forest	26383	37852	11469	+ 43.47%	
Urban and Built-up	4306	7436	3130	+ 72.68%	
Cropland	Irrig c.- 6152 Dry c. – 76341	166611	84118	+ 101.2%	
Barren or sparsely vegetated	5840	5745	95	- 1.6%	
Shrubland	106324	Open S. – 106071 Closed S.– 6126	5875	+ 5.52%	
Wetland	374	0	374	-	
Wooded Tundra	2376	1143	1233	- 51.89%	
Mixed Tundra	13	0	13	-	

NCAR

PURDUE UNIVERSITY

Model sensitivity to land-use data sets

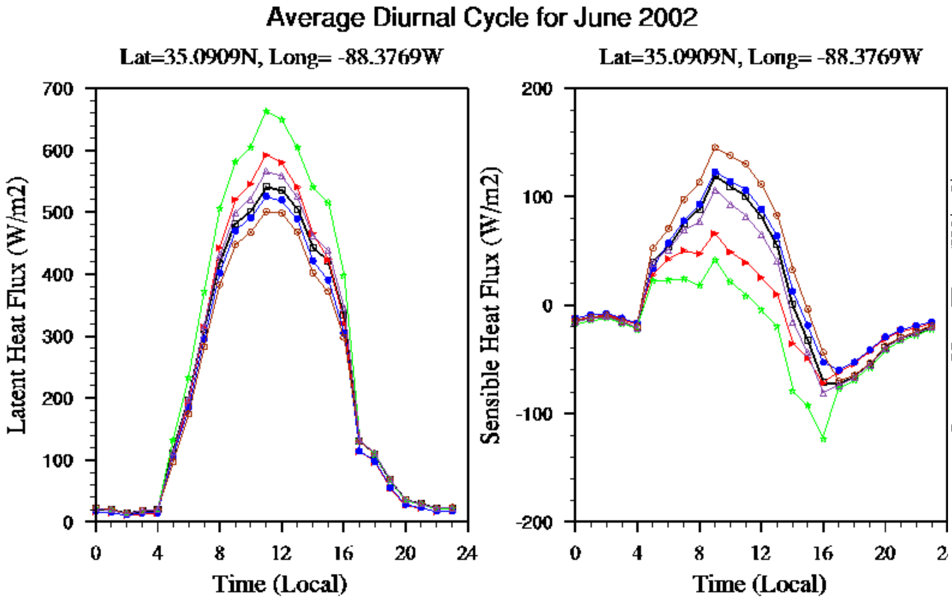
From USGS –Deciduous broadleaf forest to MODIS–cropland

Black line – using DLBF parameters

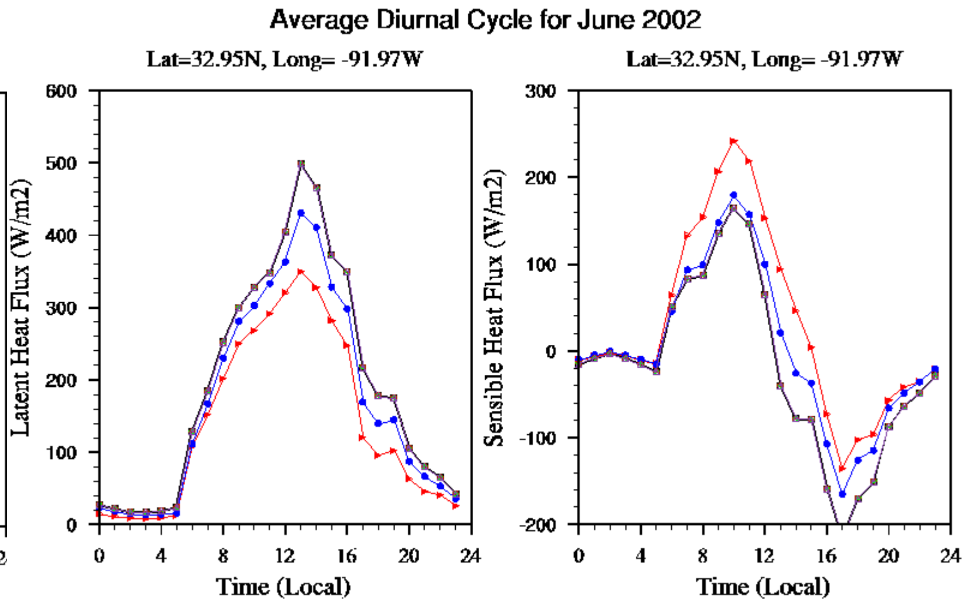
Red line – using all cropland parameters

Blue line – Using all DLBF except Z0, Green line – Using all DLBF except Rc_min,

Brown line – Using all DLBF except RGL, Purple line – using all DLBF except HS



Noah-Jarvis

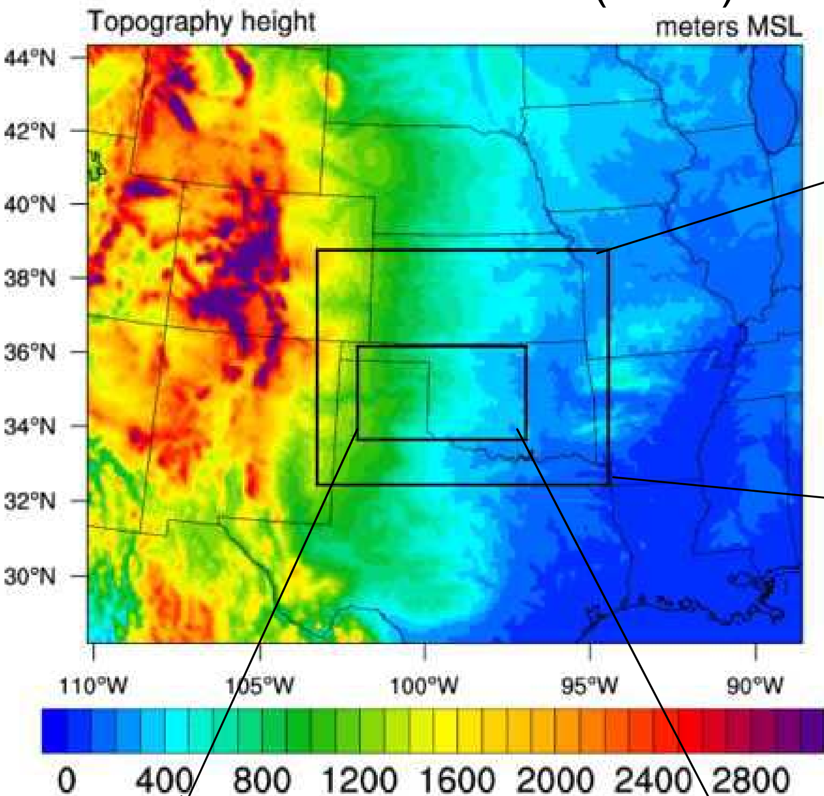


Noah-GEM

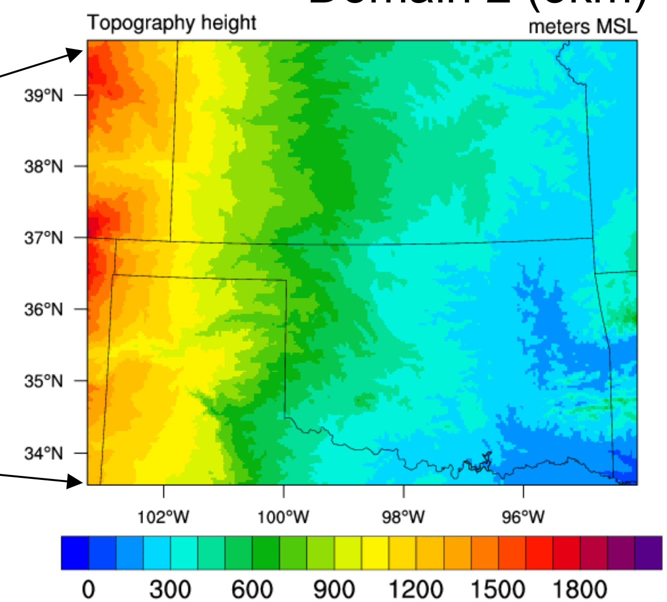
GEM's latent heat flux is more sensitive

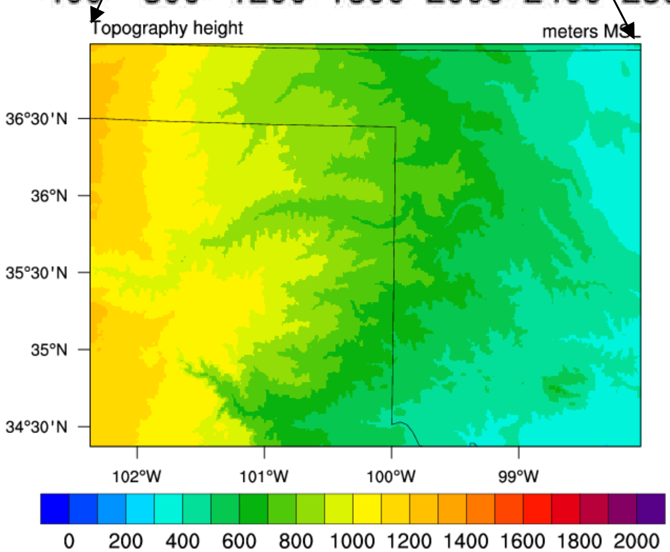
In Jarvis: Rc_min is the most sensitive parameter

Domain 1 (9Km)



Domain 2 (3km)

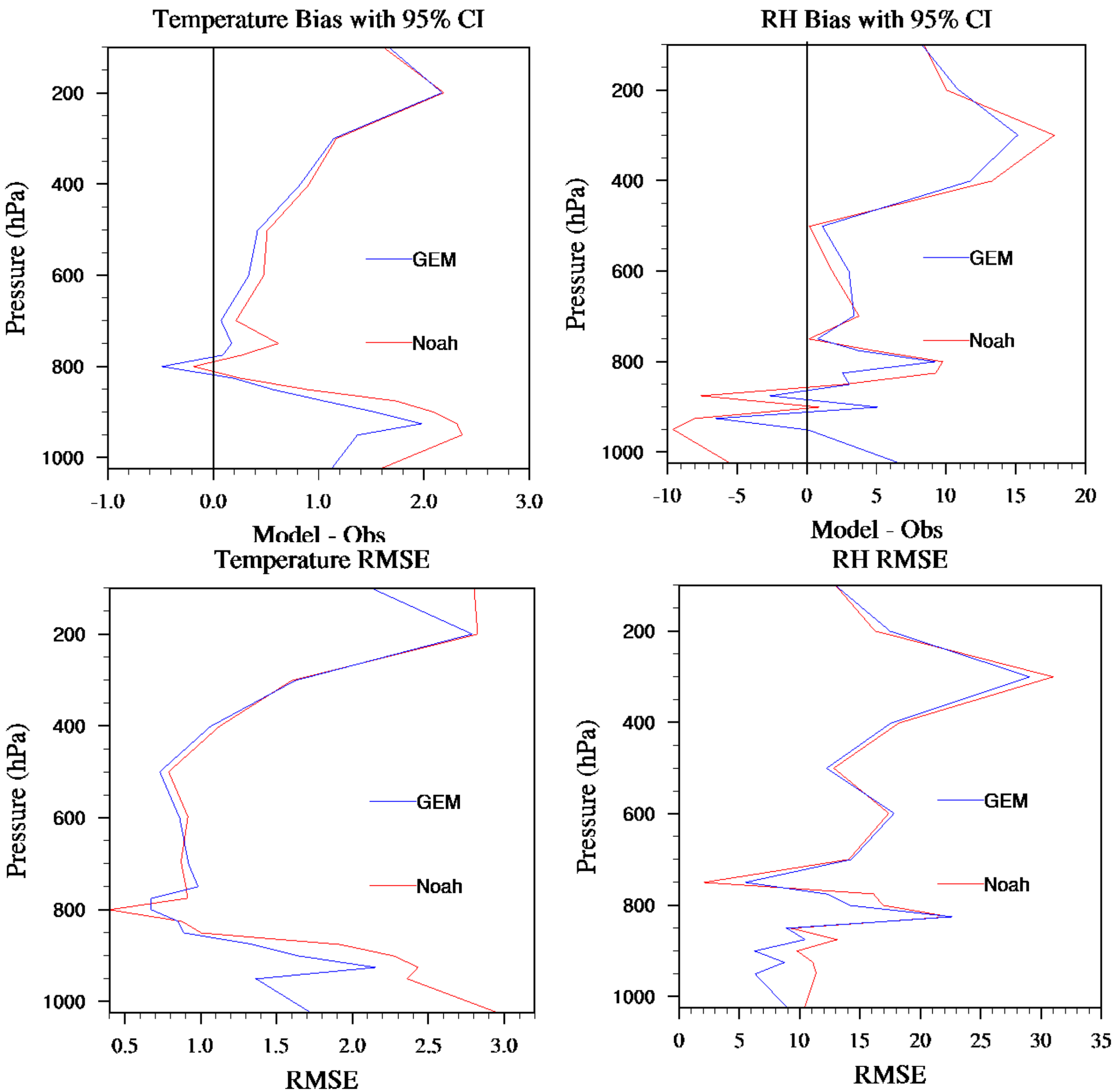




Coupled WRF/Noah/GEM simulations with MODIS land-use data

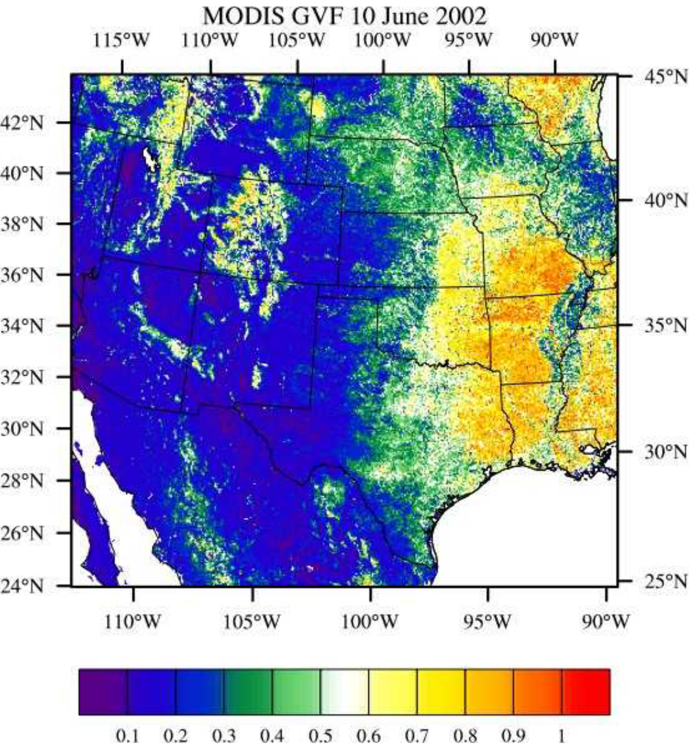
Domain 3 (1 km)

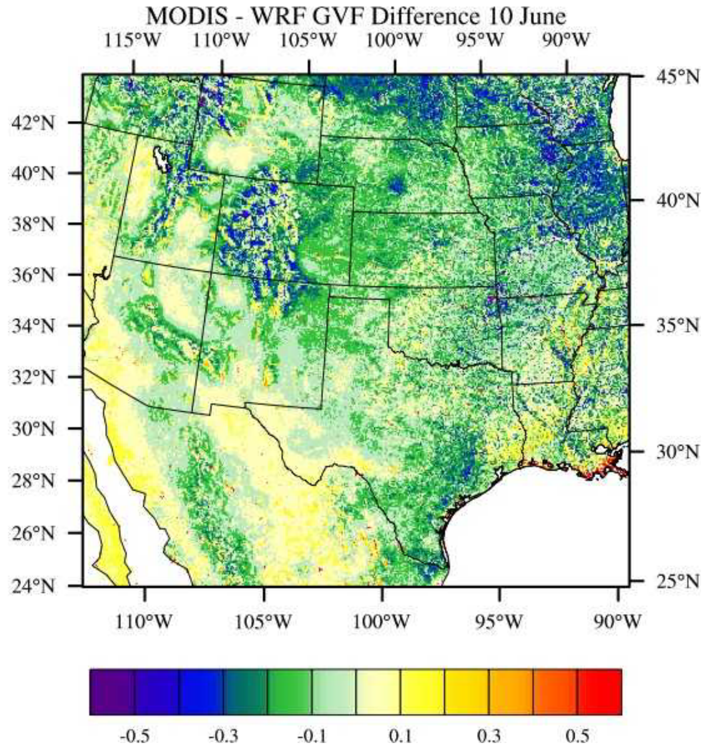
Noah/GEM improve the temperature and humidity in WRF PBL



Upper air soundings at 00Z 29 May 2002: Bias and RMSE

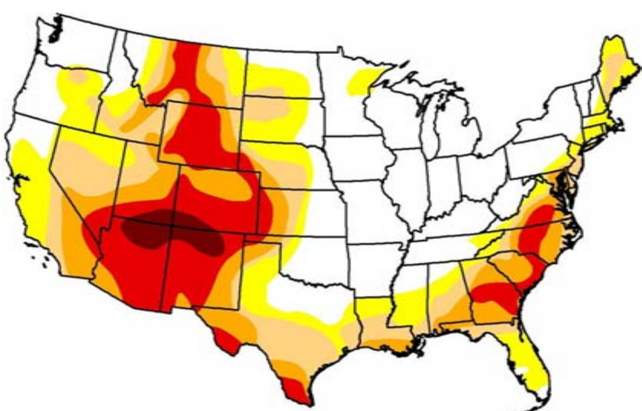
Advantage of realtime satellite data vs.WRF climatology





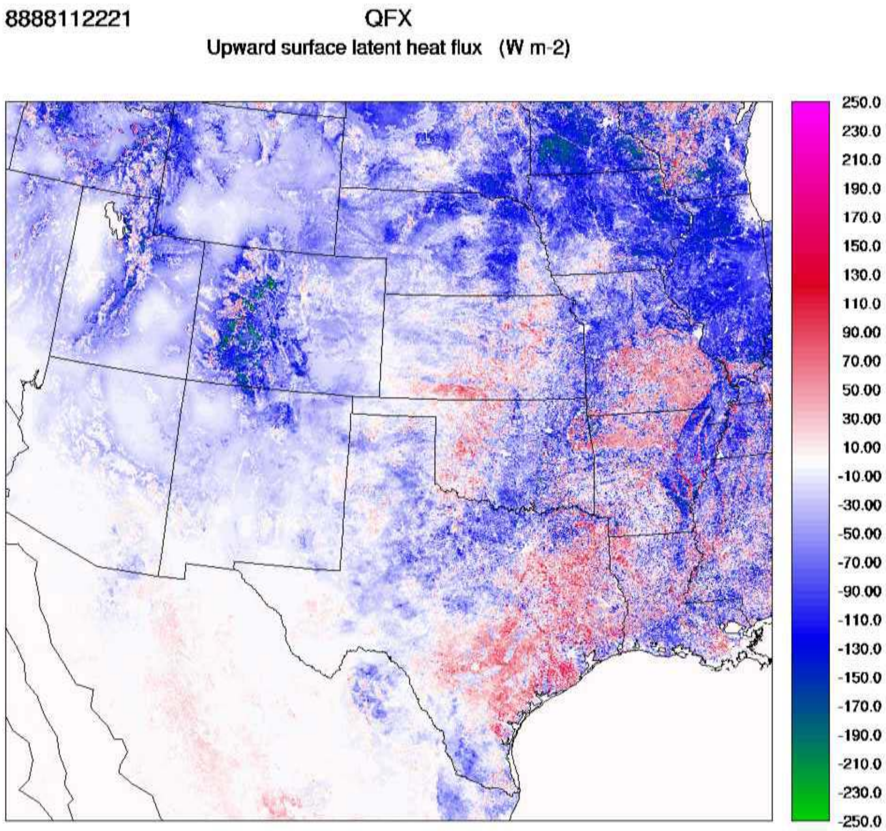
- MODIS vegetation fraction lower over most of the domain, particularly lower in the SGP region, which experienced drought in 2002.

Drought Monitor
June 10, 2002



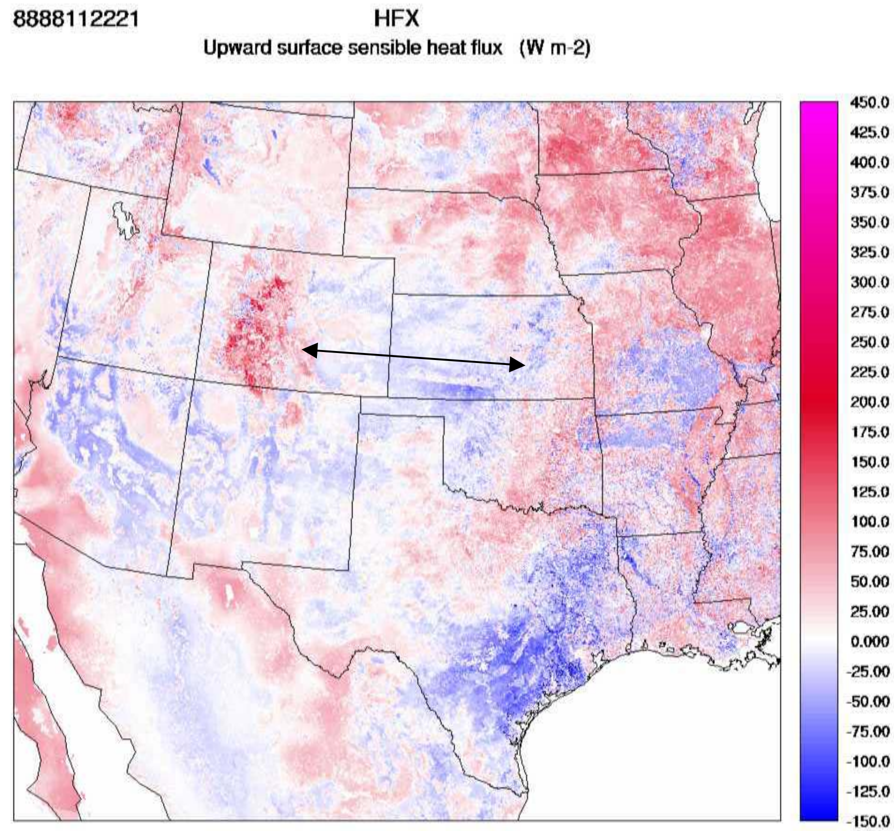
NCAR

Difference in surface sensible heat fluxes
21 Z averaged for 10-16 June 2002



Latent Heat Flux

Noah with MODIS FPAR and LAI -- without



Sensible Heat Flux

Noah with MODIS FPAR and LAI -- without

Lessons Learned

- Responses of Rc to environmental and soil conditions are fairly different in Jarvis and GEM formulations.
- That leads to large differences in soil moisture and latent heat fluxes.
- Noah-GEM produce better latent heat flux and soil moisture. But evaluation with AMERIFlux data is mixed.
- Coupled WRF/Noah/GEM simulations show the improvement of T and q in lower boundary layer.
- Fairly large differences in simulations with the new BU-NCEP MODIS land-use data.
- Future work will focus on coupled WRF simulations with new MODIS land-use and high-resolution (temporal and spatial) remote-sensing data (particularly these recently developed in JCSDA).

Derivation of Minimum Canopy Resistance

The bulk surface resistance (r_s) was retrieved from an inverted form of the Penman-Monteith equation:

$$r_s = \frac{r_a\left[\Delta\left(R_n - G\right) - \lambda E\left(\Delta - \gamma\right)\right] + \rho c_p D}{\gamma \lambda E}$$

Next, r_s was scaled by LAI to estimate the r_c following the method presented by Hatfield and Allen (1996):

$$r_c = \frac{0.3\mathrm{LAI} + 1.2}{\mathrm{LAI}} r_s$$

Finally, $r_{c_{\min}}$ was derived using an inverted form of the Jarvis relationship:

$$r_{c_{\min}} = \frac{r_{c_{\max}} f r_c \mathrm{LAI} F_2 F_3 F_4}{r_{c_{\max}}(f+1) - r_c \mathrm{LAI} F_2 F_3 F_4}$$

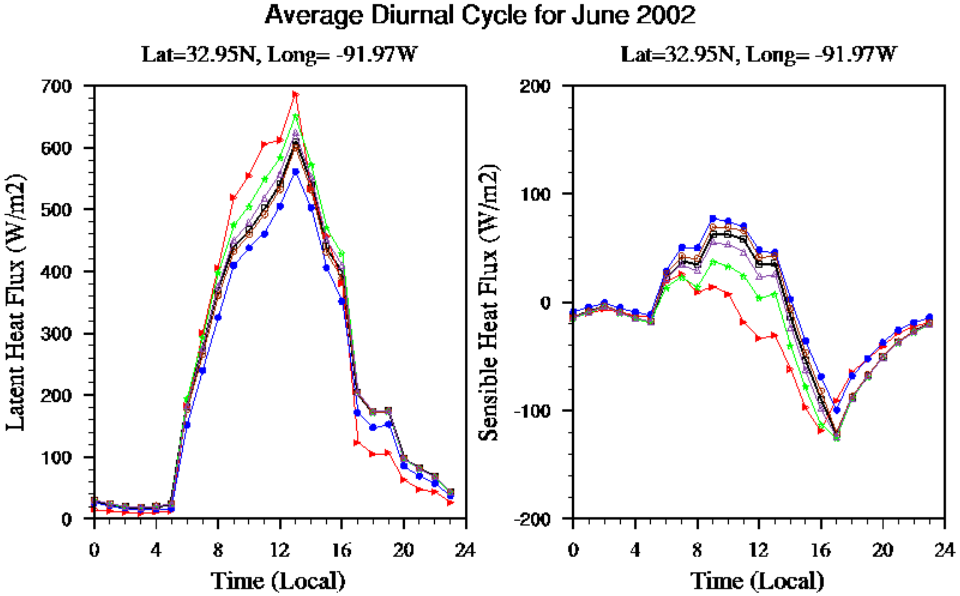
Model sensitivity to land-use data sets

From USGS–Savanna to MODIS – Grassland

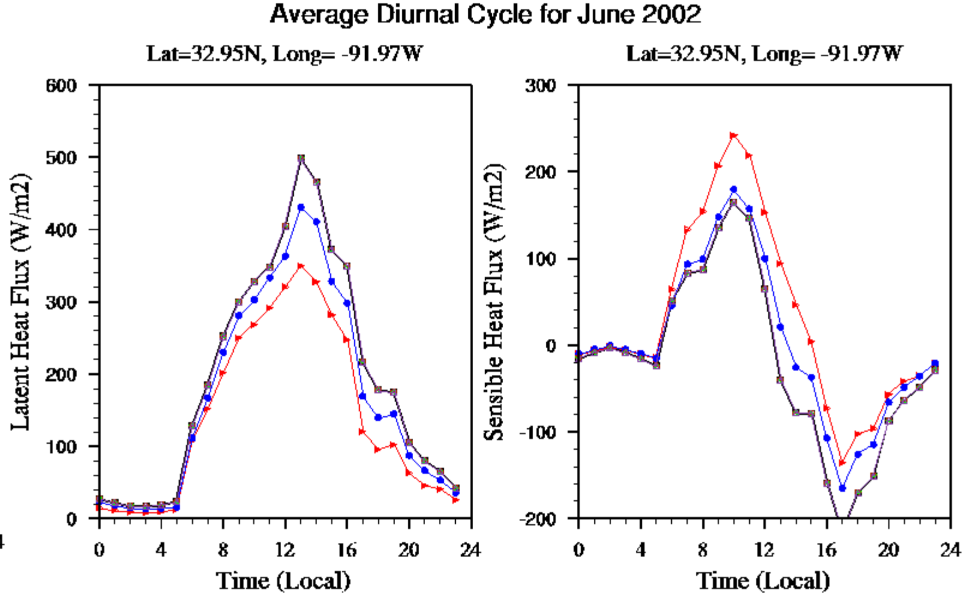
Black line – using all savanna parameters

Red line – using all grassland parameters

Blue line – Using all savanna except Z0, Green line – Using all savanna except Rc_min, Brown line – Using all savanna except RGL, Purple line – using all savanna except HS



Noah-Jarvis



Noah-GEM

GEM's latent heat flux is more sensitive

In Jarvis: Rc_min is the most sensitive parameter