Implementing Plant Hydraulic Stress in CLM

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Outline

- Motivation
- CLM4 Water Stress
- Plant Hydraulic Theory
- PHS Model and Parameterization
- Flux tower results from the model
- Next steps

Stomatal Trade-off

- Carbon assimilation has a water cost

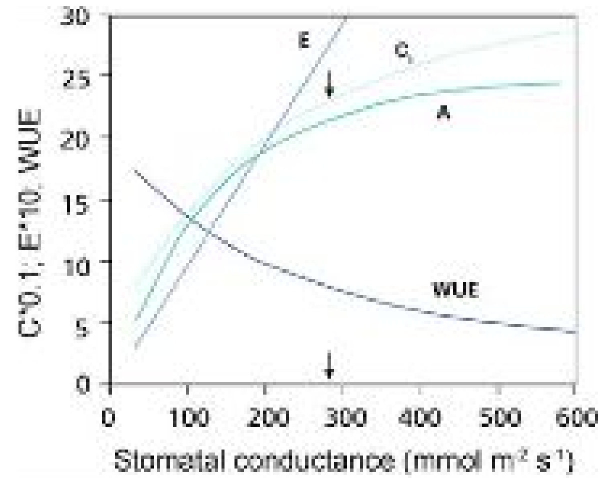

FIGURE 28. The effect of stomatal conductance (g_s) on the transpiration rate (E, mmol m^{-2} s^{-1}), rate of CO_2 assimilation (A, µmol m^{-2} s^{-1}), intercellular CO_2 concentration (C_i, µmol mol^{-1}) and photosynthetic water-use efficiency (WUE, mmol CO_2 (mol H_2O)$^{-1}$ s^{-1}) as a function of stomatal conductance. Calculations were made assuming a constant leaf temperature of 25°C and a negligible boundary layer resistance. The arrow indicates g_s at the co-limitation point of carboxylation and electron transport. For the calculations, Equations as described in Box 2A.1 and Sect. 2.2.2 have been used.

Model Drought Response

Research

New Phytologist

Confronting model predictions of carbon fluxes with measurements of Amazon forests subjected to experimental drought

Thomas L. Powell[1], David R. Galbraith[2,3], Bradley O. Christoffersen[4], Anna Harper[5,6], Hewlley M. A. Imbuzeiro[7], Lucy Rowland[8], Samuel Almeida[9], Paulo M. Brando[10], Antonio Carlos Lola da Costa[11], Marcos Heil Costa[7], Naomi M. Levine[1], Yadvinder Malhi[3], Scott R. Saleska[4], Eleneide Sotta[12], Mathew Williams[8], Patrick Meir[8] and Paul R. Moorcroft[1]

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“Model predictions … poorly replicated the response to drought treatment”

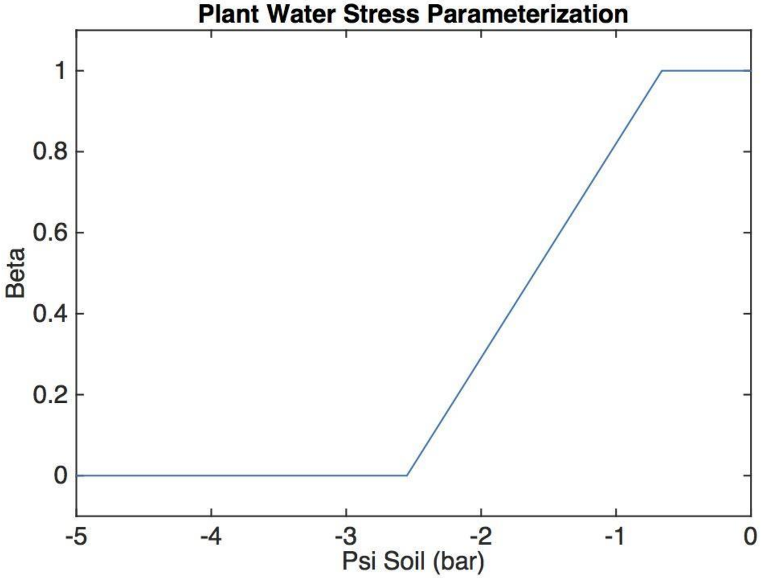
change.

• Here, carbon (C) flux predictions of five terrestrial biosphere models (Community Land Model version 3.5 (CLM3.5), Ecosystem Demography model version 2.1 (ED2), Integrated Biosphere Simulator version 2.6.4 (IBIS), Joint UK Land Environment Simulator version 2.1

CLM4.5 Water Stress - Btran

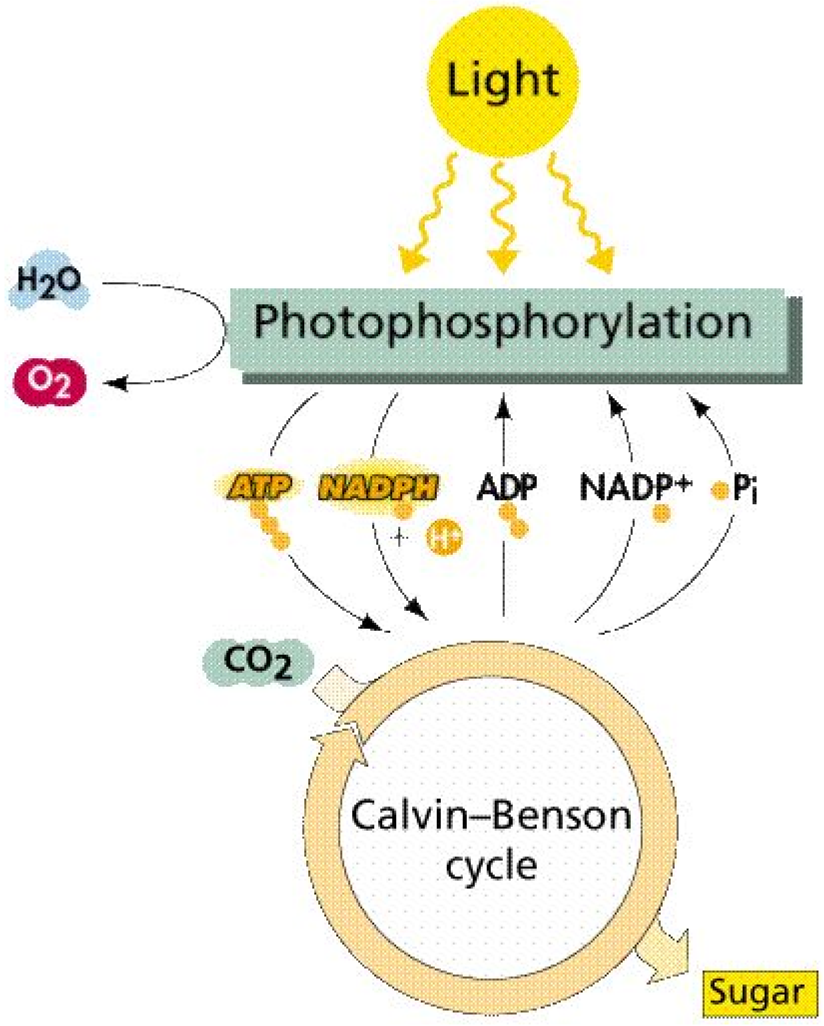
- Btran is the CLM4.5 water stress function
- Represents soil water stress
- Linear function relating stress with soil matric potential
- 1=no stress, 0=fully stressed
- Weighted average of each soil layer by root fraction

$$\beta = f(\Psi_{soil})$$



Btran limits photosynthesis

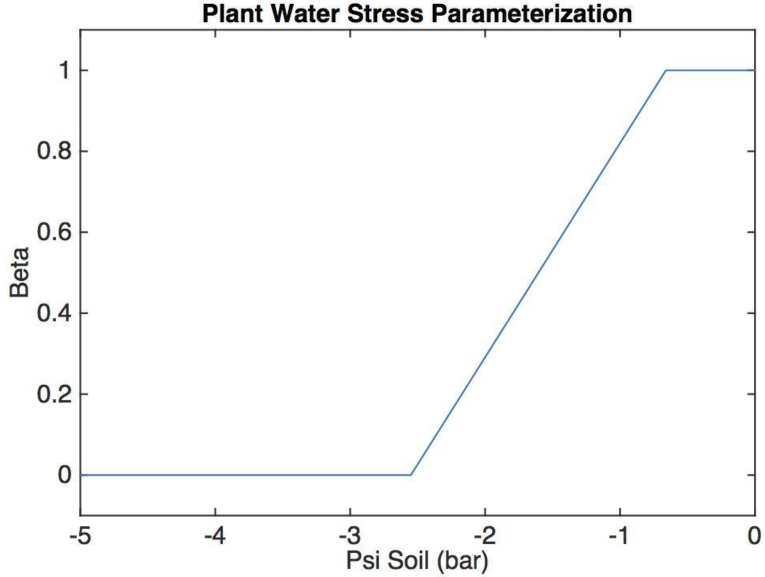
- Btran is trying to capture plant water regulation
- Btran attenuates A_c, the carboxylation-limited rate of photosynthesis
- Btran=1 is no stress, 0=fully stressed
- Stomatal conductance and transpiration calculated based on A_n



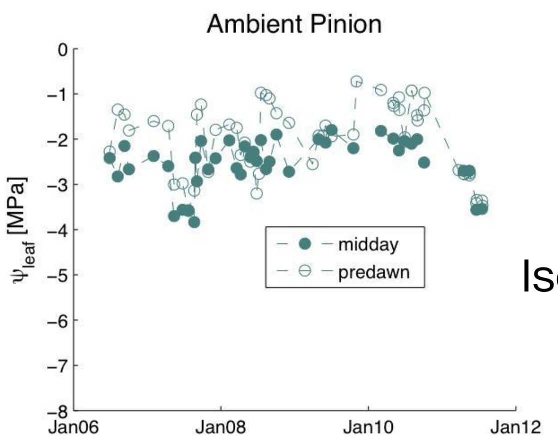
Btran limitations

- Lacks physical basis
- Poorly constrained by measurements
- Lacks flexibility to represent variable plant water use strategies

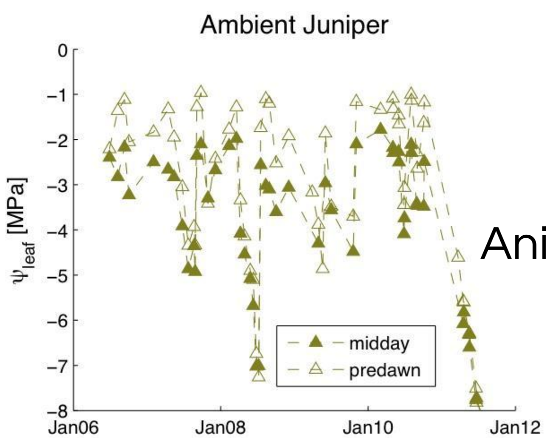
$$\beta = f(\Psi_{soil})$$



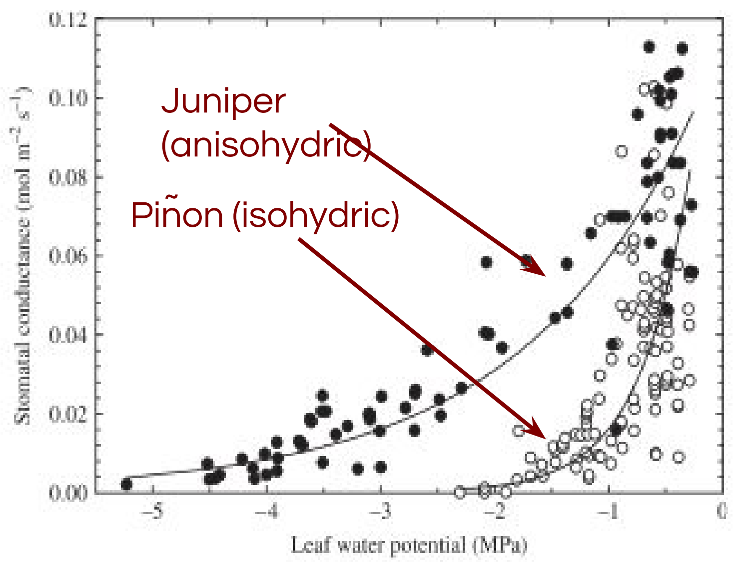
Isohydric vs. Anisohydric species



Isohydric

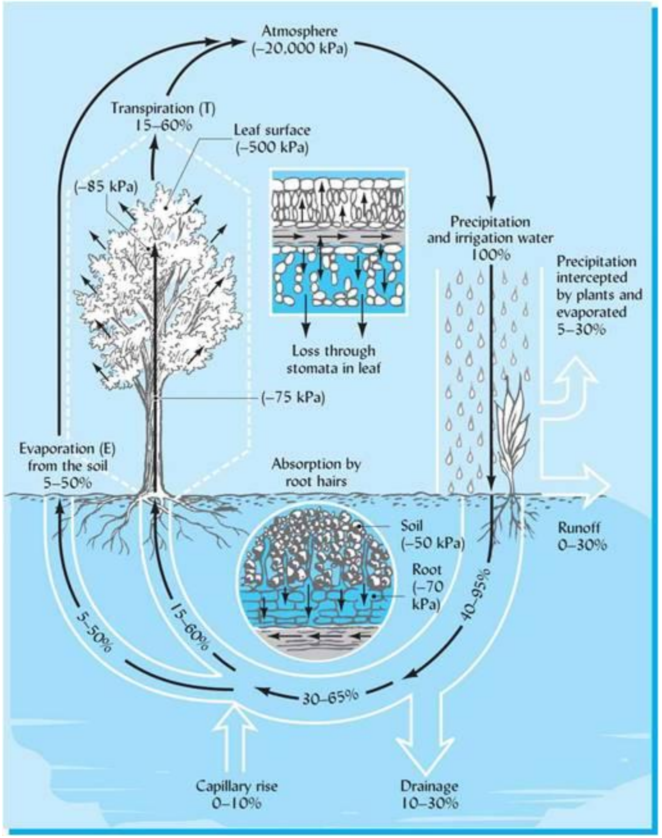


Anisohydric



Plant Water Dynamics

- How does water move within the SPAC?
- Water follows the gradient in total water potential
- Cohesion-tension theory: through cohesion and low atmospheric water potential, plants maintain tension to transport water to leaves

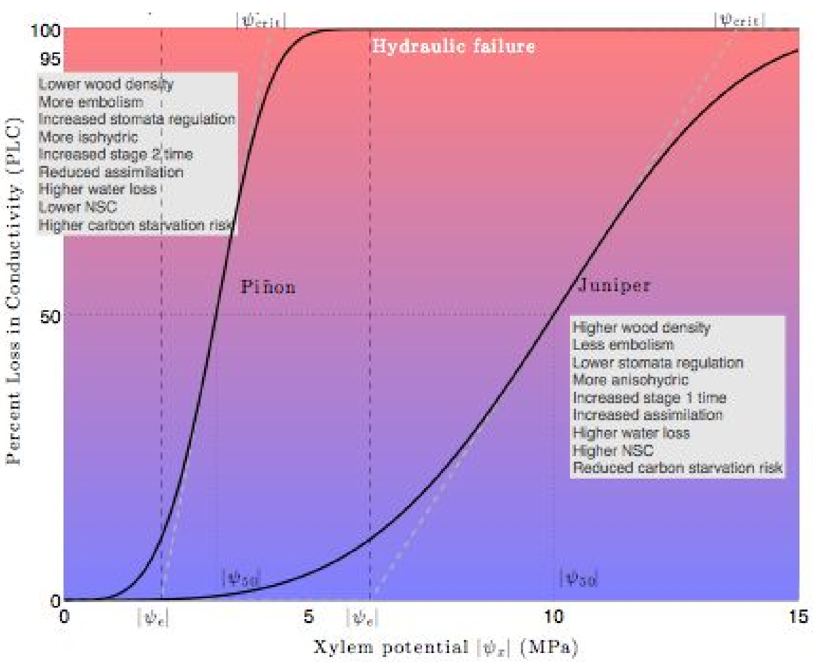


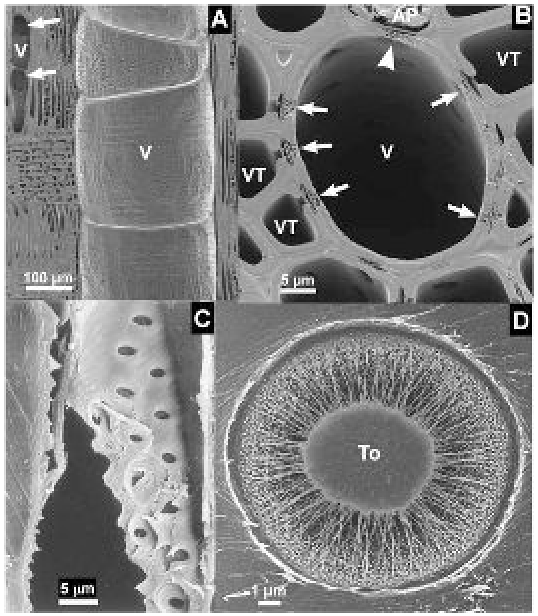
Plant Hydraulics

- Porous media approach to model water potential throughout the system
- Water flow proportional to gradient in total water potential
- $q = k \Delta\Psi$

Loss of Conductivity

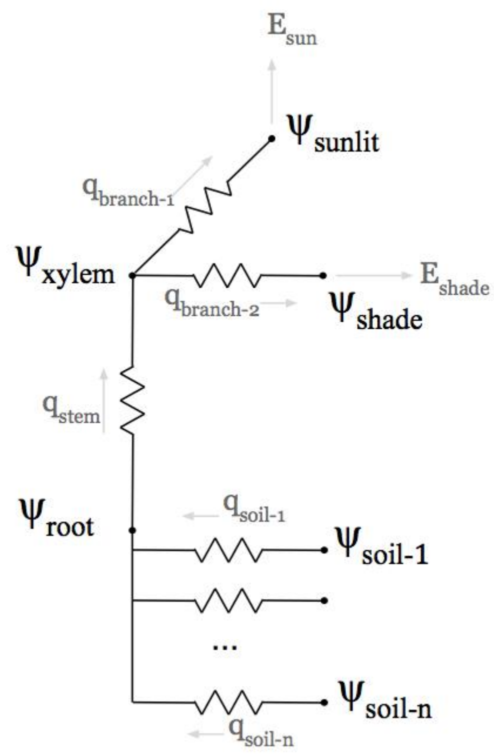
- As water potential decreases, conductivity decreases
- $q = k\,\Delta\Psi$





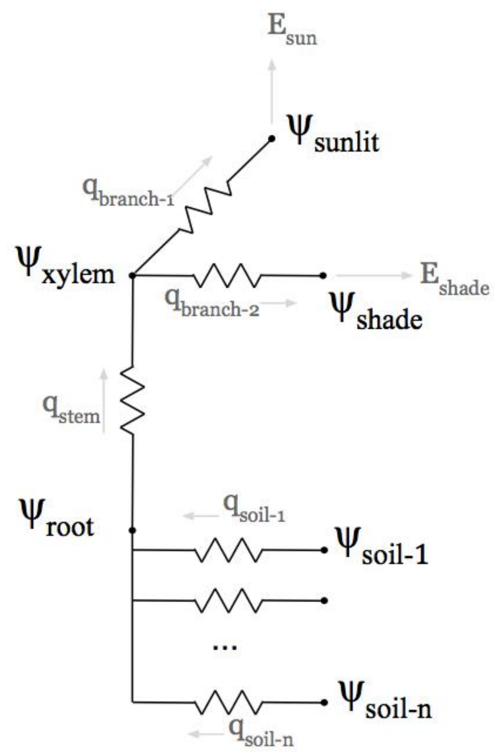
Plant Hydraulic Stress

- Model resolves water transport through the SPAC
- Water supply modeled via simple hydraulic framework
- Loss relative to unstressed transpiration modeled based on leaf-level water potential
- Water stress function used to calculate conductance, photosynthesis, and respiration

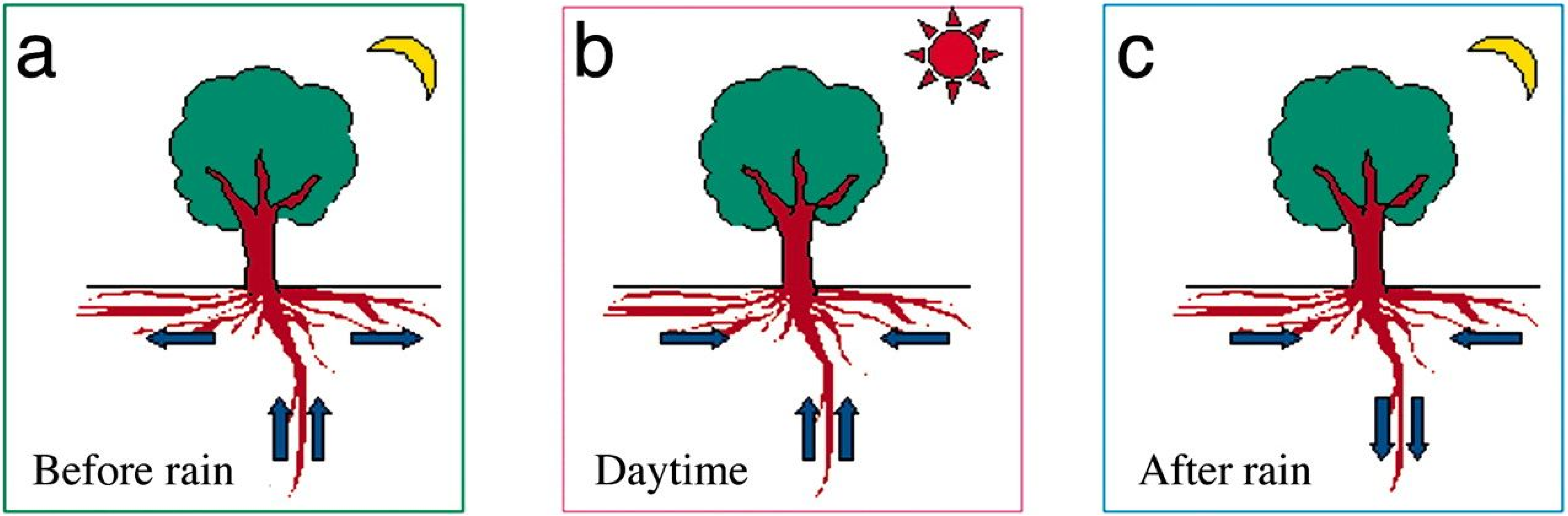


PHS vs. Btran

- PHS introduces the flexibility to model variable plant water use strategies
- Compatible with commonly measure hydraulic traits (e.g. kmax and p50)
- Same multiplicative attenuation of A_c and stomatal conductance
- Soil water uptake in PHS based directly on gradient in water potential

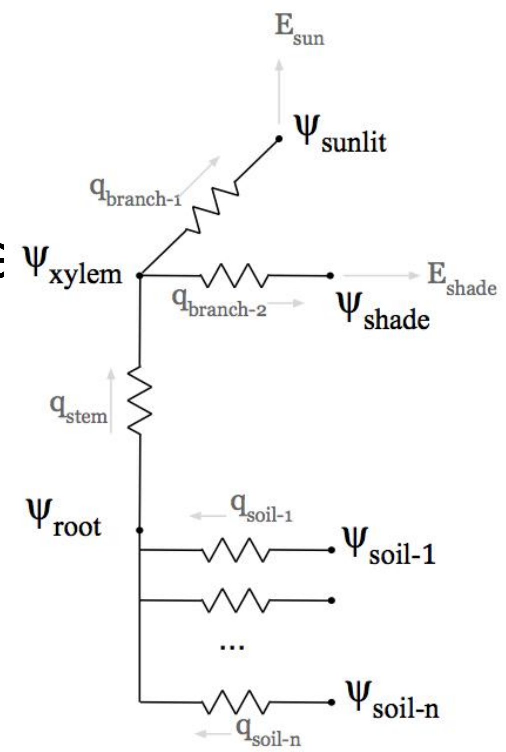


Hydraulic Redistribution



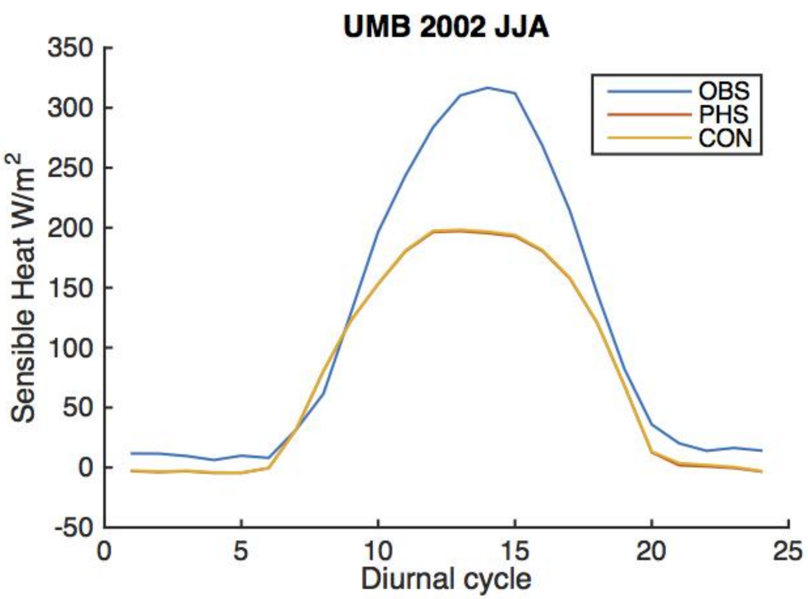
Implementation

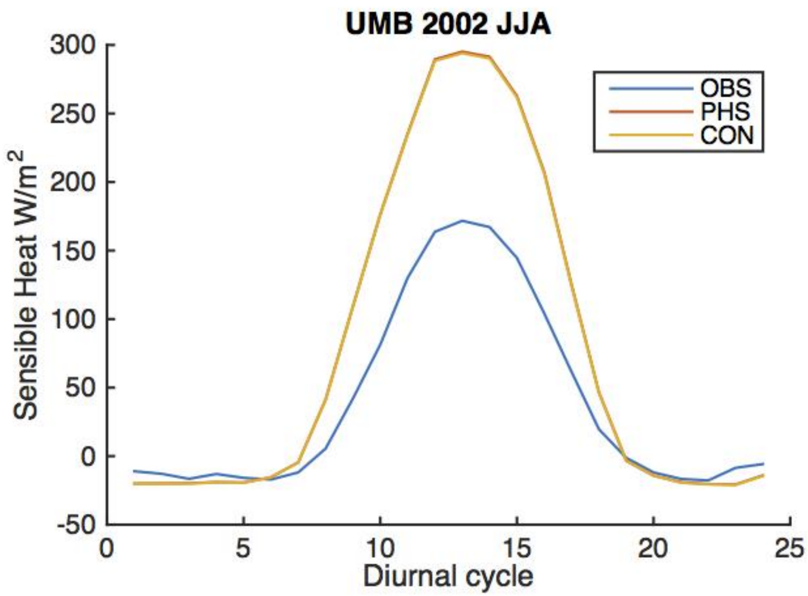
- Impossible without the help of Keith, Erik, Rosie, Dave, and the rest of the LMWG
- Naturally there were some unforesee challenges
  - Crop model
  - Irrigation
  - Drought deciduous phenology
  - Ground evaporation



Flux tower results: well-watered

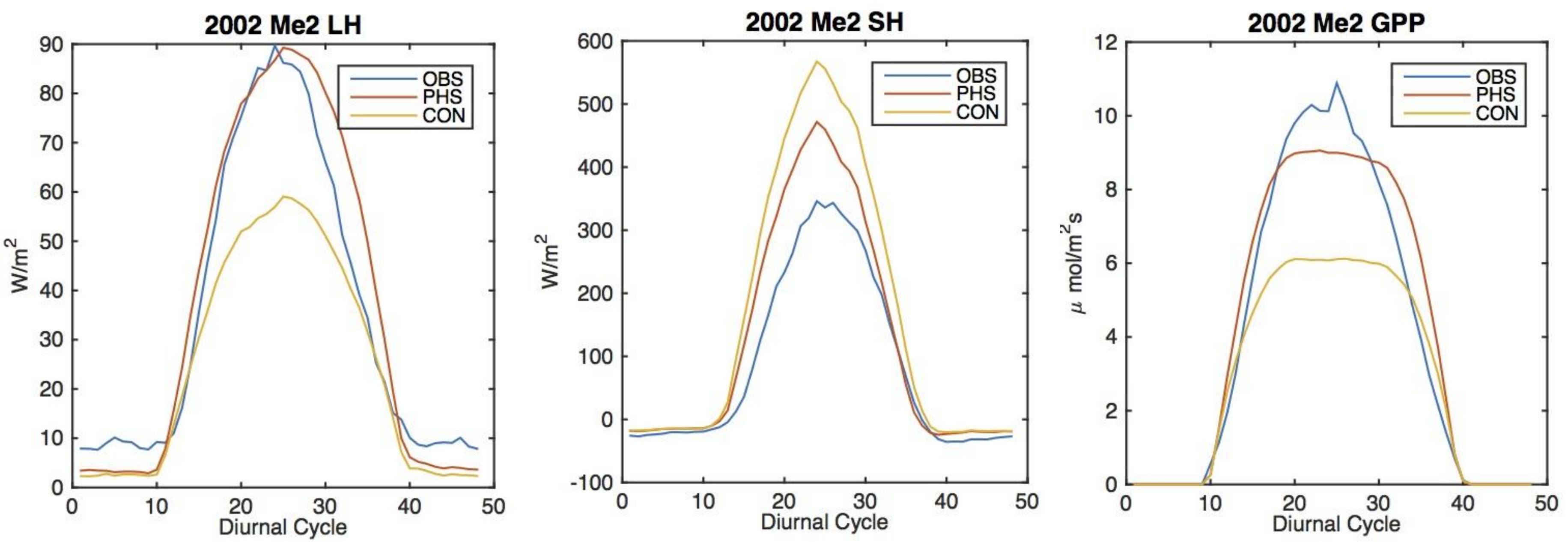
University of Michigan Biological Station



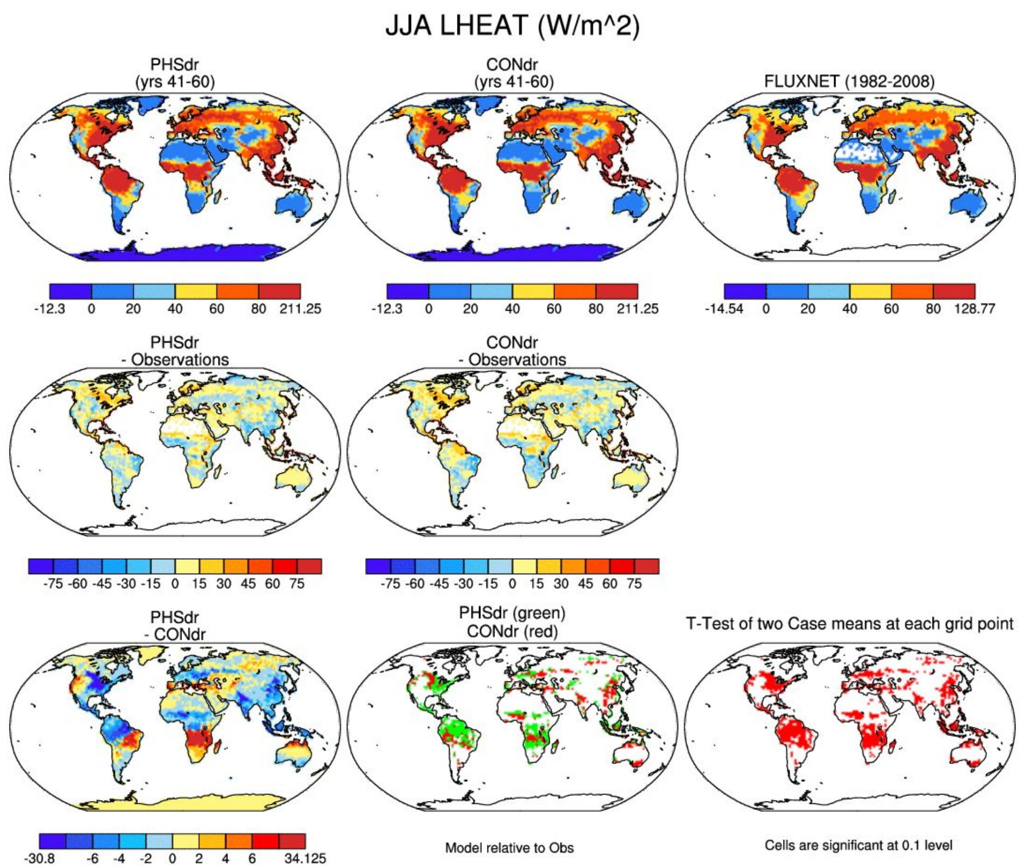


Flux tower results: Semi-arid

Metolius Intermediate Pine: Central Oregon

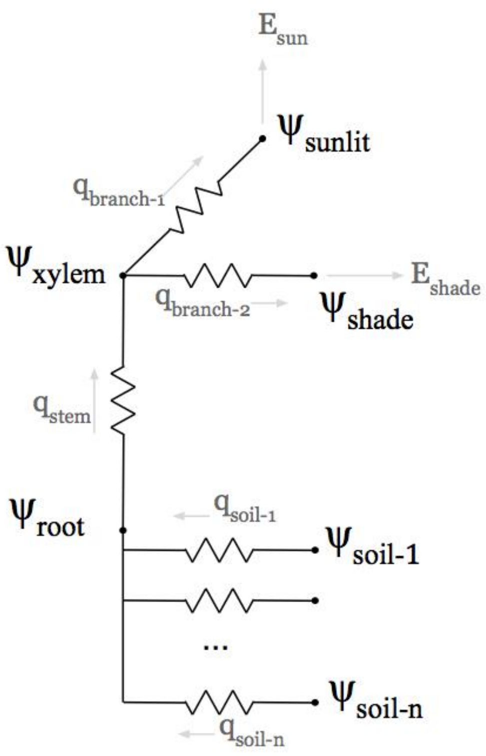


Global simulation



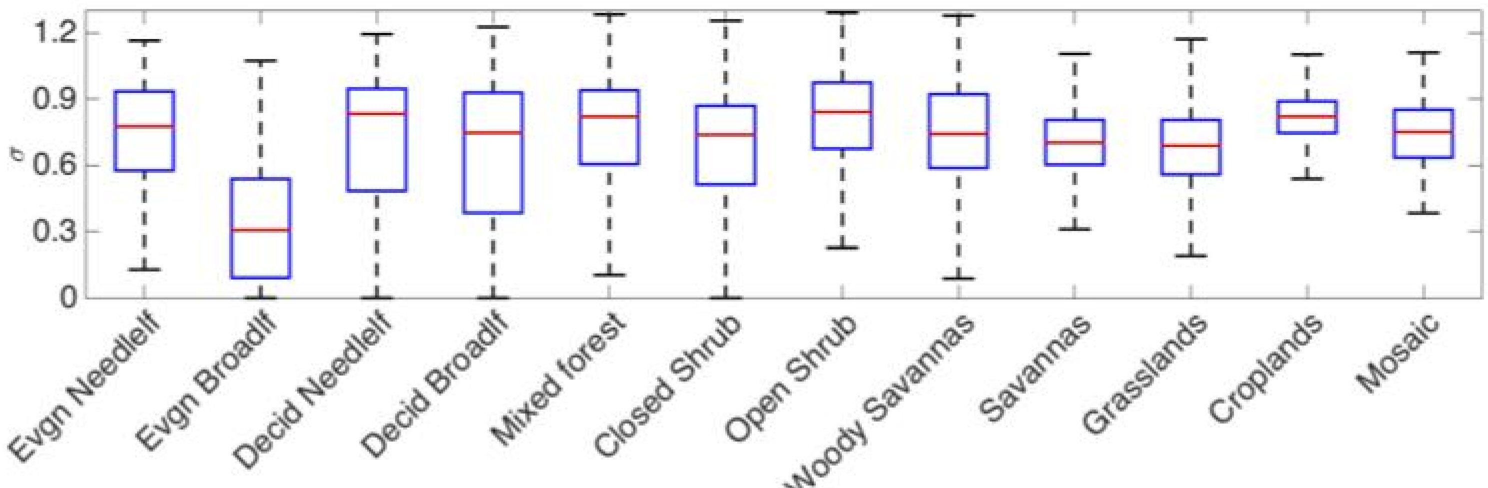
Parameter estimation

- PHS has increased flexibility to represent variable plant water use strategy vs. Btran
- But that comes along with an increased burden in the complexity of parameter estimation
- Parameter estimation is the biggest challenge with this model, but also a great source for interesting science questions



Parameter Estimation

- Are PFTs right for plant hydraulics?
- Below, ecosystem-scale isohydricity by PFT derived from VOD dynamics
- Lower values are more isohydric



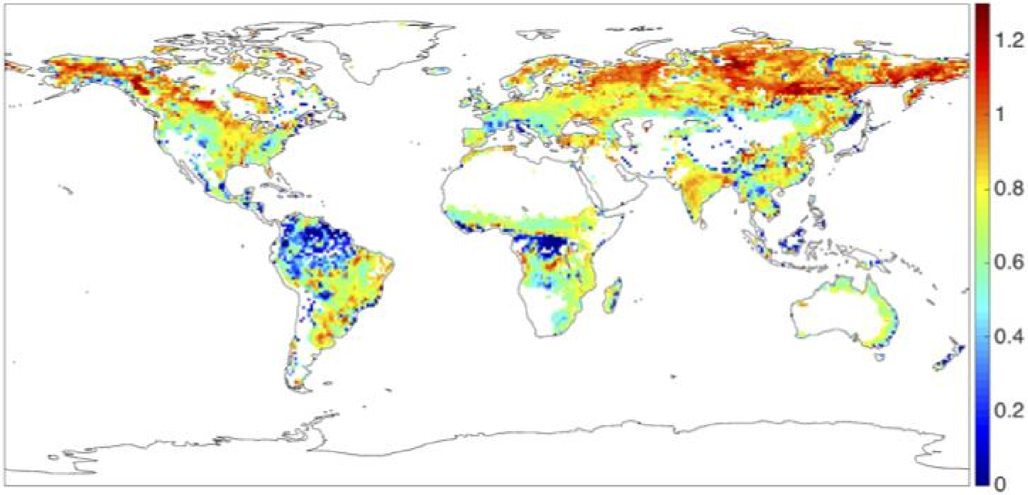
Konings and Gentine, submitted

Vegetation Optical Depth

- PHS models vegetation water status
- Allows interface with new stream of observations for model evaluation and parameterization

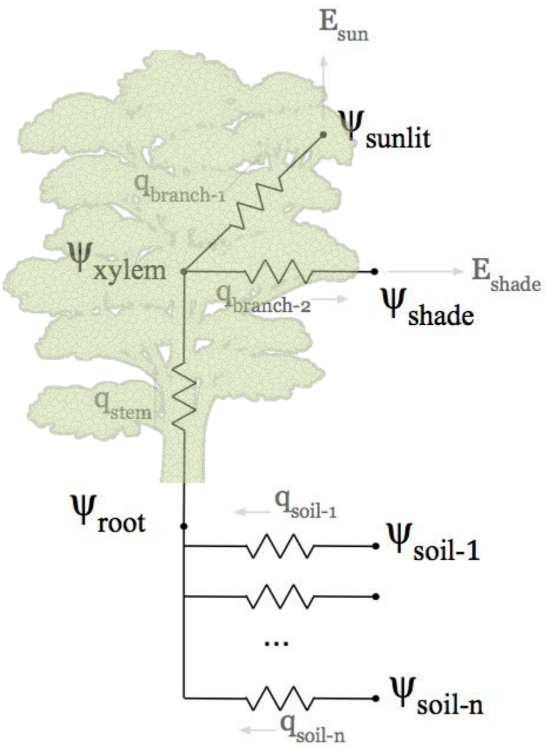
Global Variations in isohydricity slope. Lower values are more isohydric.

Konings and Gentine, submitted



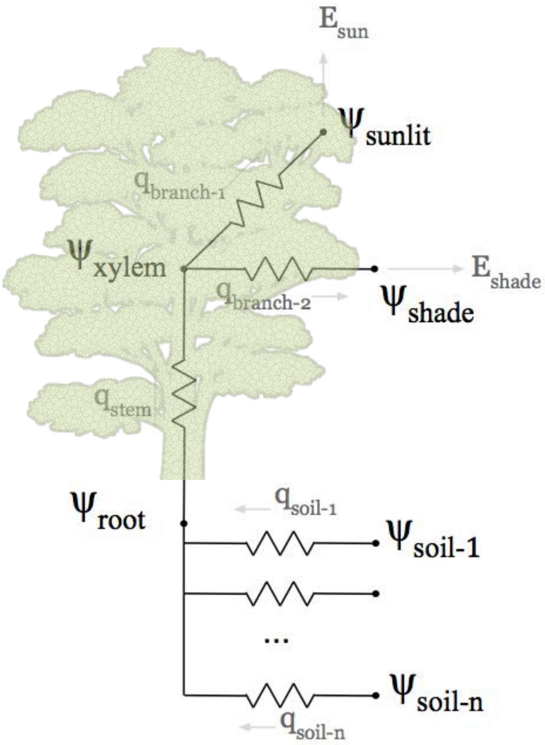
Next steps

- Global parameter estimation
- Coupled global simulations
- Drought response case studies
- Future simulations (CMIP6)



Questions?


Thank you!


E_{sun}
Ψ_{sunlit}
$q_{branch-1}$
Ψ_{xylem}
E_{shade}
$q_{branch-2}$
Ψ_{shade}
q_{stem}
Ψ_{root}
q_{soil-1}
Ψ_{soil-1}
...
Ψ_{soil-n}
q_{soil-n}