Pressure Driven Water Movement from the Bedrock to the Vegetation Canopy –

Noah-MP Research Overview at Univ of Arizona

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Noah-MP Workshop at NCAR RAL, 5/23/2023

New Developments in Noah-MP at UA

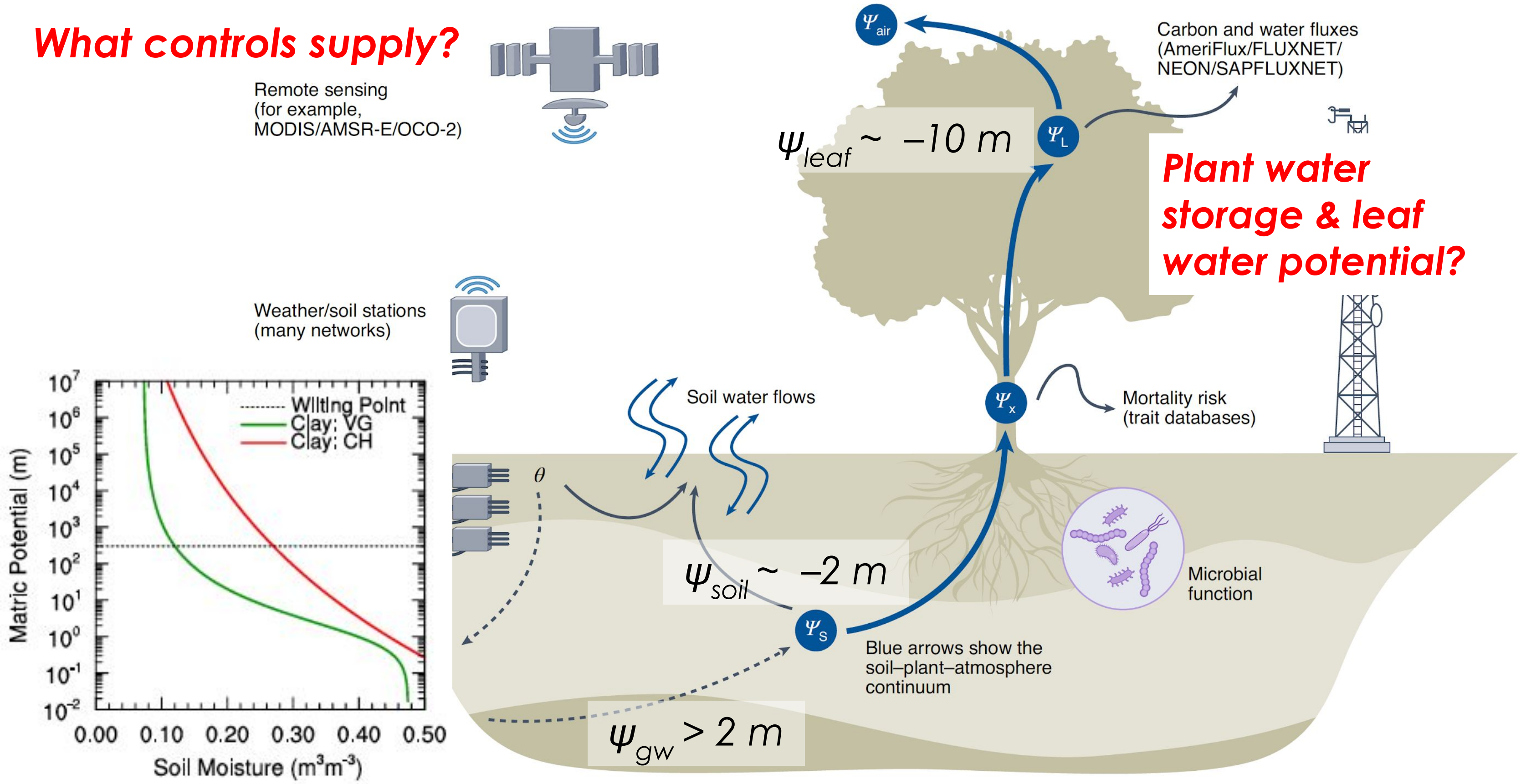
1. Canopy Heat Storage (Niu and Yang, 2004)
2. Rain-Snow Partitioning Scheme Based on T_{wet} (Wang et al., 2019)
3. Dynamic Root Model and Plant Hydraulics (Niu et al., 2020)
4. A Dual-Permeability Model Based on the Mixed-Form Richards Eq. (Niu et al., 2023)

How to represent Soil/Plant Hydraulics in models?

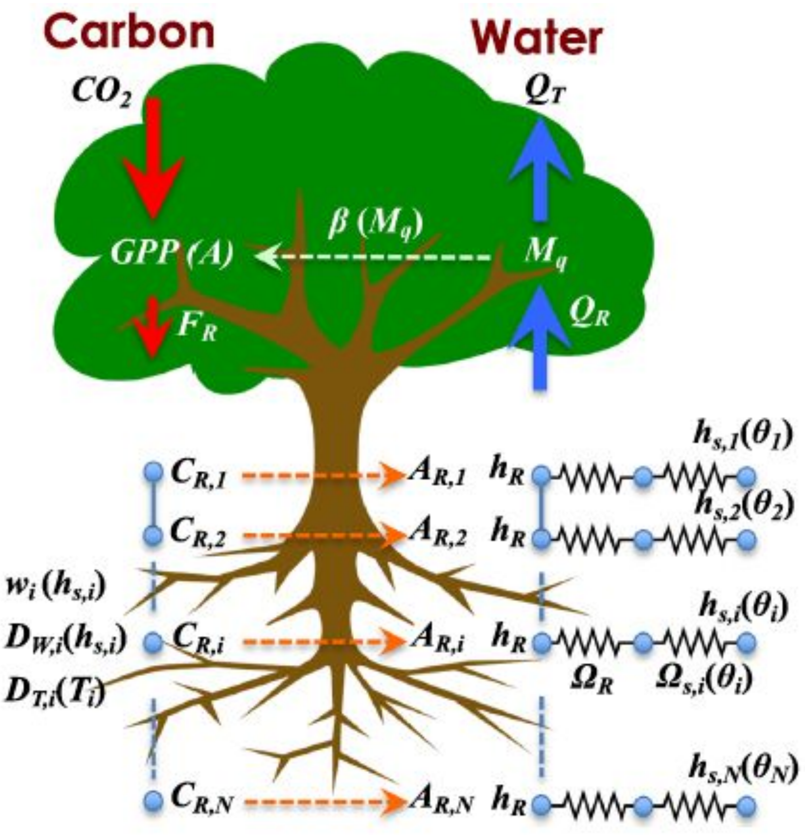
Pressure-Driven Water Movement in the Soil-Plant System

What controls E_{soil} and Transpiration? Demand & Supply

What controls supply?



Dynamic Root in Noah-MP (Niue et al., 2020)



1. *Root hydrotropism – roots grow towards water*

2. *Predicting plant water storage*

3. *Pressure driven root water uptake:*

$$h_s - h_R$$

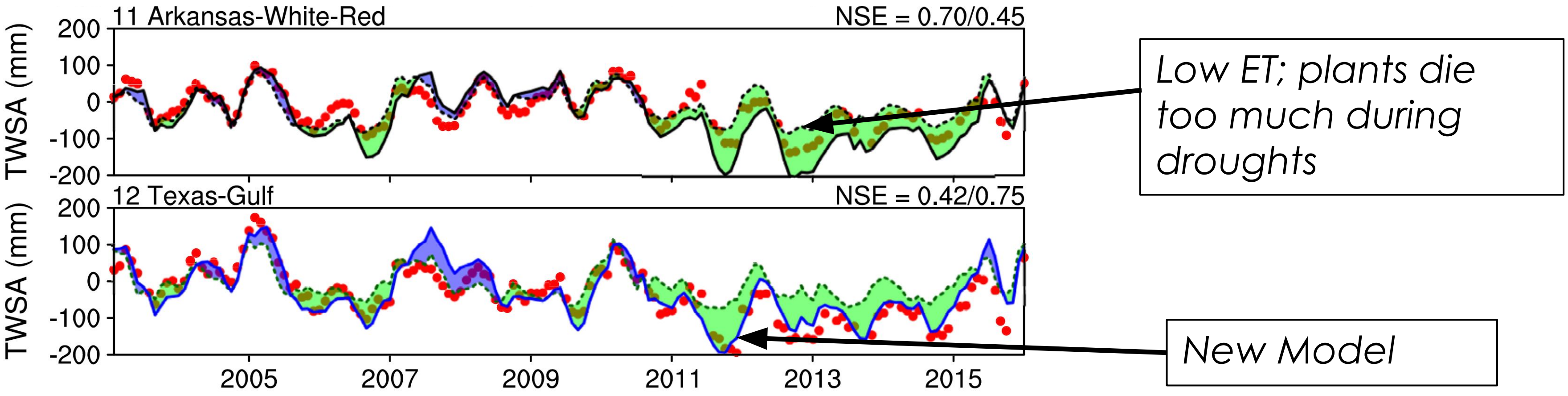
4. *New btran factor*

$$\beta = 1.0 - min(P_b, P_{b,\,wilt})/P_{b,\,wilt}$$

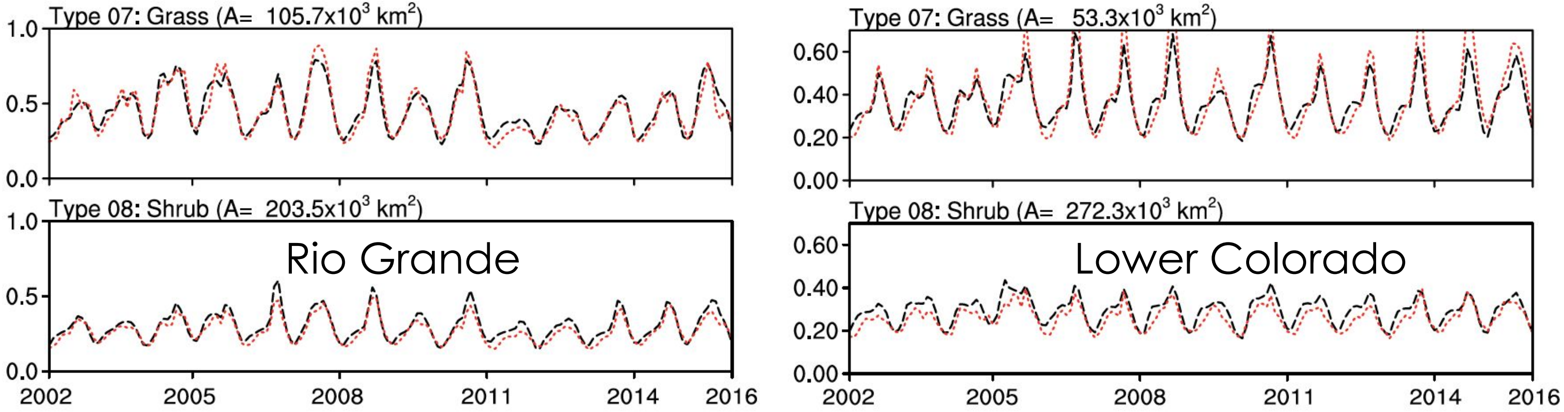
5. *Plant water retention (Rodrich & Canny, 2005):*

$$P_b \sim \kappa \frac{M_{q,\,max} - M_q}{M_{dry} + M_{q,\,max}},$$

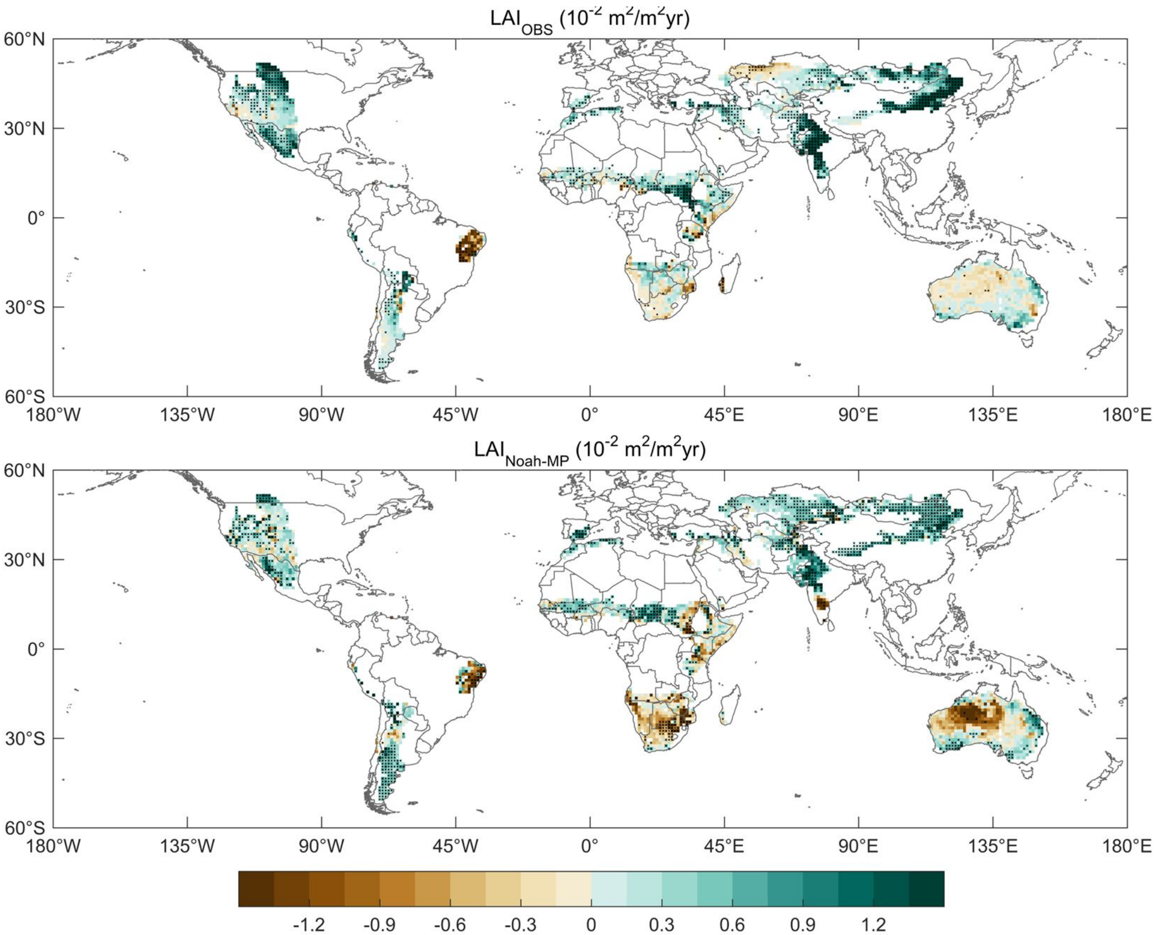
Model Improvements



Noah-MP Modeled vs. MODIS LAI (Arid Rivers)



LAI Trend in Global Water-Limited Regions



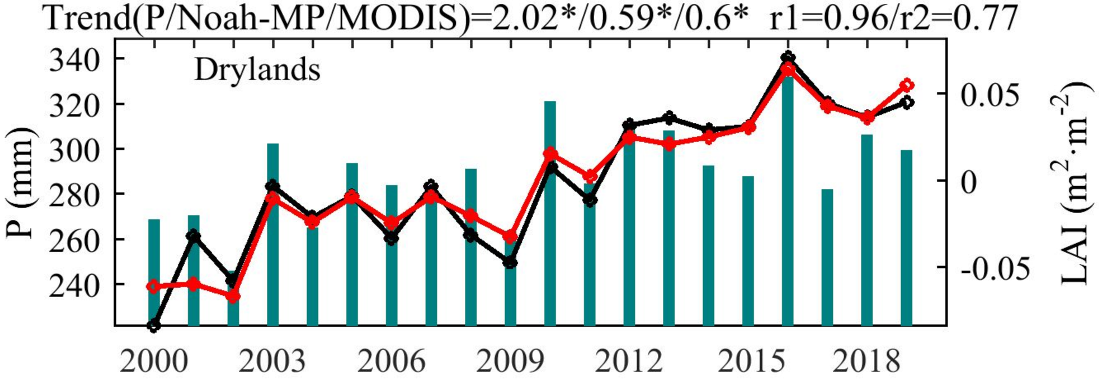
MODIS

Noah-MP

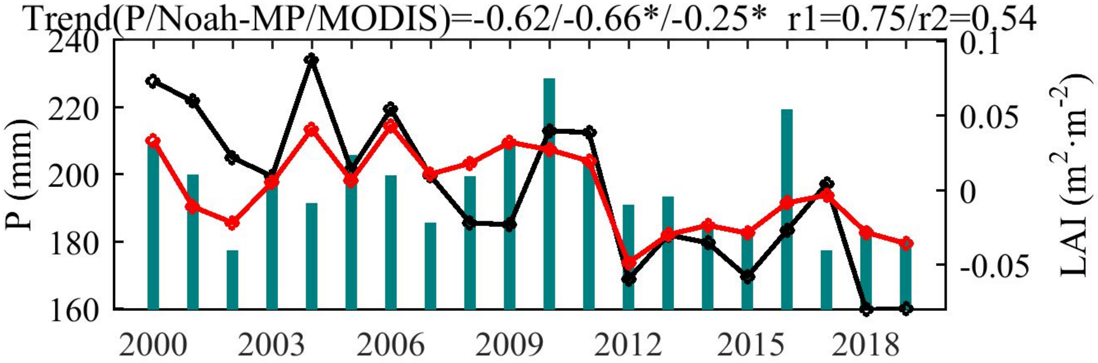
71% area in agreement

LAI Interannual Variability and Trend in Global Water-Limited Regions

"Greening" Regions



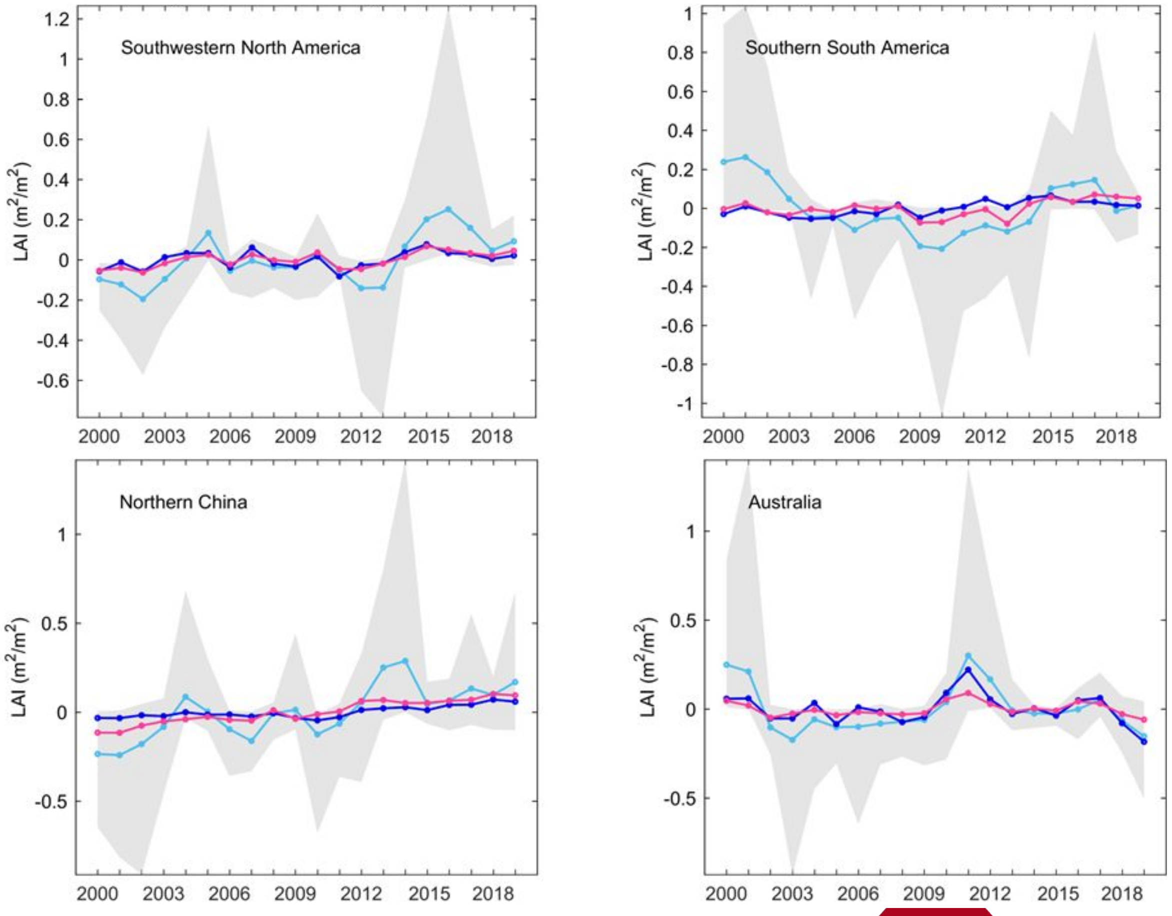
"Browning" Regions



r1: Noah-MP LAI vs MODIS LAI

r2: MODIS LAI vs Precipitation

Compared to 13 Main-Stream DGVMs in TRENDY



1. ***Other DGVMs overestimate interannual variability***
2. ***Possibly due to strong water stress during droughts***
3. ***Not only plant hydraulics but also soil hydraulics***

Representing Infiltration in LSMs

Mass-based RE:

$$\frac{\partial \theta_{liq}}{\partial t} = \frac{\partial}{\partial z}\left[K\left(\frac{\partial h}{\partial z}+1\right)\right]$$

1. *Not properly deal with saturated situations*
2. *Not represent surface ponding and infiltration of ponded water*
3. *Use Clapp & Hornberger (CH) soil hydraulics*
4. *Not represent preferential flow*

Head-based RE:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]$$

Can not conserve mass

Mixed-form RE:

$$\frac{\partial \theta_{liq}}{\partial t} = \frac{\partial}{\partial z}\left[K\left(\frac{\partial h}{\partial z}+1\right)\right]$$

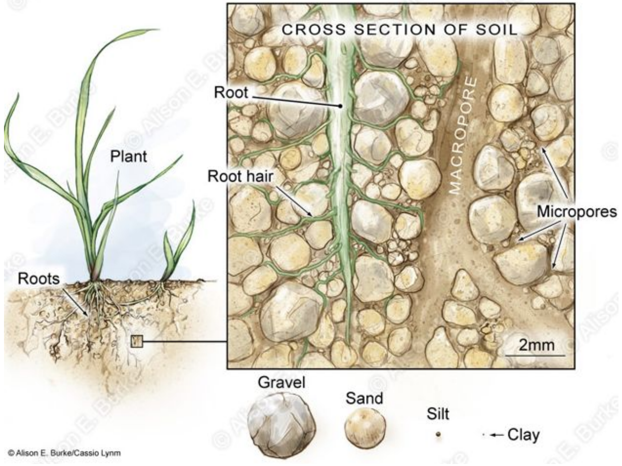
Solve h and conserve mass

Representing Preferential Flow with Surface Ponding in Noah-MP

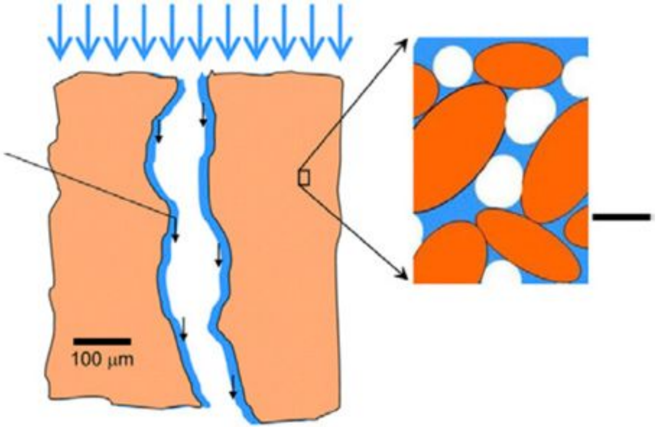
- *Most soils contains macropores*
- *Increase infiltration & recharge*
- *Reduce E_{soil};* ***Enhance T***

$$\frac{\partial \theta_f}{\partial t} = \frac{\partial}{\partial z}\left[K_f(h_f)\left(\frac{\partial h_f}{\partial z} + 1\right)\right] - \frac{\Gamma_w}{F_f}$$

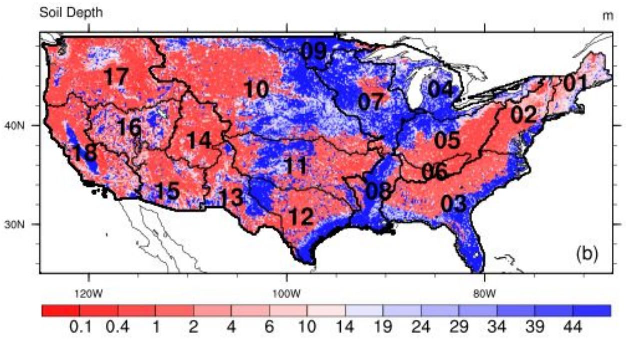
$$\frac{\partial \theta_m}{\partial t} = \frac{\partial}{\partial z}\left[K_m(h_m)\left(\frac{\partial h_m}{\partial z} + 1\right)\right] + \frac{\Gamma_w}{1-F_f}$$

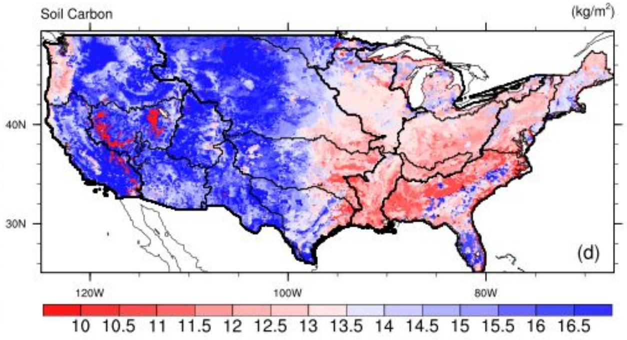


- *Surface ponding through shift between head and flux BCs*
- *Infiltration-excess occurs beyond $H_{top,max}$*
- *Provides 2 soil hydraulics schemes (VG and CH)*
- *Soil structural macropores F_f linked to SOM*
- *Surface and subsurface exchanges between the 2 domains*



Model Experiments (120-year runs)



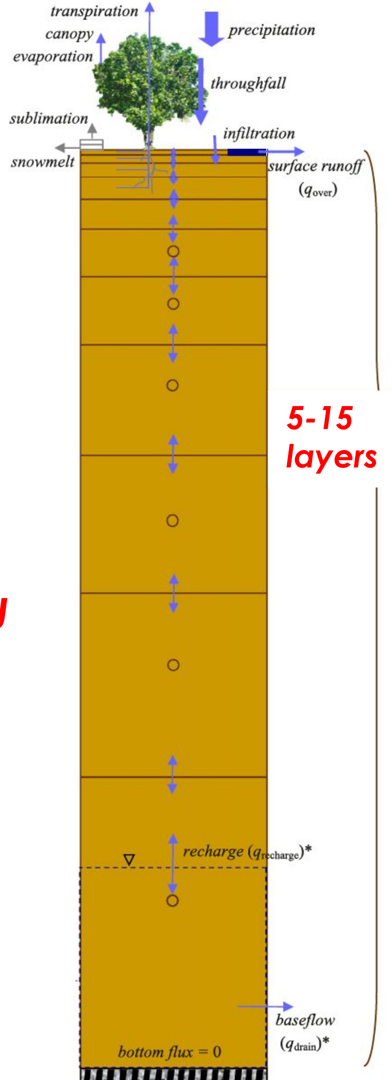


Experiment ID	Models	$H_{top,max}$ (mm)	Soil Hydraulics	% Increase in CPU / Wall-Clock Time
MF-VG-NP	Mixed-From RE	0	VG	41.94% / 12.63h
MF-VG-MP	Mixed-From RE	200	VG	31.36% / 12.17h
MF-CH	Mixed-From RE	50	CH	39.31% / 12.66h
MF-VG	Mixed-Form RE	50	VG	37.02% / **12.24h**
DPM-VG	DPM	50	VG	42.00% / 13.21h

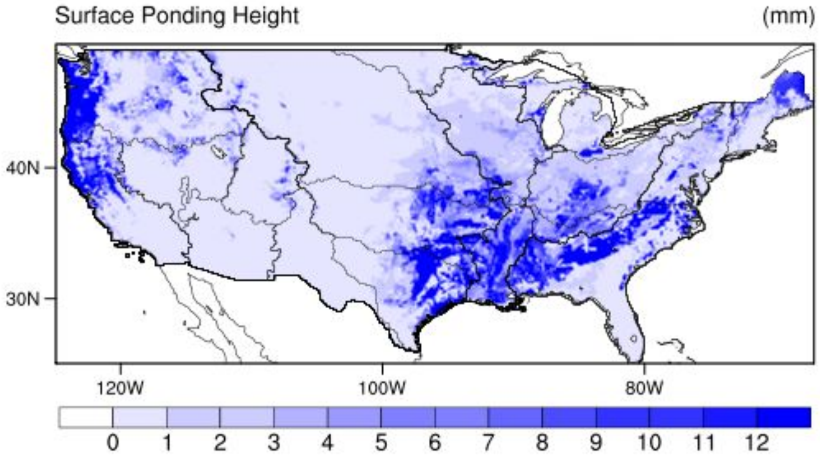
The 4-L Noah-MP takes 2302757.92s (user) and **13.07** h for a 40-year run

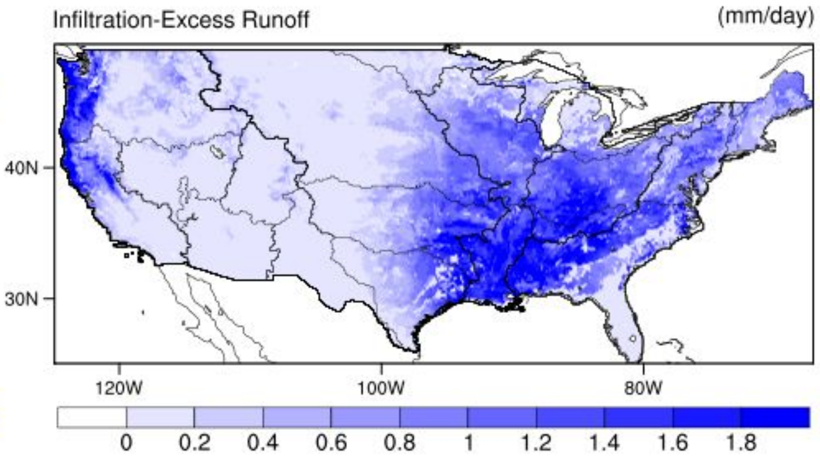
40% more CPU

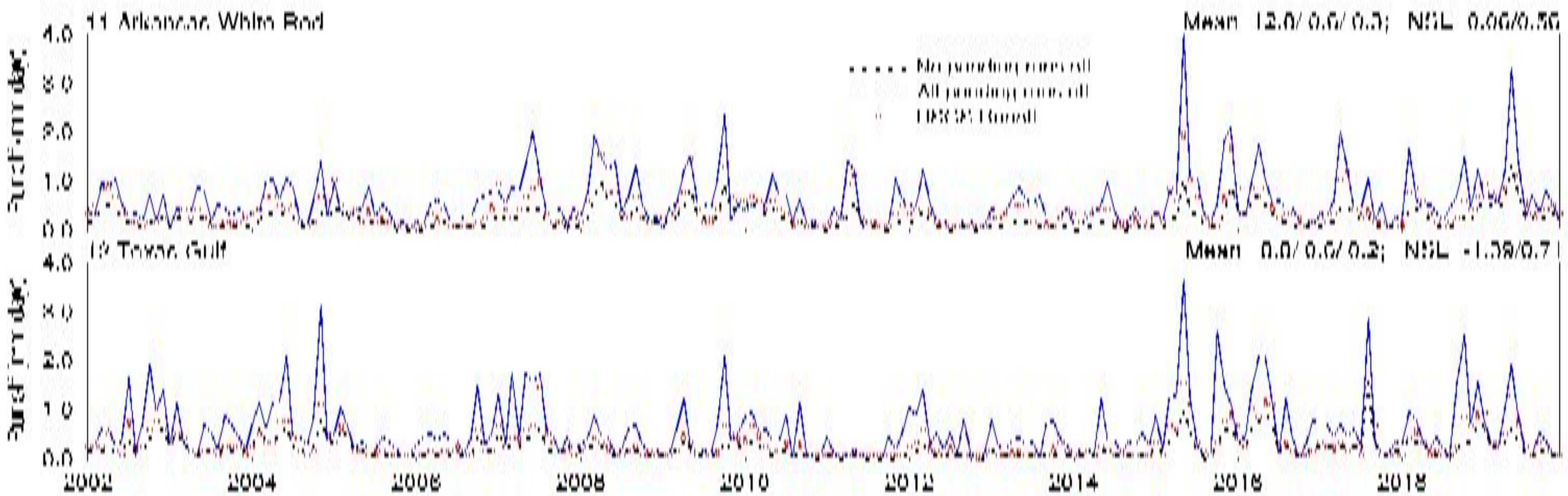
- ***How importance of surface ponding?***
- ***The effects of CH and VG on SM and E_{soil}?***
- ***The effects of the preferential flow?***



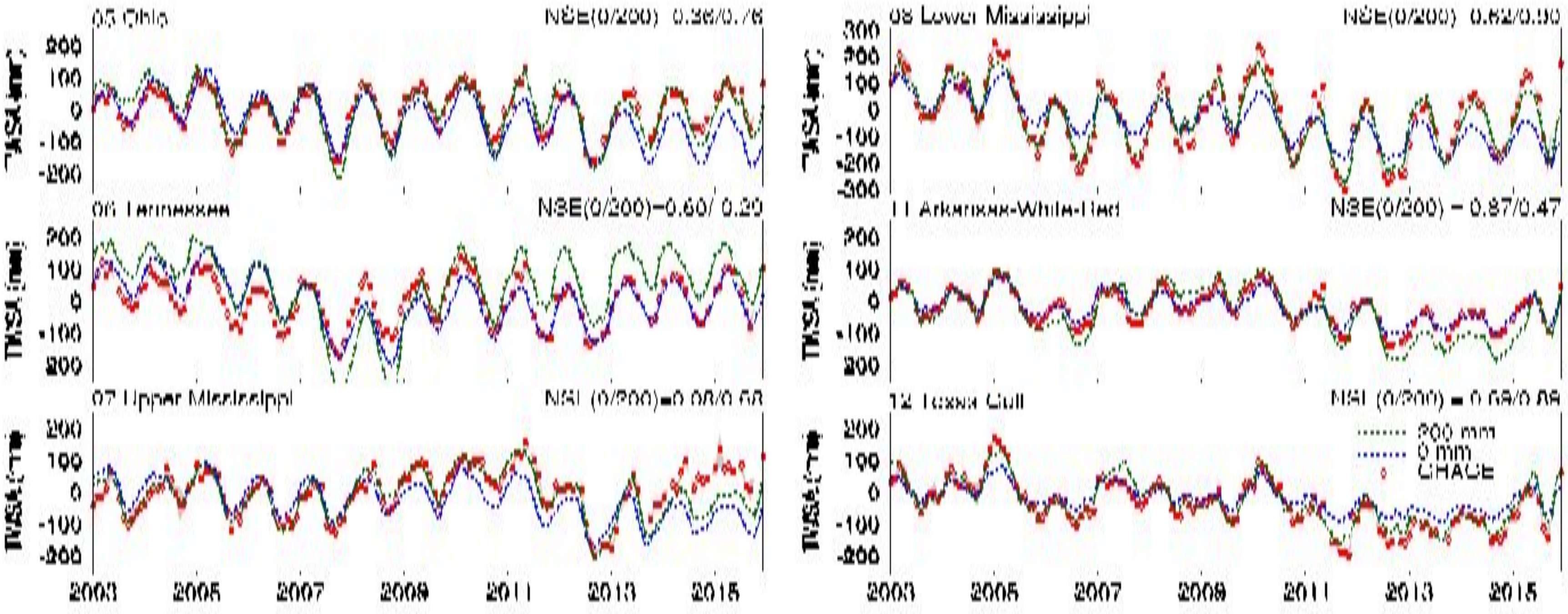
Infiltration/Runoff of Ponded Water





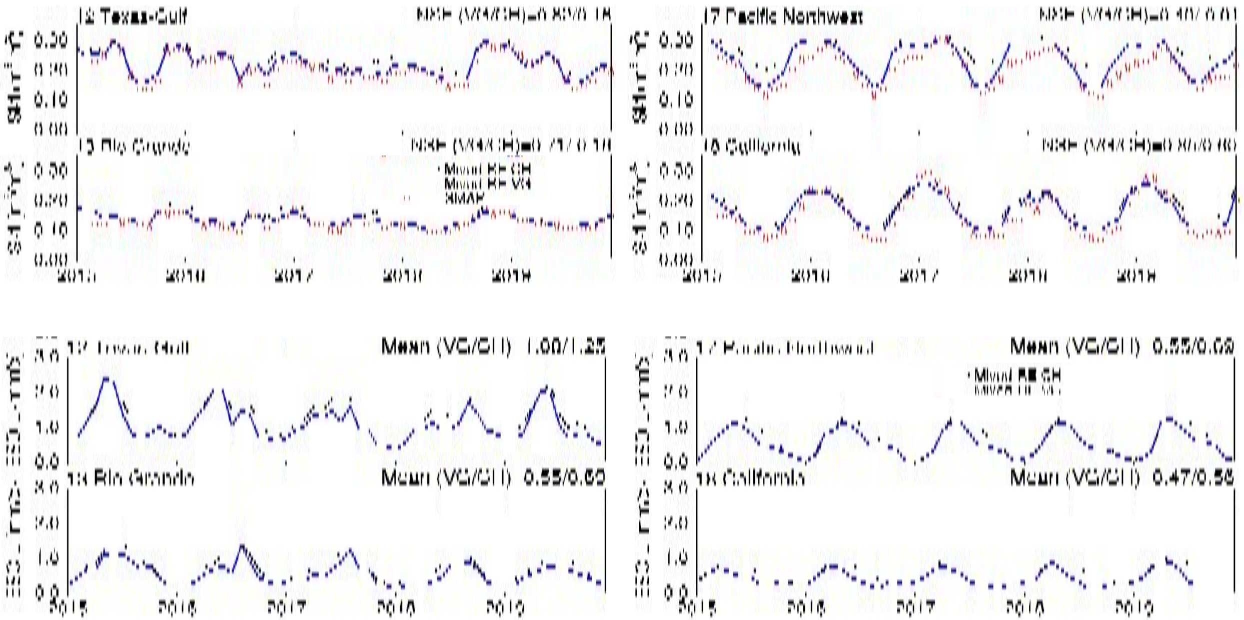


Ponded Water to TWS

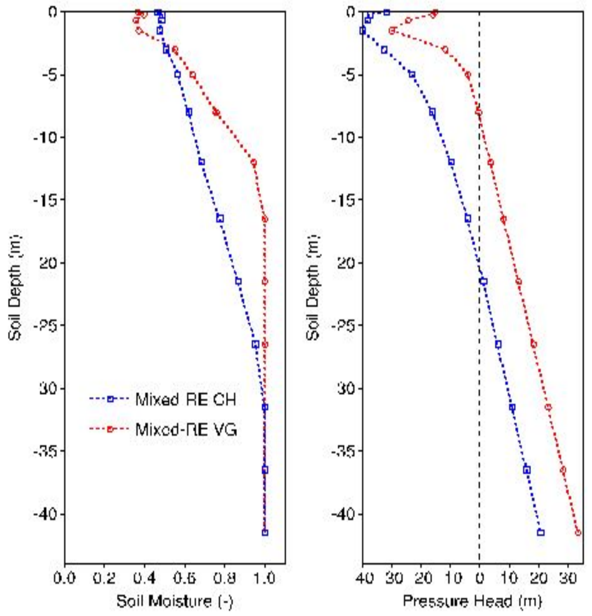


Contributes significantly to seasonal variations in TWS

Soil Hydraulics on Soil Moisture and E_{soil}



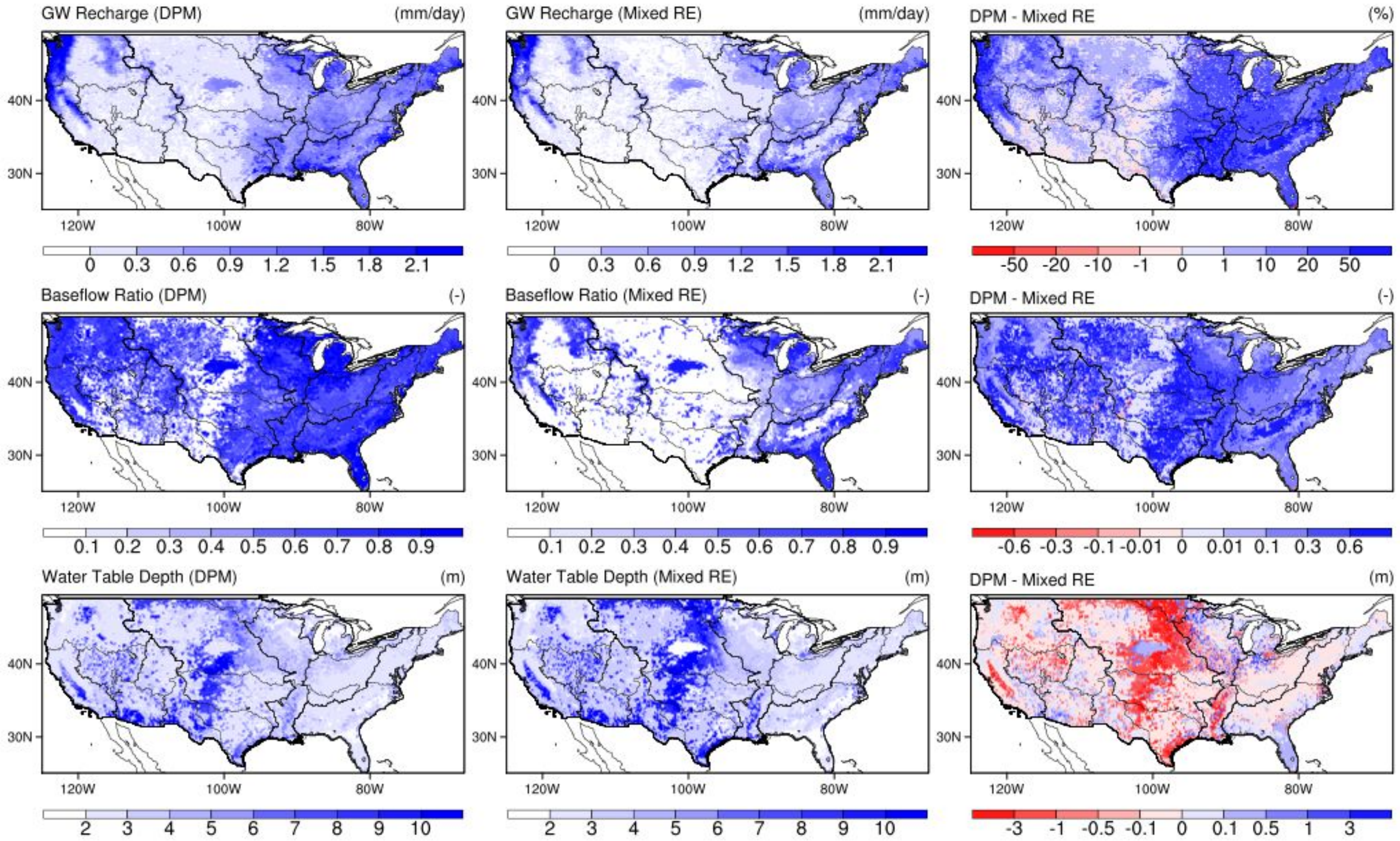
CH produces wetter surface soil and more E_{soil}



High Plain(40-year mean):

CH produces wetter surface soil but drier deep soil due to stronger capillary rise

The Effects of Preferential Flow

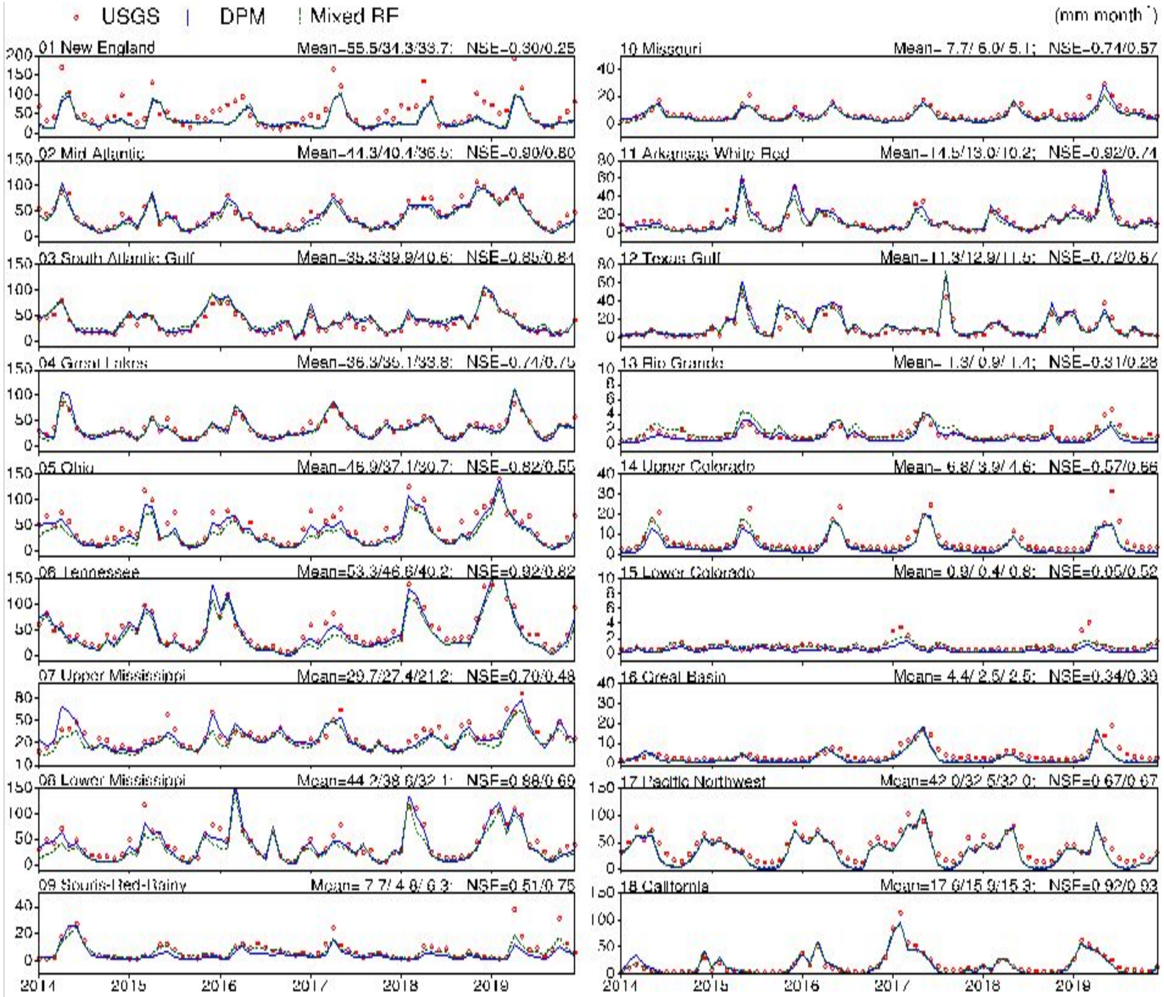


Recharge

Baseflow Ratio

Water Table Depth

The Effects of Preferential Flow



11 basins improved

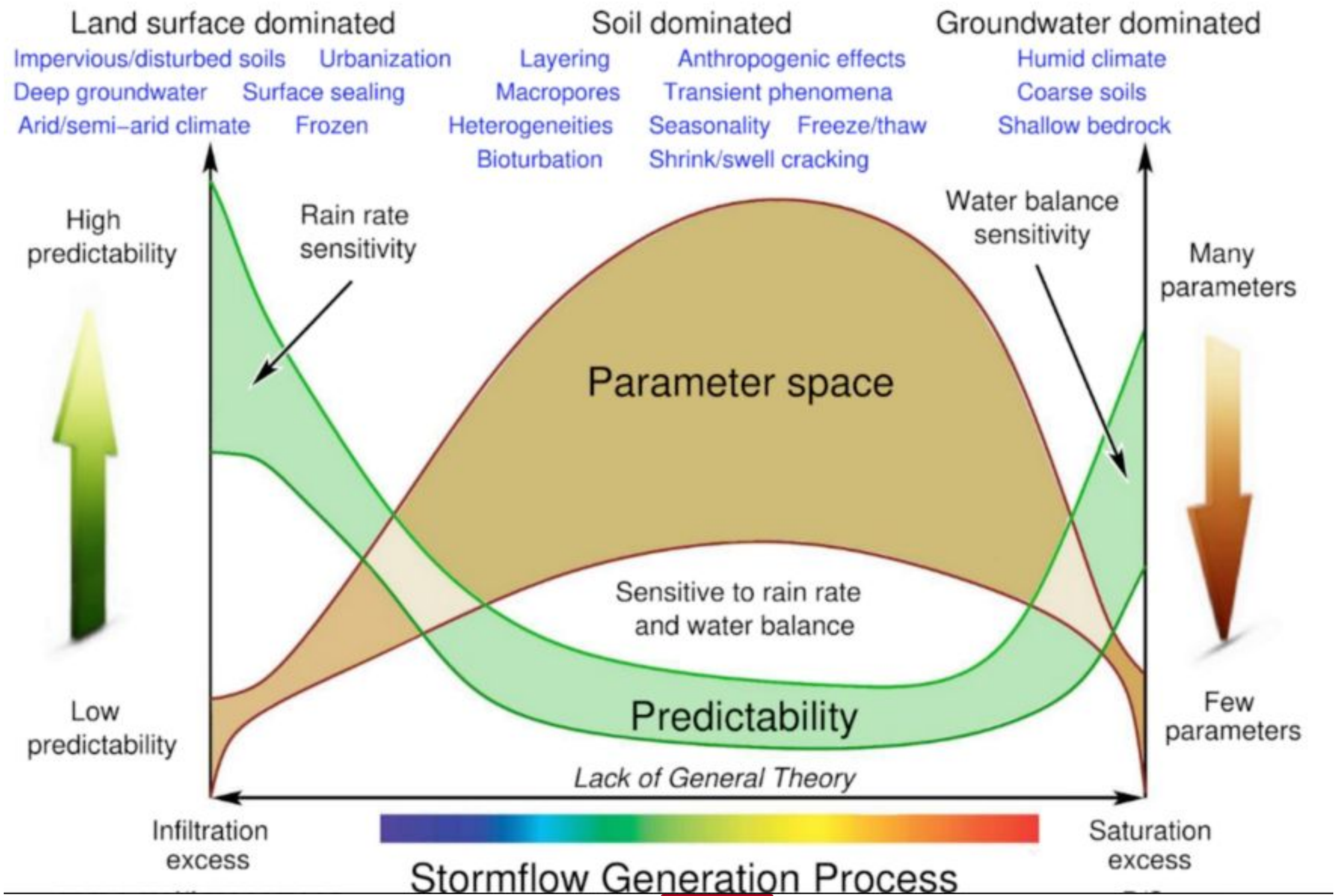
6 basins degraded

Basins with significant ponding are all improved

Uncertainties in forcing and E_{soil} and T parameters

More apparent in daily runoff

NWM (WRF/Hydro): Soil-Dominated Processes is Critical in Modeling Peak Flow

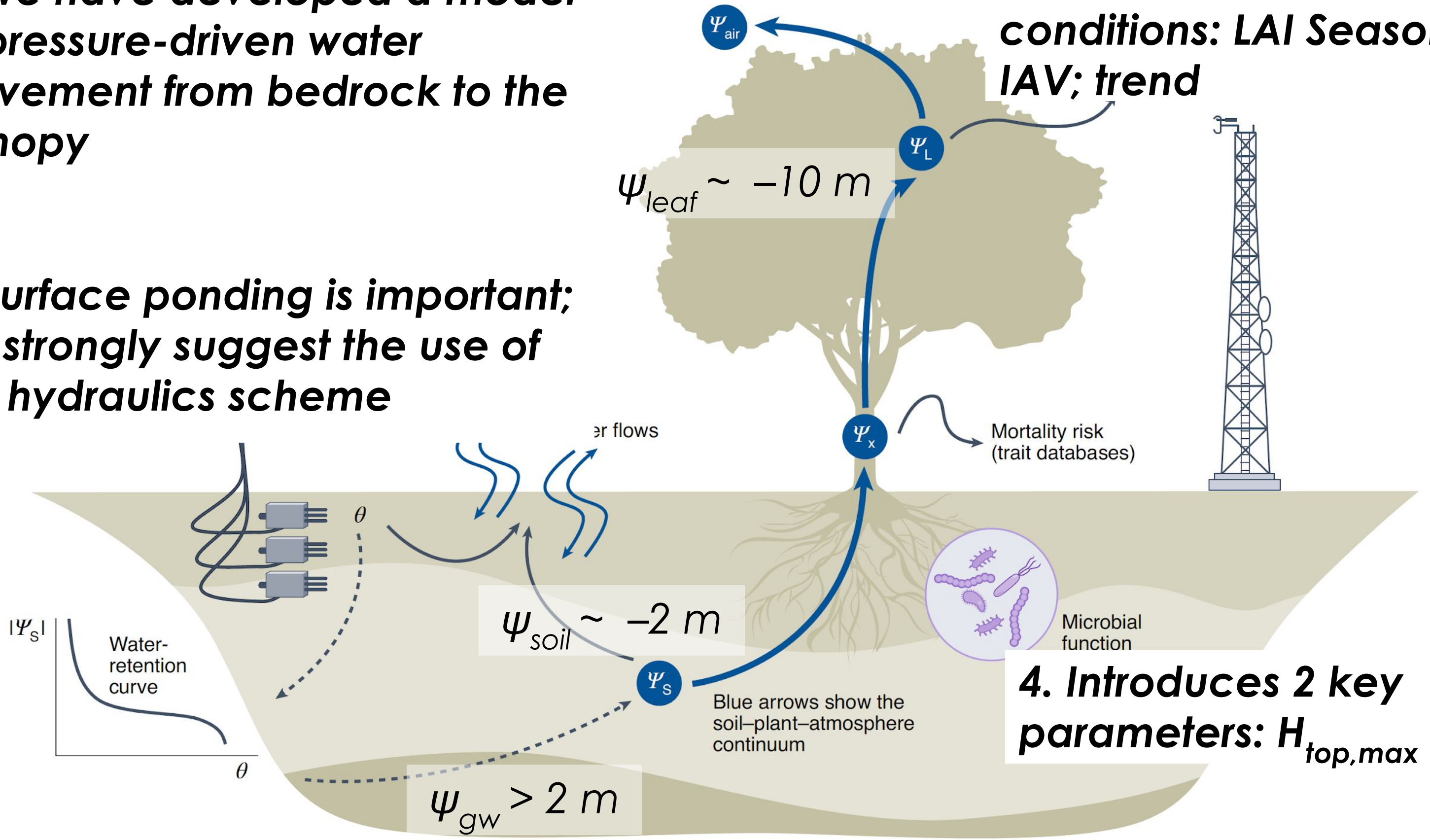


Summary

1. We have developed a model of pressure-driven water movement from bedrock to the canopy

2. The modeled plants are more resilient to drought conditions: LAI Seasonality; IAV; trend

3. Surface ponding is important; we strongly suggest the use of VG hydraulics scheme



4. Introduces 2 key parameters: $H_{top,max}$ and F_f