The Effect of Dynamic Root Water Uptake on the Land-Atmosphere Interactions of the U.S. Great Plains

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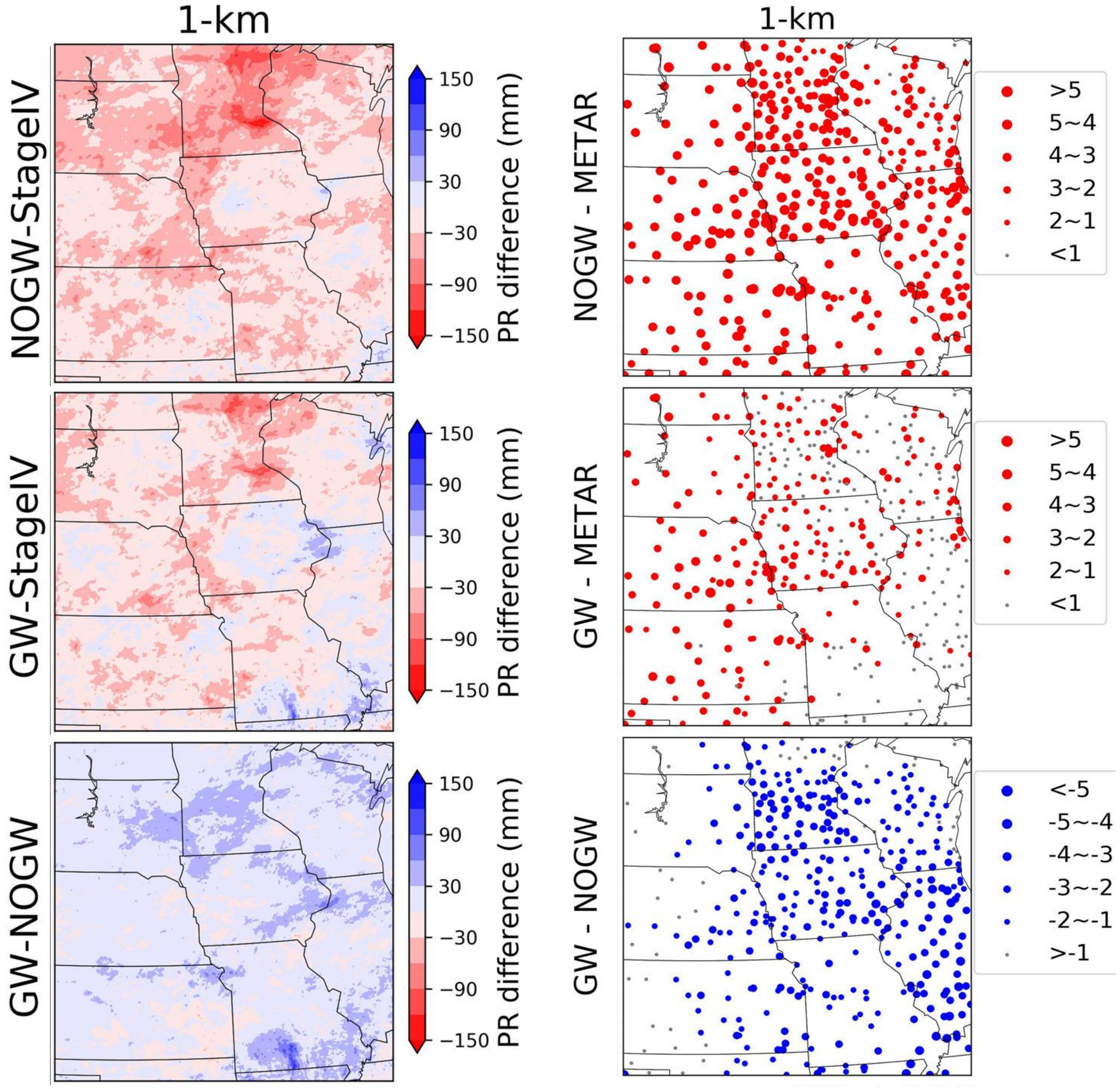
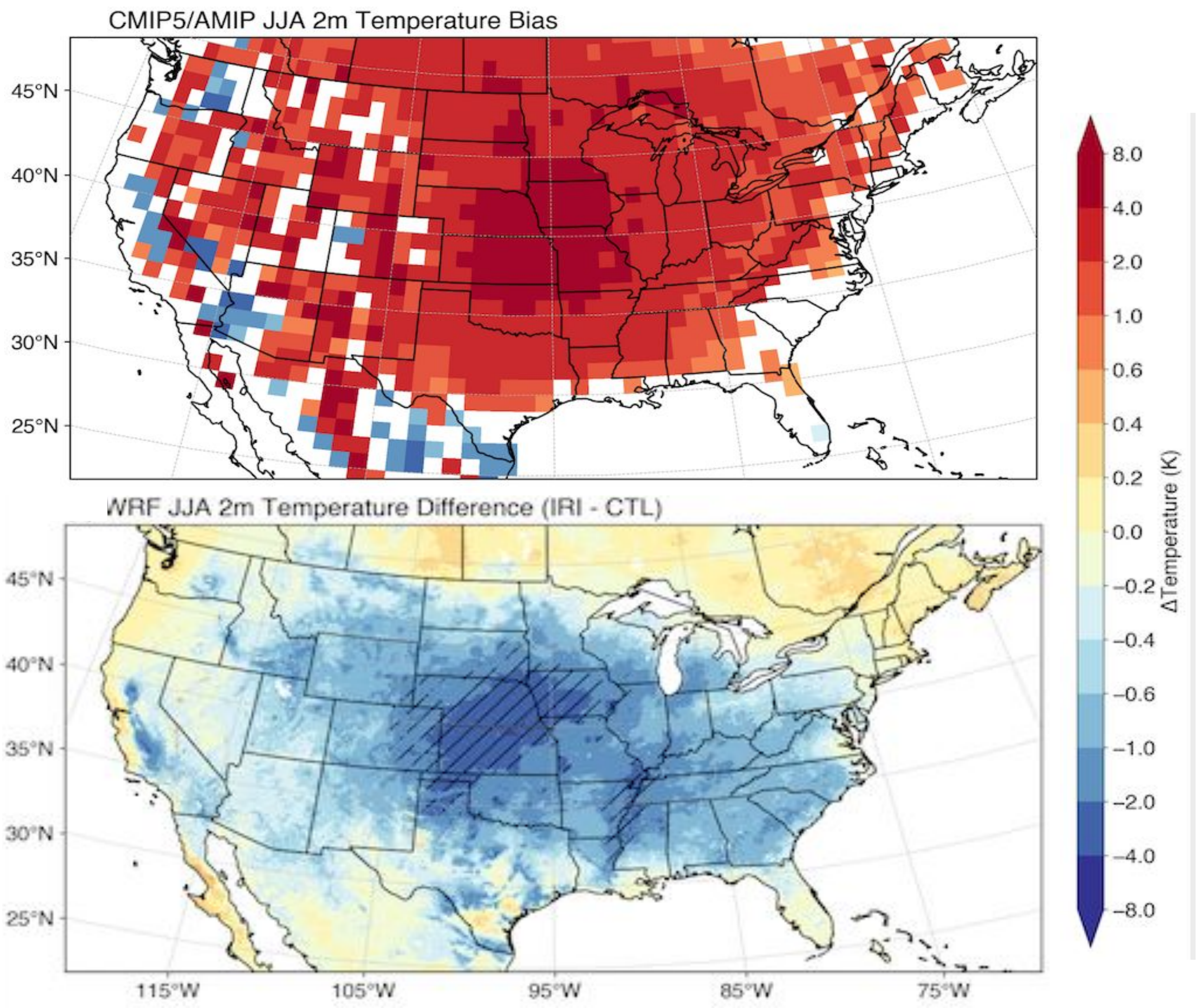
Background: climate models have warm and dry bias over the central US

Groundwater processes reduce temperature bias by ~ 2–3 °C and lower precipitation bias by half. (Barlage et al. 2021)

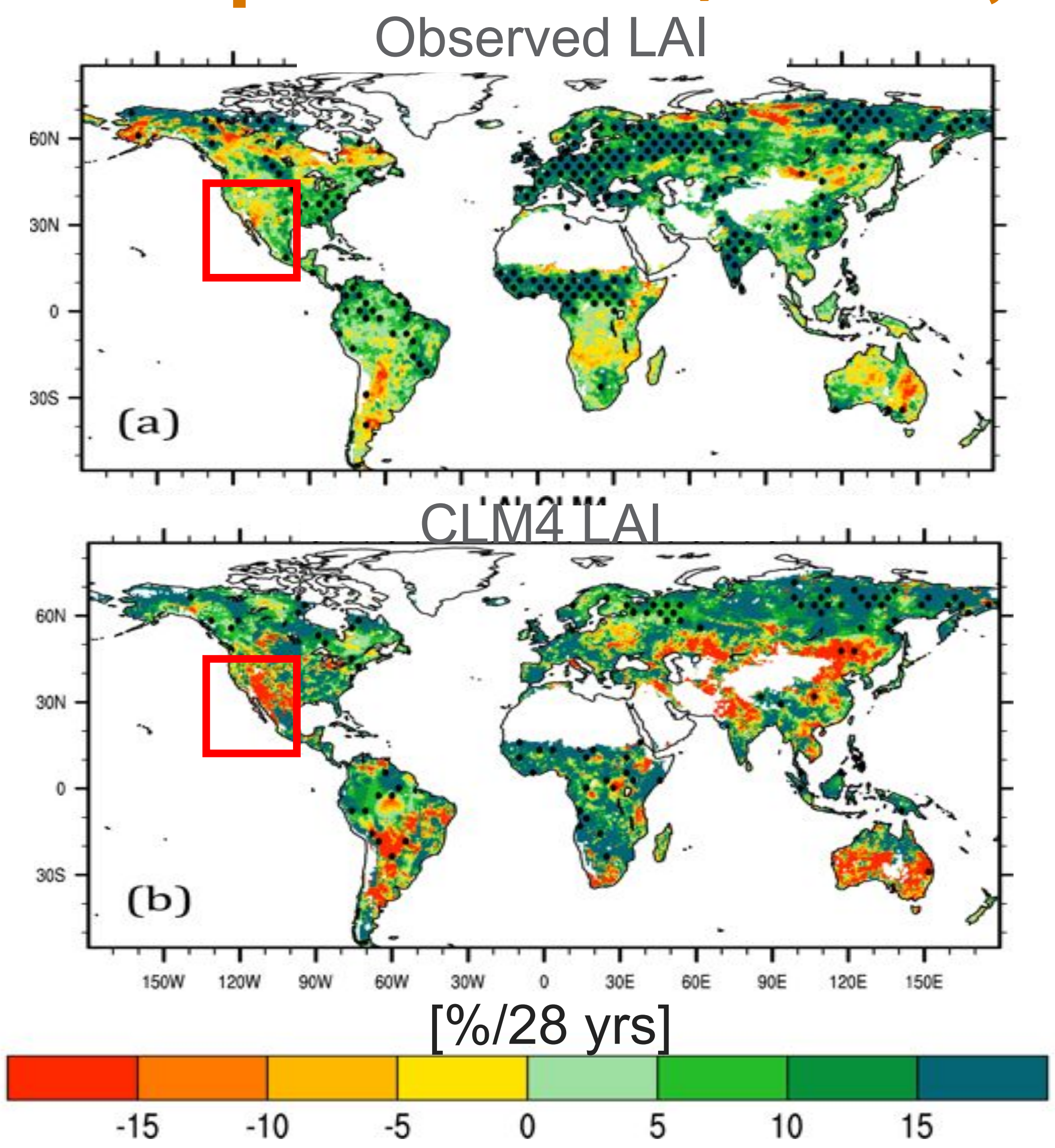


Adding irrigation alleviates the warm and dry bias (Qian et al. 2020).

- Increase the number of MCS events.



Hypothesis: current LSMs lack an adaptation mechanism for plants to survive droughts due to prescribed, static, evenly-distributed root.

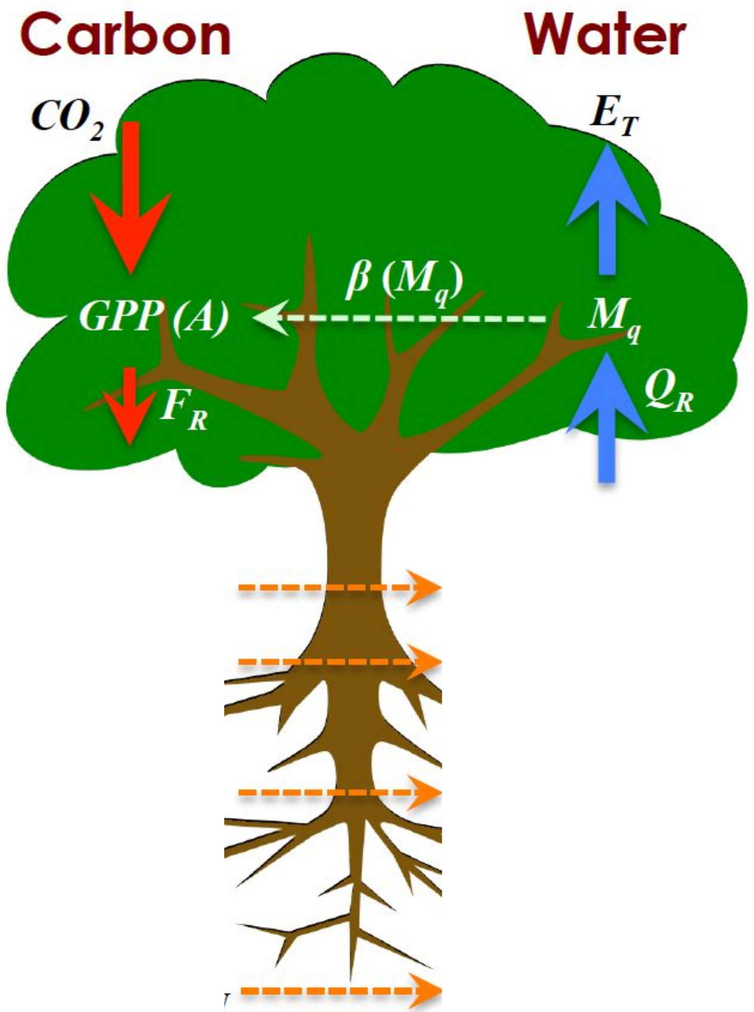


Drawbacks of static root:

- Produced lower than observed GPP, LAI and ET in drought years (Noah-MP, Ma et al. 2017).
- Decreasing trend of LAI larger than observed (CLM4, Mao et al. 2013).

Static root disconnects the interactions between changes in below ground water and nutrient resources and above ground plant carbon assimilation. (Niu et al. 2020)

Description of the dynamic root water uptake scheme:



Niu et al. 2020

Characteristics of dynamic root scheme:

- Subject to water and temperature stress
- Fraction (F_R) of *GPP* allocated to roots is greater in drought conditions
- More carbon to shallow layers and wetter layers

live root carbon ($C_{R,i}$) □ root surface area ($A_{R,i}$) □ root water uptake (Q_R) □ plant water storage (M_q) □ water availability (β) for photosynthesis (*GPP*) and transpiration (E_T).

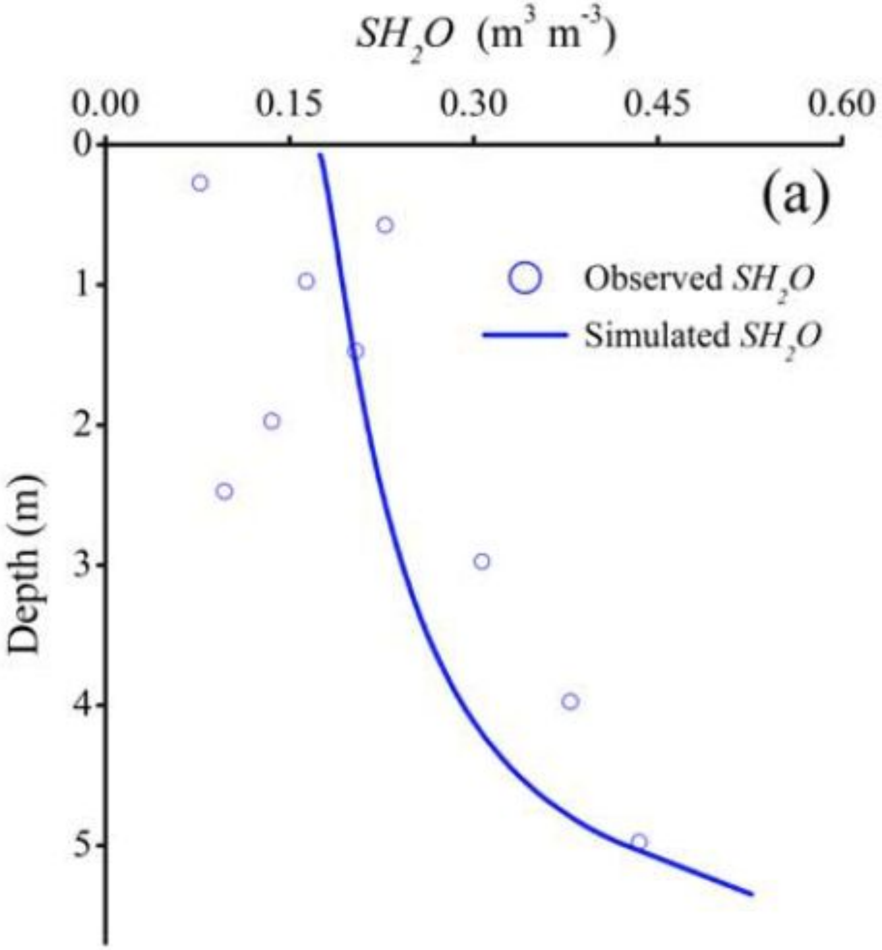
$$\frac{\Delta M_q}{\Delta t} = Q_R - Q_T$$

$$Q_R = \sum_1^{N_R} Q_{R,\,i} = \sum_1^{N_R} A_{R,\,i}\left(\frac{h_{s,\,i} - h_R}{\Omega_R + \Omega_{s,\,i}}\right)$$

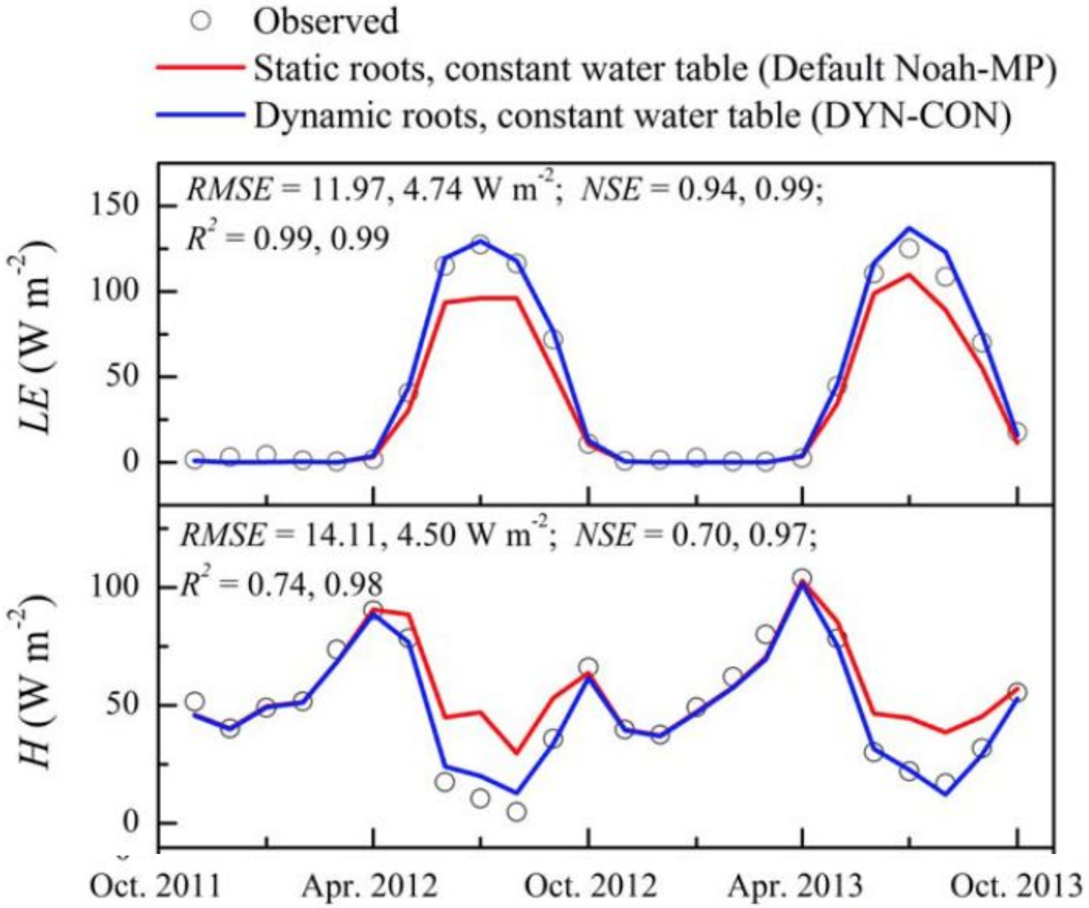
Q_R: rate of water uptake
Q_T: transpiration rate
M_q: total amount of water stored in plant tissues

$A_{R,i}$: root surface area in ith soil layer
$h_{s,i}$: soil matric suction head
h_R: root suction head

At a hyperarid site, Noah-MP with dynamic root substantially improves the simulation of surface energy and water fluxes, compared to the prescribed static root profile in the default Noah-MP.



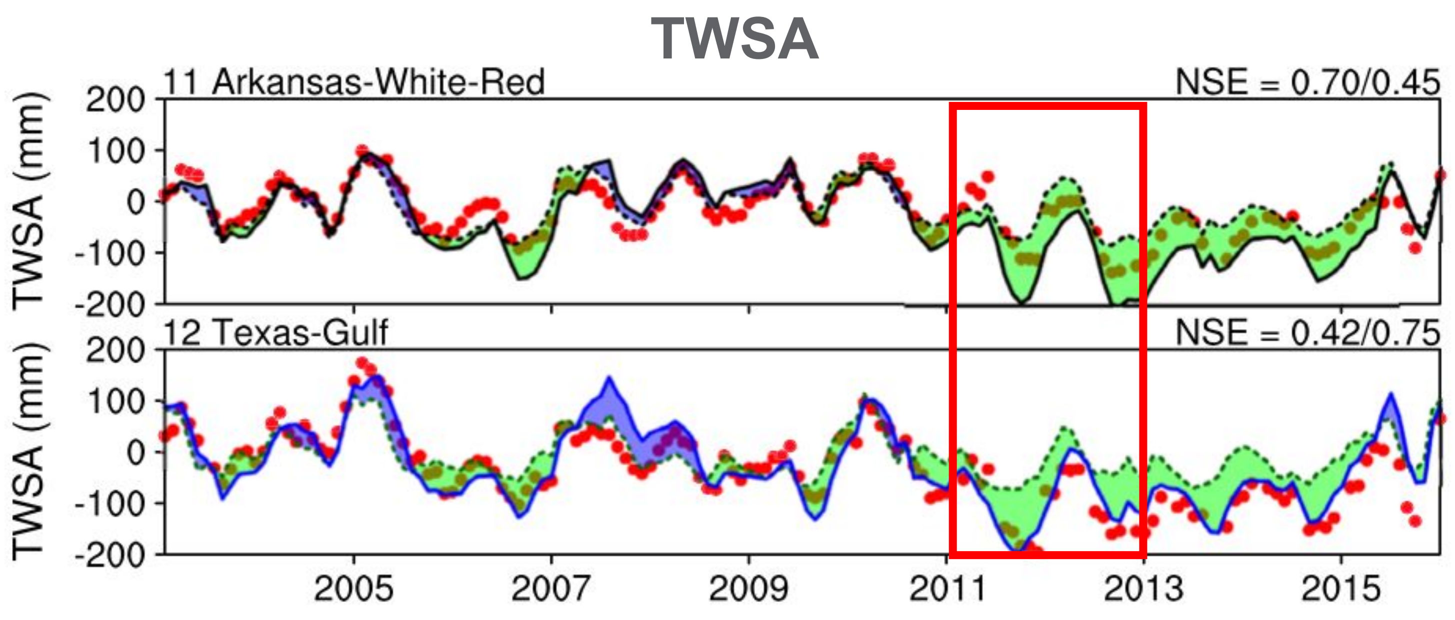
The dynamic root scheme well captures the soil moisture and root fraction compared to observations.

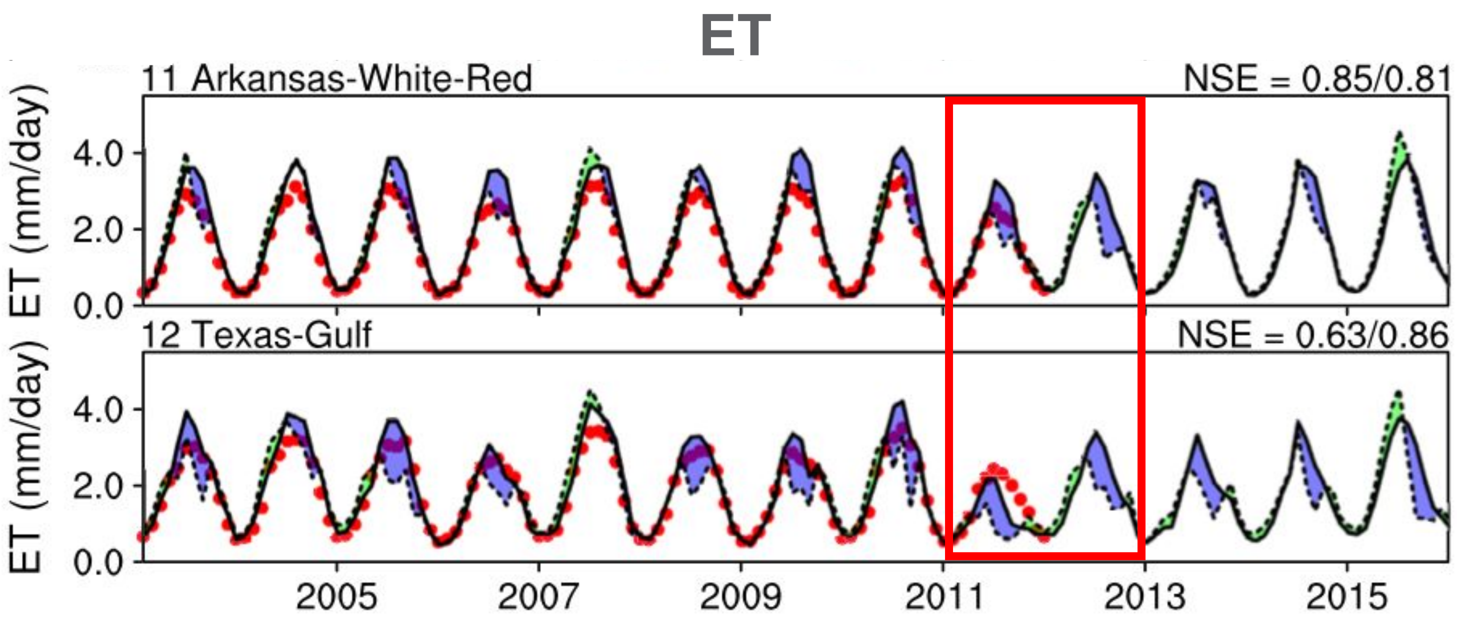


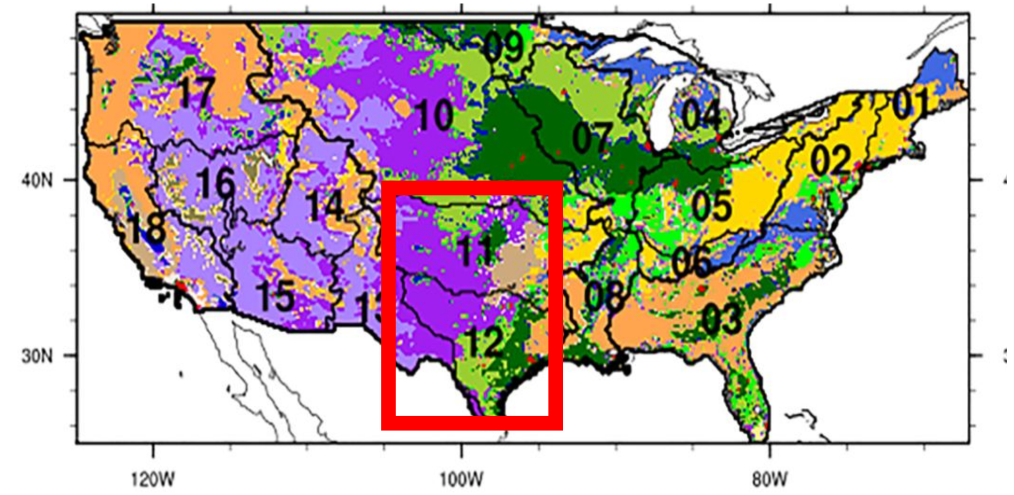
The dynamic root scheme improves the simulations of energy fluxes.

Wang et al. 2018

Compared to the static root approach, Noah-MP with dynamic root better captures the loss of long-term terrestrial water storage (TWSA) and ET during the 2012 drought year.





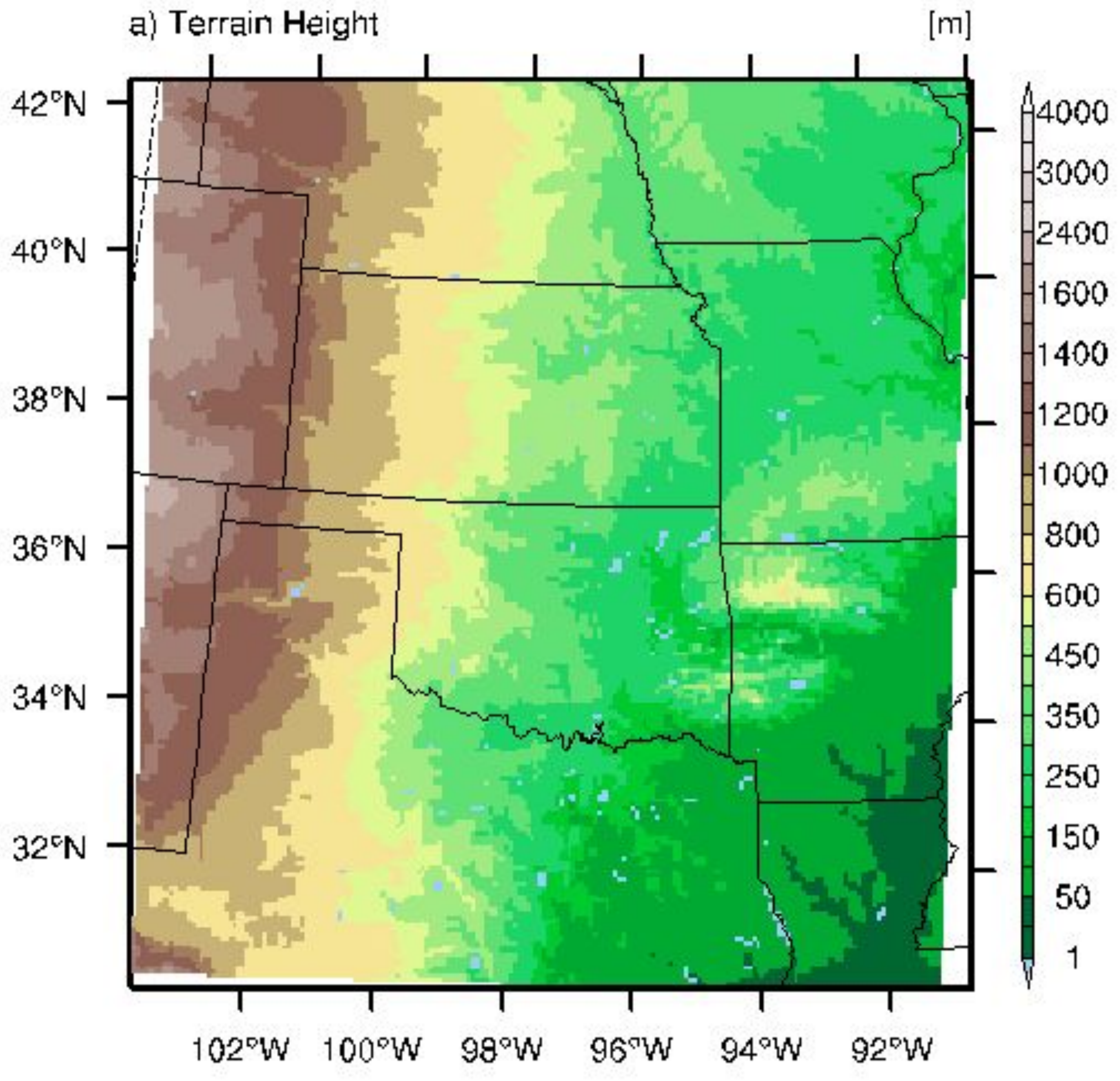


Noah-MP with dynamic root extracts water from deeper soil under water-limited or transition zone.

- **potential to alleviate the warm and dry bias in central Great Plains**

NSE: Nash-Sutcliffe efficiency

Experiment design: couple WRF with dynamic root



Version: WRF 4.4.1
Horizontal Resolution: 4 km
Reanalysis data: NCEP FNL (Final) Operational Global Analysis data
Simulation periods:
April 1 – August 31, 2012-2014
Noah-MP Land surface model: with the dynamic root and static root

Physical Parameterizations:

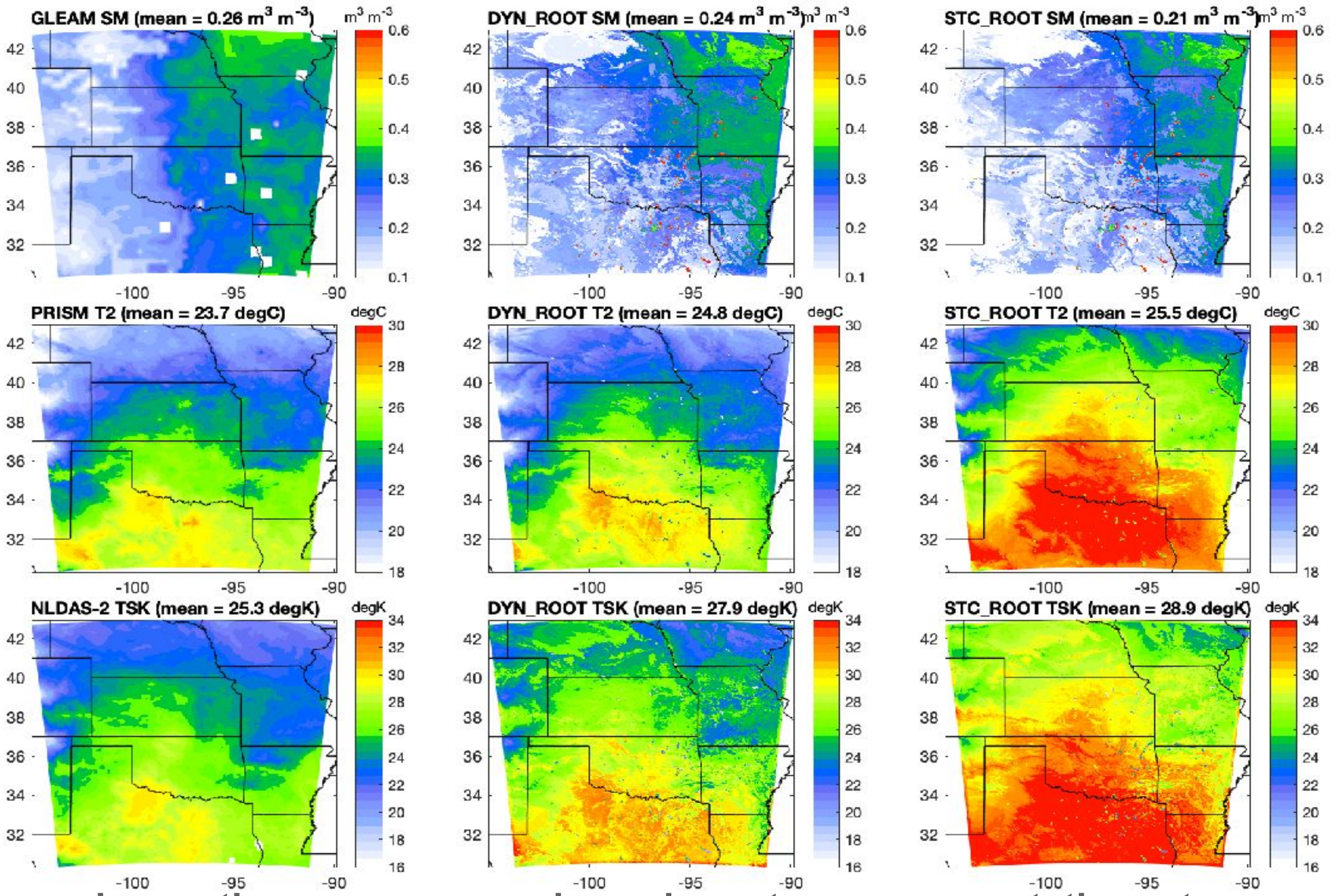
Microphysics	Thompson
Radiation	RRTMG
Planetary boundary layer	MYNN

WRF with dynamic root shows promising results compared to WRF with static root. It improves the performance of soil moisture, T2, TSK.

SM:
soil moisture at 5-cm

T2:
2-m air temperature

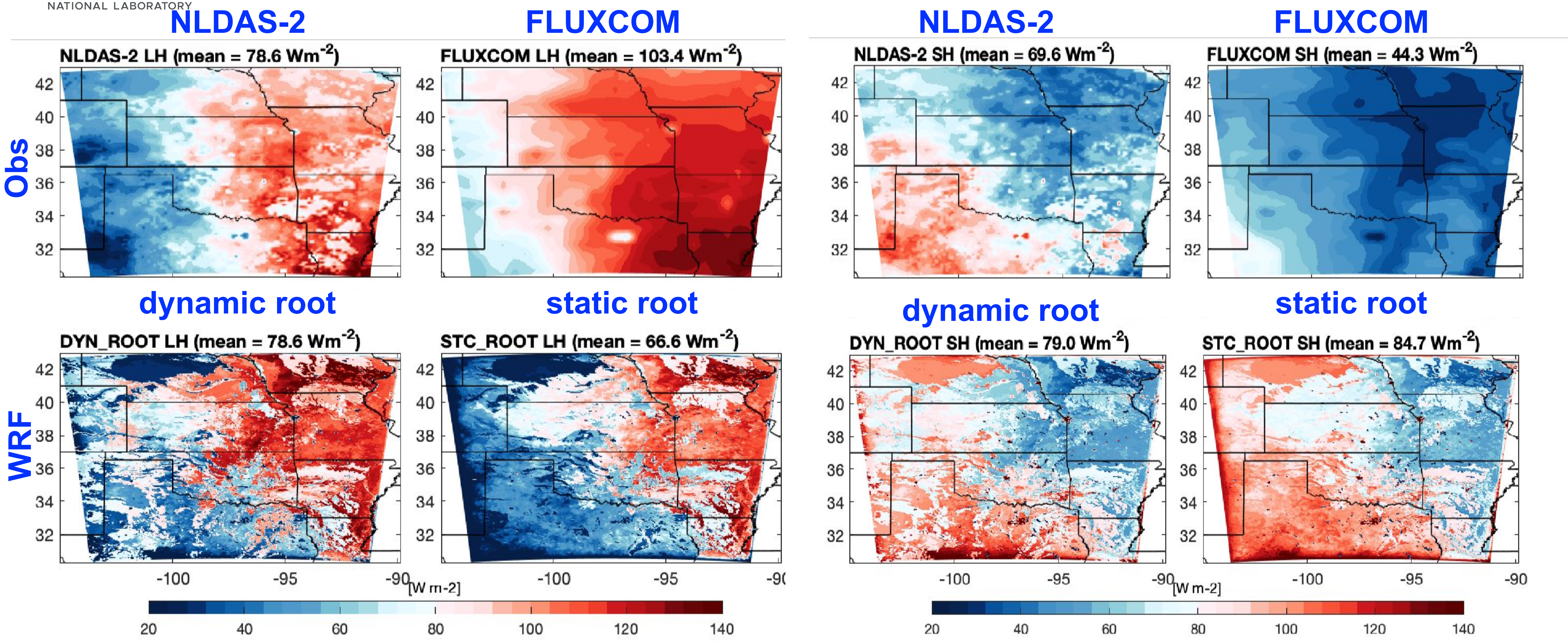
TSK:
Surface skin temperature



observation | dynamic root | static root

Latent heat flux

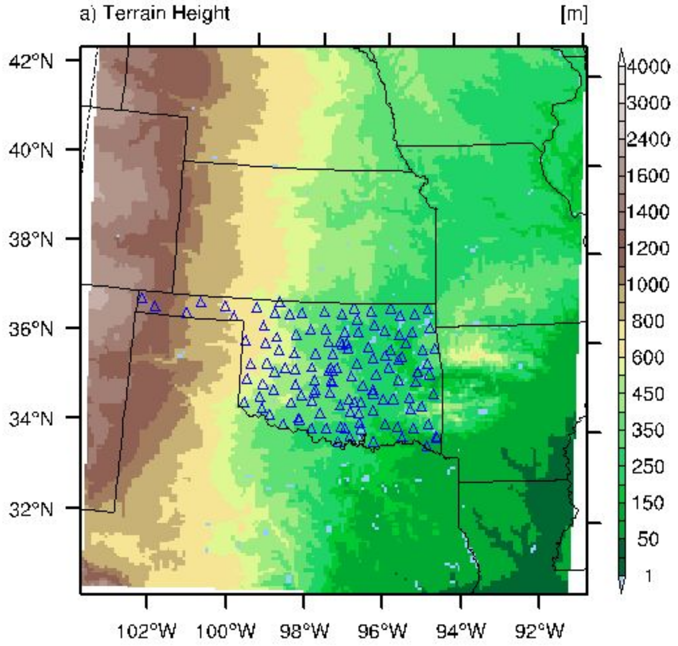
Sensible heat flux

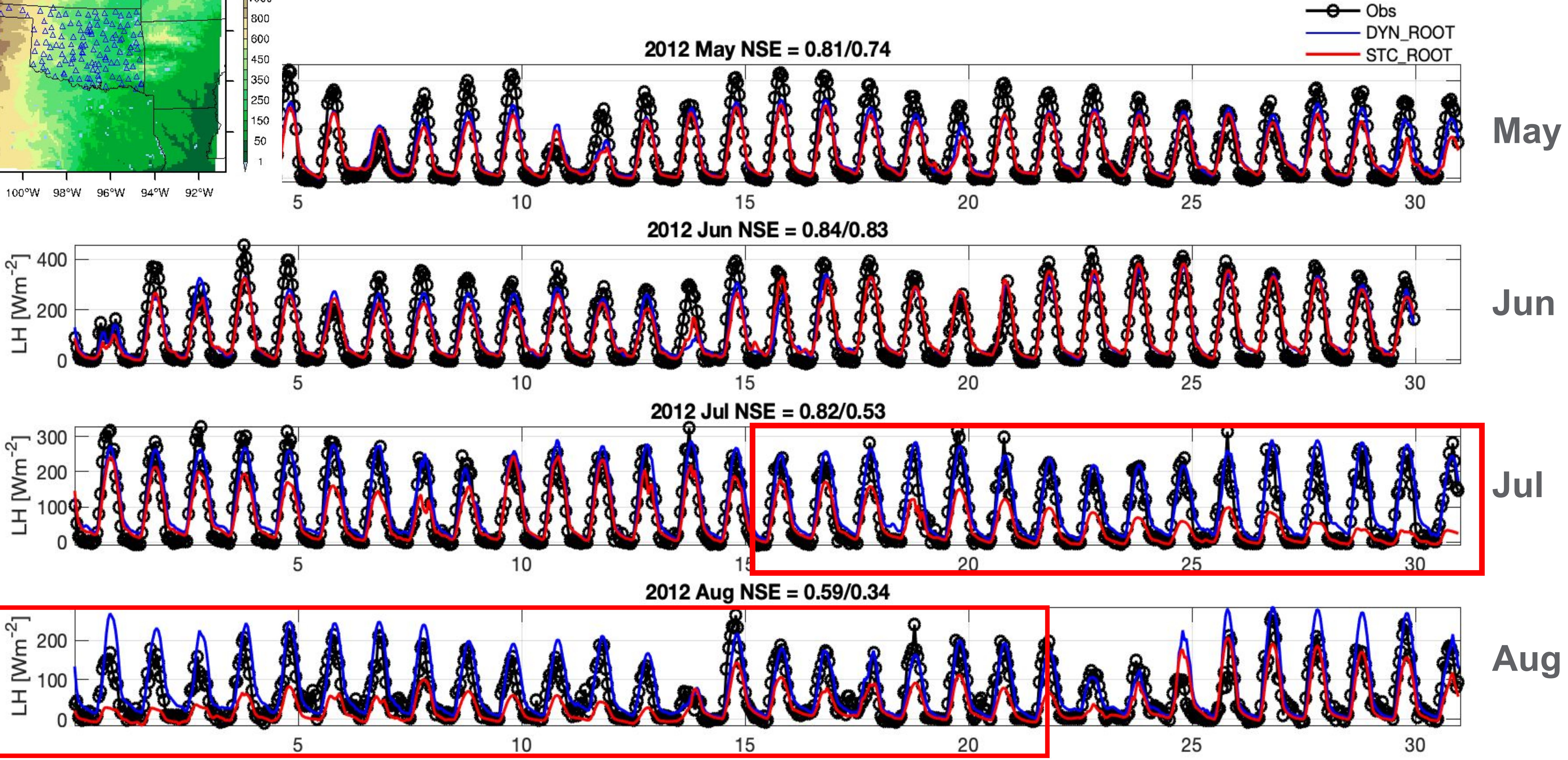


LH mean bias is reduced by 12 Wm^{-2}

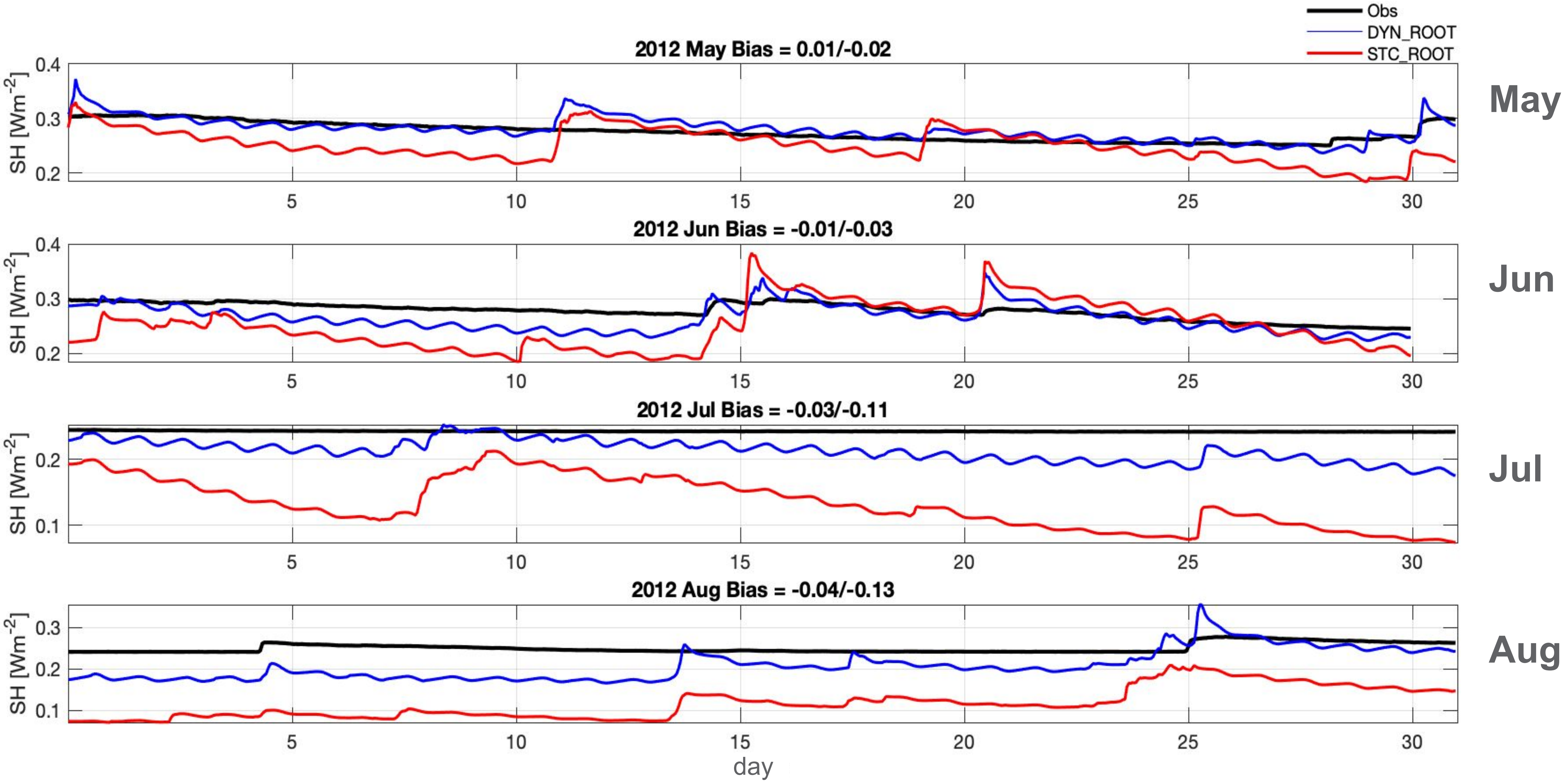
SH mean bias reduced by 5.7 Wm^{-2}

WRF with dynamic root substantially improves the simulated latent heat flux when compared with Oklahoma Mesonet observations.





When compared with the SWATS soil moisture, the simulated soil moisture by WRF with dynamic root has smaller mean bias than WRF with static root.



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Conclusions:

- Offline Noah-MP with dynamic root shows promising results at simulating surface energy fluxes and soil moisture at a hyperarid site.
- At CONUS scale, offline Noah-MP with dynamic root performs better than static root at evapotranspiration and leaf area index.
- Compared to the static root, WRF with dynamic root performs better than at simulating surface energy fluxes, soil moisture, and reduce biases in temperature over the central Great Plains.

Future work:

- Larger domain to test dynamic root impact on precipitation, and more systematic evaluation, including ET partitioning.
- Implement the root scheme to land surface models, such as ELM.
- Develop root in the vertical direction, deeper into the soil.

Acknowledgement

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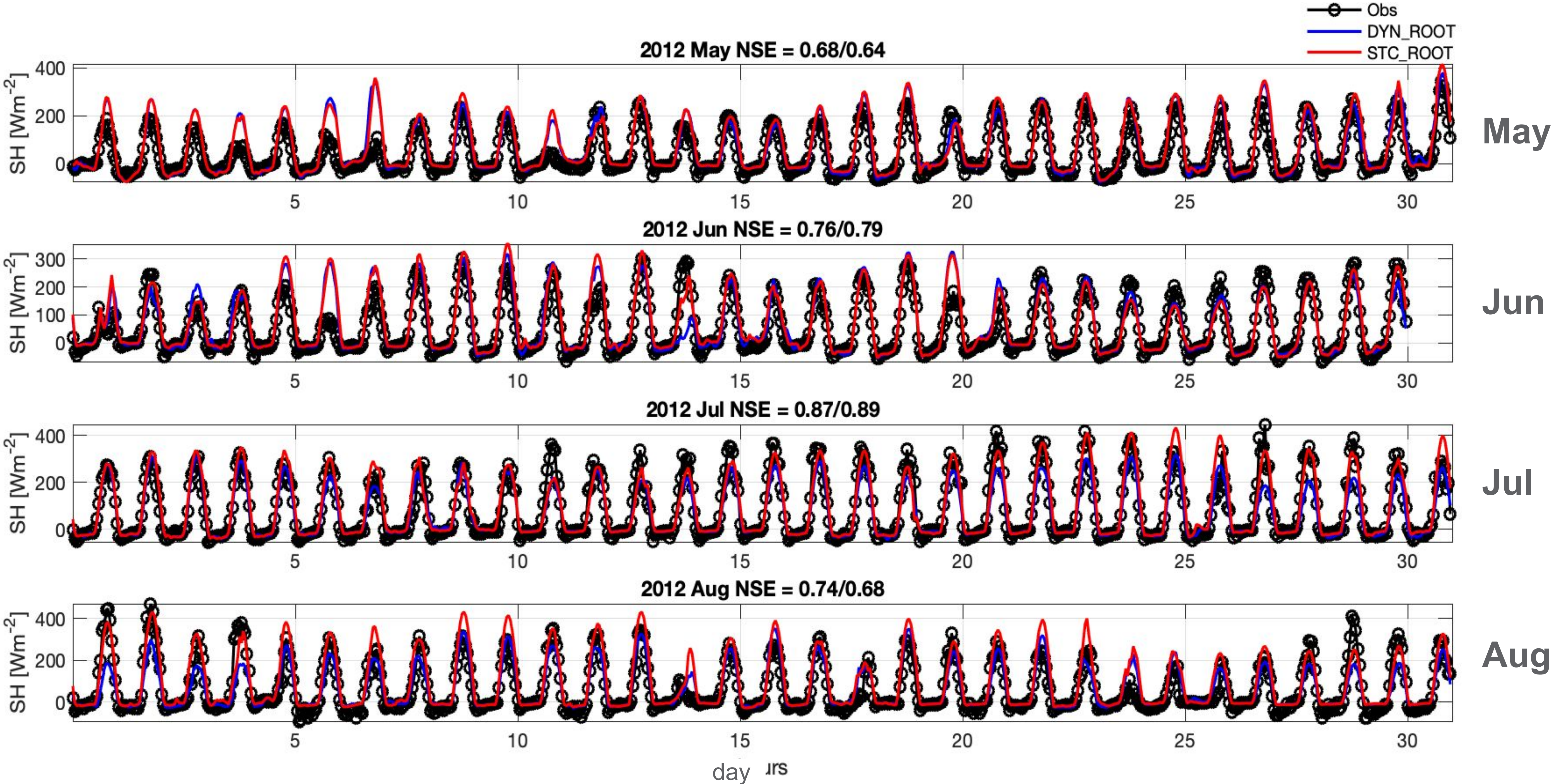
- Nersc computational resource

Thank you

The simulated sensible heat flux by WRF with dynamic and static root is equally good.



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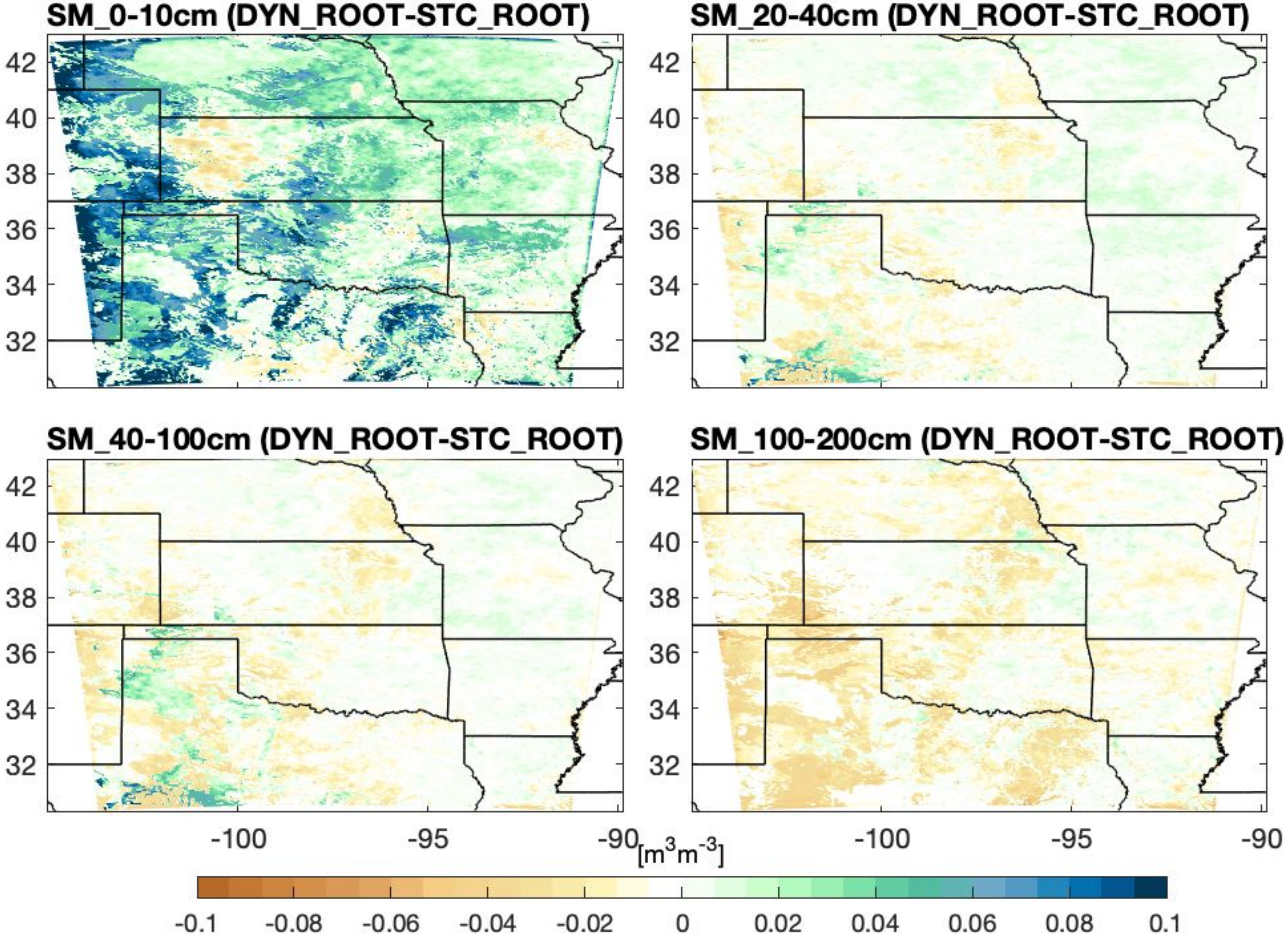

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Thank you