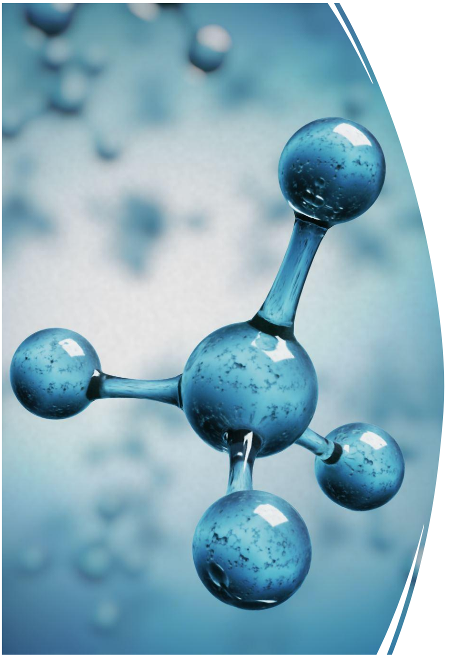
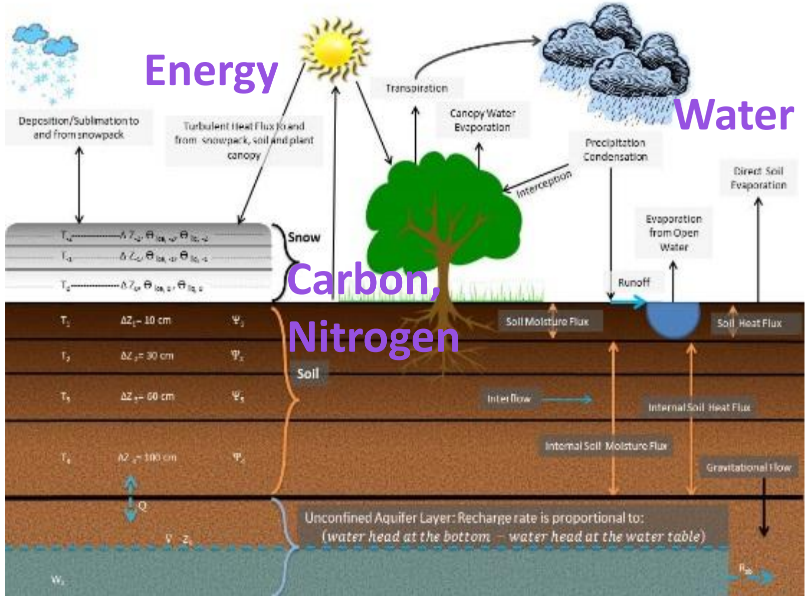
Noah-MP Research & Development @University of Texas at Austin



Zong-Liang Yang

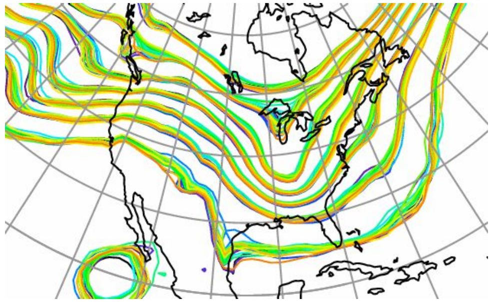
KEY CONTRIBUTORS:
LINGCHENG LI, WENLI FEI, XITIAN CAI, SEUNGWON CHUNG, MAHMOUD MBARAK, SHANSHAN SUN, MENGYAO GUO, AHMAD TAVAKOLY, CEDRIC DAVID, HUI ZHENG, PEIRONG LIN, JINGJING LIANG, ASHLEY MATHENY, DANIELLA REMPE, DAVID DICARLO, MARC HESSE, DEV NIYOGI

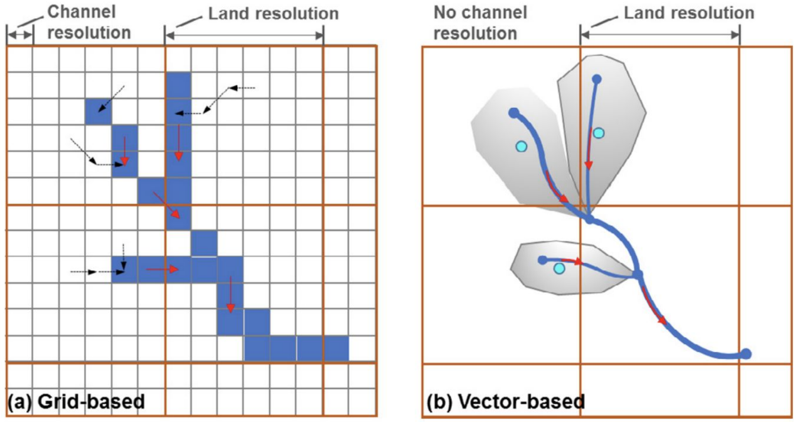


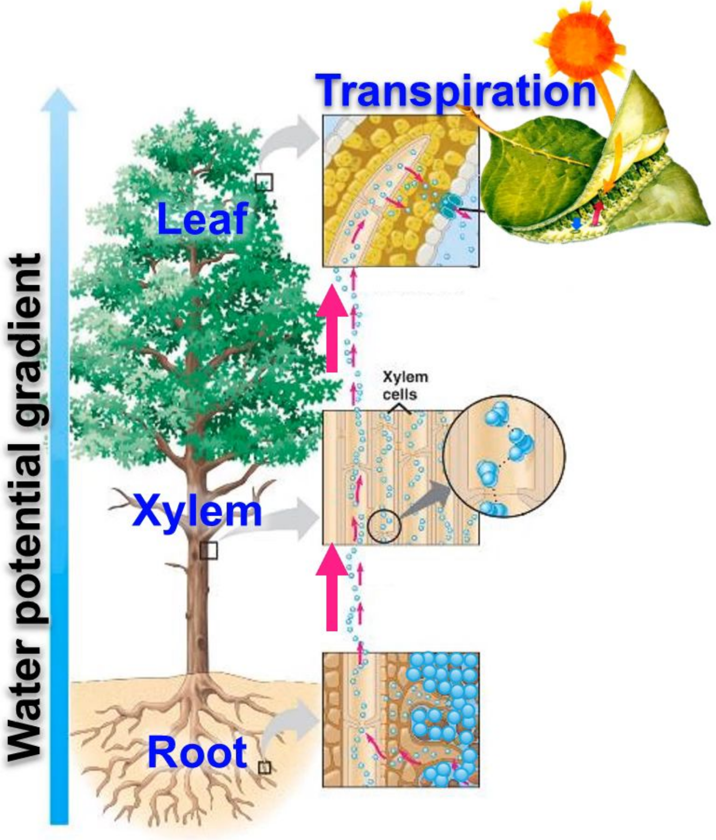
Noah-MP Workshop, Boulder, CO
May 23, 2023

Outline

- Plant Hydraulics (Noah-MP-PHS)
- Carbon–Nitrogen (Noah-MP-CN)
- WRF-Hydro-RAPID
- Data Assimilation (Noah-MP-DART)
- Preferential Flow
- Crops
- Flood & Inundation







Zong-Liang Yang | liang@jsg.utexas.edu

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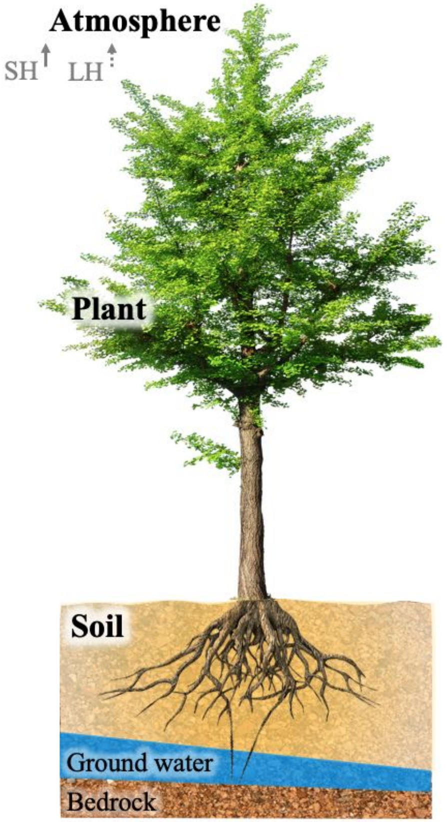
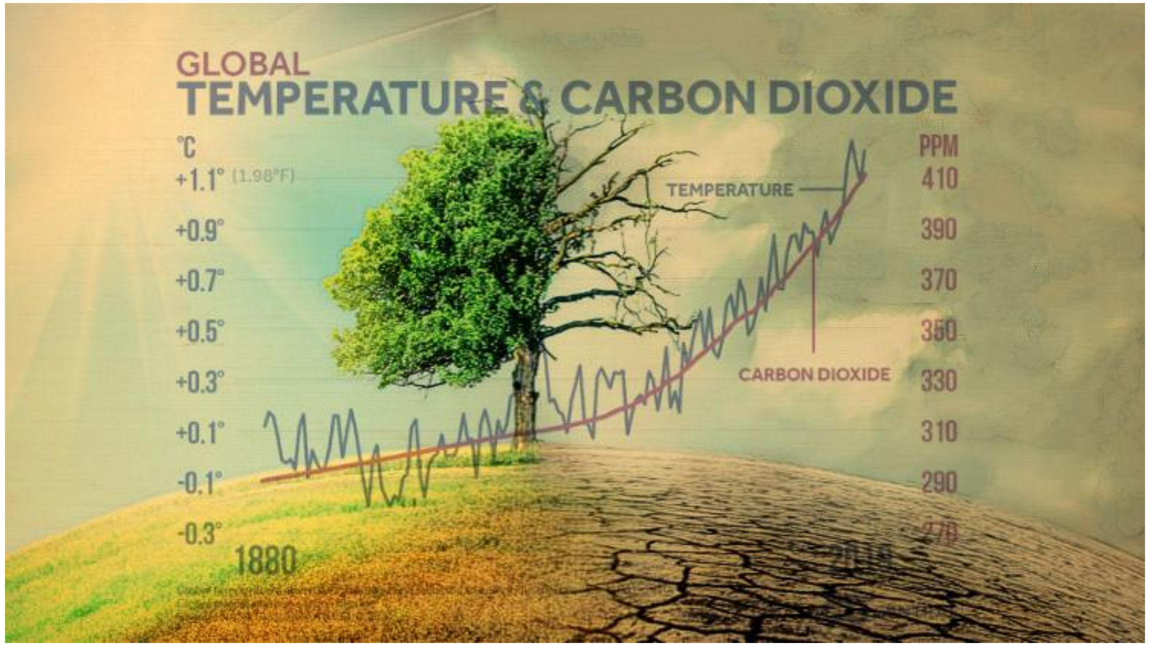
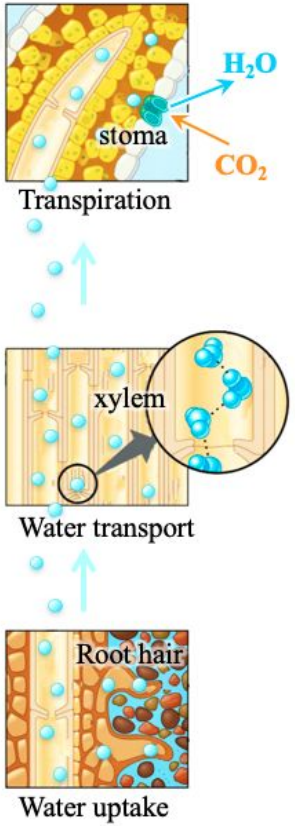
Plant Hydraulics: Key to Understanding Ecosystem Response in a Changing Climate



Soil-plant-atmosphere continuum (SPAC)





Plant Hydraulics

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Plant Hydraulics

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JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2020MS002214

Representation of Plant Hydraulics in the Noah-MP Land Surface Model: Model Development and Multiscale Evaluation

Lingcheng Li[1], Zong-Liang Yang[1], Ashley M. Matheny[1], Hui Zheng[2], Sean C. Swenson[3], David M. Lawrence[3], Michael Barlage[4], Binyan Yan[1], Nate G. McDowell[5], and L. Ruby Leung[5]

[1]Jackson School of Geosciences, University of Texas at Austin, Austin, TX, USA, [2]Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China, [3]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, CO, USA, [4]Environmental Modeling Center, NOAA/NWS/NCEP, College Park, MD, USA, [5]Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA, USA

Key Points:

- Noah-MP-PHS improves the water and carbon simulations over the default soil hydraulics schemes, especially under dry soil conditions
- Noah-MP-PHS captures different plant hydraulic behaviors between the "cavitation risk-averse" maple and the "cavitation risk-prone" oak
- Plant water storage plays a vital role in water and carbon fluxes and relieves xylem hydraulic stress during soil moisture dry-down periods

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

Z.-L. Yang and A. M. Matheny,
liang@jsg.utexas.edu;
ashley.matheny@jsg.utexas.edu

Citation:

Li, L., Yang, Z.-L., Matheny, A. M., Zheng, H., Swenson, S. C., Lawrence, D. M., et al. (2021). Representation of plant hydraulics in the Noah-MP land surface model: Model development and multiscale evaluation. *Journal of Advances in Modeling Earth Systems*, *13*, e2020MS002214. https://doi.org/10.1029/2020MS002214

Abstract Plants are expected to face increasing water stress under future climate change. Most land surface models, including Noah-MP, employ an idealized "big-leaf" concept to regulate water and carbon fluxes in response to soil moisture stress through empirical soil hydraulics schemes (SHSs). However, such schemes have been shown to cause significant uncertainties in carbon and water simulations. In this paper, we present a novel plant hydraulics scheme (PHS) for Noah-MP (hereafter, Noah-MP-PHS), which employs a big-tree rather than big-leaf concept, wherein the whole-plant hydraulic strategy is considered, including root-level soil water acquisition, stem-level hydraulic conductance and capacitance, and leaf-level anisohydricity and hydraulic capacitance. Evaluated against plot-level observations from a mature, mixed hardwood forest at the University of Michigan Biological Station and compared with the default Noah-MP, Noah-MP-PHS better represents plant water stress and improves water and carbon simulations, especially during periods of dry soil conditions. Noah-MP-PHS also improves the asymmetrical diel simulation of gross primary production under low soil moisture conditions. Noah-MP-PHS is able to reproduce different patterns of transpiration, stem water storage and root water uptake during a 2-week dry-down period for two species with contrasting plant hydraulic behaviors, i.e., the "cavitation risk-averse" red maple and the "cavitation risk-prone" red oak. Sensitivity experiments with plant hydraulic capacitance show that the stem water storage enables nocturnal plant water recharge, affects plant water use efficiency, and provides an important buffer to relieve xylem hydraulic stress during dry soil conditions.

Plant Hydraulics

"Big Leaf"

✔ Soil hydraulics: yes

✗ Plant hydraulics: no

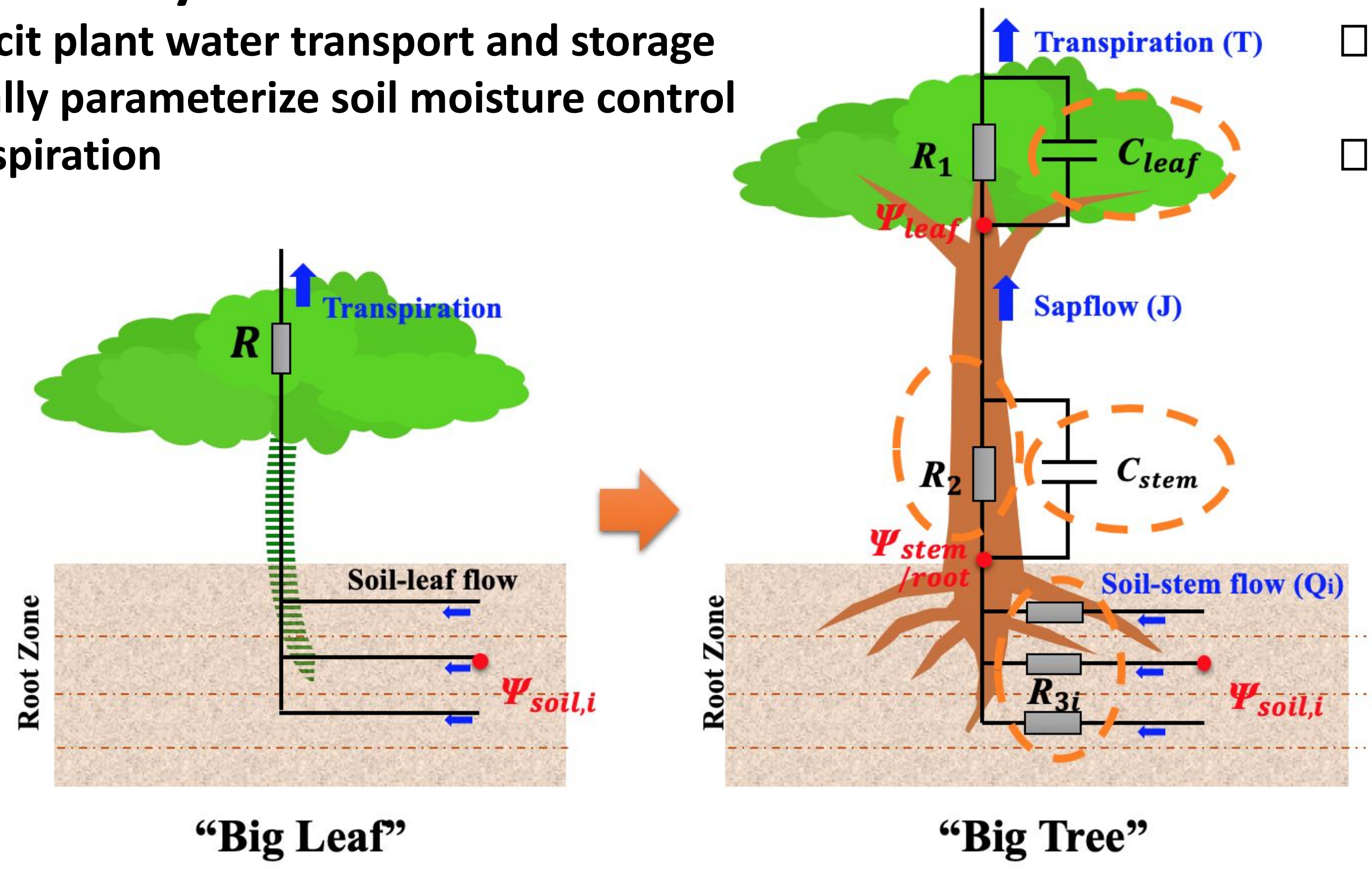
- ☐ No explicit plant water transport and storage
- ☐ Empirically parameterize soil moisture control on transpiration

"Big Tree"

✔ Soil hydraulics: yes

✔ Plant hydraulics: yes

- ☐ Represent whole-plant (root–stem–leaf) hydraulic strategy
- ☐ Explicitly consider plant water storage



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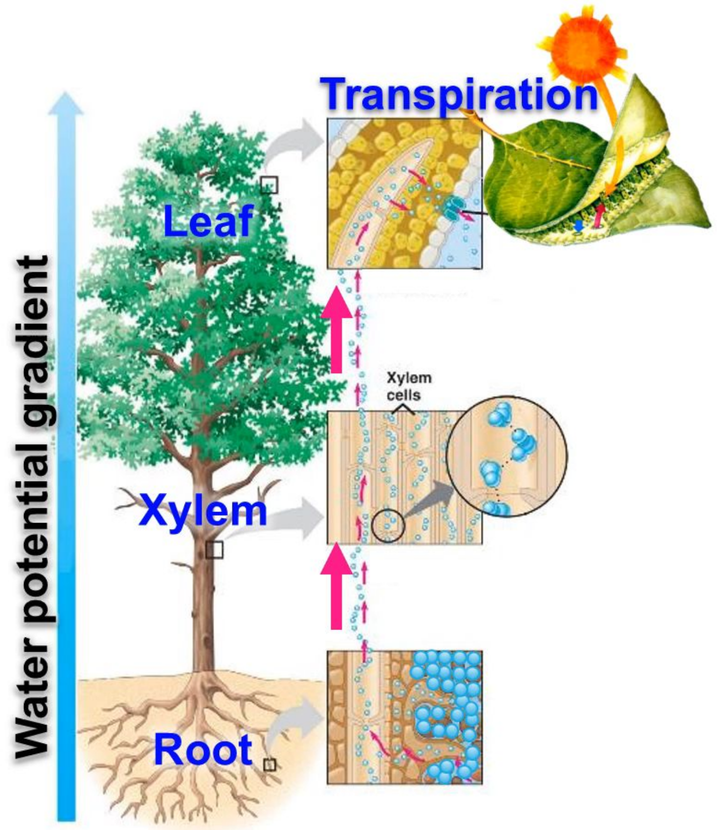
Plant Hydraulics Requires 14 Parameters



	Parameter	Description	Units
Leaf	TLP	Turgor loss point (LWP when photosynthetic capacity rate halves)	mm
	C_{leaf}	Leaf water capacitance	1
	a_3	Empirical parameter controlling plant water stress	unitless
Stem (xylem)	$K_{s,\text{sat}}$	Sapwood-area-specific saturated xylem hydraulic conductivity	mm/s
	P_{50}	Stem water potential at 50% loss of conductivity	mm
	C_{stem}	Stem water capacitance	m^{-1}
	S_{sap}	Specific sapwood area index	m^2/m^2
	V_{sap}	Specific sapwood volume index	m^3/m^2
	h_c	Canopy height	mm
	a_1	Empirical parameter controlling length of water flow route	unitless
	a_2	Empirical parameter controlling xylem hydraulic conductance	unitless
Root	$f_{\text{root-shoot}}$	Fine root area to shoot (i.e., leaf area + stem area) ratio	m^2/m^2
	Root depth	Fine rooting depth (also used in SHSs)	m
	Root ratio	Fine root distribution in root zone each layer (also used in SHSs)	unitless

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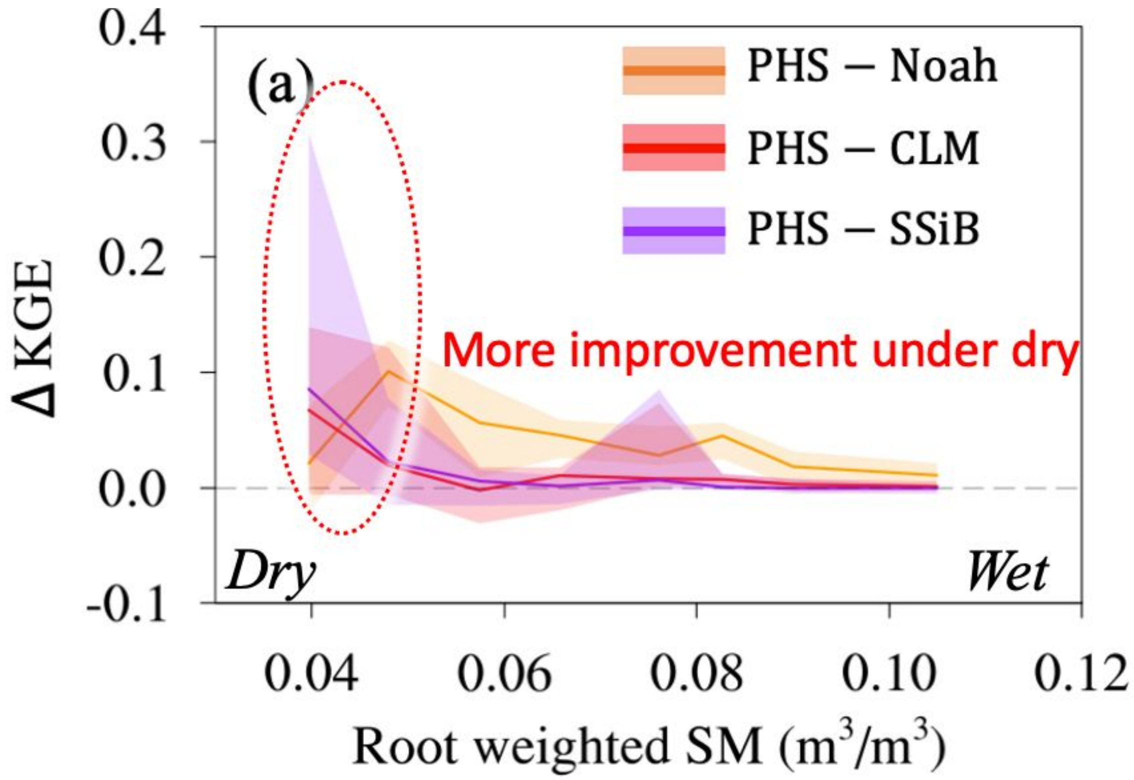
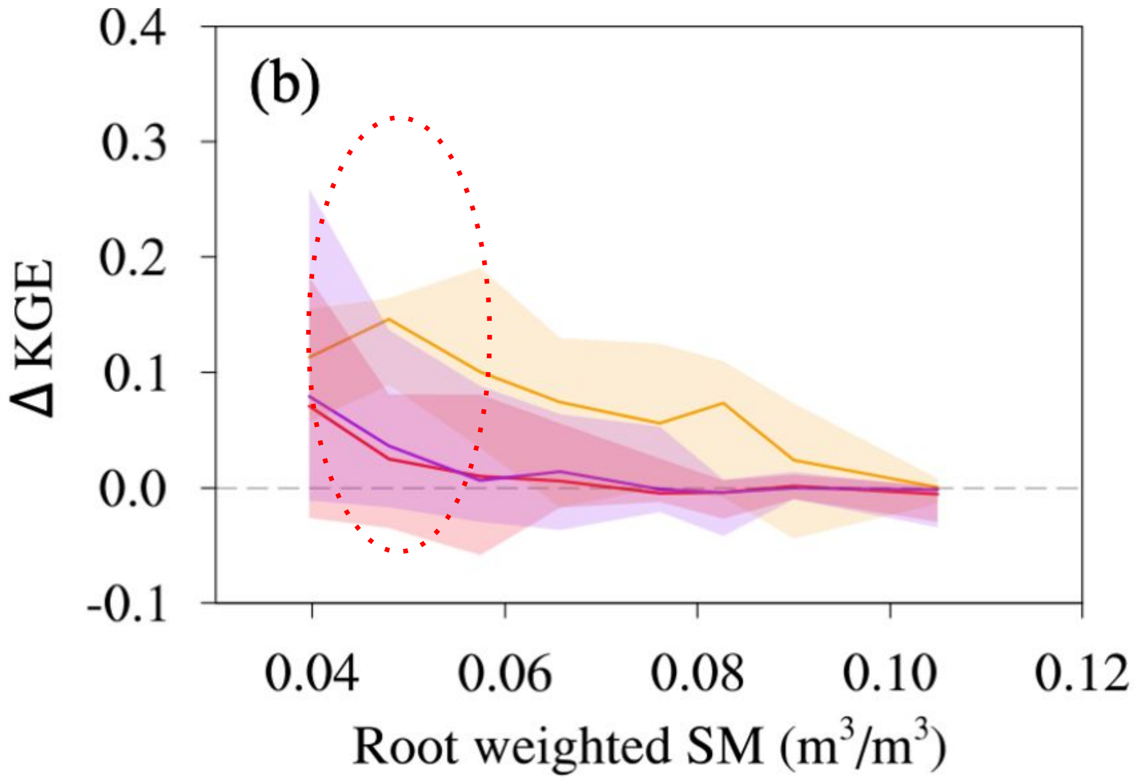
Plant Hydraulics: Evaluation at Local FLUXNET Site

Transpiration

GPP





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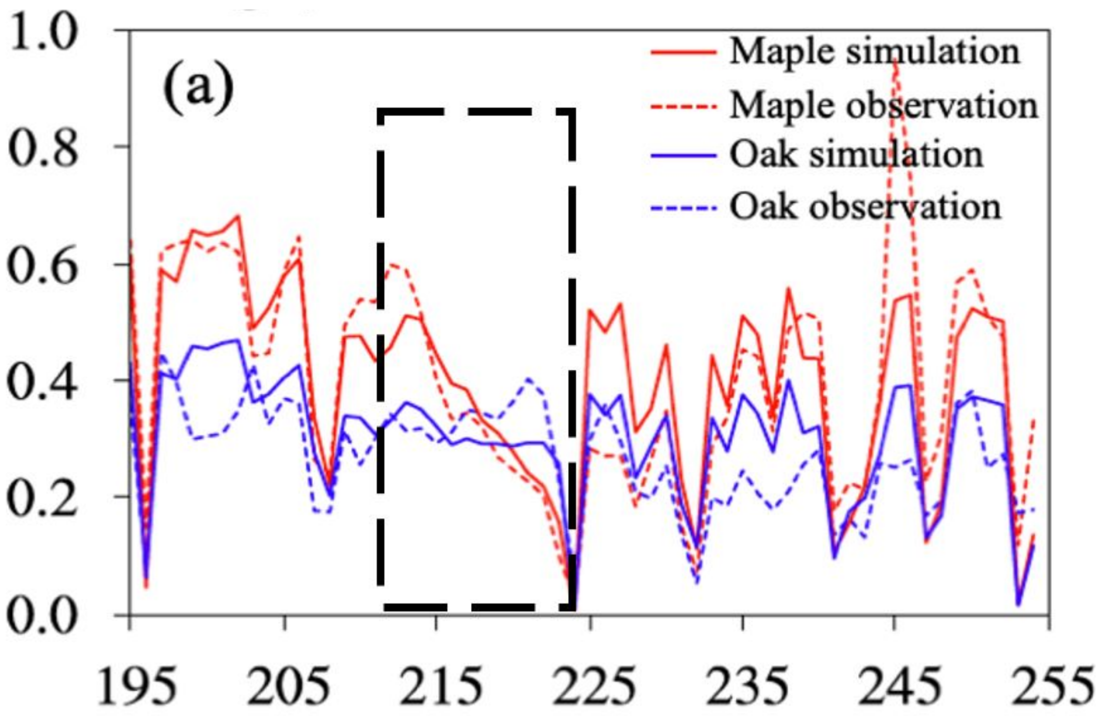
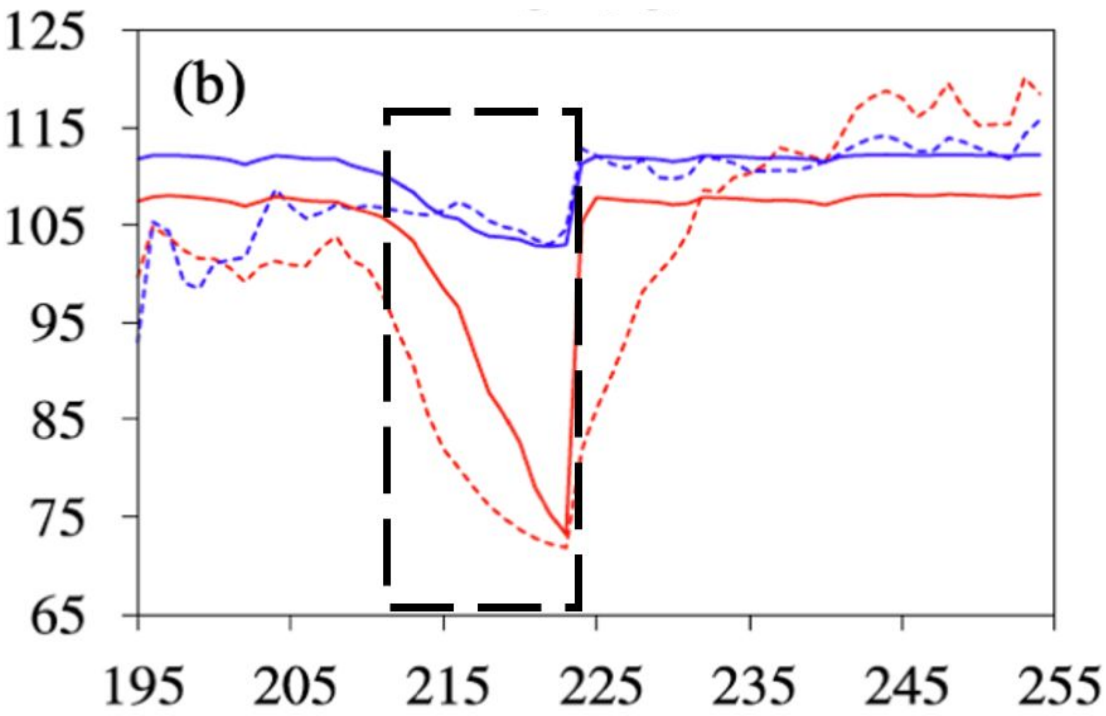
Plant Hydraulics: Maple (risk-averse) vs Oak (risk-prone) (US-UMB)

Transpiration (g/s)



Stem water storage (kg)



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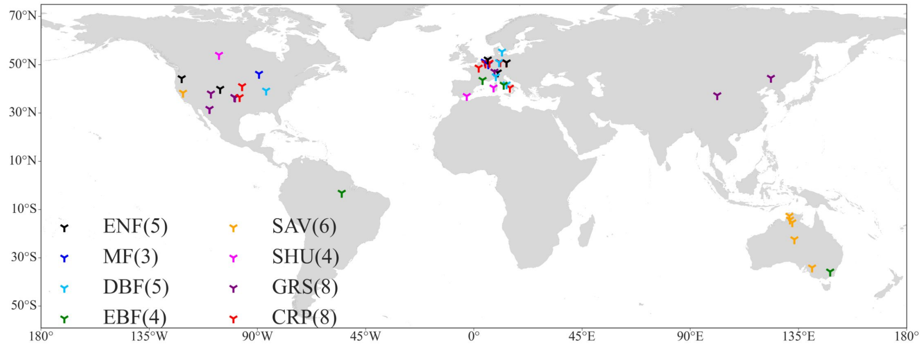
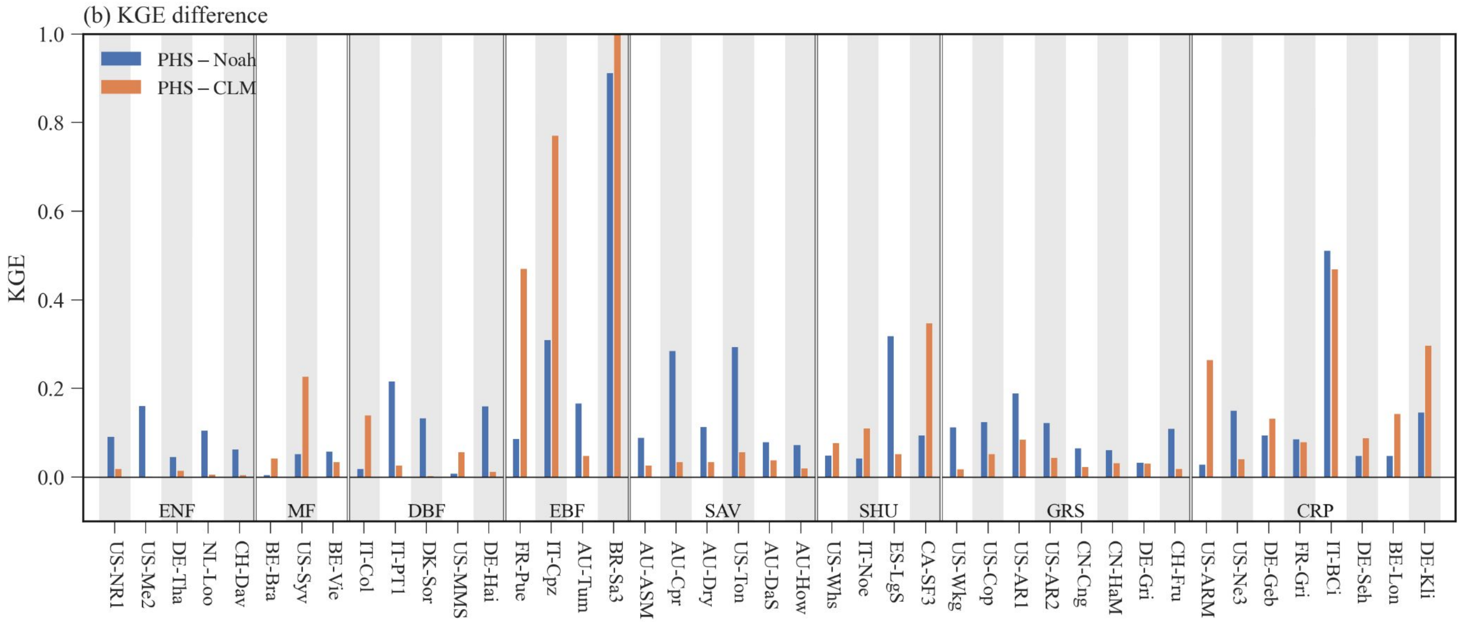
Plant Hydraulics: Global FLUXNET Sites

Based on the application of PHS at multiple FLUXNET sites, PHS outperforms Noah and CLM with a larger KGE.



KGE improvement



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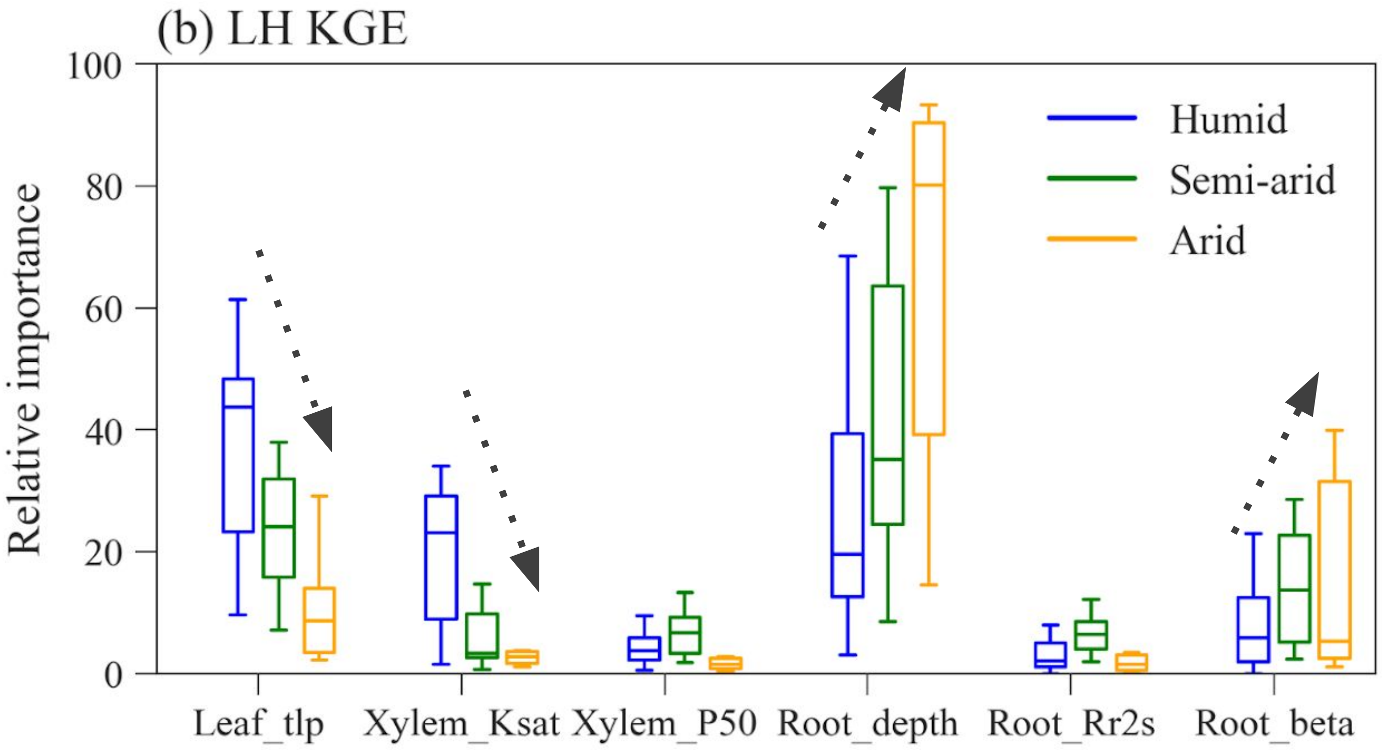
Plant Hydraulics: Global FLUXNET Sites

Sensitivity analysis, from humid to arid conditions

- Leaf and stem parameters show decreased importance.
- Root parameters show increased importance.



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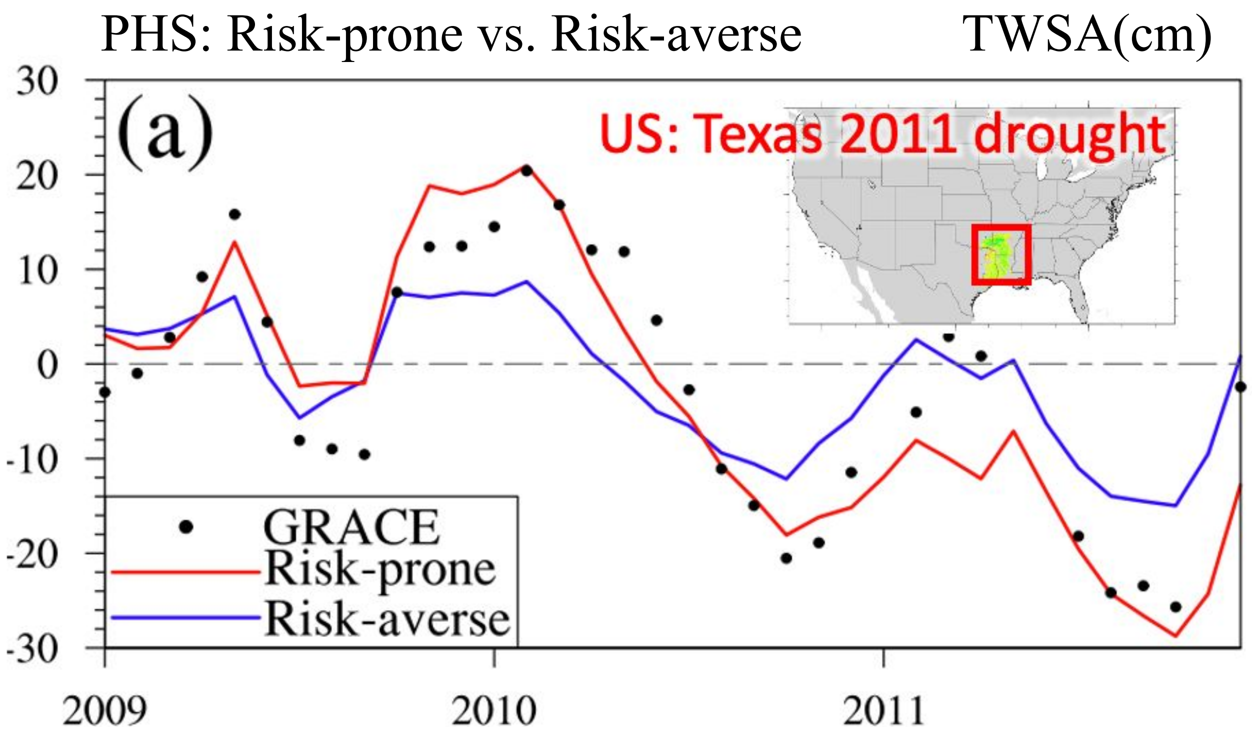
Plant Hydraulics Improves TWSA During Drought in the US



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Plant Hydraulics: Top Downloaded & Top Cited

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2020MS002214

Key Points:

- Noah-MP-PHS improves the water and carbon simulations over the default soil hydraulics schemes, especially under dry soil conditions
- Noah-MP-PHS captures different

Representation of Plant Hydraulics in the Noah-MP Land Surface Model: Model Development and Multiscale Evaluation

Lingcheng Li[1], Zong-Liang Yang[1], Ashley M. Matheny[1], Hui Zheng[2], Sean C. Swenson[3], David M. Lawrence[3], Michael Barlage[4], Binyan Yan[1], Nate G. McDowell[5], and L. Ruby Leung[5]

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Representation of Plant Hydraulics in the Noah-MP Land Surface Model: Model Development and Multiscale Evaluation

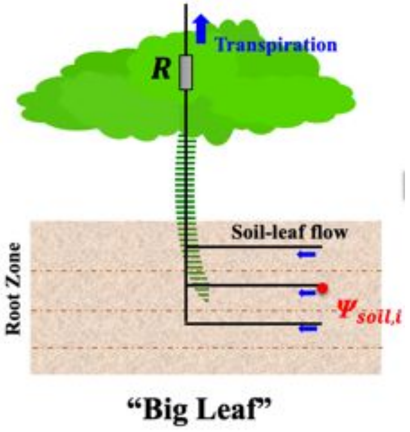
Among work published in an issue between 1 January 2021 – 15 December 2022.

Li et al. (2021) JAMES

Representing β in "Big Leaf" and "Big Tree" Models

Soil hydraulics scheme (SHSs)

- Soil moisture
- Soil water potential



"Big Leaf"

Noah

$$\beta = \sum_{i=1}^{N_{root}} \frac{\Delta z_i}{z_{root}} \min\left(1.0, \frac{\theta_{liq,i} - \theta_{wilt}}{\theta_{ref} - \theta_{wilt}}\right)$$

CLM

$$\beta = \sum_{i=1}^{N_{root}} \frac{\Delta z_i}{z_{root}} \min\left(1.0, \frac{\psi_{wilt} - \psi_i}{\psi_{wilt} - \psi_{sat}}\right)$$

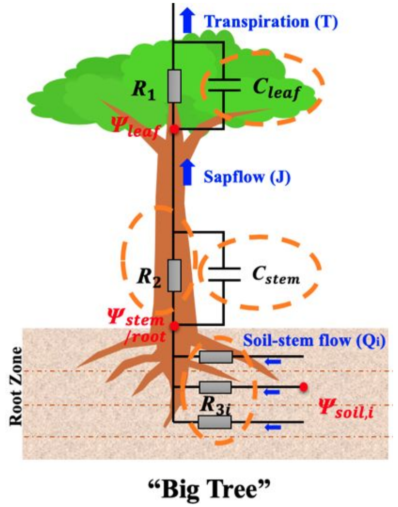
SSiB

$$\beta = \sum_{i=1}^{N_{root}} \frac{\Delta z_i}{z_{root}} \min\left(1.0, 1.0 - e^{-c_2 \ln(\psi_{wilt}/\psi_i)}\right)$$

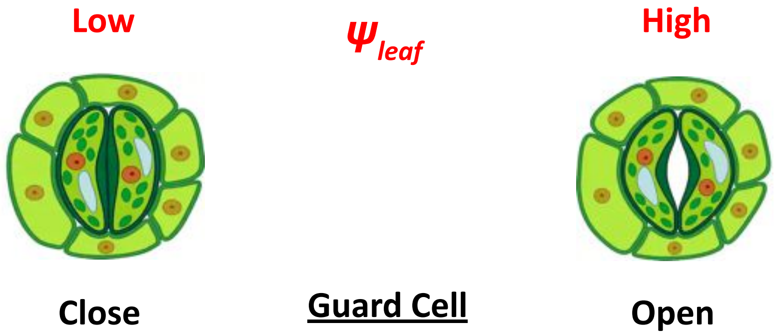
Plant hydraulics scheme (PHS)

- leaf water potential

$$\beta = [1 + (\frac{\psi_{leaf}}{TLP})^{a3}]^{-1}$$



"Big Tree"



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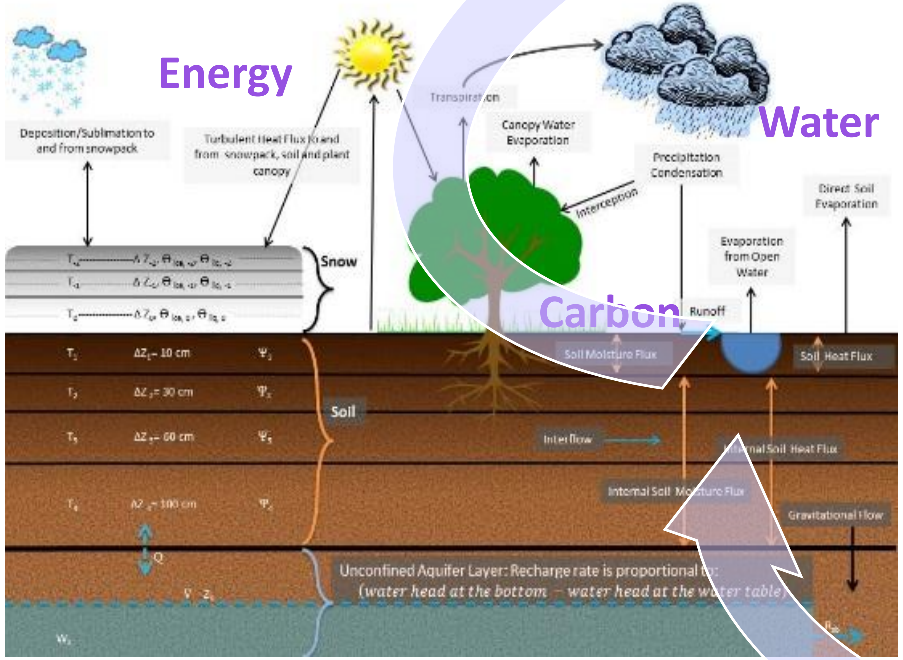
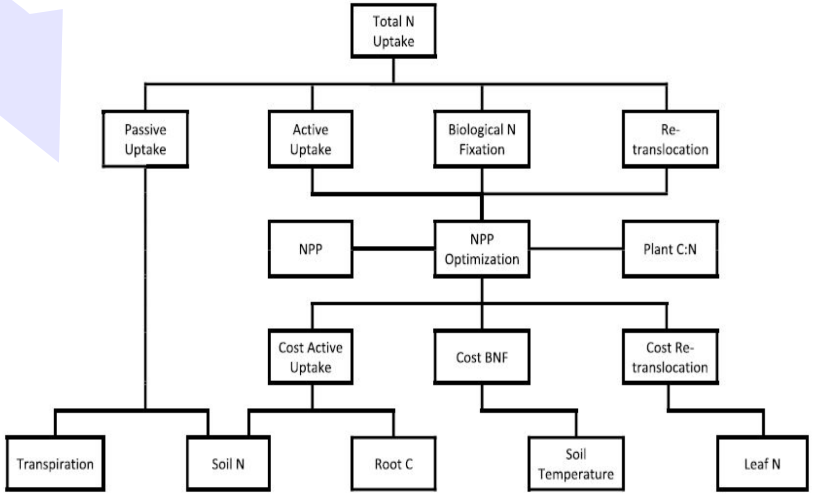
Noah-MP with Terrestrial Carbon and Nitrogen Dynamics

Niu et al. (2011)
Neitsch et al. (2011)
Fisher et al. (2010)

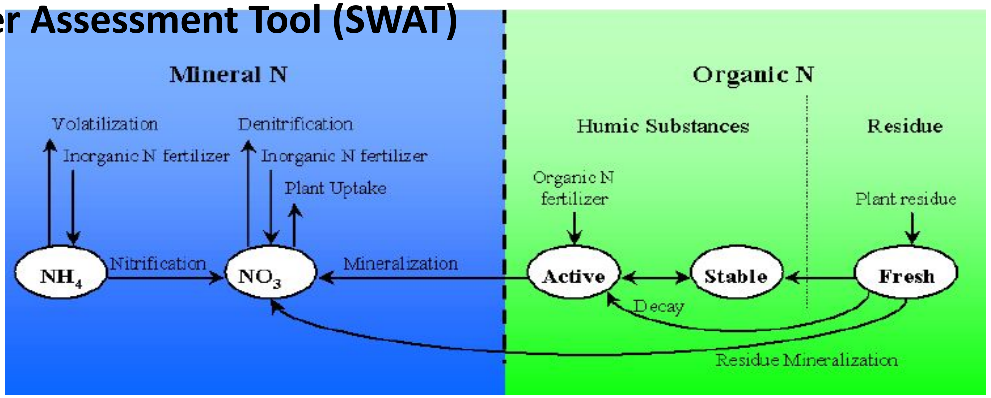
Biological fixation & Nitrogen uptake



Fixation and Uptake of Nitrogen (FUN)



Soil and Water Assessment Tool (SWAT)



Soil nitrogen pathway & storage

Cai et al. (2016) GMD; Liang et al. (2020) AAS; Chung et al., 2023

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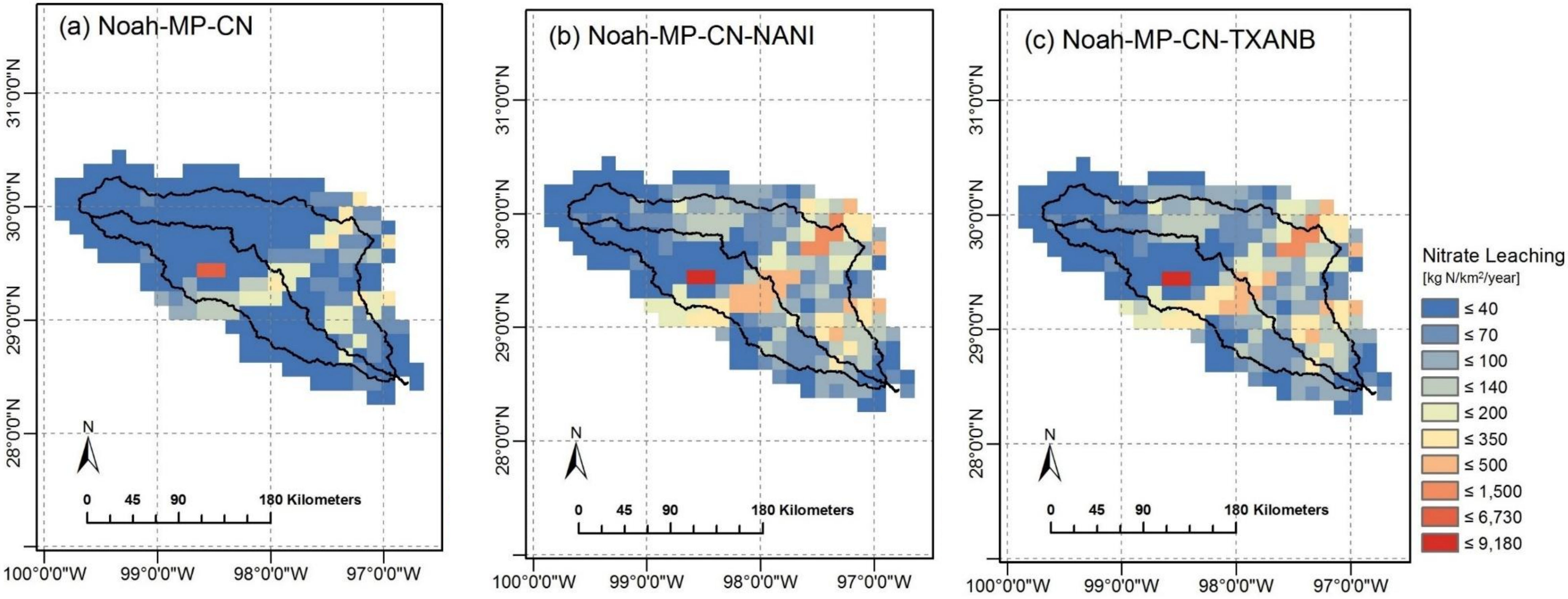
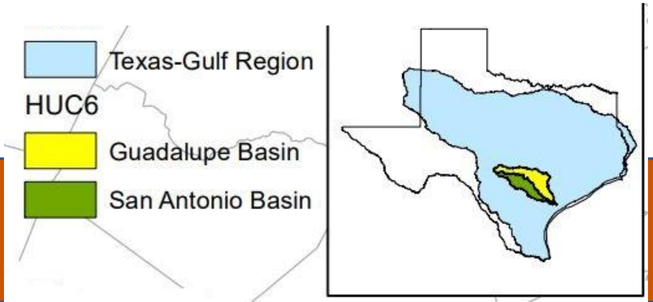
Regional Nitrate Leaching





Zong-Liang Yang | liang@jsg.utexas.edu

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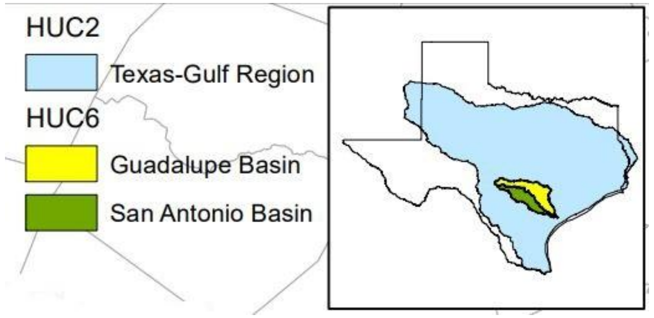
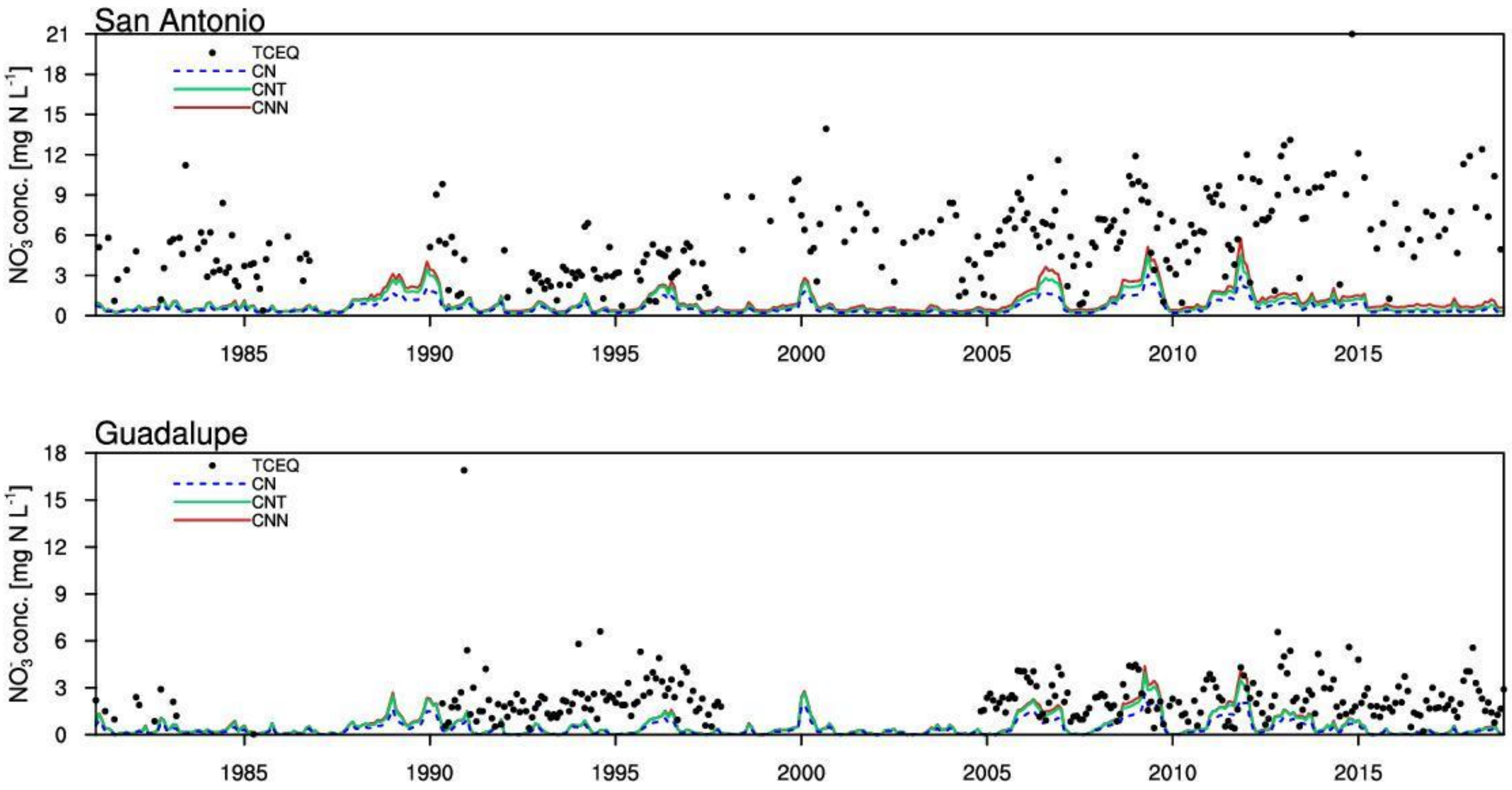
Regional Nitrate Leaching





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WRF-Hydro-RAPID

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ELSEVIER

Implementation of a vector-based river network routing scheme in the community WRF-Hydro modeling framework for flood discharge simulation

Peirong Lin[a], Zong-Liang Yang[a,b,*], David J. Gochis[c], Wei Yu[c], David R. Maidment[d], Marcelo A. Somos-Valenzuela[e], Cédric H. David[f]

Citation: 48

Insights into Hydrometeorological Factors Constraining Flood Prediction Skill during the May and October 2015 Texas Hill Country Flood Events

PEIRONG LIN

Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas

LARRY J. HOPPER JR.

NOAA/NWS Austin/San Antonio Weather Forecast Office, New Braunfels, Texas

ZONG-LIANG YANG

Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas, and Key Laboratory of Regional Climate-Environment Research for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

MARK LENZ AND JON W. ZEITLER

NOAA/NWS Austin/San Antonio Weather Forecast Office, New Braunfels, Texas

(Manuscript received 23 February 2018, in final form 12 July

Citation: 31

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

Vol. 54, No. 1 AMERICAN WATER RESOURCES ASSOCIATION February 2018

SPATIOTEMPORAL EVALUATION OF SIMULATED EVAPOTRANSPIRATION AND STREAMFLOW OVER TEXAS USING THE WRF-HYDRO-RAPID MODELING FRAMEWORK[1]

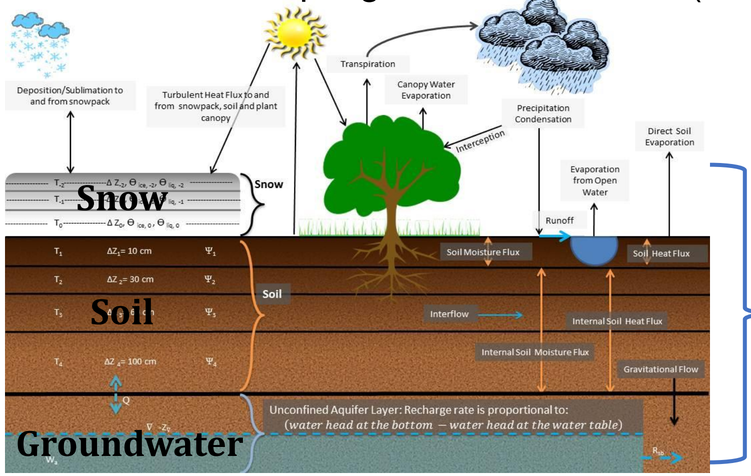
Peirong Lin, Mohammad Adnan Rajib, Zong-Liang Yang, Marcelo Somos-Valenzuela
Merwade, David R. Maidment, Yan Wang, and Li Chen[2]

Citation: 65

Noah-MP-DART TWS Data Assimilation System

NLDAS-2 testbed

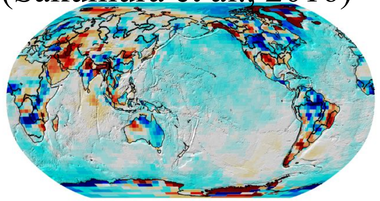
Noah-MP with simple groundwater model (SIMGM)



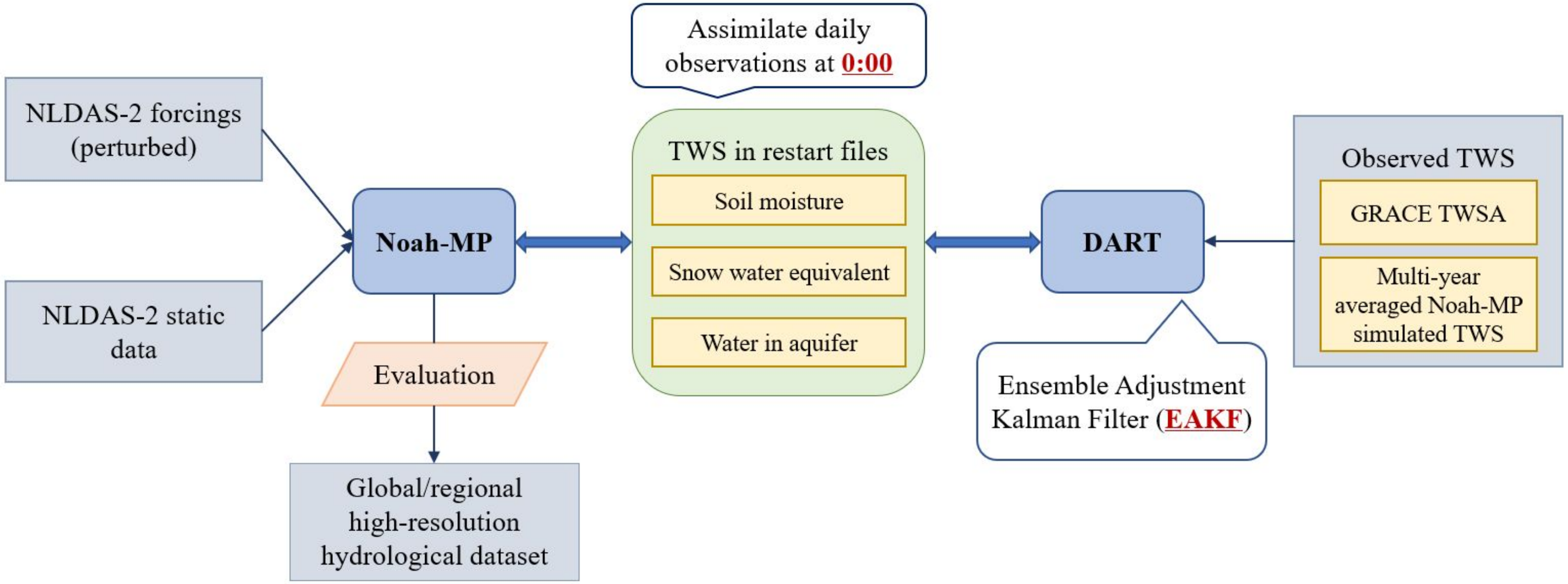
Assimilation

Daily RSWM GRACE terrestrial water storage (TWS)

(Sakumura et al., 2016)



- Domain:
  25°N—43°N
  125°W—75°W
- Experimental period:
  2009.07-2011.06
- Ensemble size:
  20



Zong-Liang Yang | liang@jsg.utexas.edu

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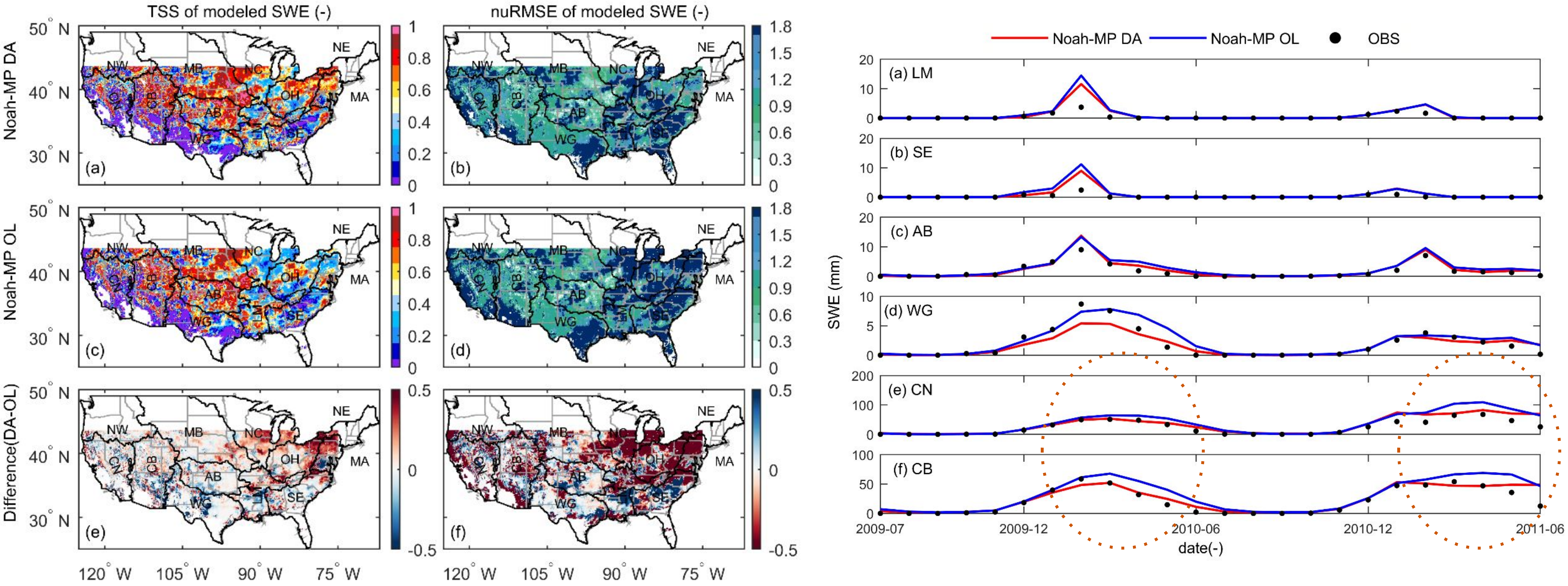
TWS DA Improves Deep Snow Simulations



TWS DA improves snow water equivalent (SWE) simulation more significantly in deep snow areas.
TWS DA can reduce the overestimation of winter snow peaks in Noah-MP.

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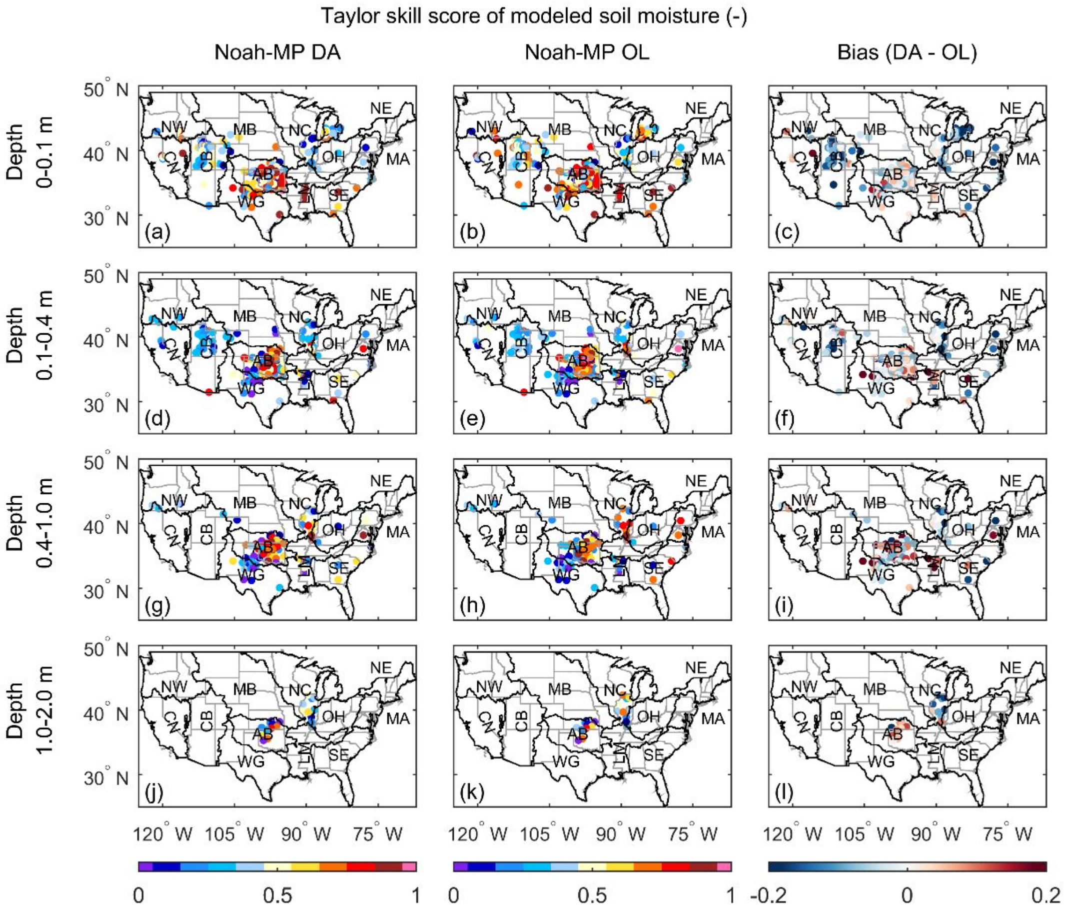
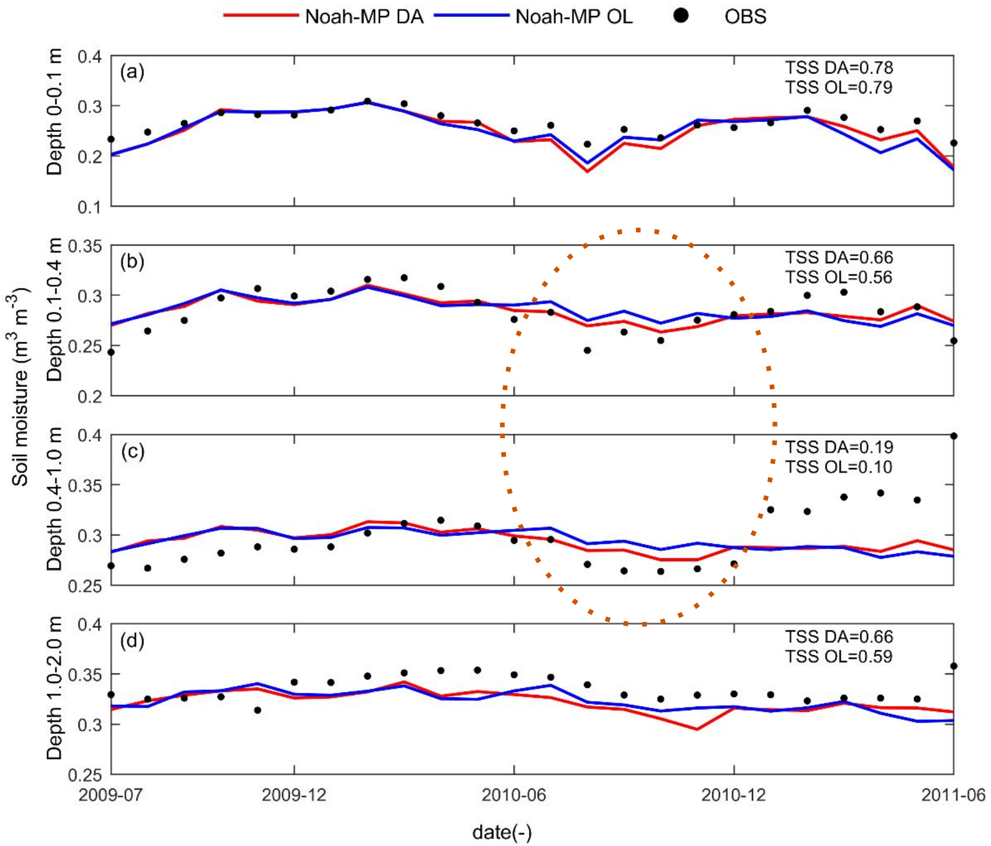
TWS DA Improves Deep Soil Moisture Simulations



An example: soil moisture simulation in Arkansas (AB)

DA: data assimilation OL: Open-loop



At surface layers, soil moisture ensemble simulation has low spread due to constraints from atmospheric forcings, limiting the potential improvement from DA. As soil depth increases, DA improvement gradually enhances.

Zong-Liang Yang | liang@jsg.utexas.edu

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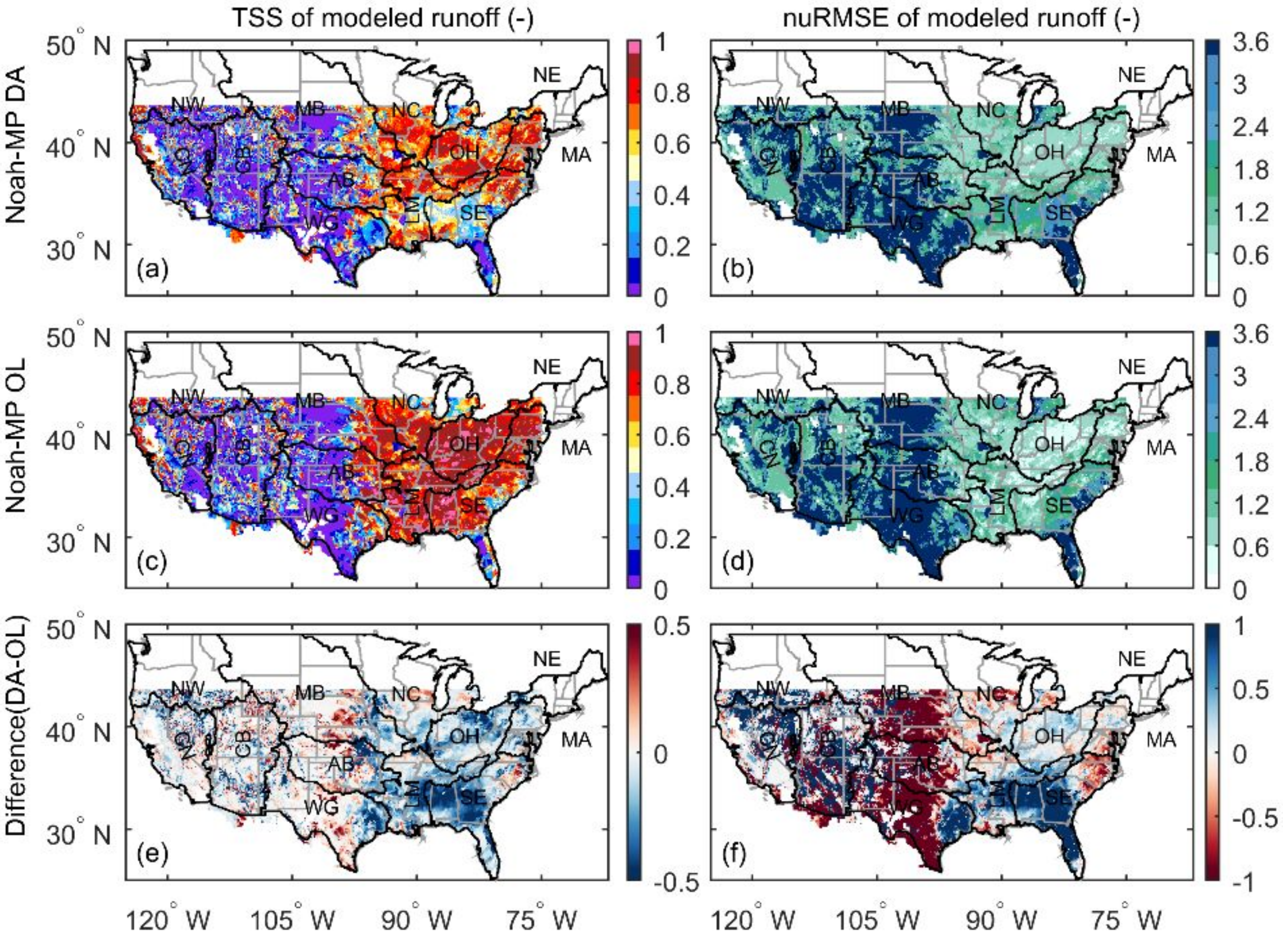
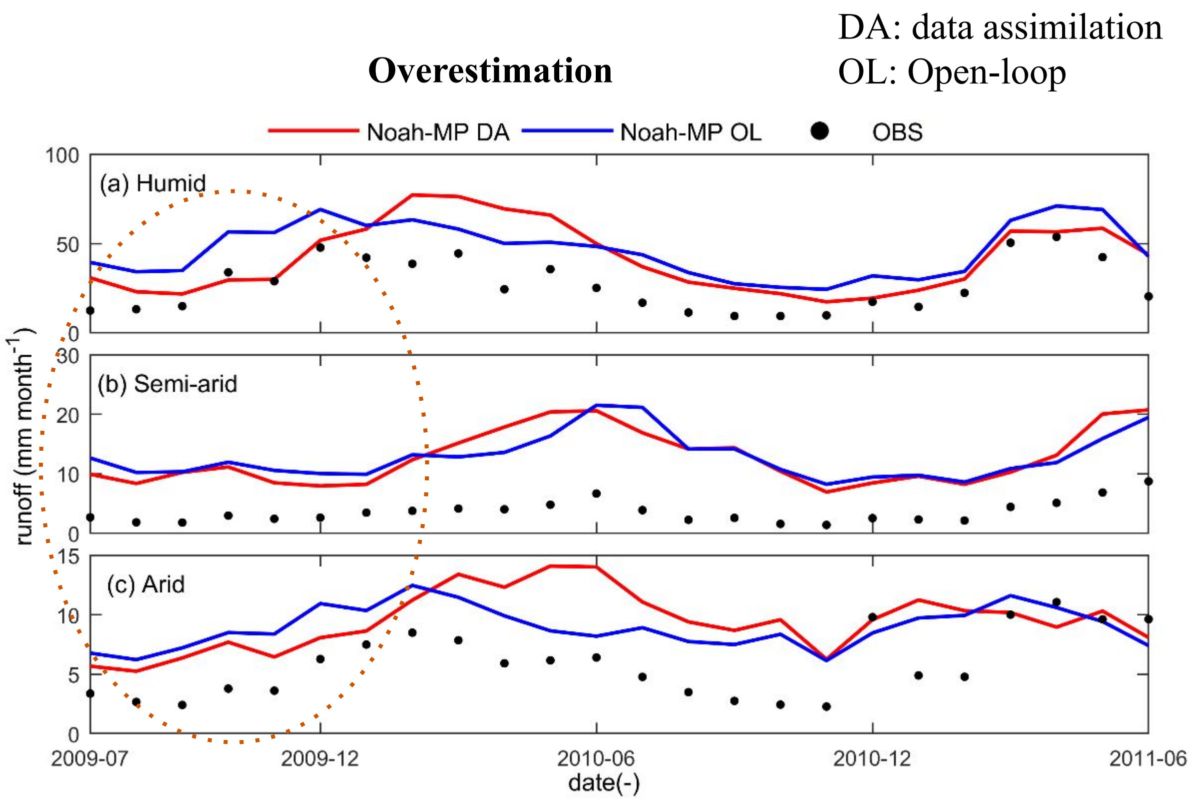
TWS DA Improves Runoff Simulations in Arid/Semi-Arid Regions



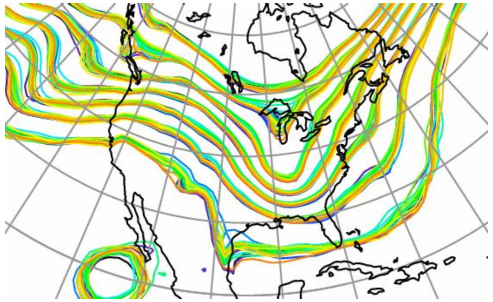


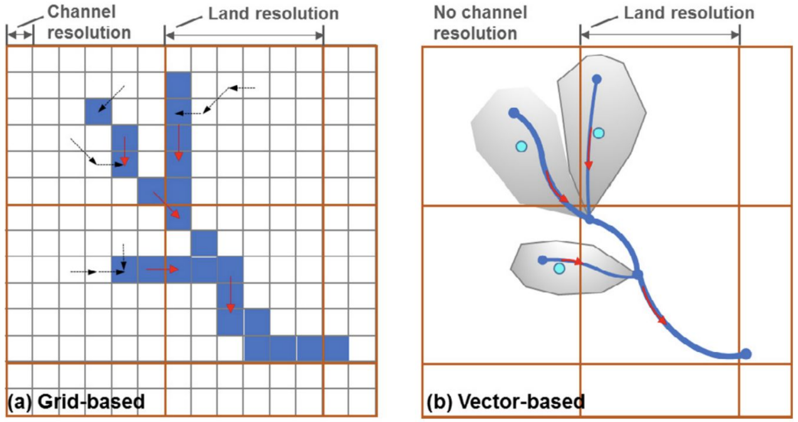
TWS DA improves runoff simulation in arid and semi-arid regions, with a notable reduction in RMSE over the semi-arid areas. TWS DA captures the temporal variation of runoff better than OL, while there is a slight overestimation in the spring of 2010.

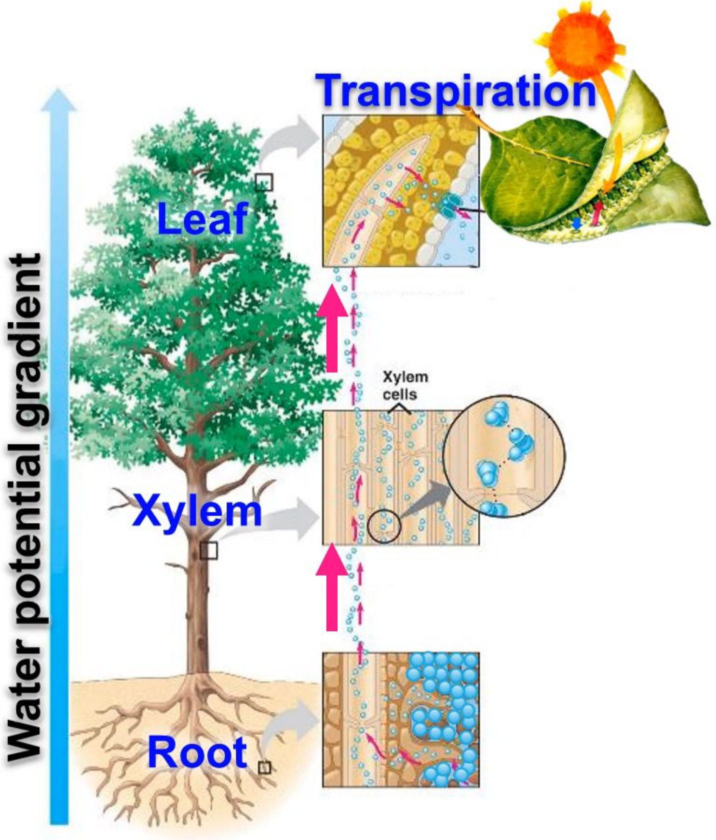
Zong-Liang Yang | liang@jsg.utexas.edu

Summary

- Plant Hydraulics (Noah-MP-PHS)
- Carbon–Nitrogen (Noah-MP-CN)
- WRF-Hydro-RAPID
- Data Assimilation (Noah-MP-DART)
- Preferential Flow
- Crops
- Flood & Inundation







Zong-Liang Yang | liang@jsg.utexas.edu

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Department of Geological Sciences

Thank you!

Questions, Comments?

Selected Publications

- Cai, X.*, **Yang, Z.-L.**, Fisher, J. B., Zhang, X., Barlage, M., and Chen, F. 2016: Integration of nitrogen dynamics into the Noah-MP land surface model v1.1 for climate and environmental predictions, Geosci. Model Dev., 9, 1–15, https://doi.org/10.5194/gmd-9-1-2016.
- Li, L. C.*, **Z.-L. Yang**, A. M. Matheny, H. Zheng, S. C. Swenson, D. M. Lawrence, M. Barlage, B.Y. Yan, N. G. McDowell, and L. R. Leung, 2021: Representation of plant hydraulics in the Noah-MP land surface model: Model development and multi-scale evaluation, *Journal of Advances in Modeling Earth Systems*, https://doi.org/10.1029/2020MS002214.
- Liang, J. J.*, **Z.-L. Yang**, X. T. Cai, P. R. Lin*, H. Zheng, and Q. Y. Bian*, 2020: Modeling the impacts of nitrogen dynamics on regional terrestrial carbon and water cycles over China with Noah-MP-CN, *Advances in Atmospheric Sciences*, **37** (7), 679–695, https://doi.org/10.1007/s00376-020-9231-6.
- Lin, P. R.*, **Z.-L. Yang**, D. J. Gochis, W. Yu, D. R. Maidment, M. A. Somos-Valenzuela, and C. H. David, 2018: Implementation of a vector-based river network routing scheme in the community WRF-Hydro modeling frameowork for flood discharge simulation, *Environmental Modelling and Software* **107**, 1–11, https://doi.org/10.1016/j.envsoft.2018.05.018.
- Souto, L., J. Yip, W.-Y. Wu*, B. Austgen, E. Kutanoglu, J. Hasenbein, **Z.-L. Yang**, C. W. King, and S. Santoso, 2022: Power system resilience to floods: Modeling, impact assessment, and mid-term mitigation strategies, *International Journal of Electrical Power and Energy Systems*, **135**, 107545, https://doi.org/10.1016/j.ijepes.2021.107545.

Zong-Liang Yang | liang@jsg.utexas.edu

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