Integrating a photosynthesis-based canopy resistance model and satellite data in Noah

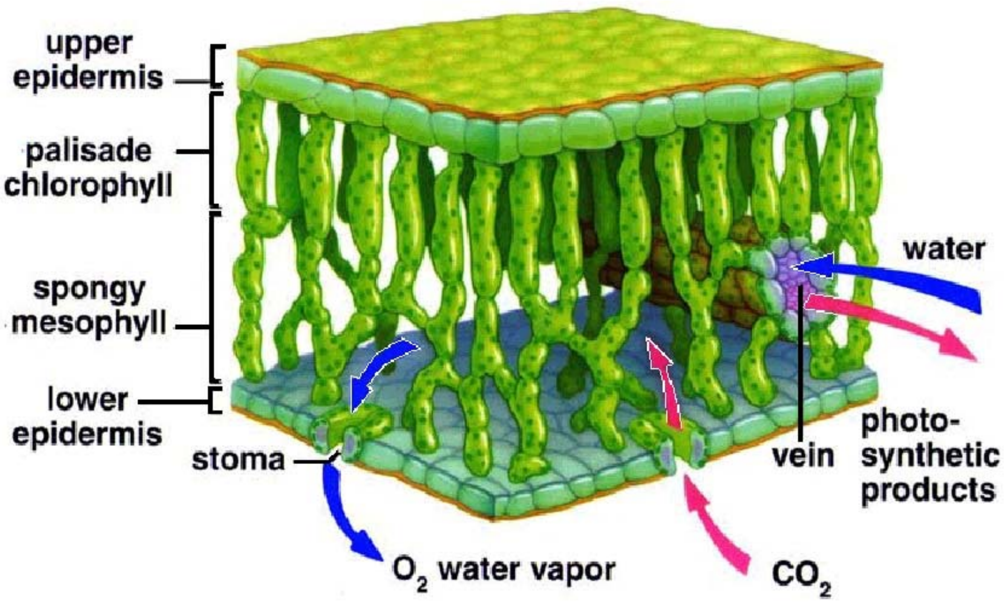
Anil Kumar[1,2], Fei Chen[1], Dev Niyogi[2], Kevin Manning[1],
Mike Ek[3], Kenneth Mitchell[3] ,
Joseph Alfieri[2]

[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

Motivations

- Evapotranspiration is the most effective and sustainable way to transport water vapor to the atmosphere
- Jarvis-type canopy resistance (Rc) formulation still widely used in coupled NWP/LSM models (e.g., WRF/Noah)
  - Jarvis-type scheme relies on minimum stomatal resistance (difficult to measure)
- This effort explores the use of advanced Rc schemes and modern-era remote-sensing data to improve
  - water vapor in WRF/Noah
  - deposition velocity in WRF-Chem/Noah
- Study conducted in
  - Long-term uncoupled runs
  - Coupled WRF/Noah runs
  - USGS and the new MODIS LULC dataset



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)

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

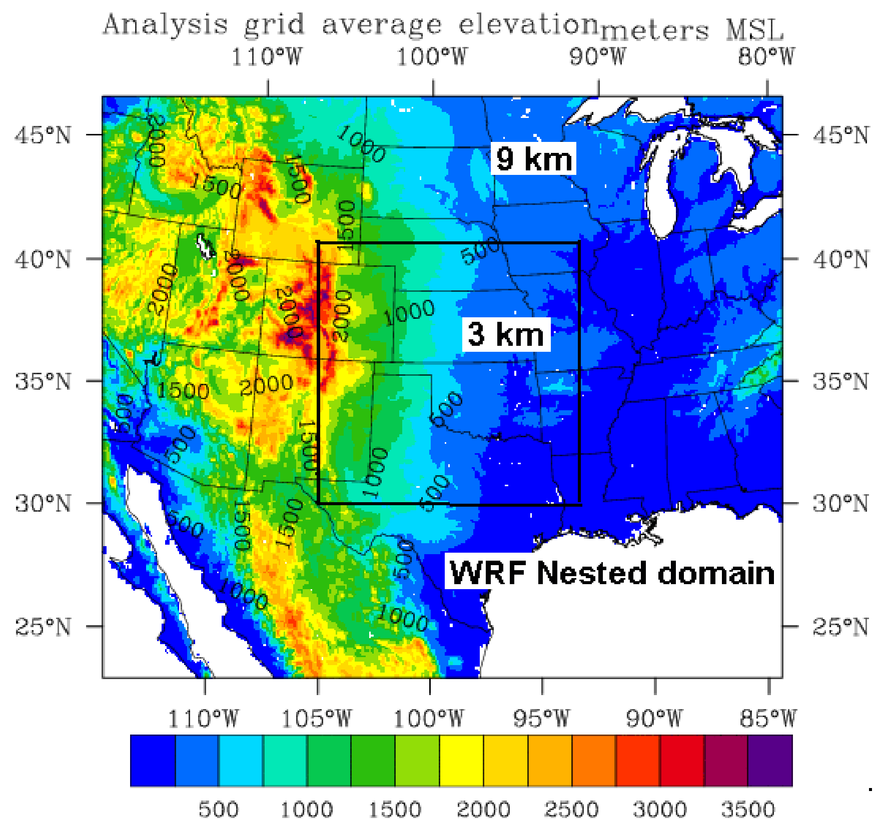
hs – relative humidity at leaf surface
ps – Surface atmospheric pressure
An – net CO2 assimilation or photosynthesis rate
Cs – CO2 concentration at leaf surface
m and b are linear coeff based on gas exchange consideration

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

NCAR High-resolution Land Data Assimilation System:

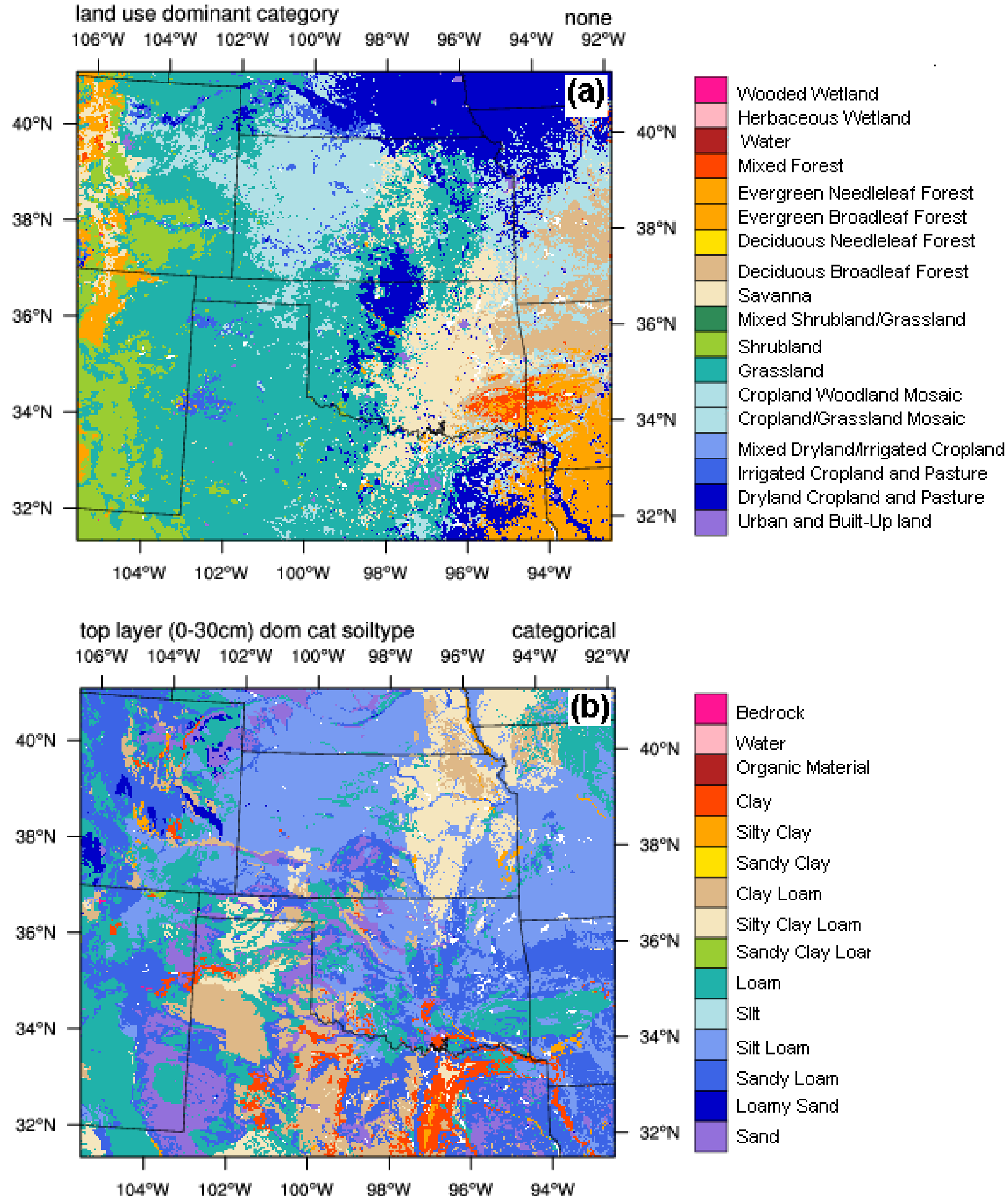
Capturing Small-Scale Surface Variability

- 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

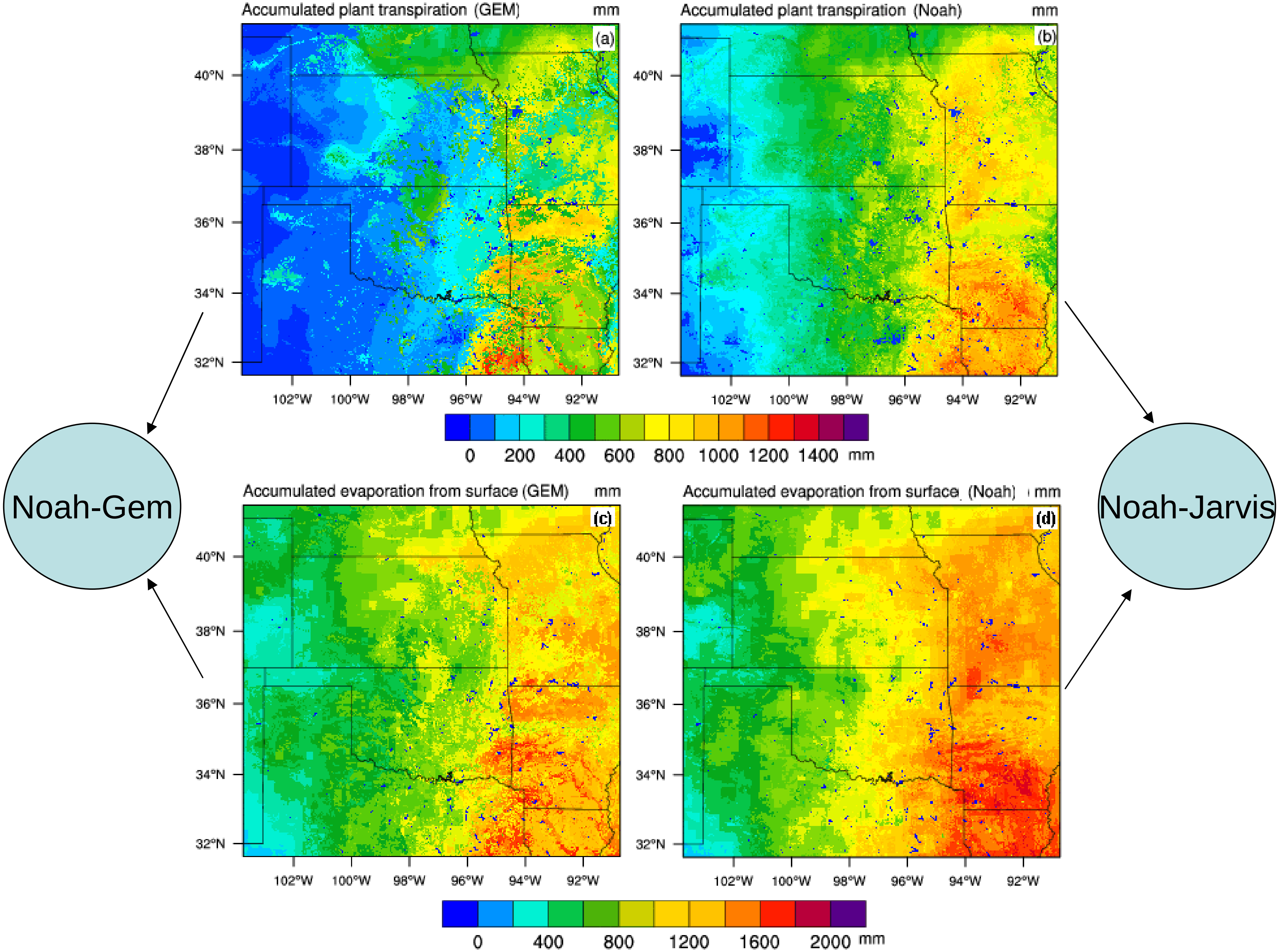


HRLDAS executed from January 2001 - July 2002

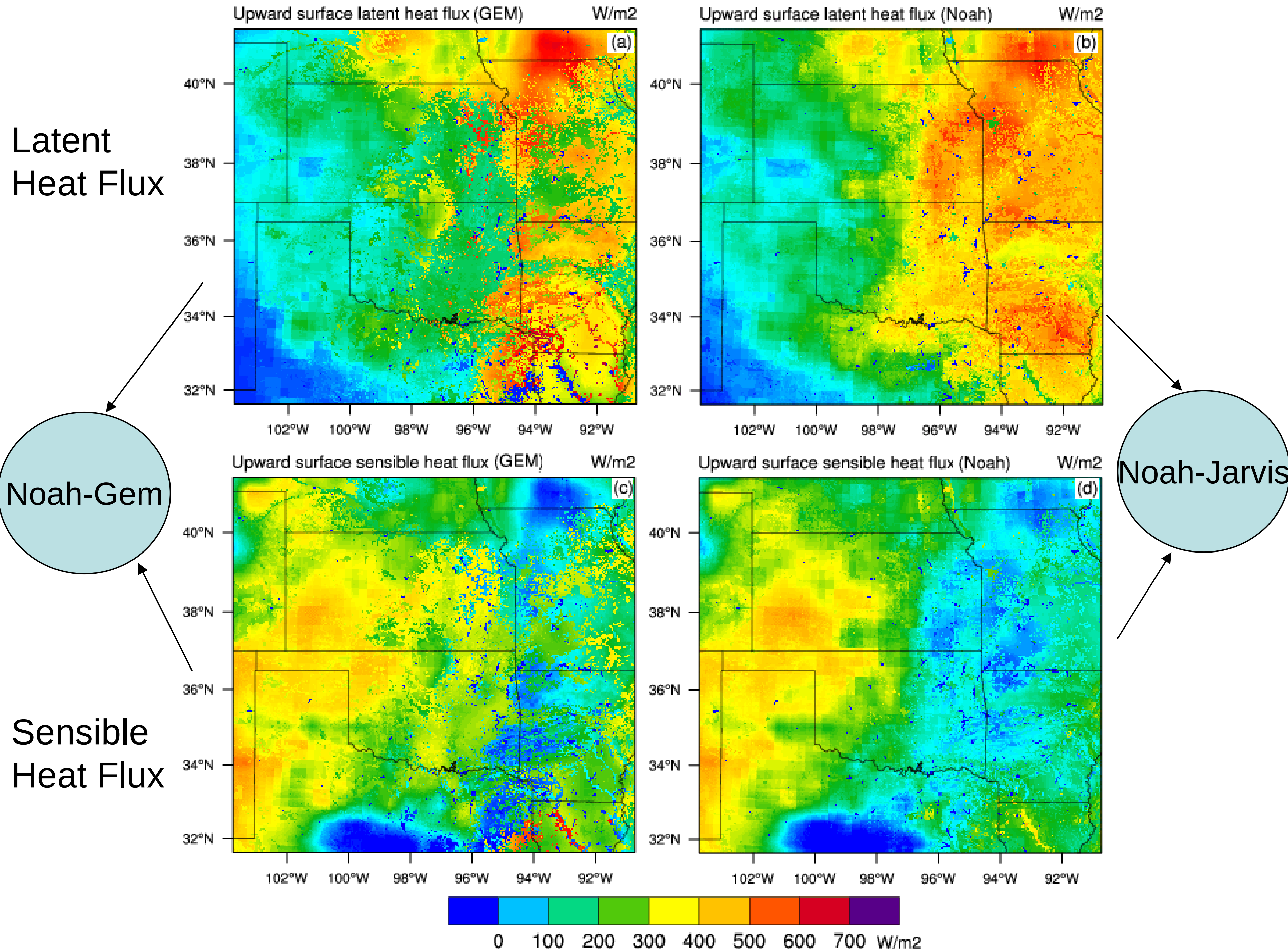
HRLDAS reference: Chen et al., 2007 (JAMC, vol 46, 694-713)



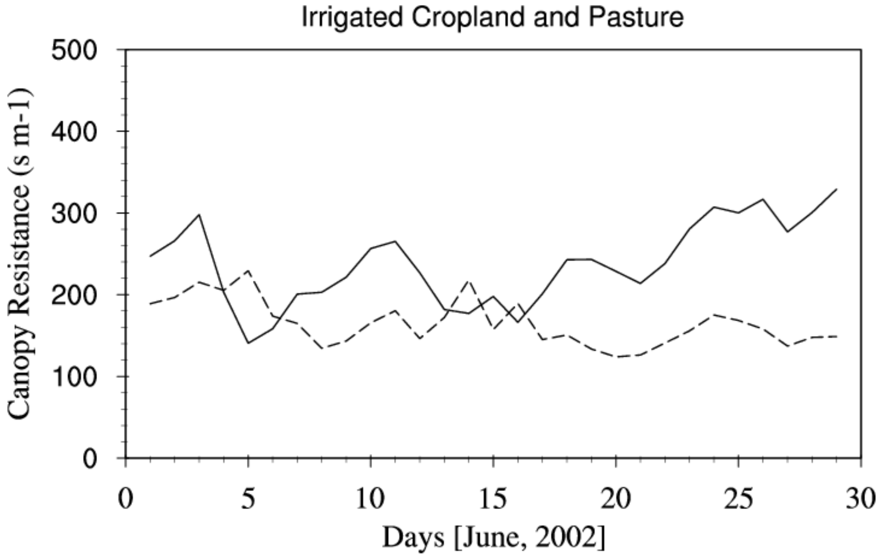
land use dominant category
none
(a)
Wooded Wetland
Herbaceous Wetland
Water
Mixed Forest
Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Savanna
Mixed Shrubland/Grassland
Shrubland
Grassland
Cropland Woodland Mosaic
Cropland/Grassland Mosaic
Mixed Dryland/Irrigated Cropland
Irrigated Cropland and Pasture
Dryland Cropland and Pasture
Urban and Built-Up land
top layer (0-30cm) dom cat soiltype
categorical
(b)
Bedrock
Water
Organic Material
Clay
Silty Clay
Sandy Clay
Clay Loam
Silty Clay Loam
Sandy Clay Loar
Loam
Silt
Silt Loam
Sandy Loam
Loamy Sand
Sand

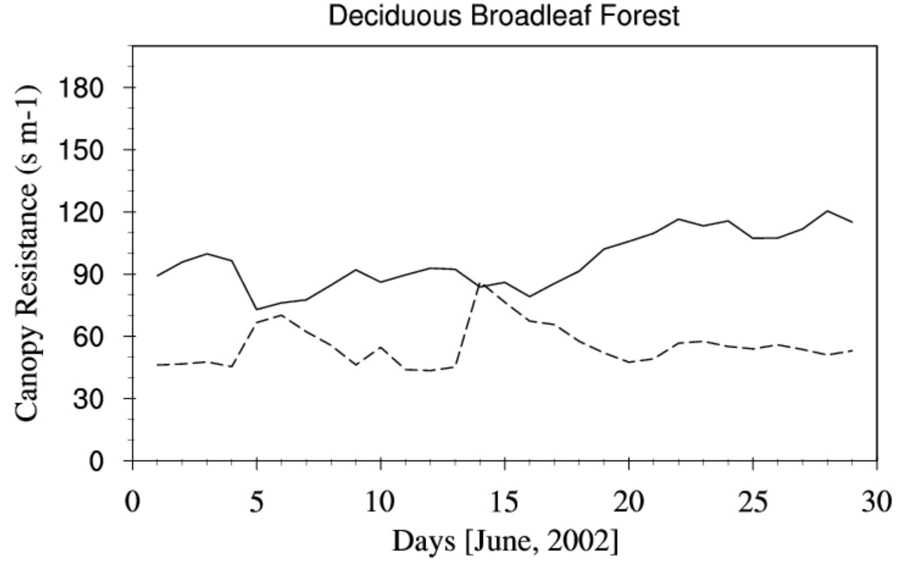


Accumulated plant transpiration (GEM) mm
(a)
Accumulated plant transpiration (Noah) mm
(b)
40°N
38°N
36°N
34°N
32°N
102°W
100°W
98°W
96°W
94°W
92°W
0 200 400 600 800 1000 1200 1400 mm
Noah-Gem
Noah-Jarvis
Accumulated evaporation from surface (GEM) mm
(c)
Accumulated evaporation from surface (Noah) mm
(d)
0 400 800 1200 1600 2000 mm

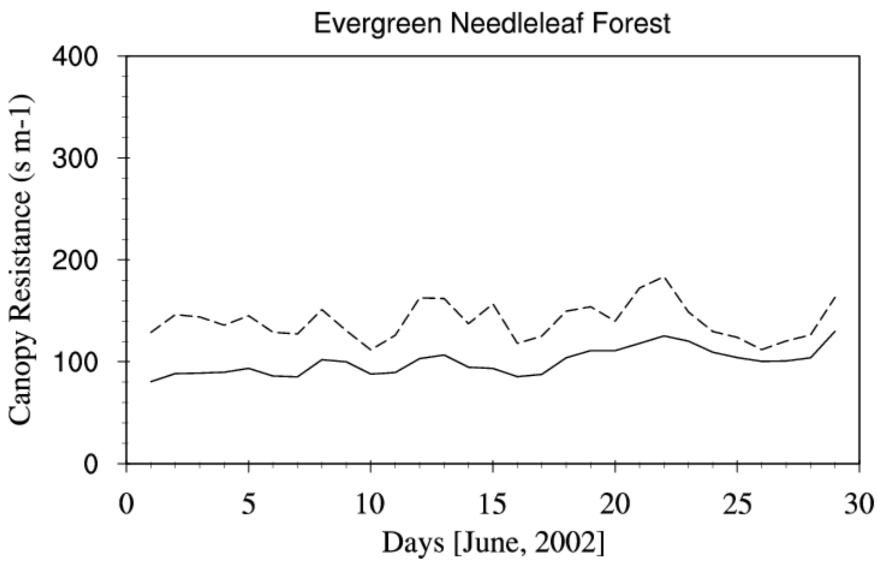

Upward surface latent heat flux (GEM)
W/m2
(a)
Upward surface latent heat flux (Noah)
W/m2
(b)
Upward surface sensible heat flux (GEM)
W/m2
(c)
Upward surface sensible heat flux (Noah)
W/m2
(d)
40°N
38°N
36°N
34°N
32°N
102°W
100°W
98°W
96°W
94°W
92°W
Latent
Heat Flux
Sensible
Heat Flux
Noah-Gem
Noah-Jarvis
0
100
200
300
400
500
600
700
W/m2

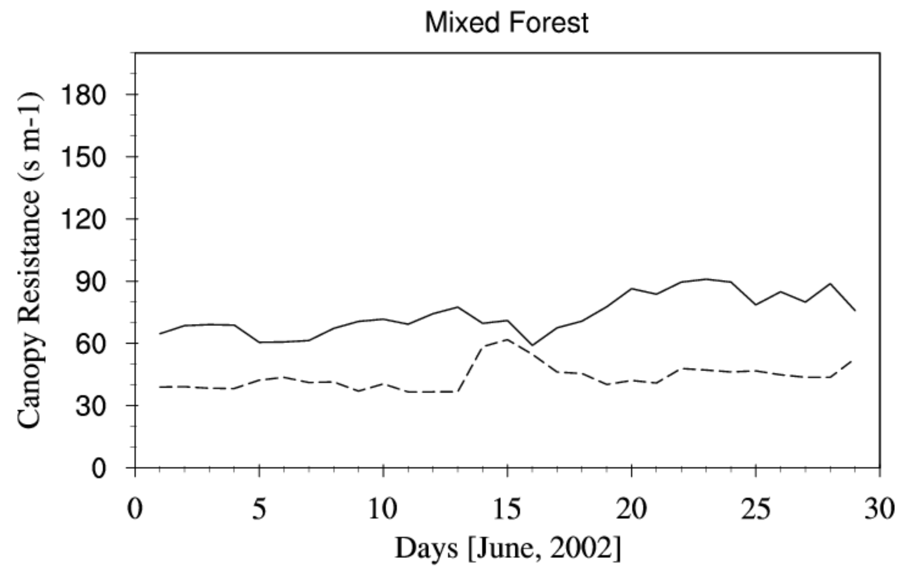
Canopy resistance



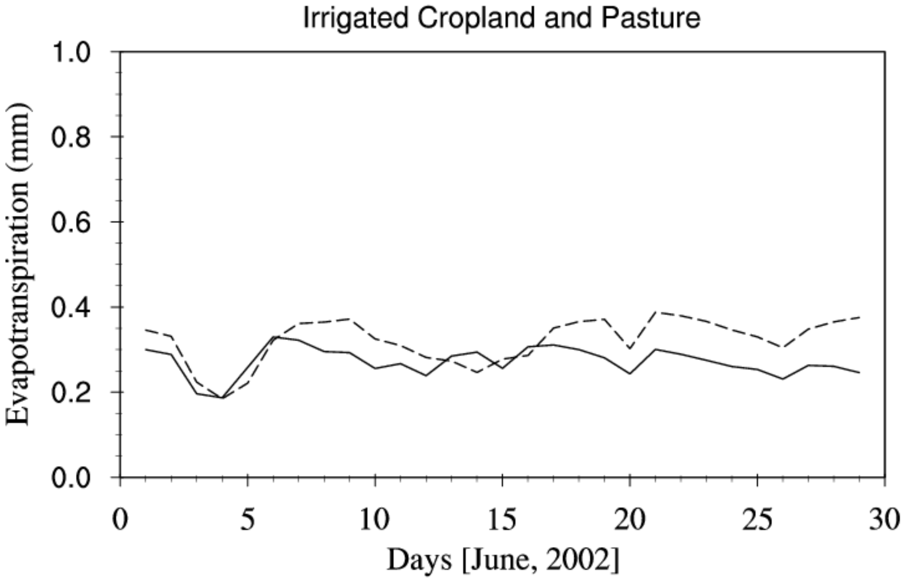


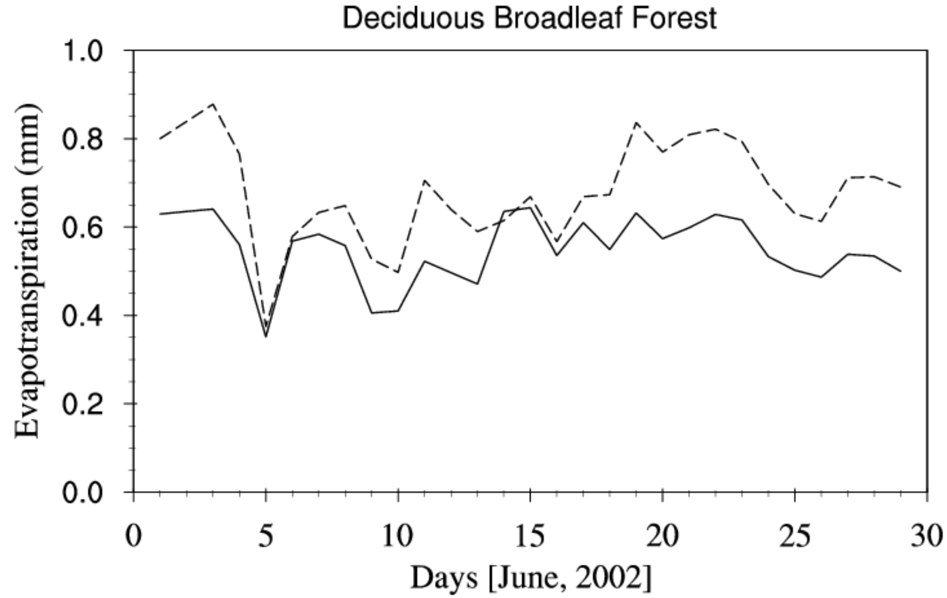
Solid Line: Noah-Jarvis
Dash Line: Noah-Gem



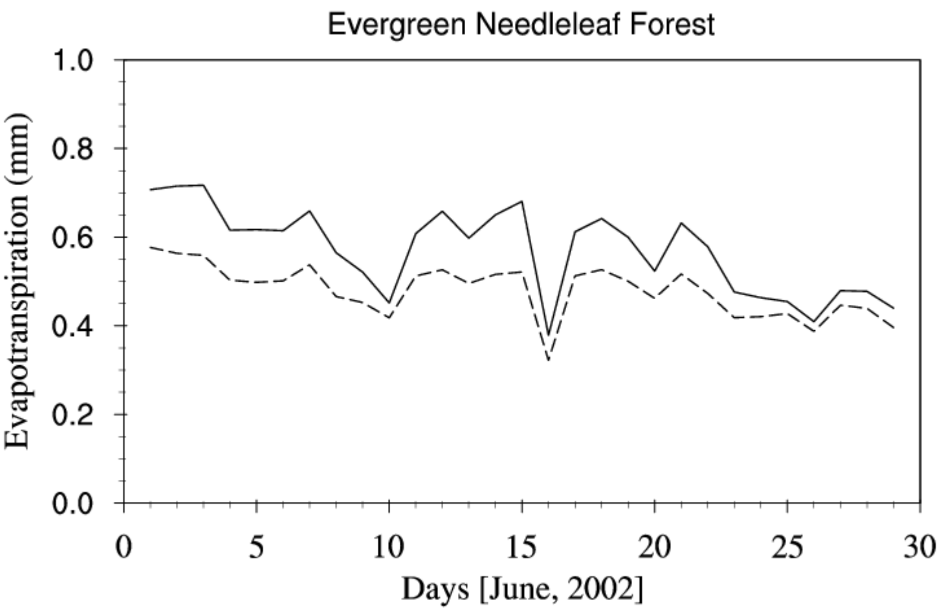


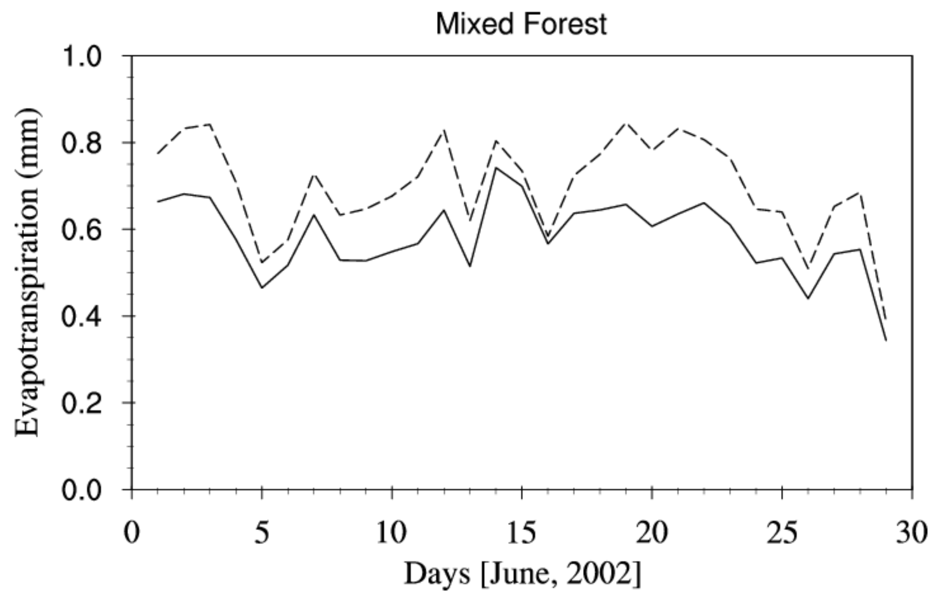
Evapotranspiration



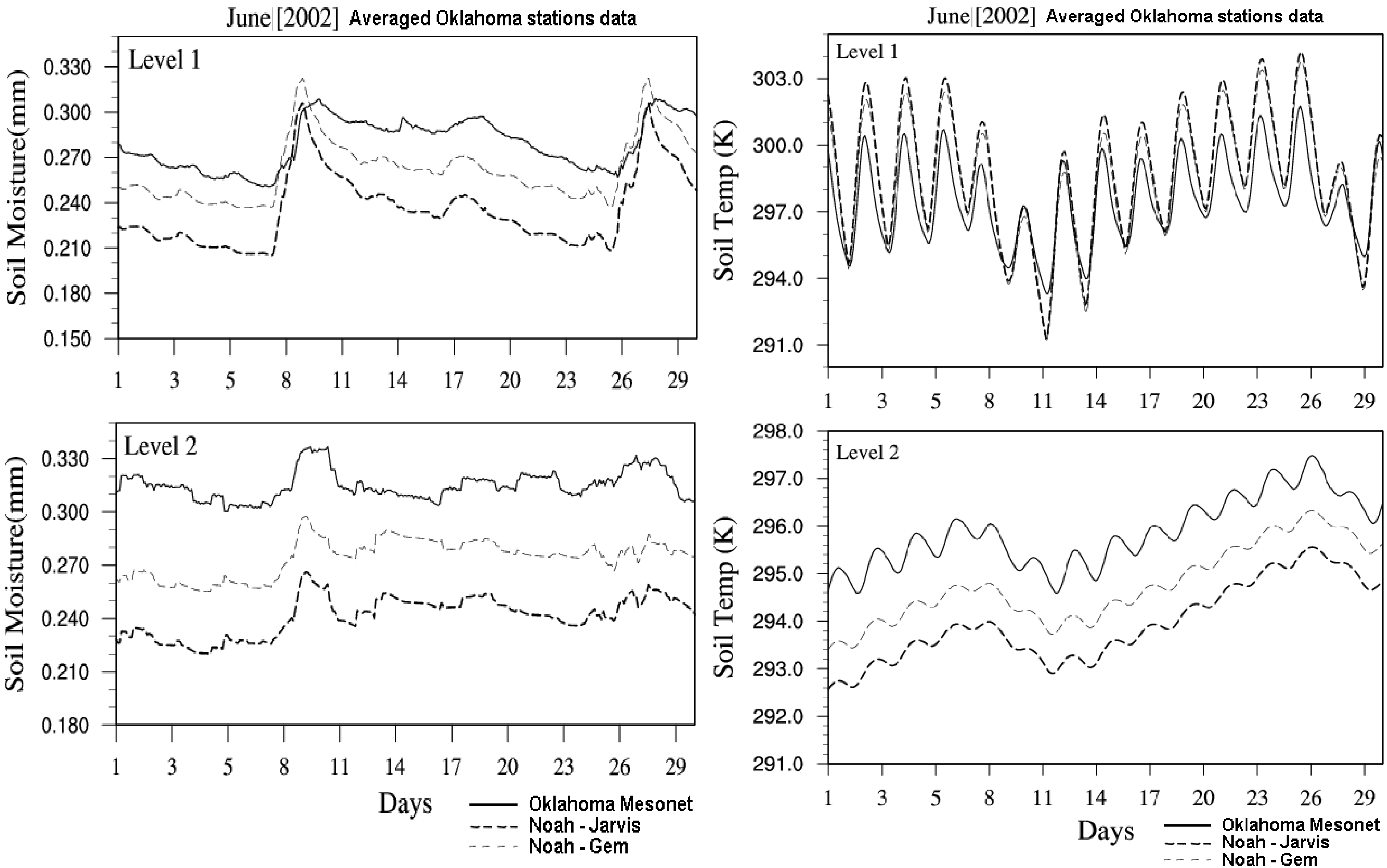


Solid Line: Noah-Jarvis
Dash Line: Noah-Gem

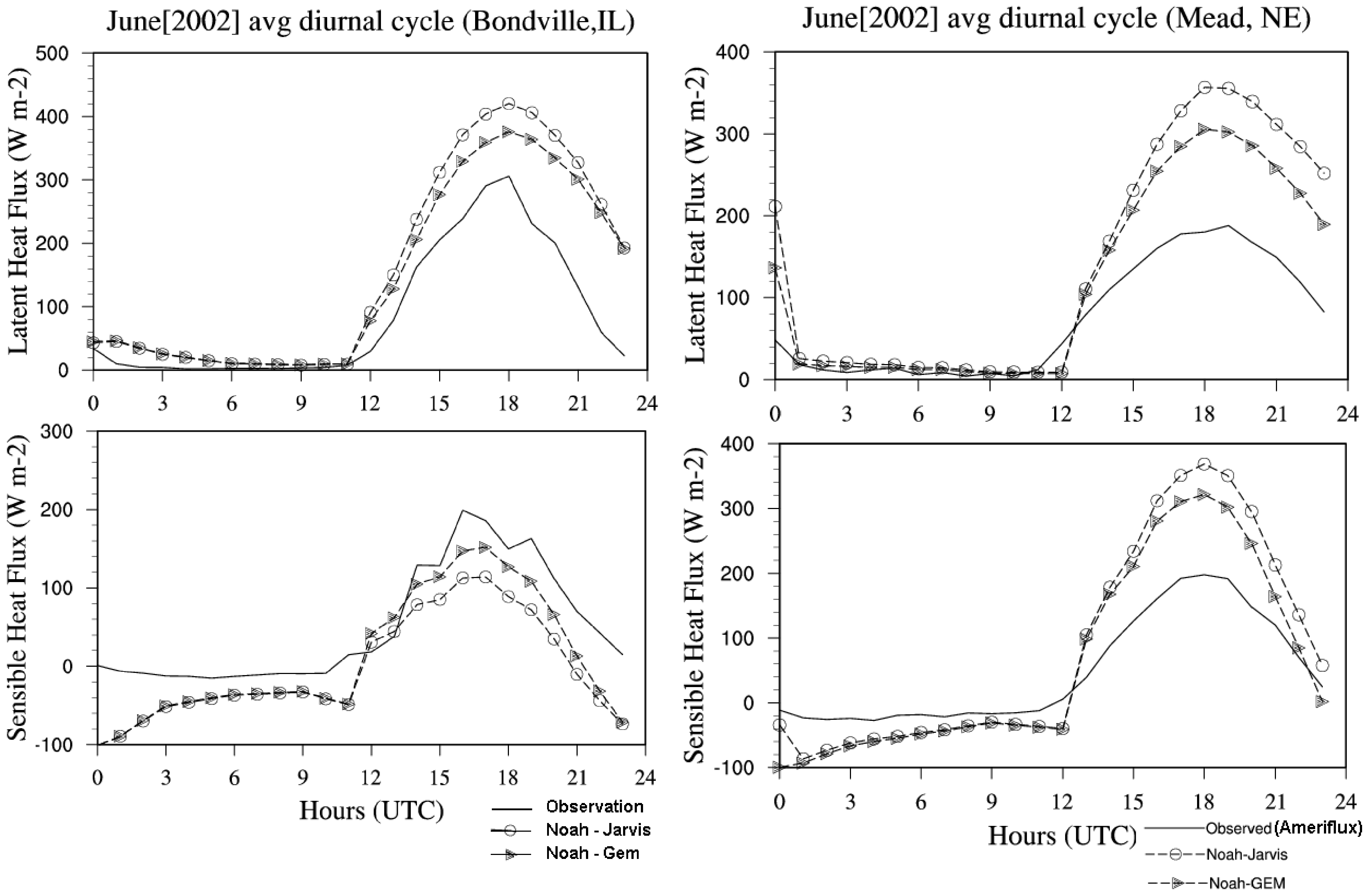




Soil moisture and temperature
averaged over ~80 Oklahoma Mesonet stations



Model comparison with AMERIFLUX site



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

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

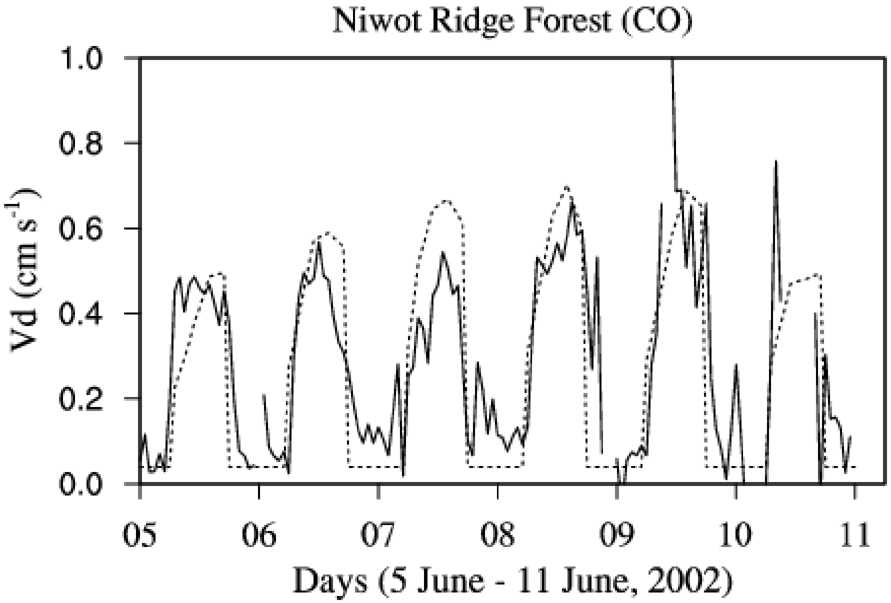
Free convection:

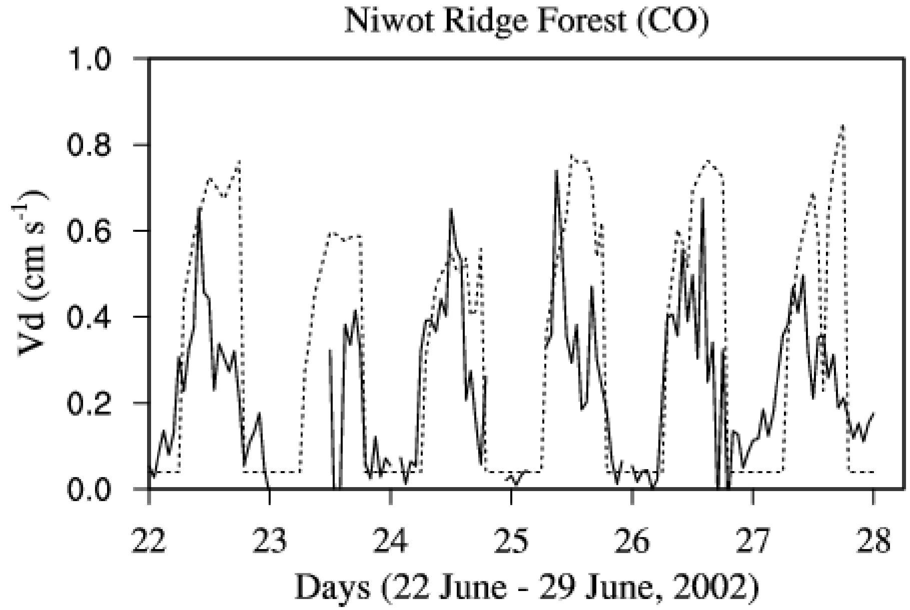
3. Canopy resistance (Rc) from GEM

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

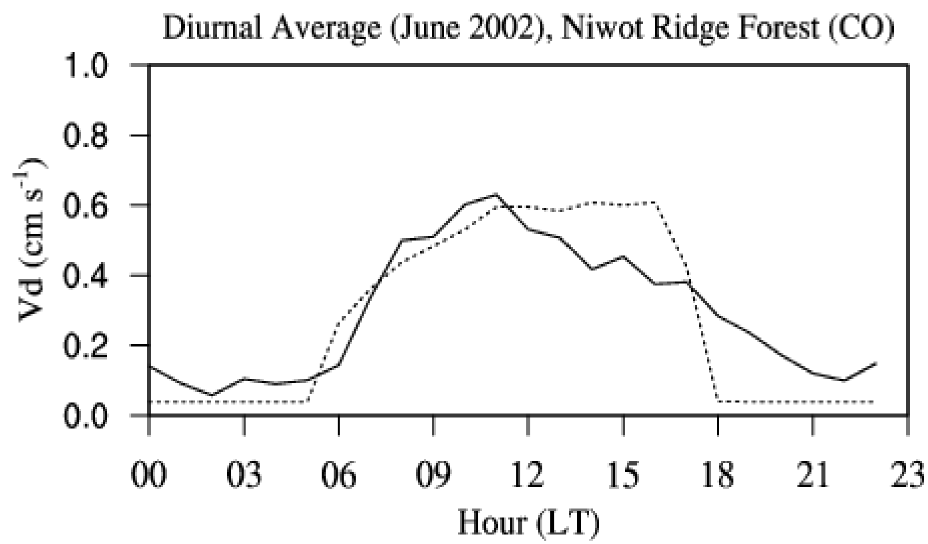
$$R_c = \frac{1}{g_s}$$

Dry Deposition Velocity (cm s-1)

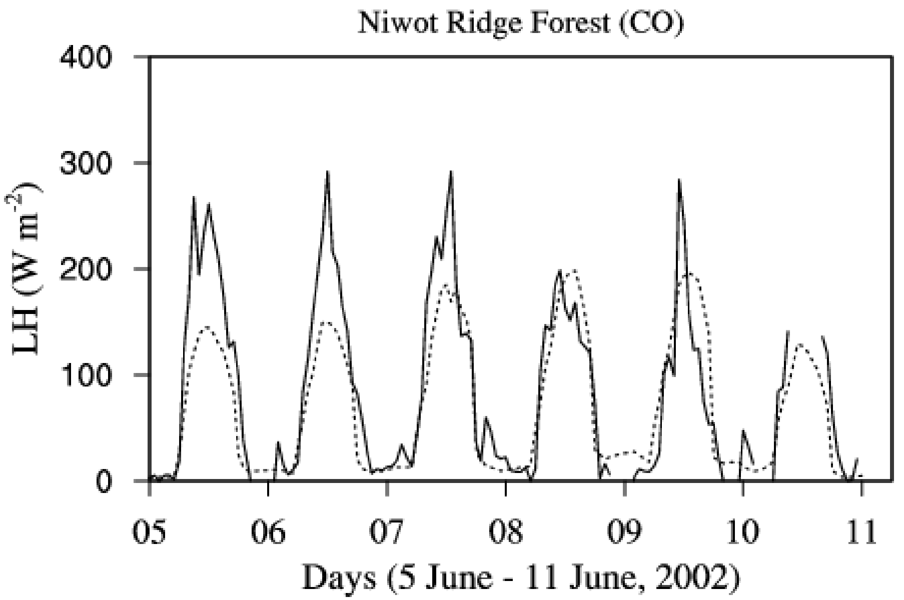


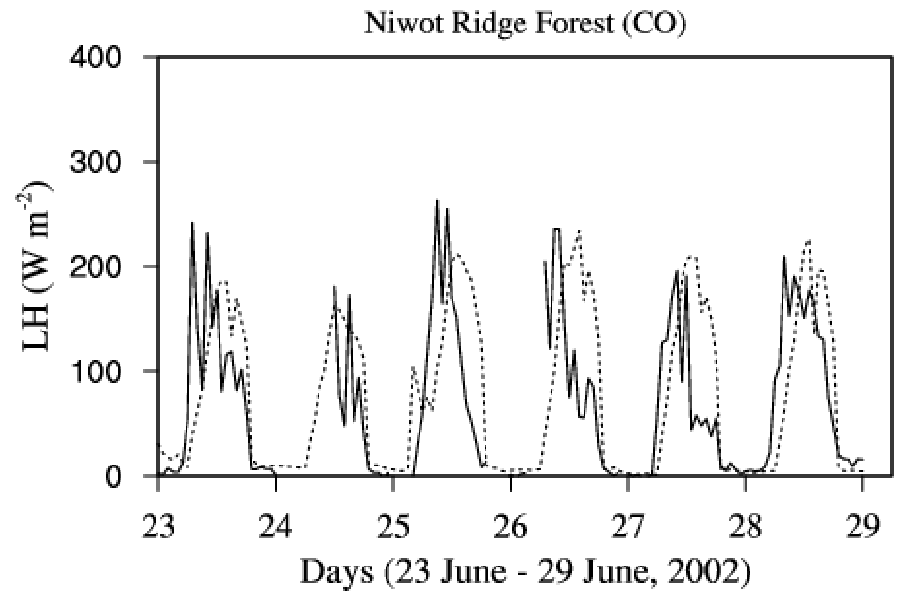


Dotted Line: Noah-GEM
Solid Line: Observed

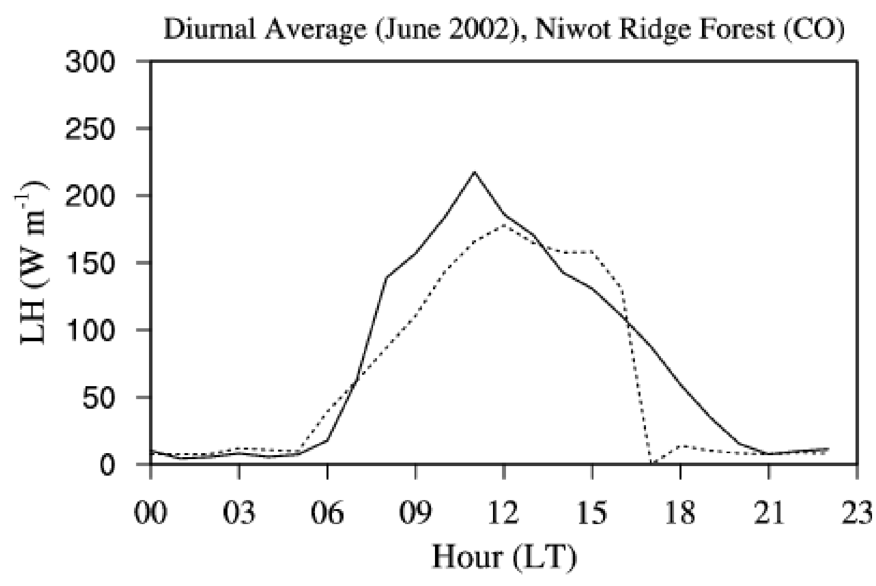


Latent Heat flux

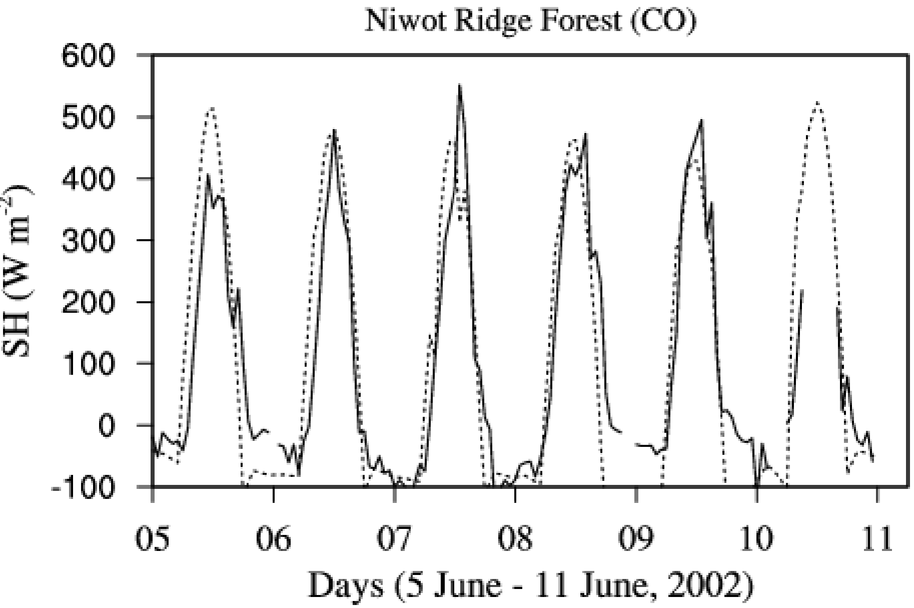


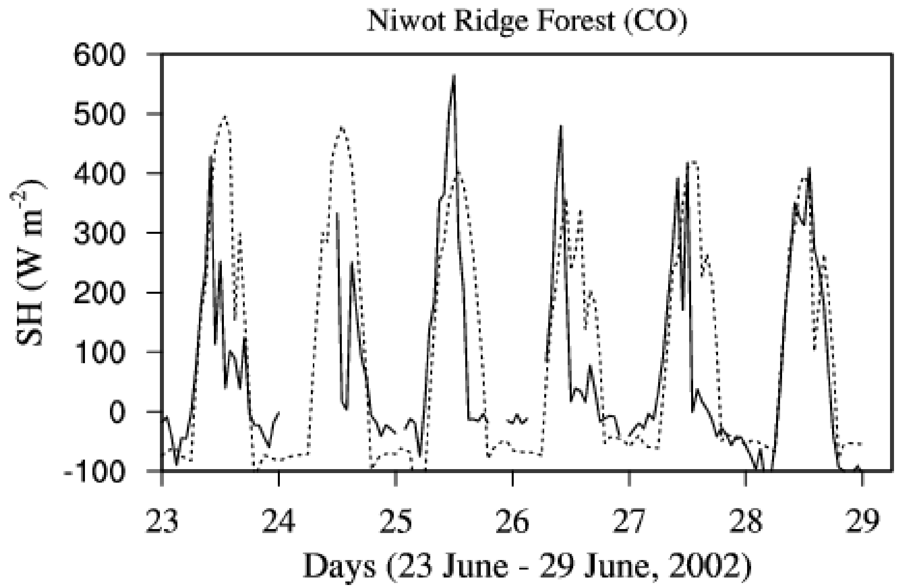


Dotted Line: Noah-GEM
Solid Line: Observed

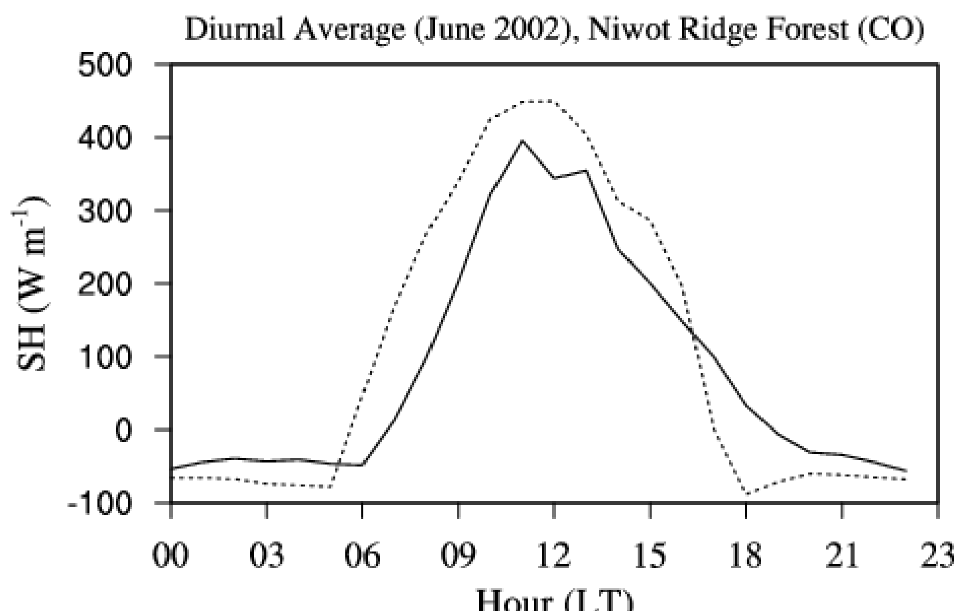


Sensible Heat flux

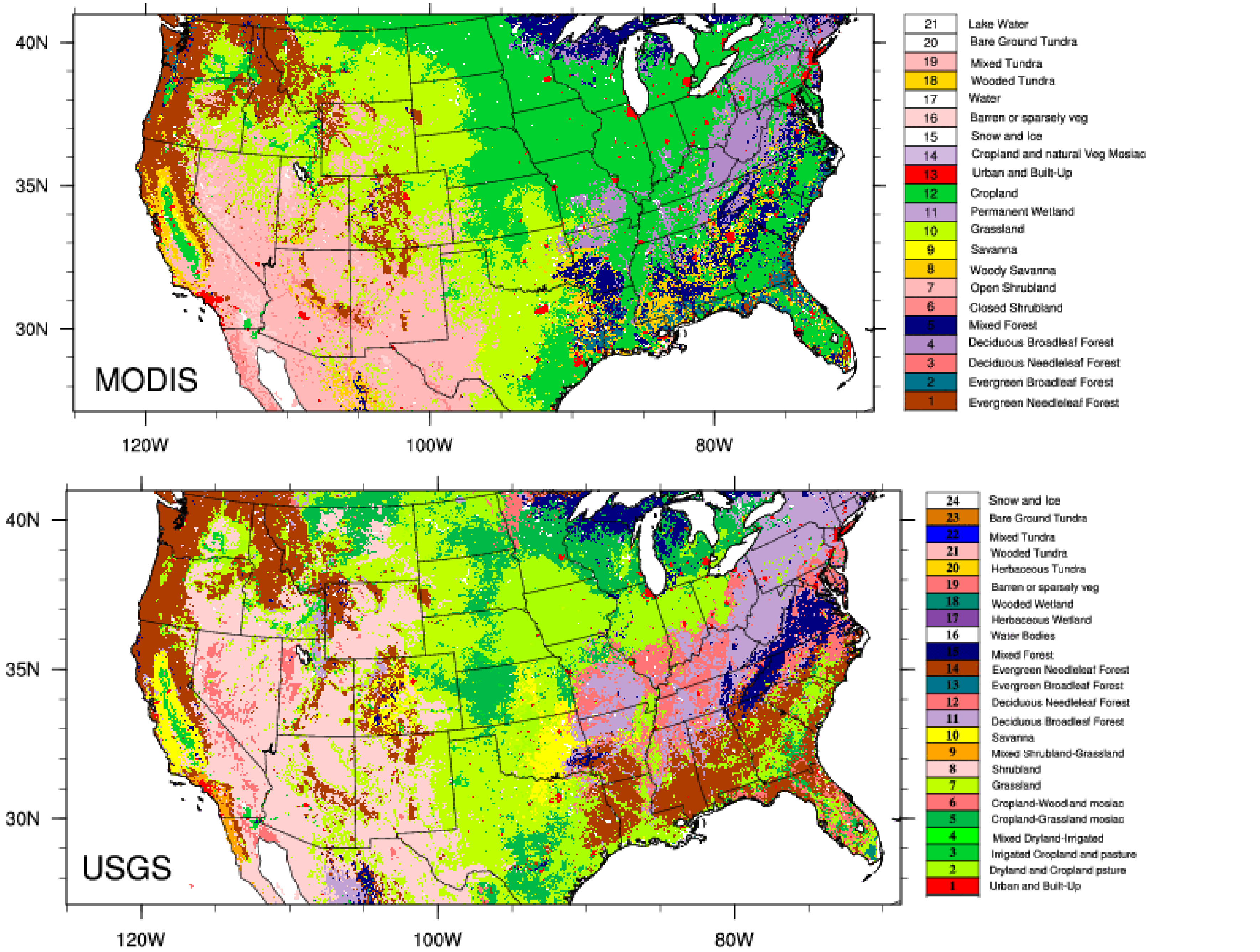




Dotted Line: Noah-GEM
Solid Line: Observed



MODIS and USGS Difference



Conclusion

- 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 (especially for evergreen forest and grassland).
- Noah-GEM produce better latent heat flux and soil moisture.
- Dry deposition velocity estimation is in good agreement with observed over Niwot site (CO). Analysis and verification is still way with WRF-Chem.
- New MODIS vegetation distribution is different from USGS and GEM model evaluation is underway with MODIS landuse. Need to explore a better use of today’s high-resolution (temporal and spatial) remote-sensing data (particularly these recently developed in JCSDA)