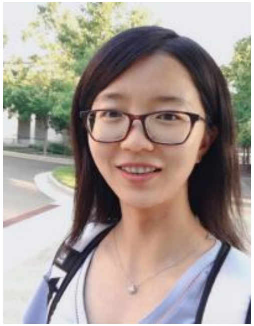
Plant hydraulics accentuates the effects of atmospheric moisture stress on transpiration

Yanlan Liu[1,2], Mukesh Kumar[3], Xue Feng[4], Gabriel G. Katul[5], **Alexandra G. Konings[1]**

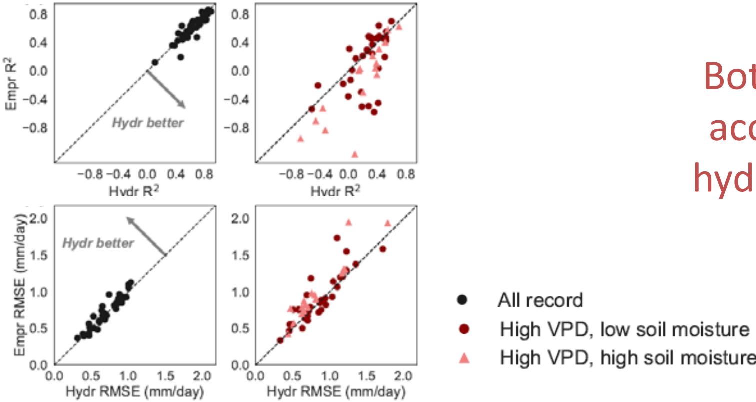


[1]Stanford University, [2]The Ohio State University, [3]University of Alabama, [3]University of Minnesota, Twin Cities, [4]Duke University

Remote Sensing Ecohydrology Group

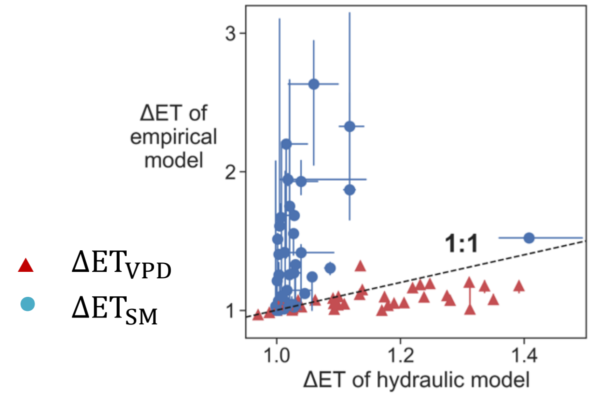
One-slide summary (more details in following slides)

We compared plant hydraulic & empirical (soil moisture-based) models of ET



Both models are about equally accurate overall, but the plant hydraulic model better captures high-VPD conditions

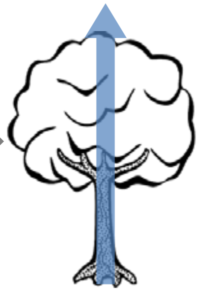
This occurs because empirical models have compensating errors between too little sensitive to VPD and too much sensitivity to soil moisture



…suggests effects of future, hotter droughts on ET might be underestimated

Transpiration is driven by two sources of water stress

Transpiration

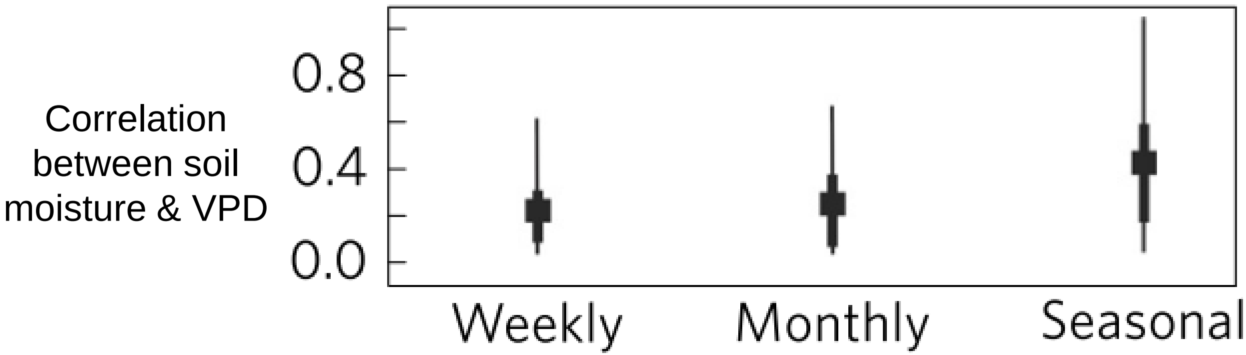


Soil moisture

Vapor pressure deficit (VPD)

Soil moisture and VPD are correlated

High correlations between soil moisture and VPD at Ameriflux sites

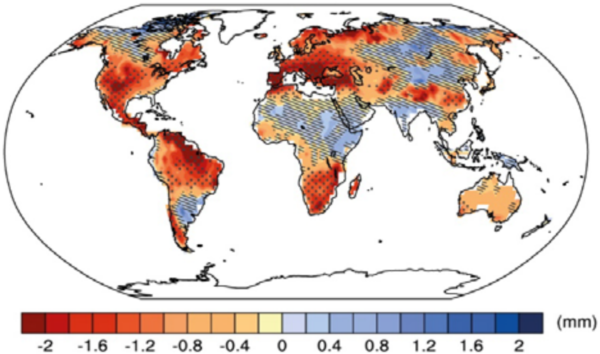


Novick et al., 2016, Nature Climate Change
doi.org/10.1038/nclimate3114

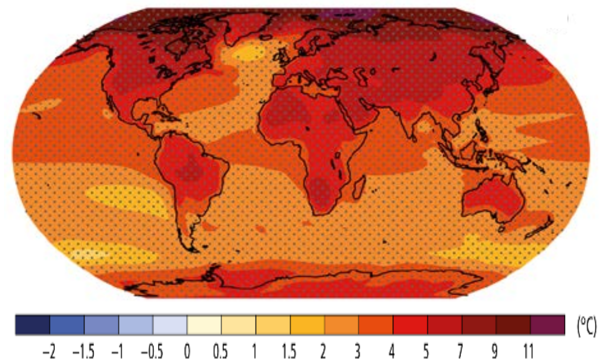
Q: Can our models of transpiration correctly account for VPD & soil moisture, or is there compensation?

Important, because trends in soil moisture & VPD diverge

Projected soil moisture changes are heterogeneous & uncertain



Projected VPD increases significantly everywhere due to rising temperatures



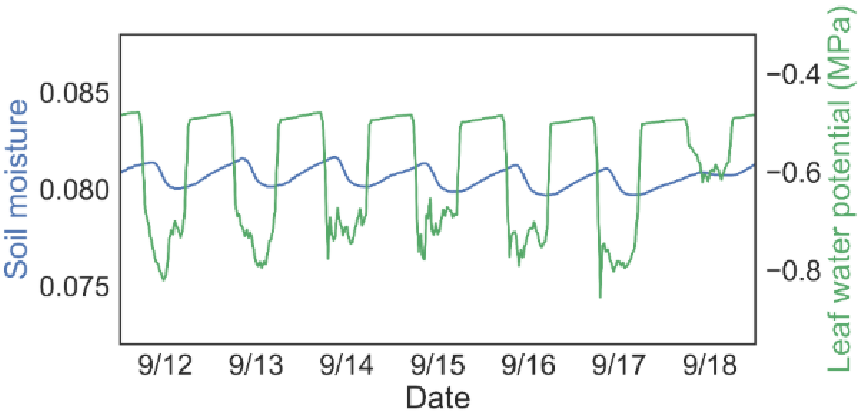
Figures show projected change in 2081-2100 relative to 1986-2005 (RCP 8.5, IPCC AR5)

→ accurate ET models therefore need to disentangle soil moisture and VPD effects correctly

Wrinkle: the role of plant hydraulics in water stress response

Stomatal regulation directly depends on Ψ_L (leaf water potential), not on soil moisture

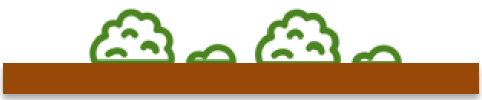
Ψ_L dynamics influenced by hydraulic traits & differ from soil moisture!



Most models of transpiration neglect hydraulics

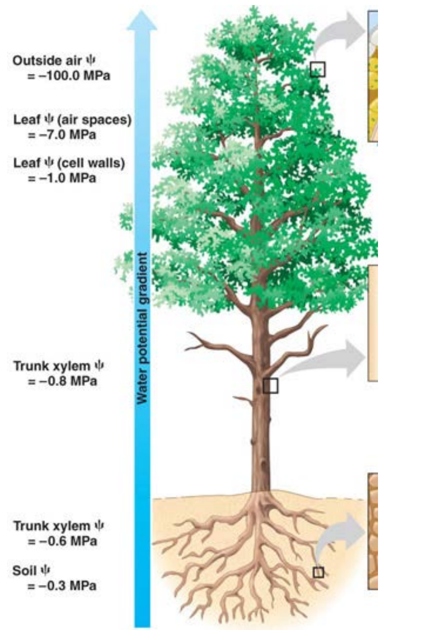
Classic/empirical models

$g_s = g_s(sm)$



Actual stomata

$g_s = g_s(\psi_L)$



Questions answered in this study

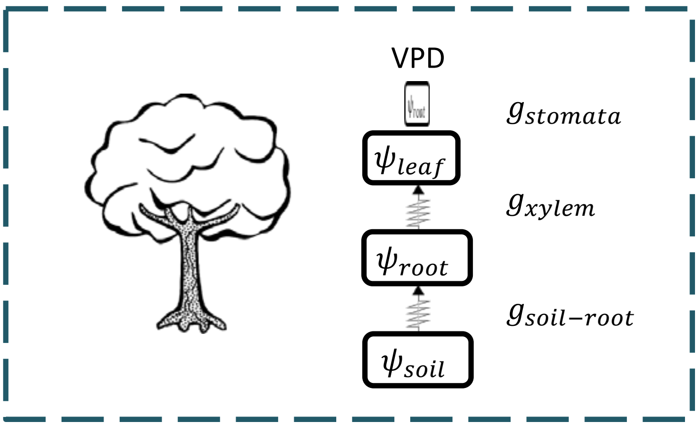
Can empirical models correctly capture future ET under higher VPD?

Can plant hydraulics improve ET prediction?

Approach: compare empirical and hydraulic models

1) Widely used empirical model $g_s = g_s^*(sm)(1 - m \ln \mathrm{VPD})$

2) Plant hydraulic model $g_s = g_s^*(\psi_{leaf})(1 - m(\psi_{leaf}) \ln \mathrm{VPD})$



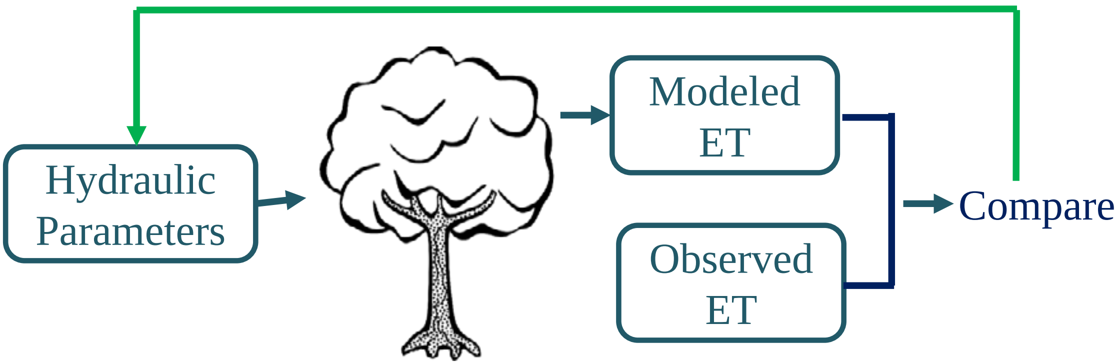
- Use hydraulic resistance model with stomatal optimization
- Can be rewritten analytically to have form analogous to that of empirical model…but temporally variable *m* and different g_s^*

Use model-data fusion to parametrize models correctly

Challenge: ecosystem-scale hydraulic parameters unknown

MCMC optimizes hydraulic parameters that minimize ET model error

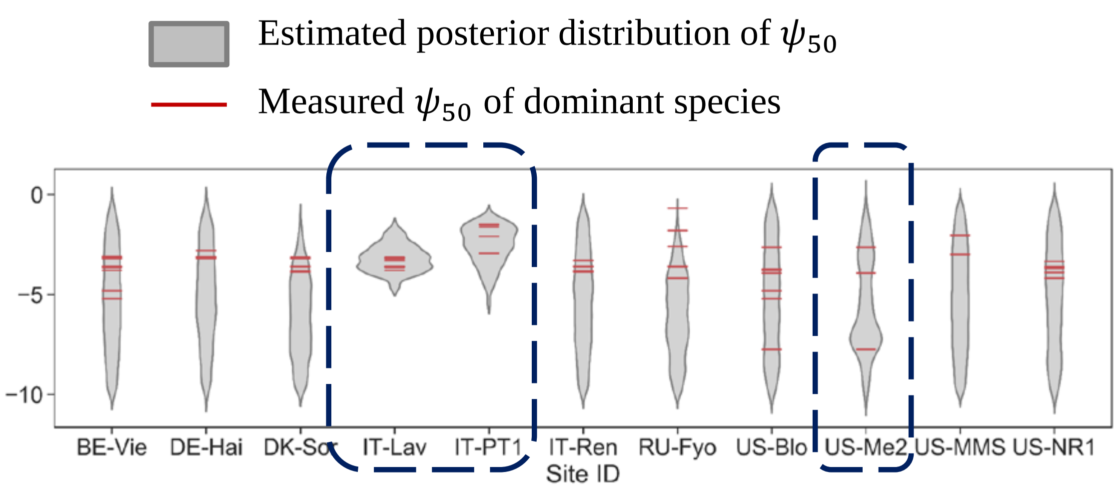
Probabilistic estimation (Markov chain Monte Carlo)



Apply to 40 flux sites across globe

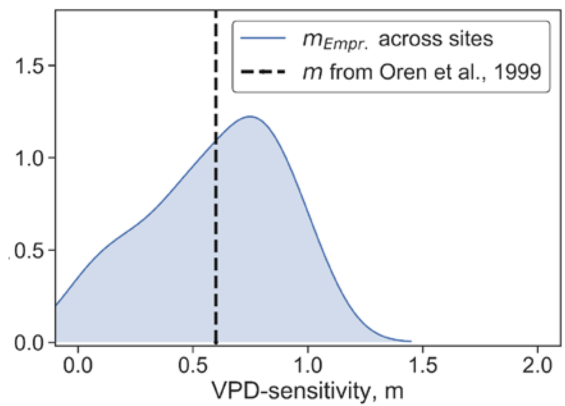
Retrieved parameters match observations reasonably well

1

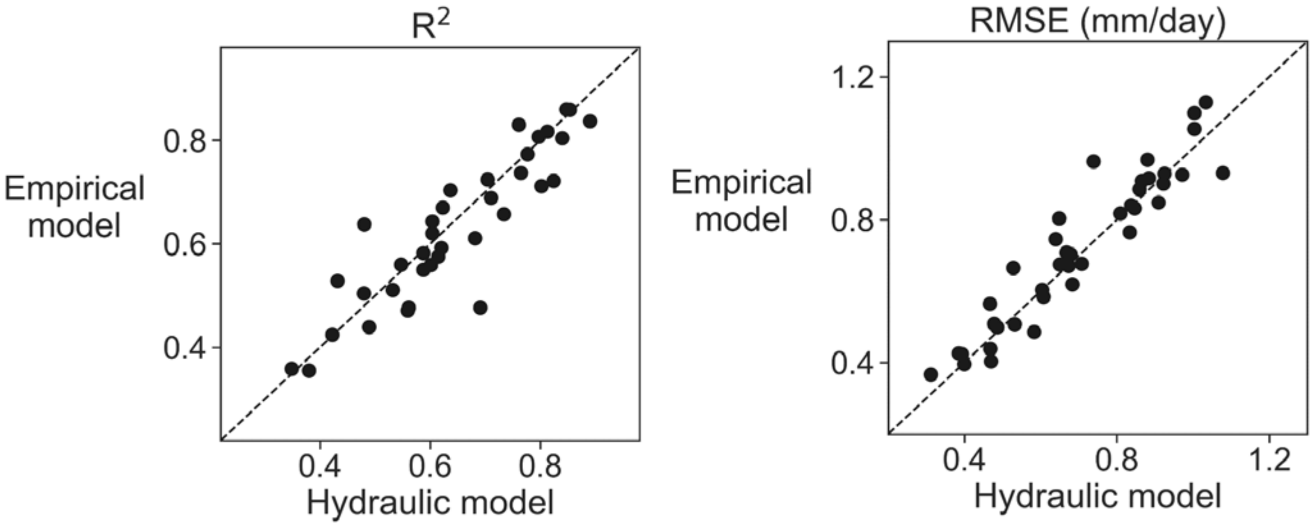


2

Probability density function across sites



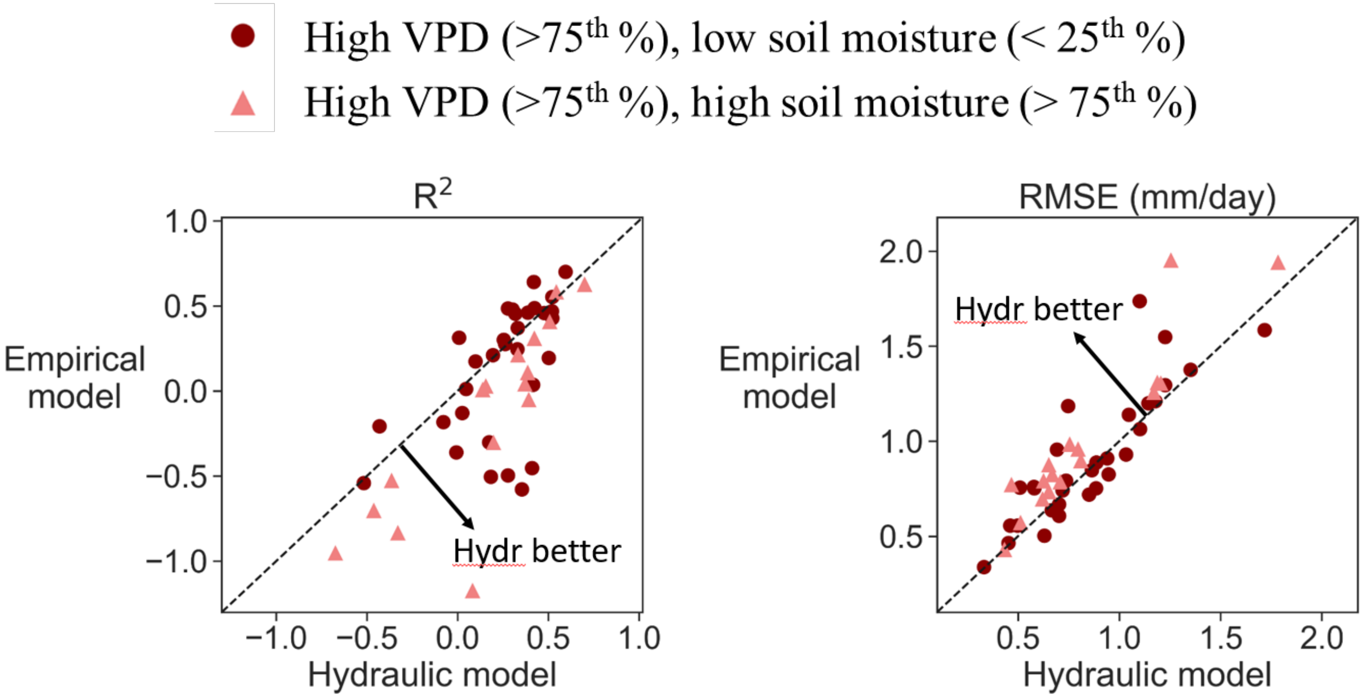
For full record, hydraulic & empirical stats ~ equally good



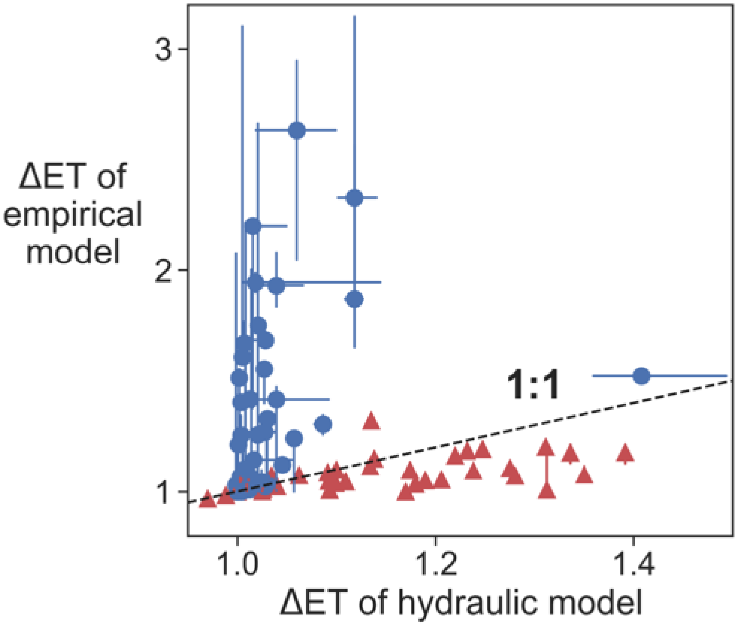
- Model performance calculated at one site, across entire record

Plant hydraulics improves ET estimation under high VPD

Calculate error statistics only under specified conditions



How much is ET restricted by each of SM and VPD?



▲ $$\Delta ET_{VPD} = \frac{ET\ (g_s(\text{no VPD stress}))}{ET}$$

● $$\Delta ET_{SM} = \frac{ET(g_s(\text{no SM stress}))}{ET}$$

The empirical model underestimates VPD-restriction on ET, but compensates by overestimating soil moisture restriction

Implications for a high VPD climate

1) Current large-scale models likely underestimate reductions of ET and ecosystem productivity during future hotter droughts

2) Need to incorporate plant hydraulics in Earth system models

See paper for more detailed explanation

Liu, Y., M. Kumar, G.G. Katul, X. Feng, and A.G. Konings (2020). Plant hydraulics enhances atmospheric moisture stress on transpiration. *Nature Climate Change,* accepted.

Coming to a Nature Climate Change issue near you!