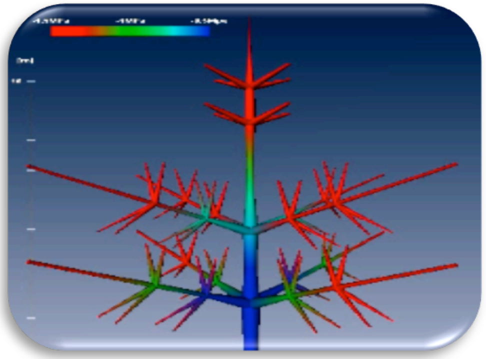
The role of tree hydraulic traits in response to soil water availability





Gil Bohrer, Golnaz Mirfenderesgi

Department of Civil, Environmental and Geodetic Engineering
Ohio State University

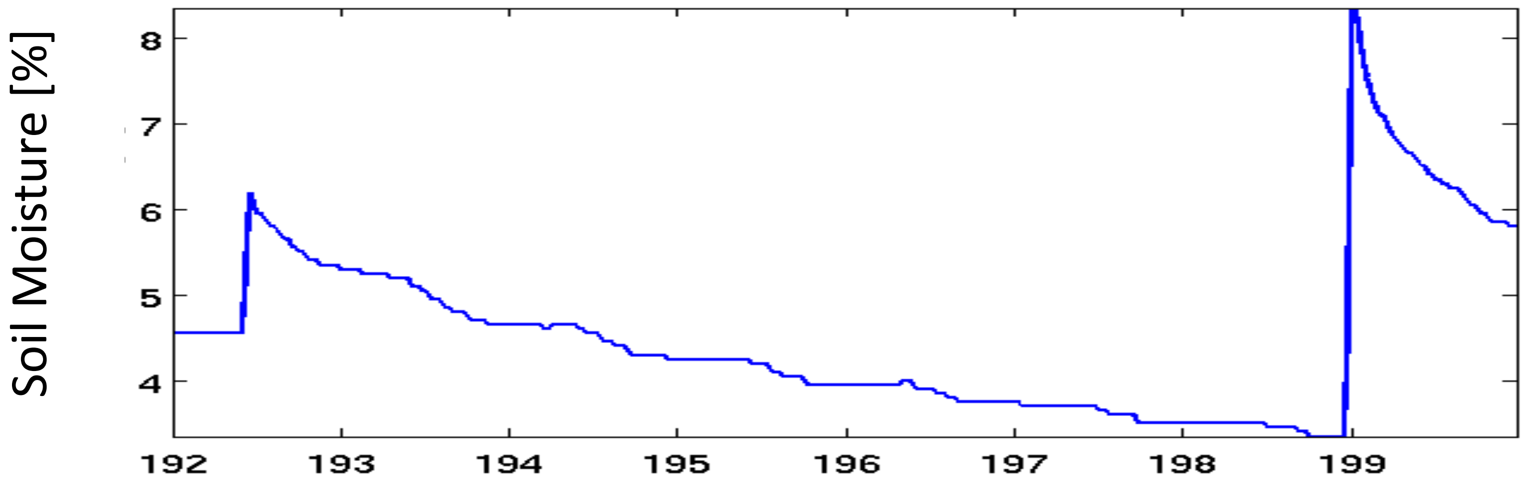
Ashley M. Matheny
Jackson School of Geosciences, University of Texas at Austin

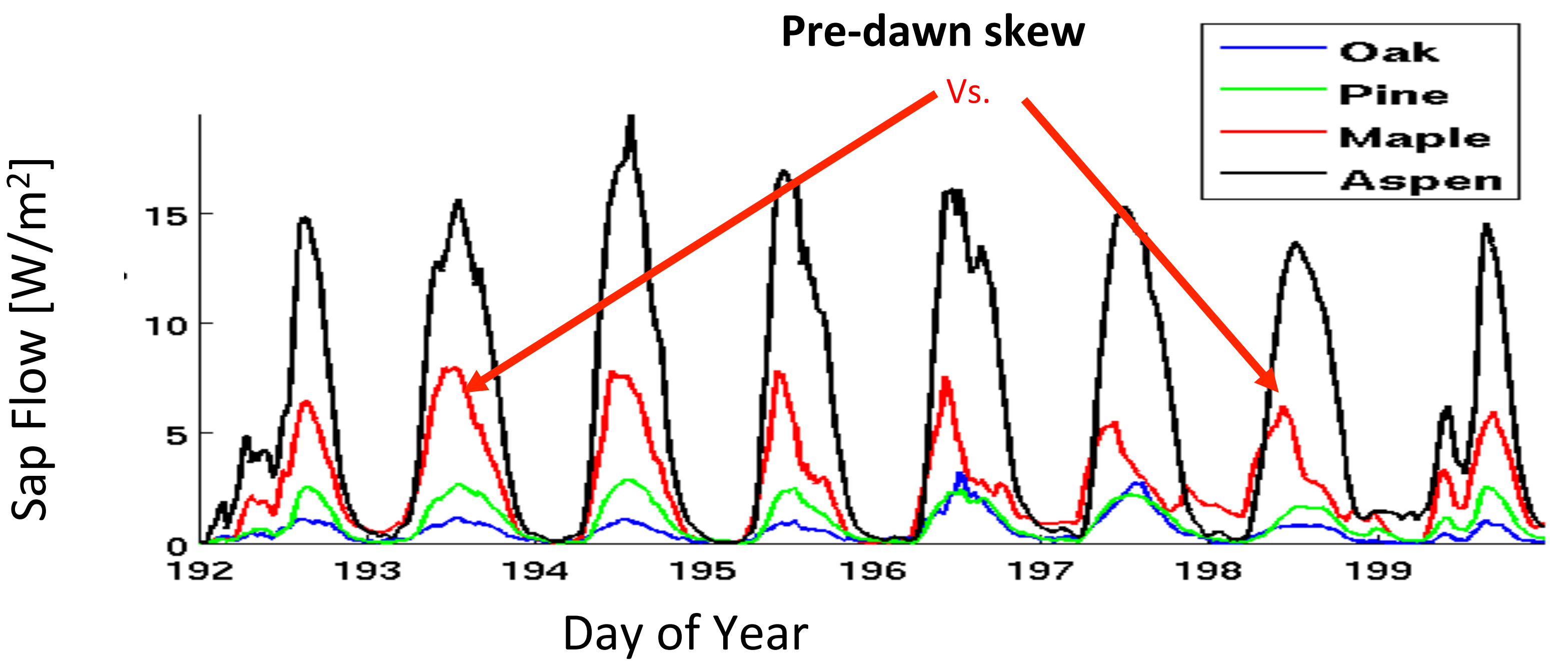
US-UMd 2007-

US-UMB 1999-

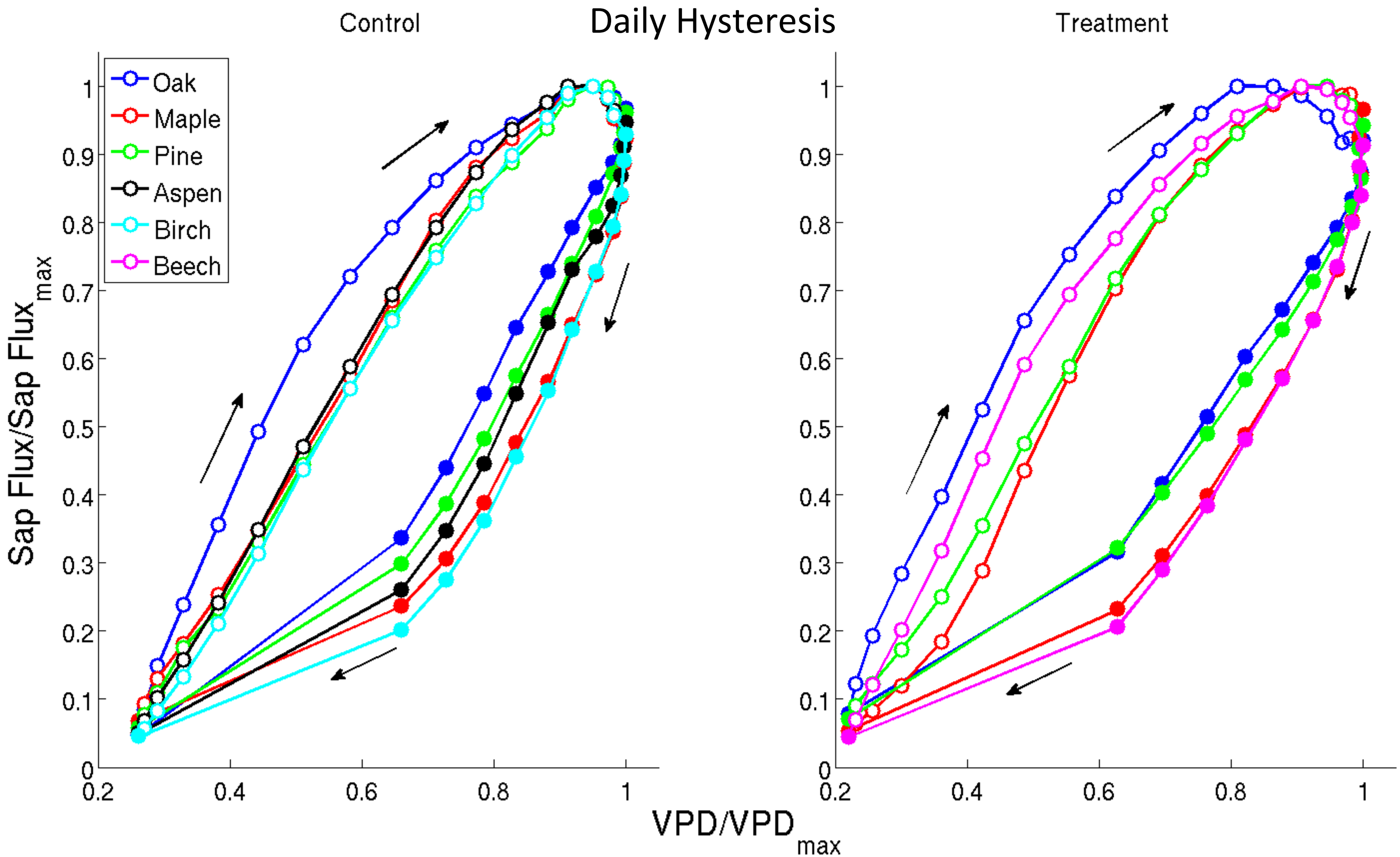
Site level sap-flux 2011-

"Mini-drought" in UMBS



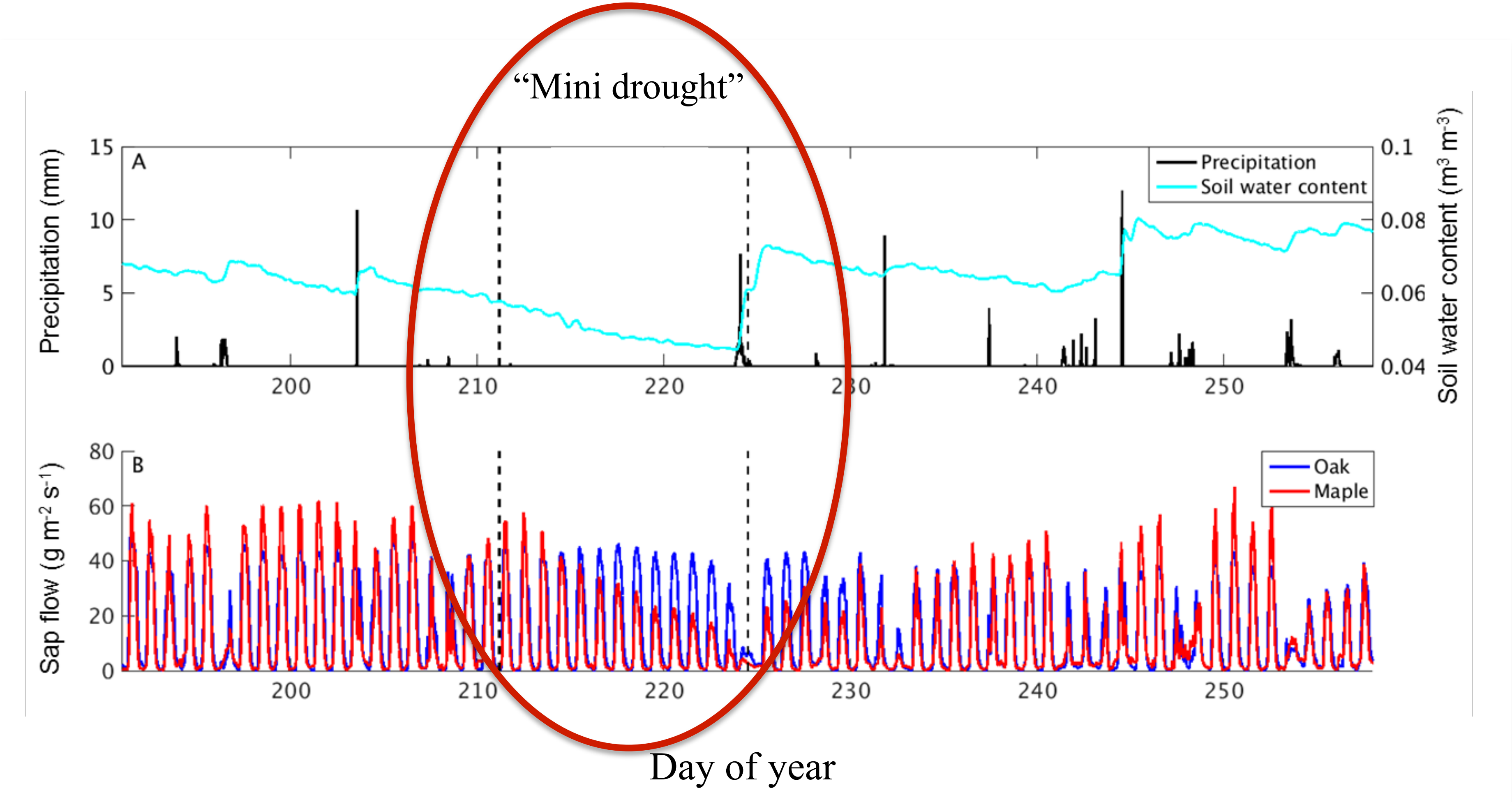


Overall - more hydrodynamic stress in disturbed forest



Matheny et al 2014 *JGR-Biogeosci.*

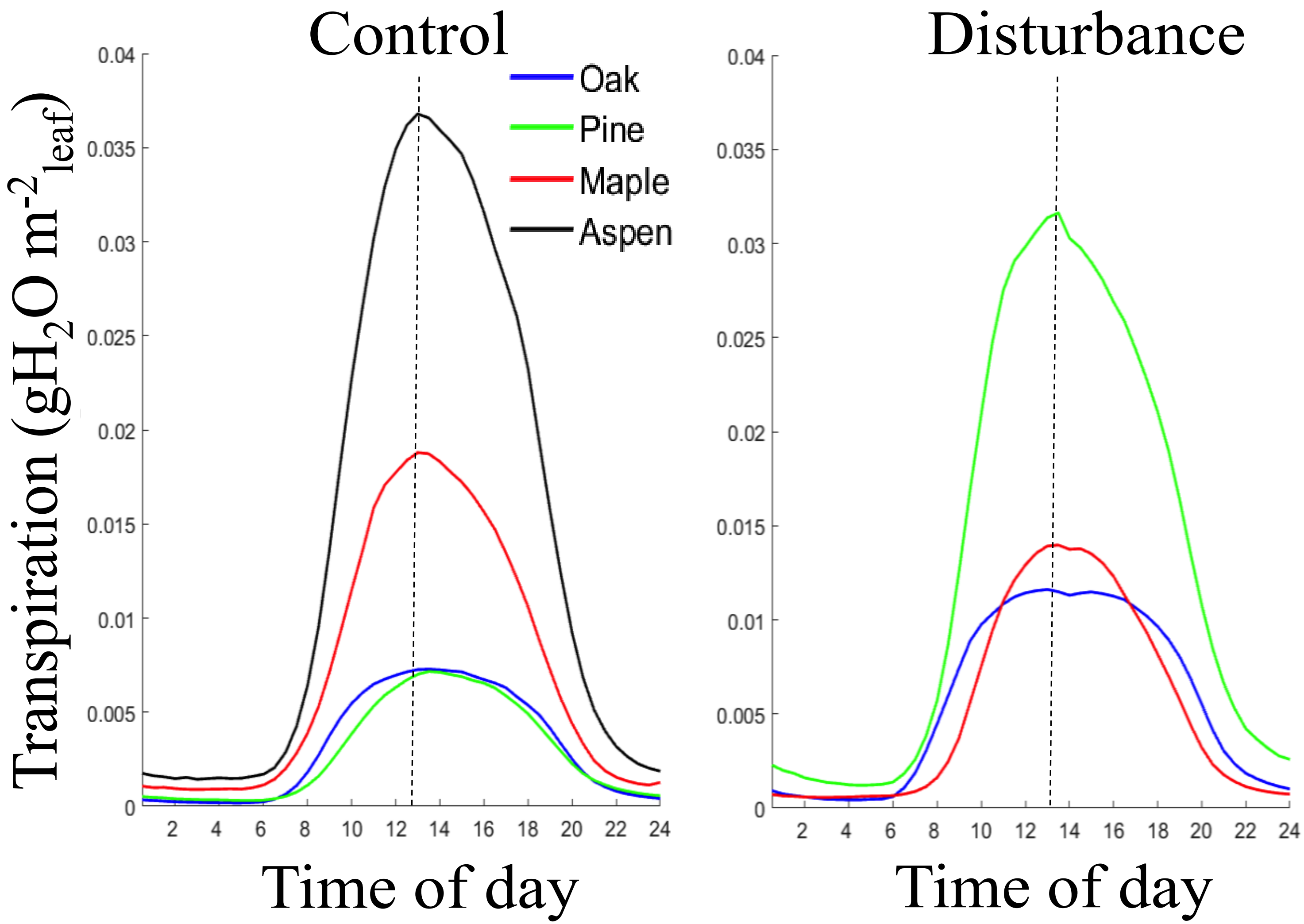
Species-specific dynamics during dry conditions



- Matheny et al. 2016, Ecohydrology

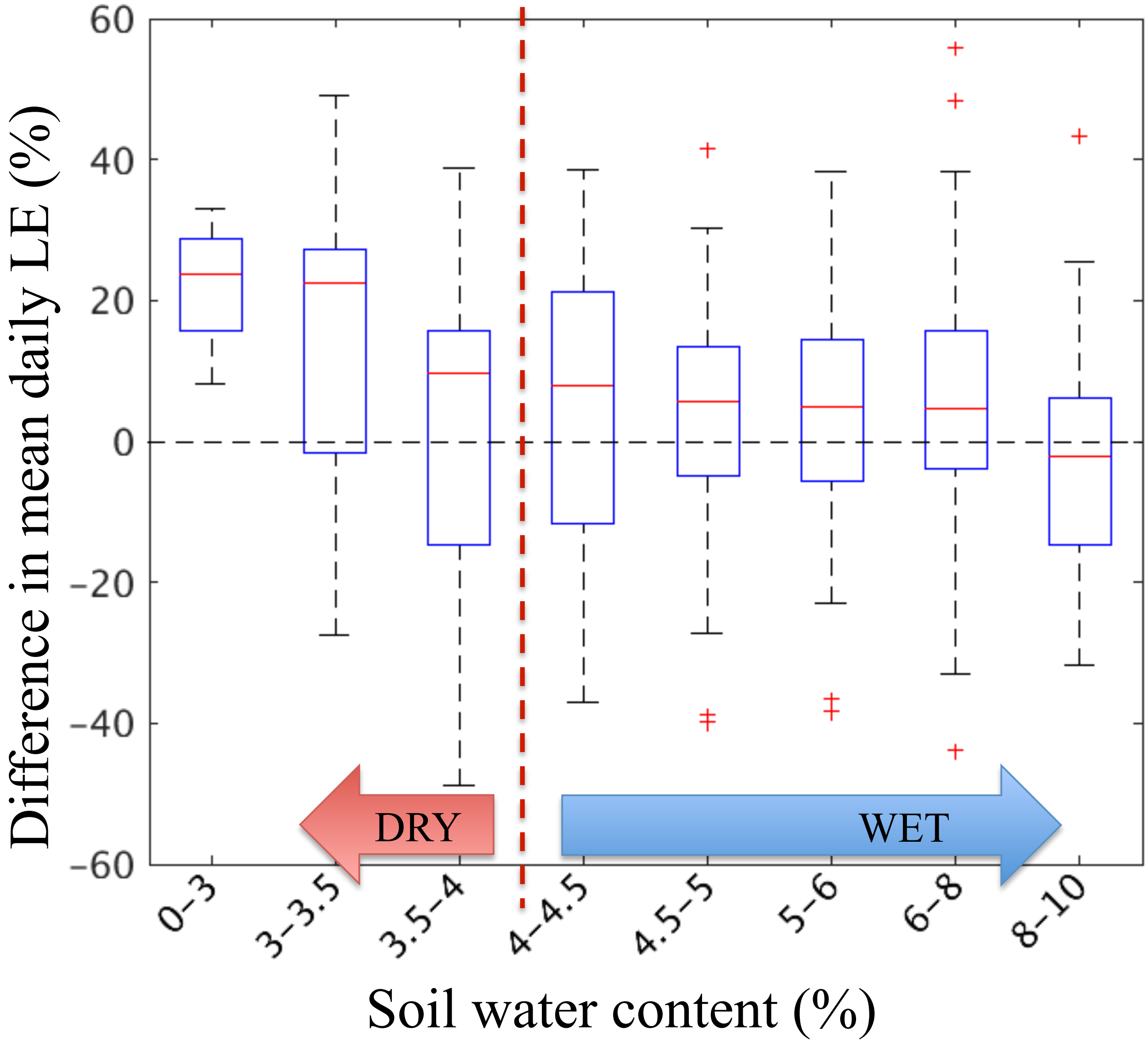
Within PFT - Not all trees handle stress as well

The curious tale of oak and maple

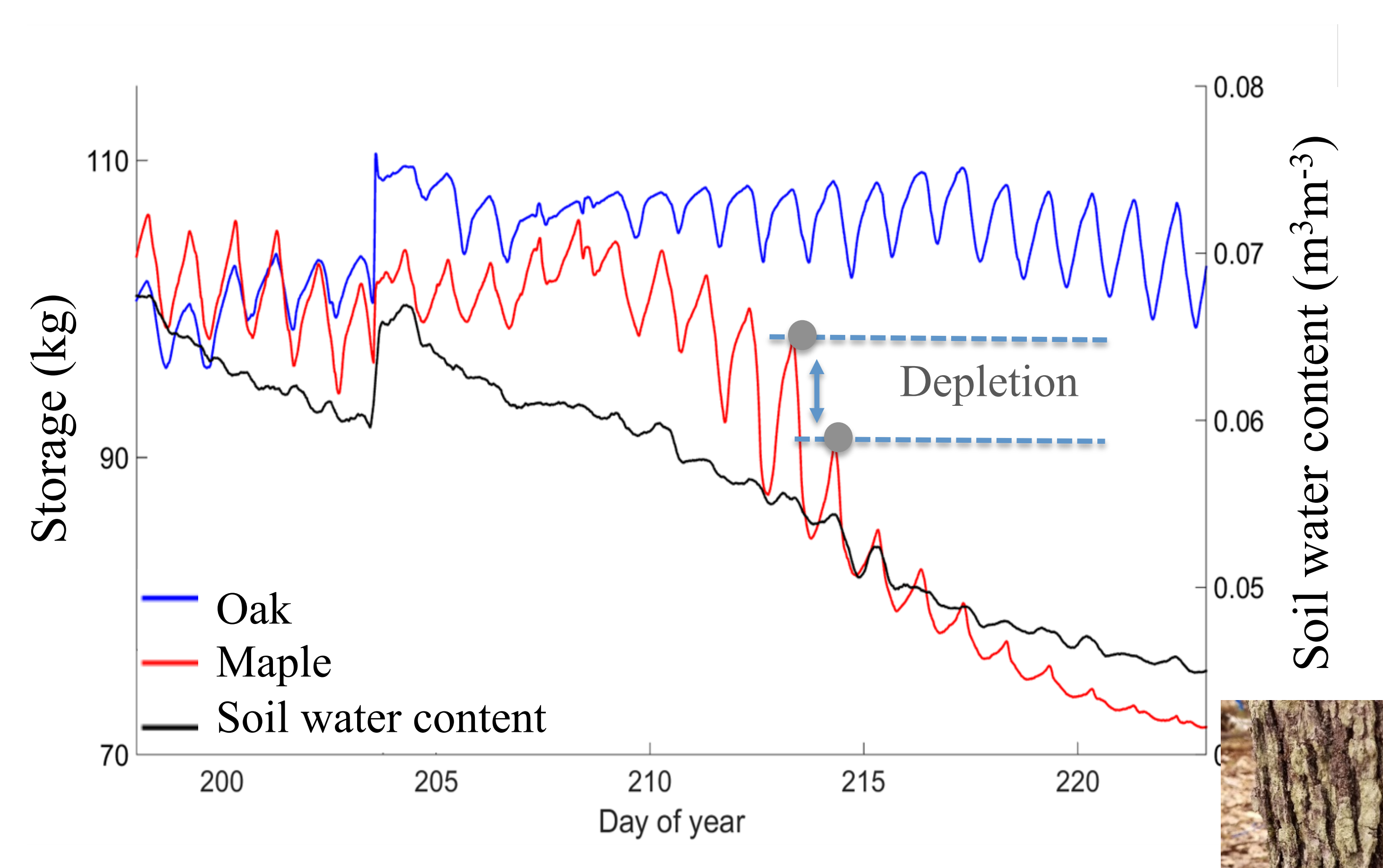


- Matheny et al. 2014, JGR Biogeosciences

Dry soil produces largest plot-scale differences



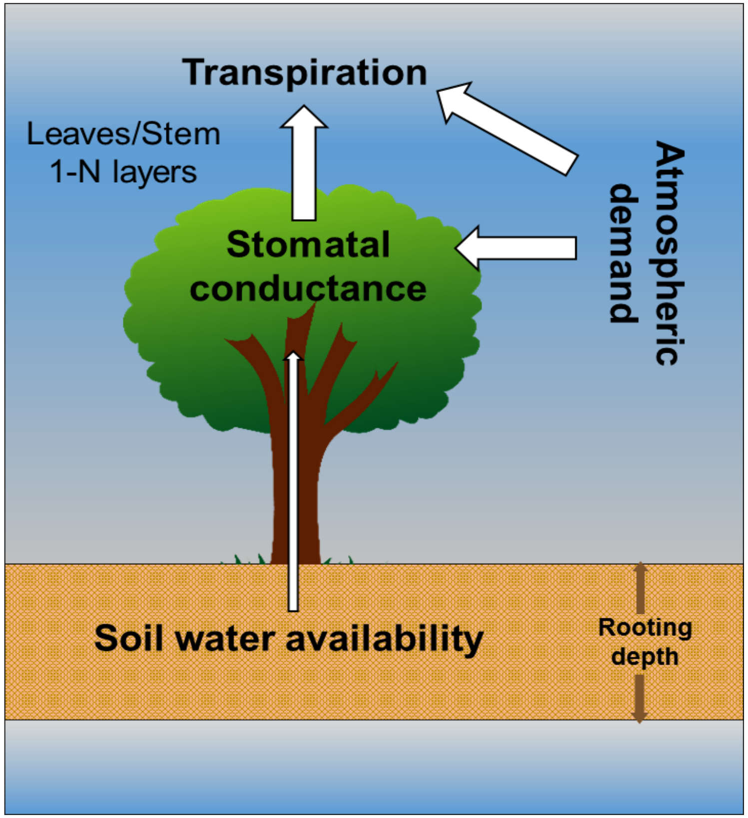
Water storage dynamics with declining soil water



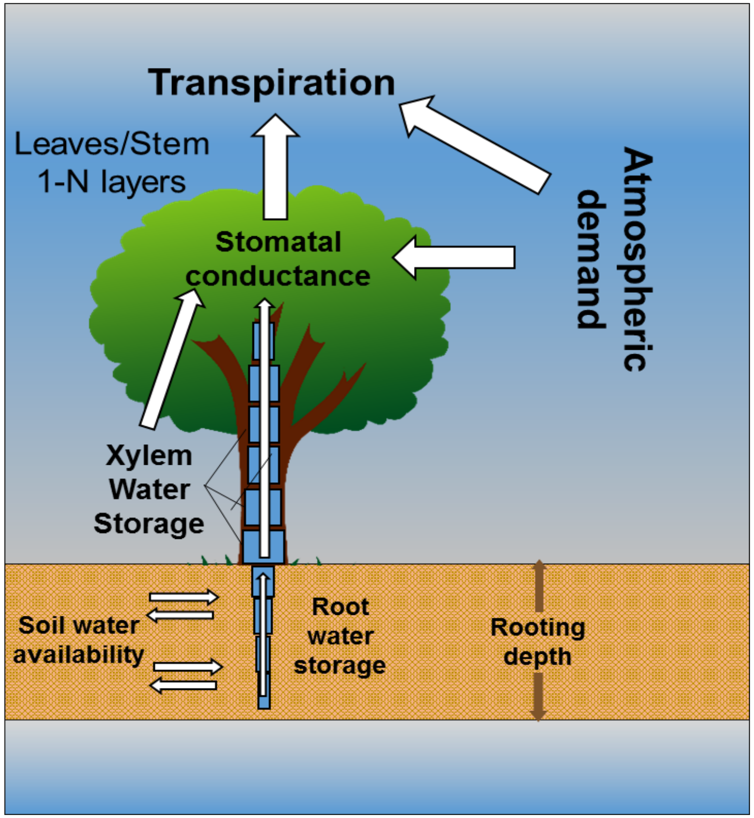
- Matheny et al. 2015, Ecosphere
- Matheny et al 2018, JoVE

Hydrodynamic modeling of transpiration

Non-hydrodynamic

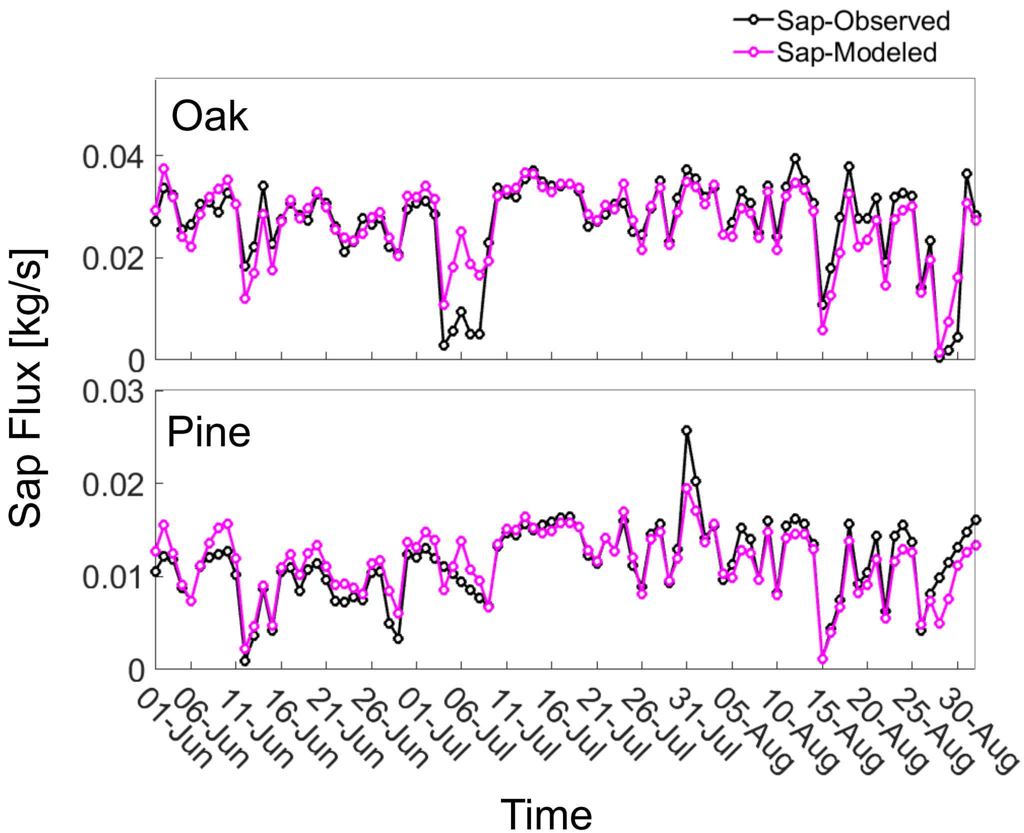


Hydrodynamic (FETCH2)

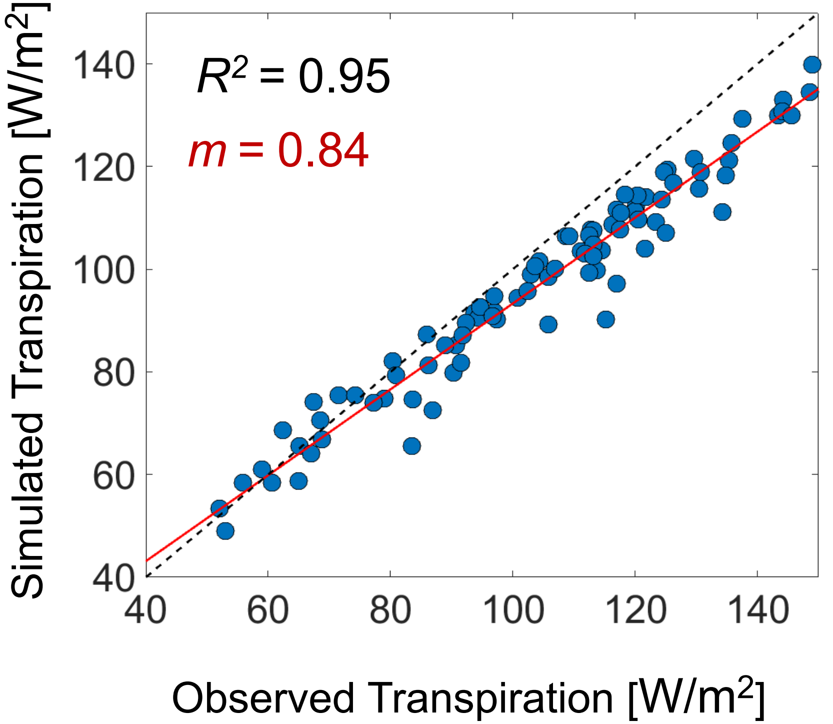


- ❑ **Externally**
  - ✓ Meteorological conditions:
    - ○ PAR
    - ○ Wind speed
    - ○ VPD
    - ○ Humidity
  - ✓ Soil Moisture
- ❑ **Internally**
  - ✓ Plant water potential

FETCH2 evaluation, Silas Little, NJ



Mirfenderesgi et al., [2016]
JGR Biogeosciences



Model-defined traits

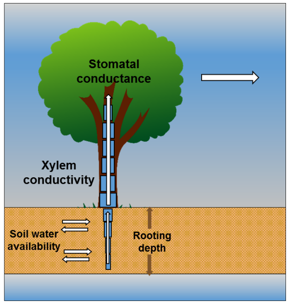
Leaf-trait parameters

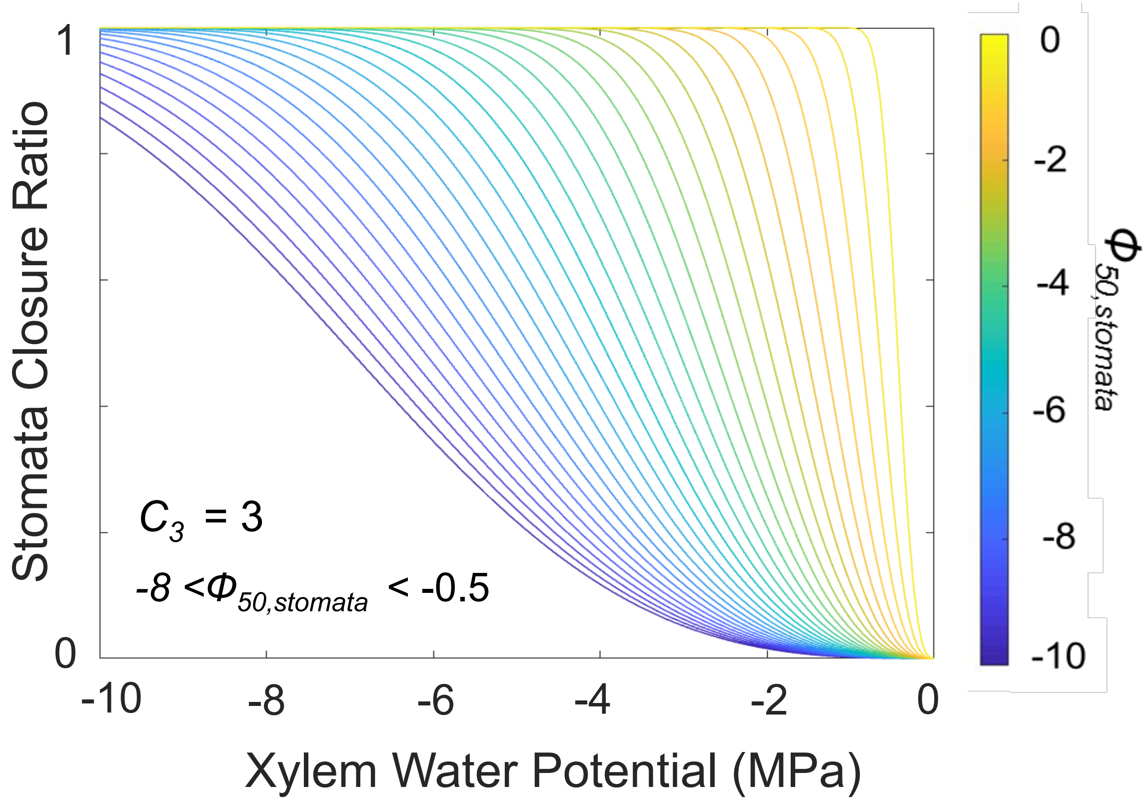
$\Phi_{50,stomata}$

$$El_{stem}(z,t) = NHL_{stem}(z,t) \times \exp\left[-\left(\frac{-\Phi(z,t-1)}{\Phi_{50,stomata}} \right) \right]$$

Forcing

Stomata response to xylem water potential





Mirfenderesgi et al., [2018] Ecohydrology

Examples of whole-plant responses

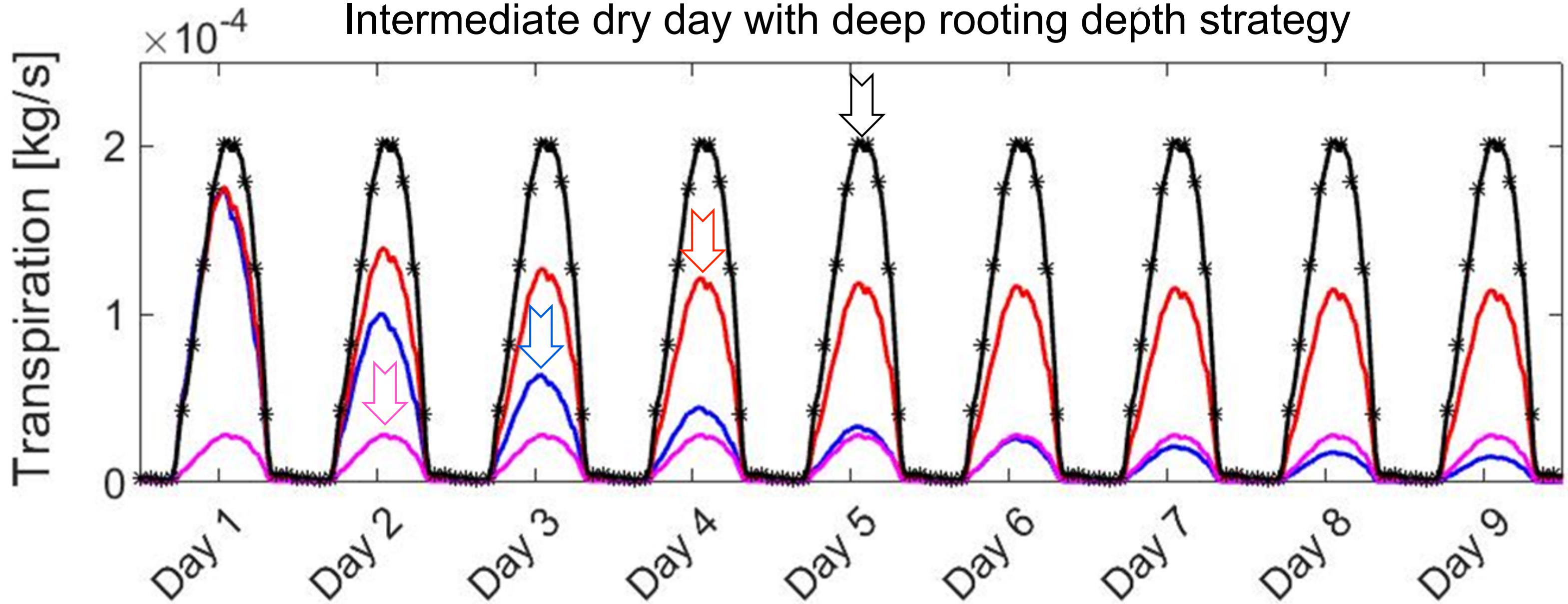
Insensitive leaf Cavitation resistant xylem: $\Phi_{50,stomata}$ = -2.7 (MPa), $\Phi_{50,stem}$ = -2.7 (MPa)

Sensitive leaf Cavitation resistant xylem: $\Phi_{50,stomata}$ = -0.9 (MPa), $\Phi_{50,stem}$ = -2.9 (MPa)

Insensitive leaf Cavitation prone xylem: $\Phi_{50,stomata}$ = -2.5 (MPa), $\Phi_{50,stem}$ = -1 (MPa)

Sensitive leaf Cavitation prone xylem: $\Phi_{50,stomata}$ = -0.9 (MPa), $\Phi_{50,stem}$ = -0.7 (MPa)

Intermediate dry day with deep rooting depth strategy

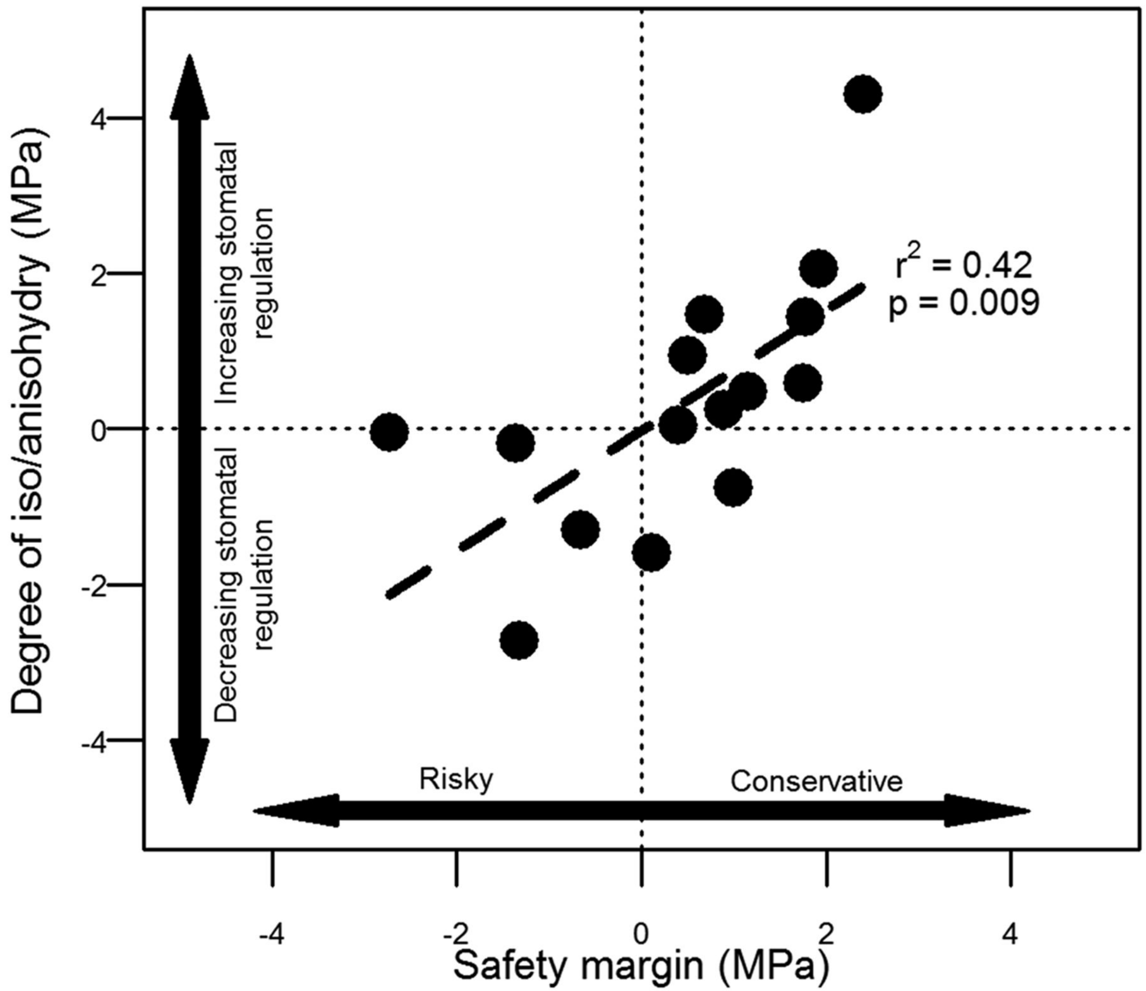


Safety margin as an emergent trait

Hydraulic safety margin:

$\Phi_{min,stem} - \Phi_{50,stem}$

Skelton et al. PNAS 2015



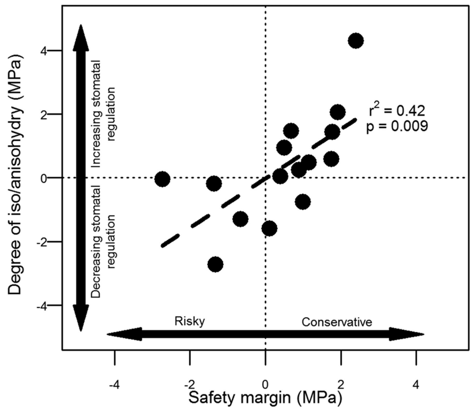
Quantifying the safety-efficiency trade-off

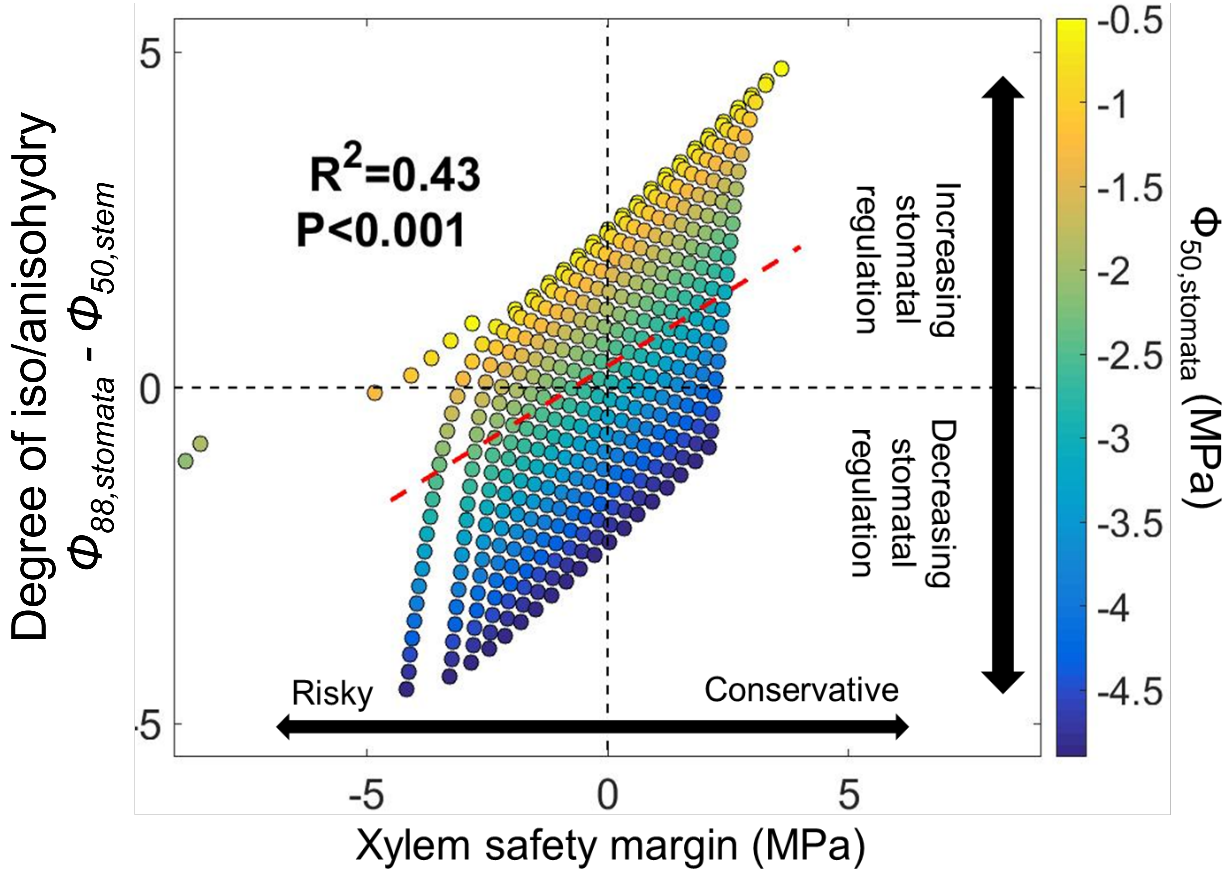
Safety-efficiency trade-off →

Emergent property of leaf-xylem trait complex

- ❑ Dry day
- ❑ Deep roots

Mirfenderesgi et al., [2018]
Ecohydrology





$\Phi_{min,stem} - \Phi_{50,stem}$

Project Funding:

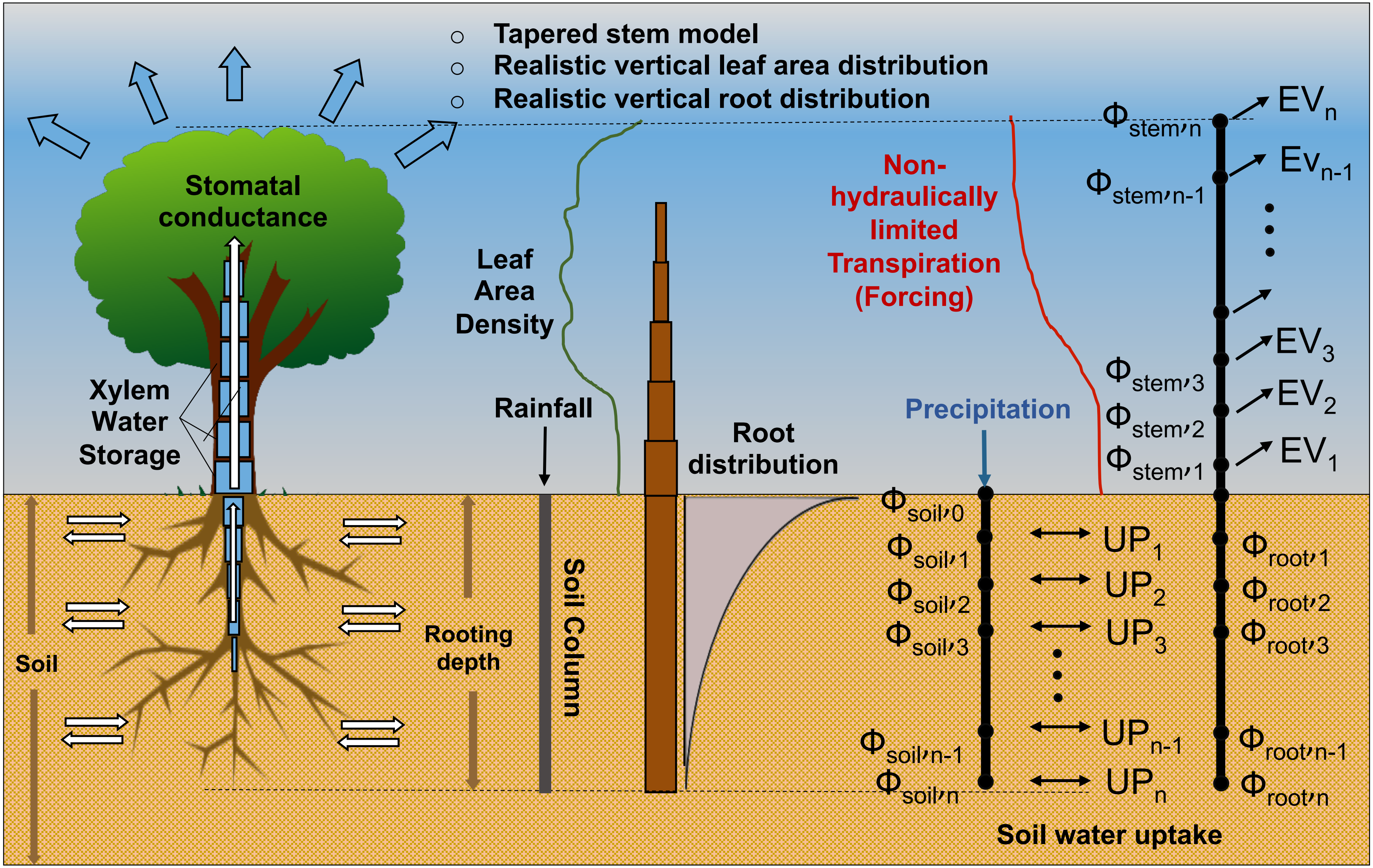
National Science Foundation
WHERE DISCOVERIES BEGIN

SERVING SCIENCE AND SOCIETY • DOE Biological and Environmental Research Program

AmeriFlux

University of Michigan Biological Station (UMBS)

Finite-difference Ecosystem-scale Tree Crown Hydrodynamics Model (FETCH2)



Governing equations

❑ Root water hydraulic (root-stem)

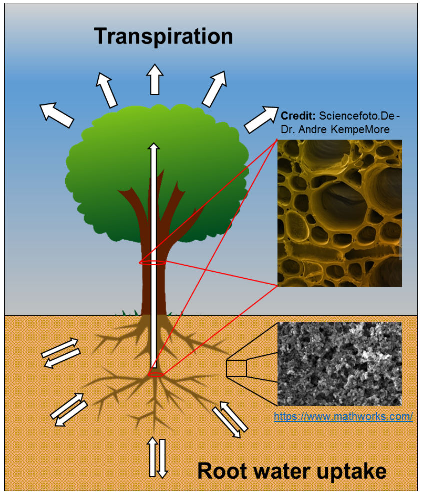
$$C_{root}(z,t)^{(c)} \frac{\partial \Phi_{root}(z,t)}{\partial t} = \frac{\partial}{\partial z}\left[K_{ax,root}(\Phi_{root}(z,t))^{(c)}\left(\frac{\partial \Phi_{root}(z,t)}{\partial z} - \rho g\right)\right] + \frac{El_{root,c}(z,t)}{\Delta z}$$

Root water uptake

❑ Stem water hydraulic (stem-leaf)

$$C_{stem}(z,t)^{(c)} \frac{\partial \Phi_{stem}(z,t)}{\partial t} = \frac{\partial}{\partial z}\left[K_{stem}(\Phi_{stem}(z,t))^{(c)}\left(\frac{\partial \Phi_{stem}(z,t)}{\partial z} - \rho g\right)\right] - \frac{El_{stem,c}(z,t)}{\Delta z}$$

Transpirational water sink



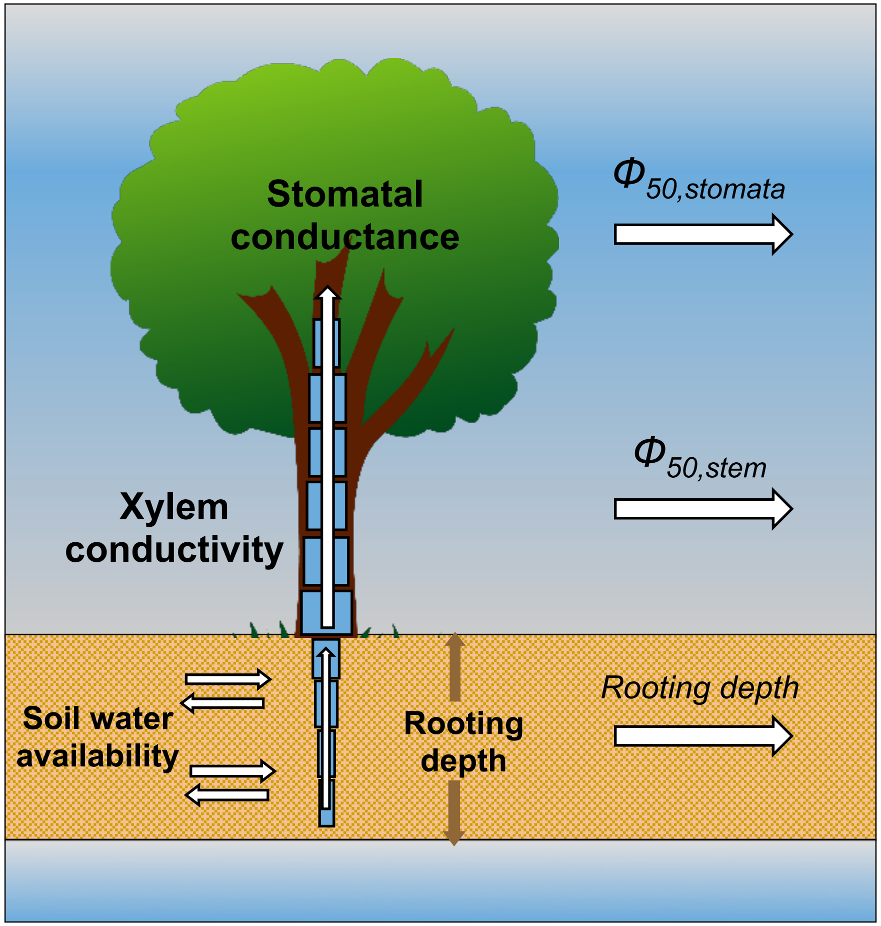
❑ Transpiration (leaf-air)

$$El_{stem}(z,t) = NHL_{stem}(z,t)\times\exp\left[-\left(\frac{-\Phi_{stem}(z,t-1)}{\Phi_{50,stomata}}\right)^{c_3}\right]$$

Xylem water potential

Φ	Water potential	C	Capacitance
El	Water flux	z	Vertical height
K	Conductivity	t	Time
NHL	Non-hydrodynamically Limited		

Tissue-level traits → Emergent tree-level strategies



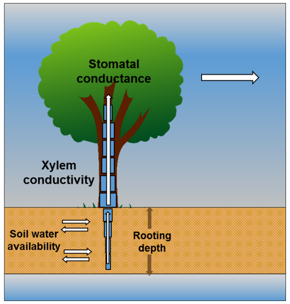
Model-defined traits

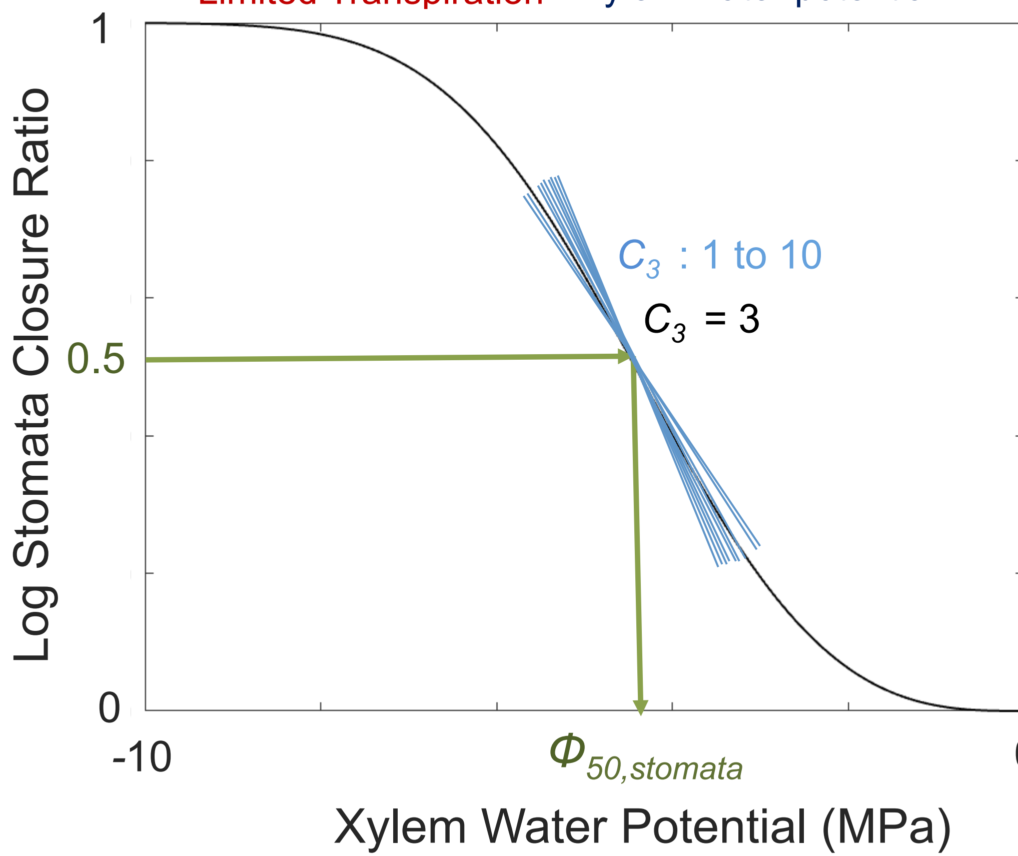
Leaf-trait parameters

$$El_{stem}(z,t) = NHL_{stem}(z,t) \times \exp\left[-\left(\frac{-\Phi(z,t-1)}{\Phi_{50,stomata}}\right)\right]$$

Forcing: Non-Hydrodynamically Limited Transpiration

Stomata response to xylem water potential

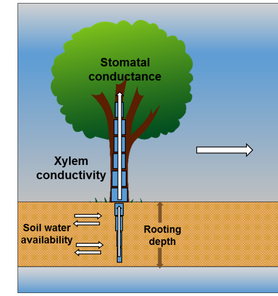


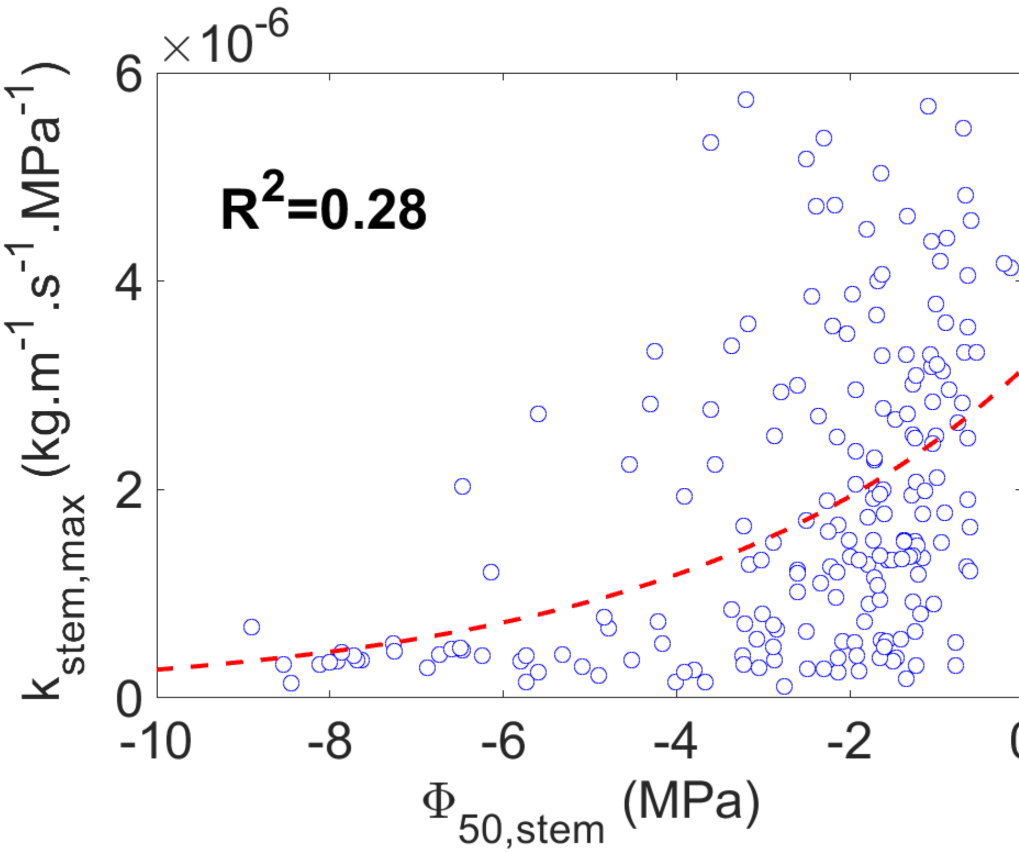


Reducing degrees of freedom in trait parameter-space

Stem-trait parameters

$$K_{stem}\left(\Phi_{stem}(z,t)\right)=A_{stem,Sap}\,f\left(\Phi_{50,stem}\right)\exp\left[-\left(\frac{-\Phi_{stem}(z,t)}{\Phi_{50,stem}}\right)^{c_{2,stem}}\right]$$





Observations - TRY database
Manzoni et al., [2013], *New Phytol.*

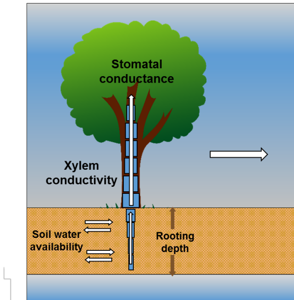
$$k_{stem,\max}=3.154\times\exp\left(-2.08\Phi_{50,stem}\right)$$
$$=f\left(\Phi_{50,stem}\right)$$

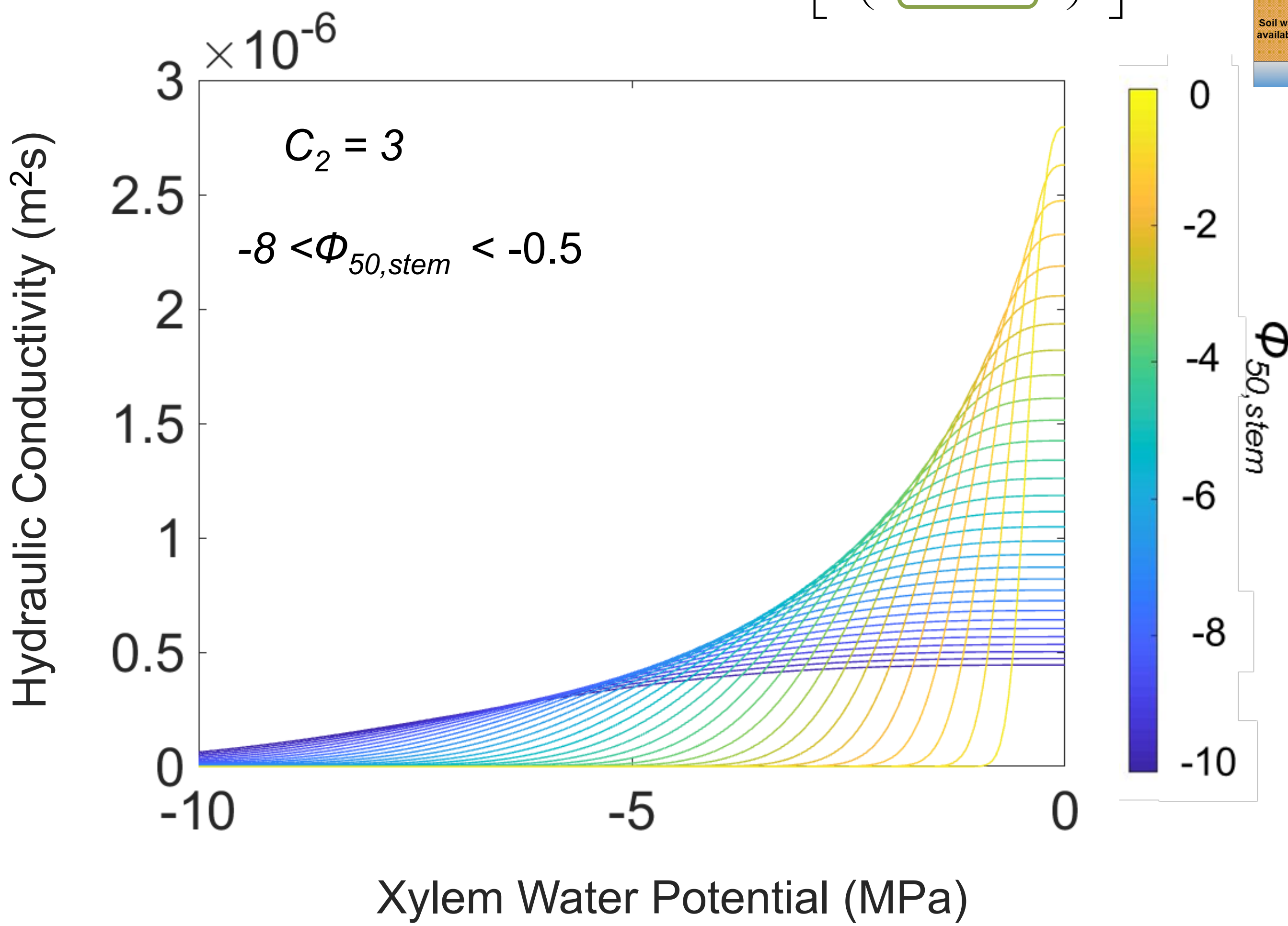
Model-defined traits

Stem-trait parameters

$\Phi_{50,stem}$

$$K_{stem}\left(\Phi_{stem}(z,t)\right) = A_{stem,Sap}\, f\left(\Phi_{50,stem}\right) \exp\left[-\left(\frac{-\Phi_{stem}(z,t)}{\Phi_{50,stem}}\right)^{3}\right]$$

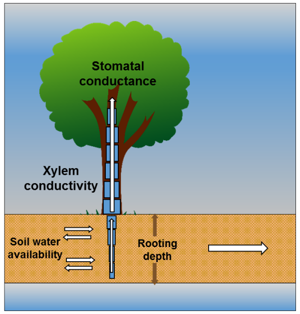


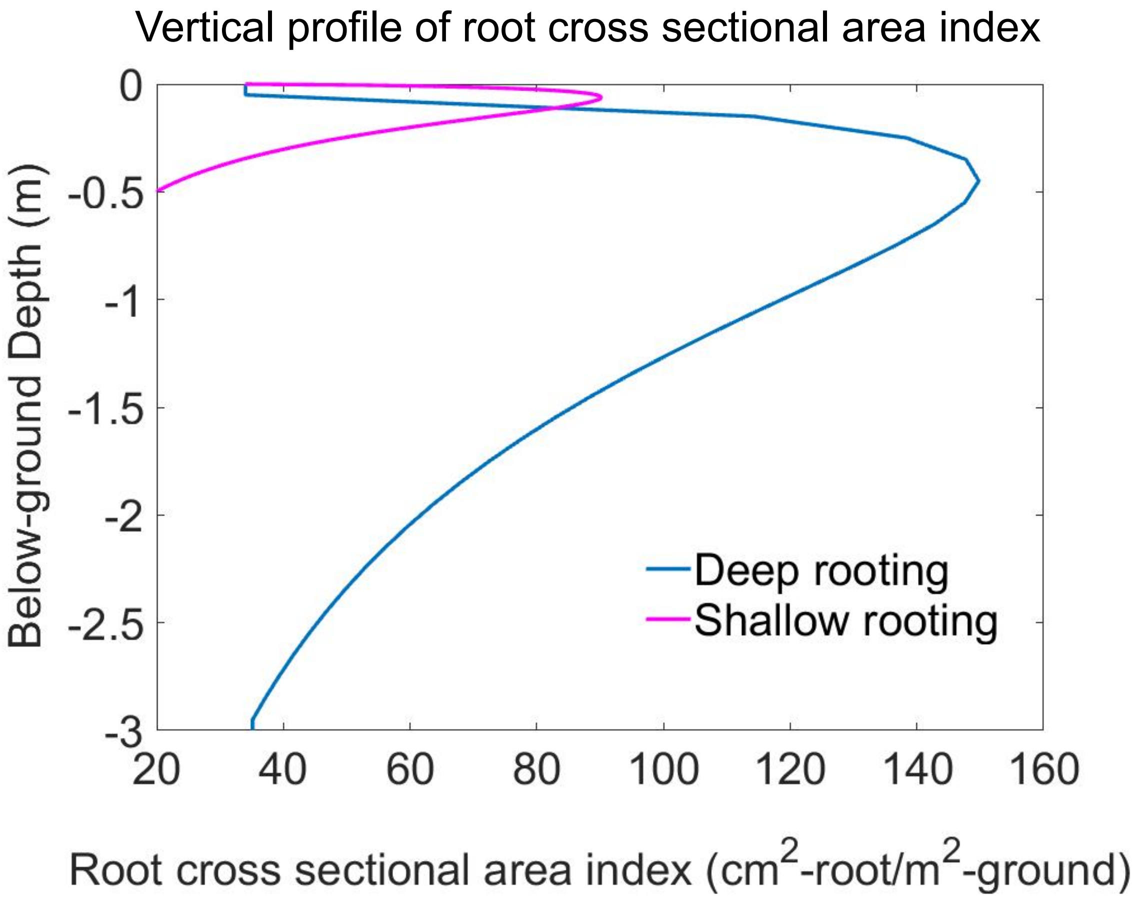


Model-defined traits

Root-trait parameters

➡ *Rooting depth*

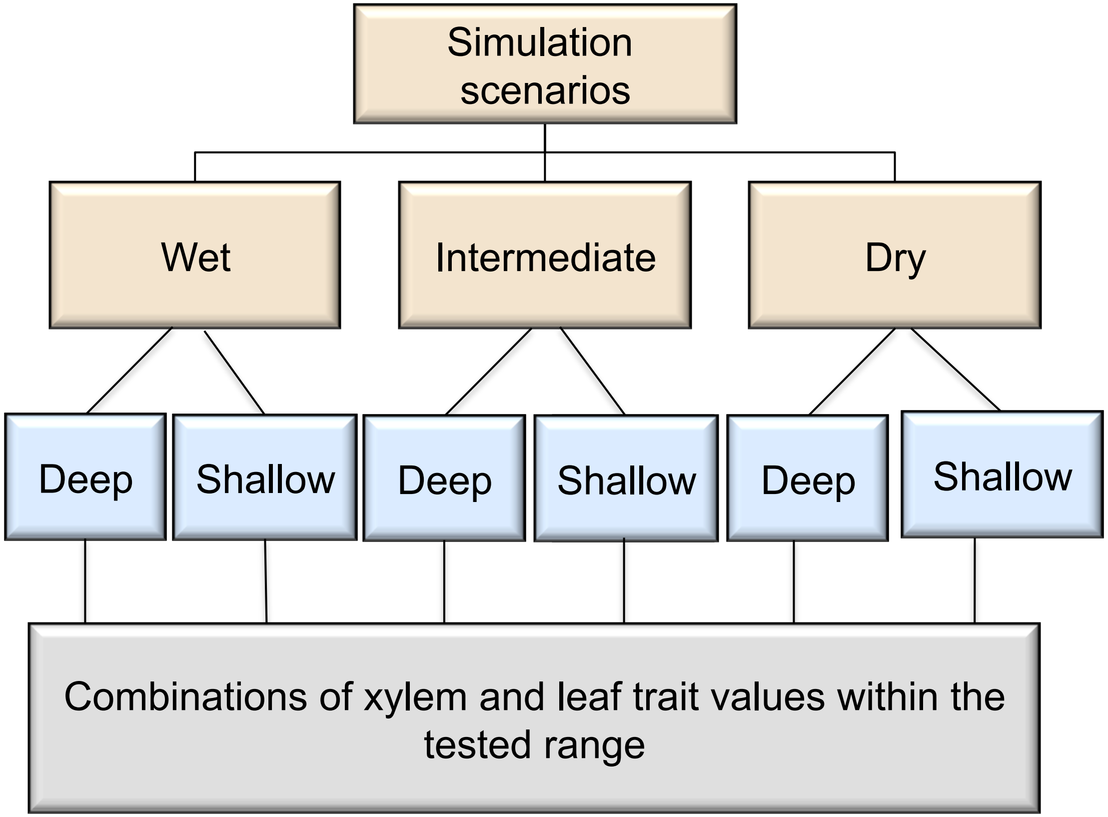




Experimental set up

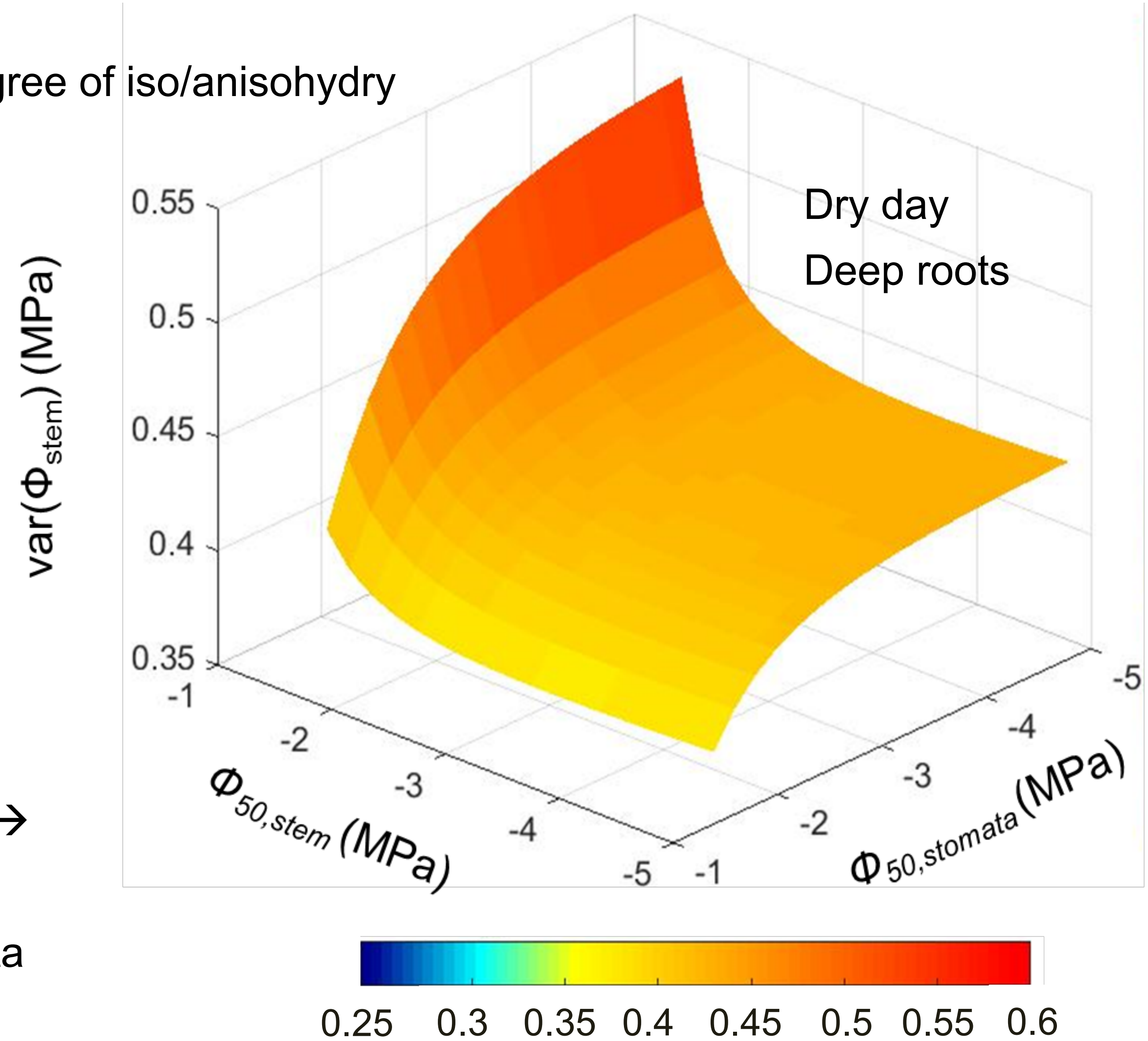
In silico virtual experiment:

- ❑ Virtual model tree
- ❑ Observation-based stereotypical environmental forcing
- ❑ 2 rooting strategies
- ❑ 2-D leaf+xylem parameter space
- ❑ Fully factorial design



Emergent whole-plant hydraulic strategy

Degree of iso/anisohydry



Maximum anisohydry →

Sensitive xylem

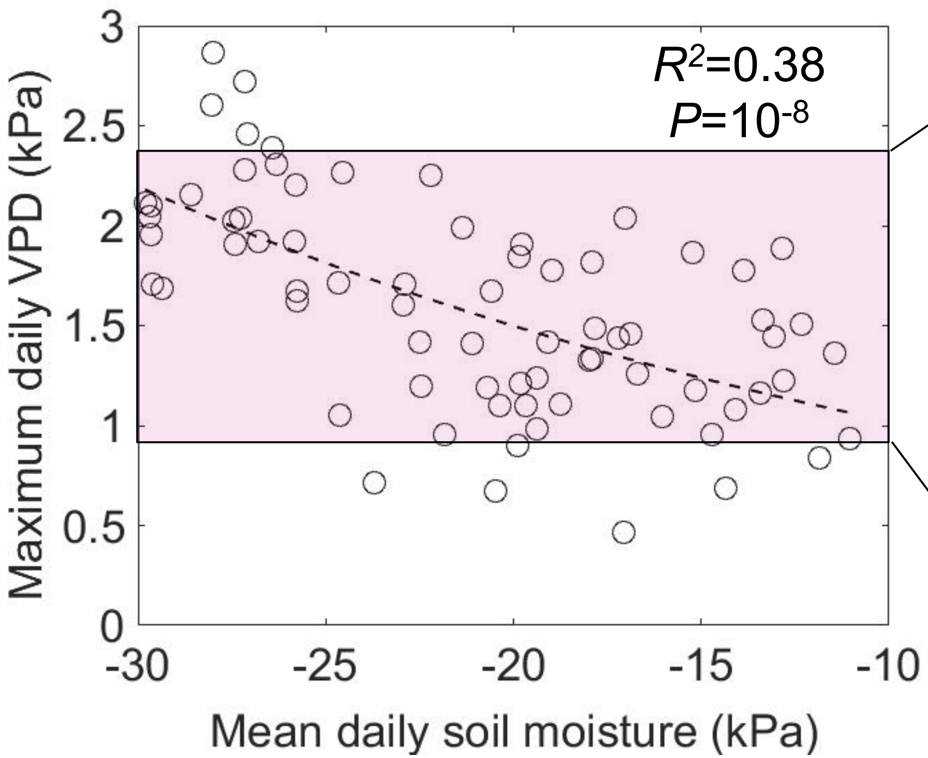
Insensitive stomata

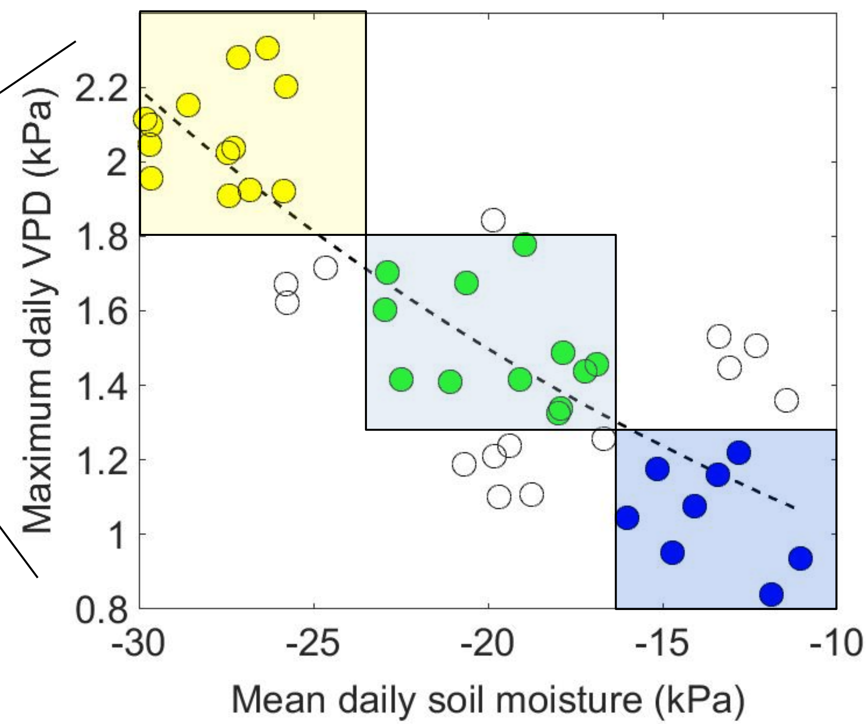
Stereotypical environmental conditions

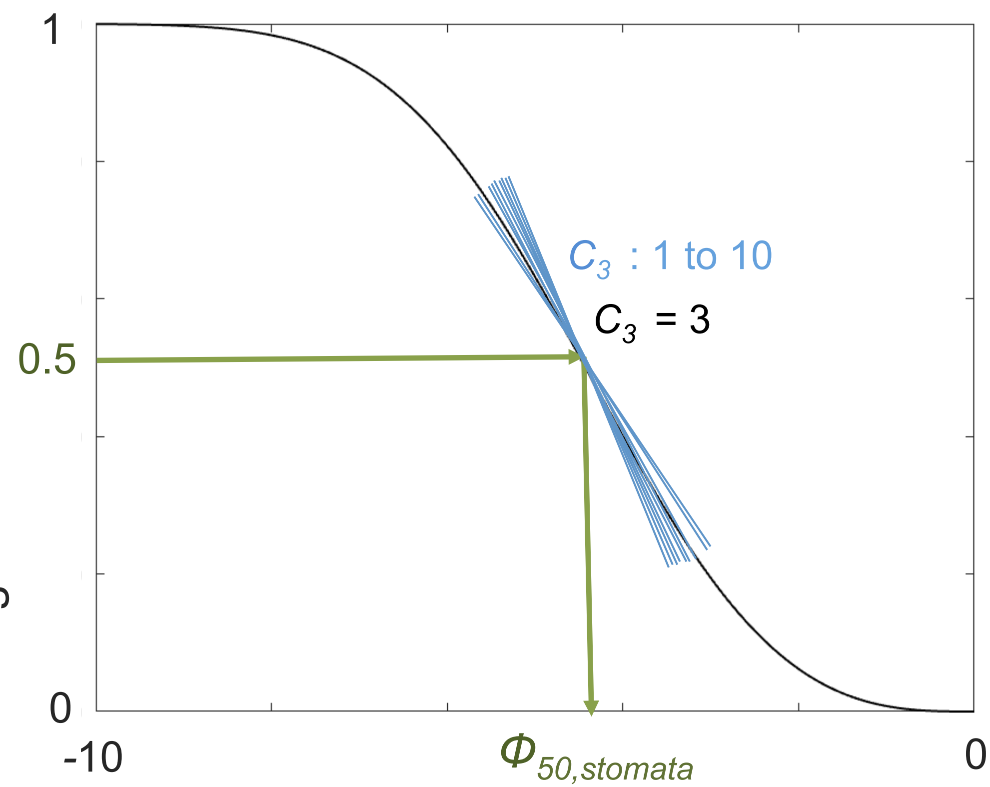
- ❑ Vapor pressure deficit (**VPD**)
- ❑ Soil water content (**SWC**)

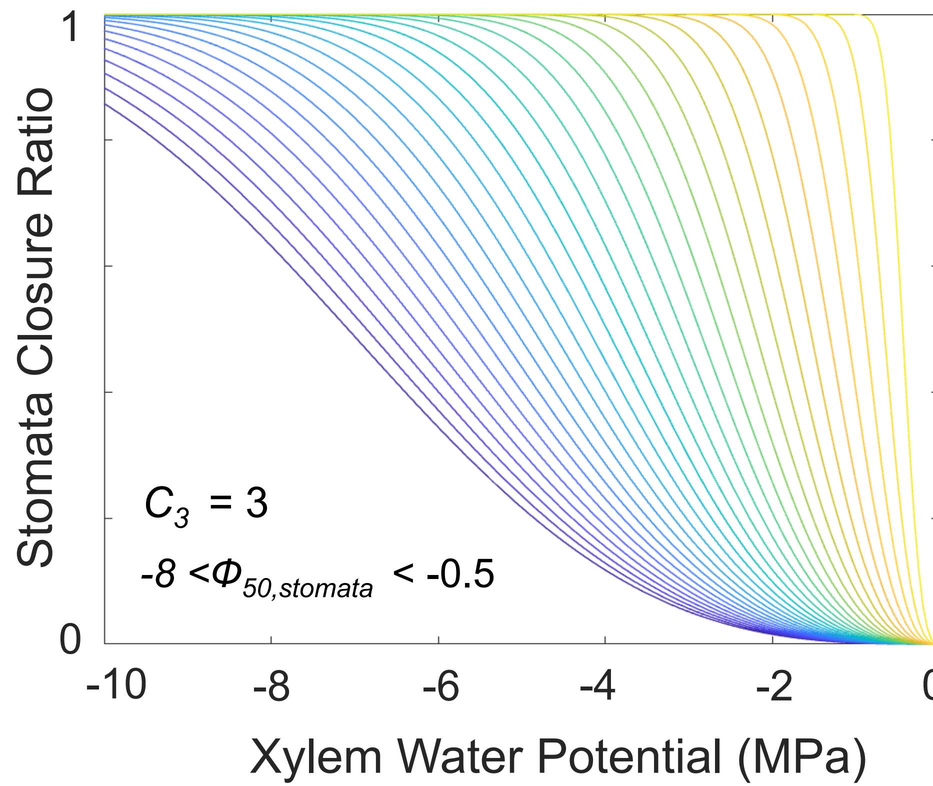
→

- Dry
- Intermediate
- Wet

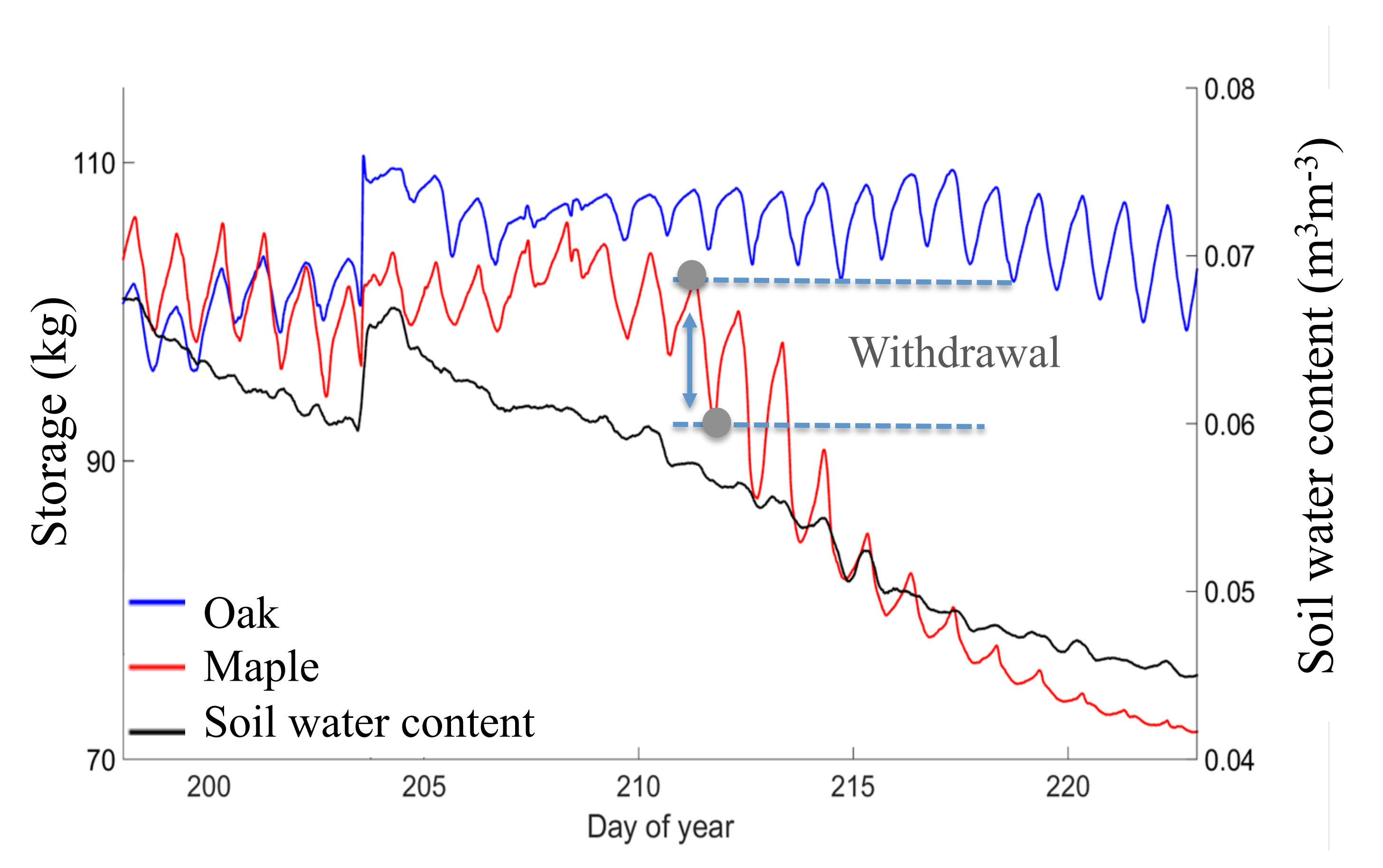





1
0.5
0
-10
0
C_3 : 1 to 10
C_3 = 3
$\Phi_{50,stomata}$


Stomata Closure Ratio
1
0
-10
-8
-6
-4
-2
C_3 = 3
-8 <$\Phi_{50,stomata}$ < -0.5
Xylem Water Potential (MPa)

Water storage dynamics with declining soil water



- Matheny et al. 2015, Ecosphere

Water storage dynamics with declining soil water