Implementing Plant Hydraulics in the Community Land Model

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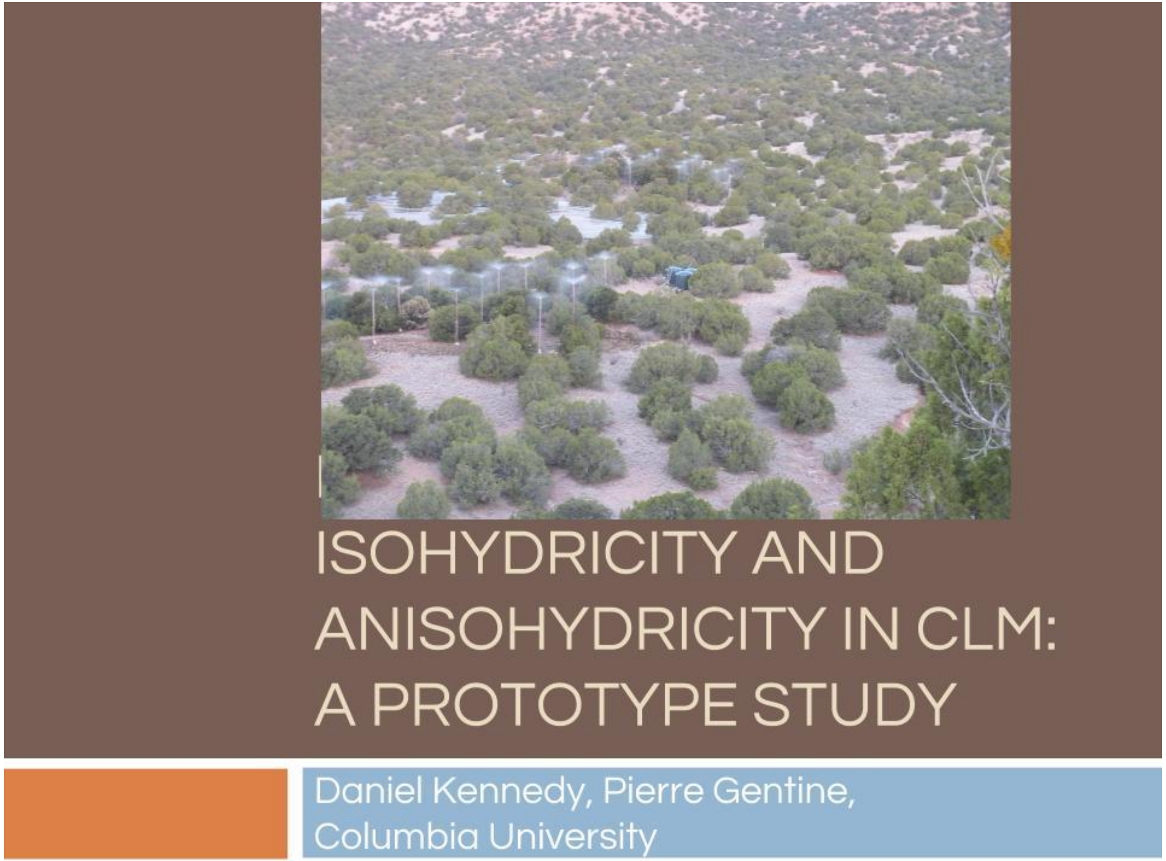
photo: Aaron Ellison

How I started with CLM:

2015
land model working group winter meeting



RESOURCES

Hosted visit, Summer 2016

Computing time

MORE RESOURCES

Rosie Fisher

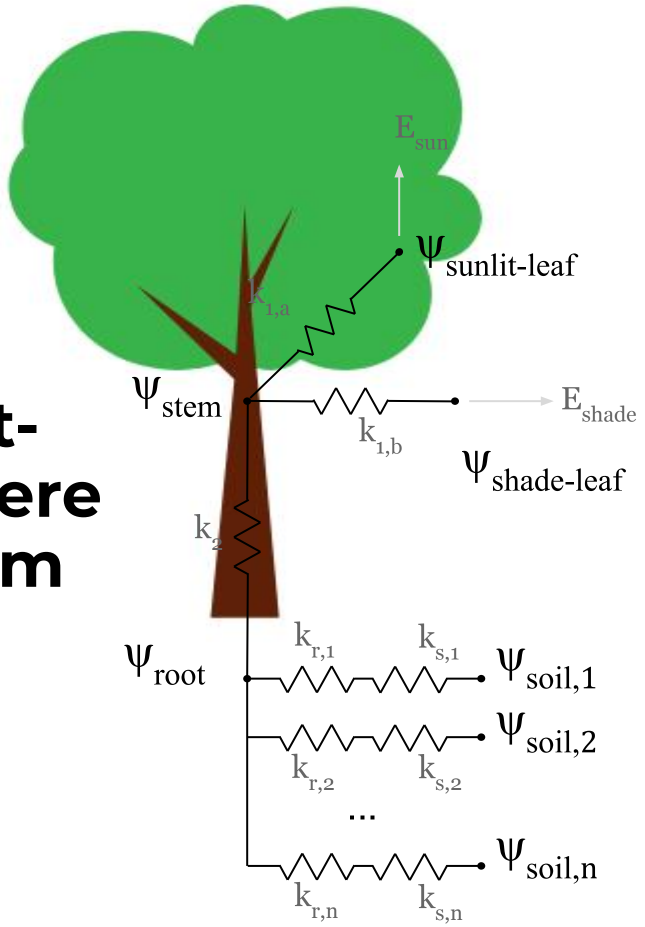
Keith Oleson

Plant **H**ydraulic **S**tress

fundamentally has two jobs:

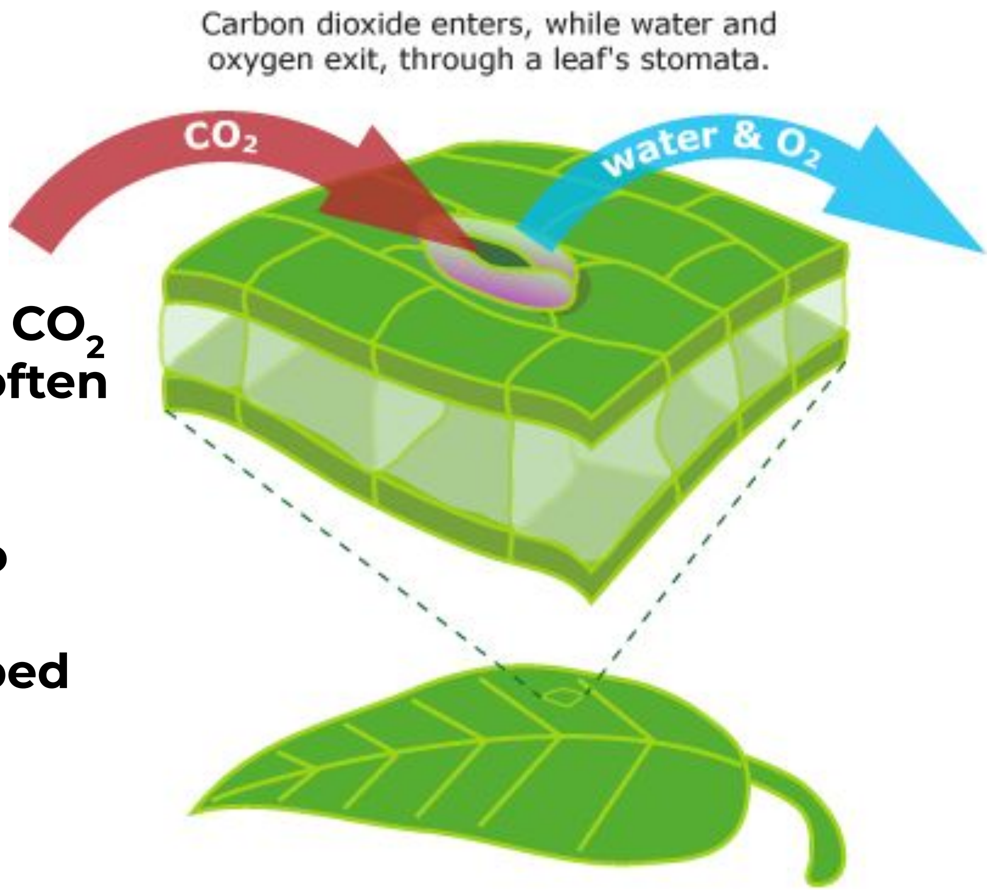
- how much water stress (β)?
- where in the soil column is the transpiration coming from?

Soil-plant-atmosphere continuum model



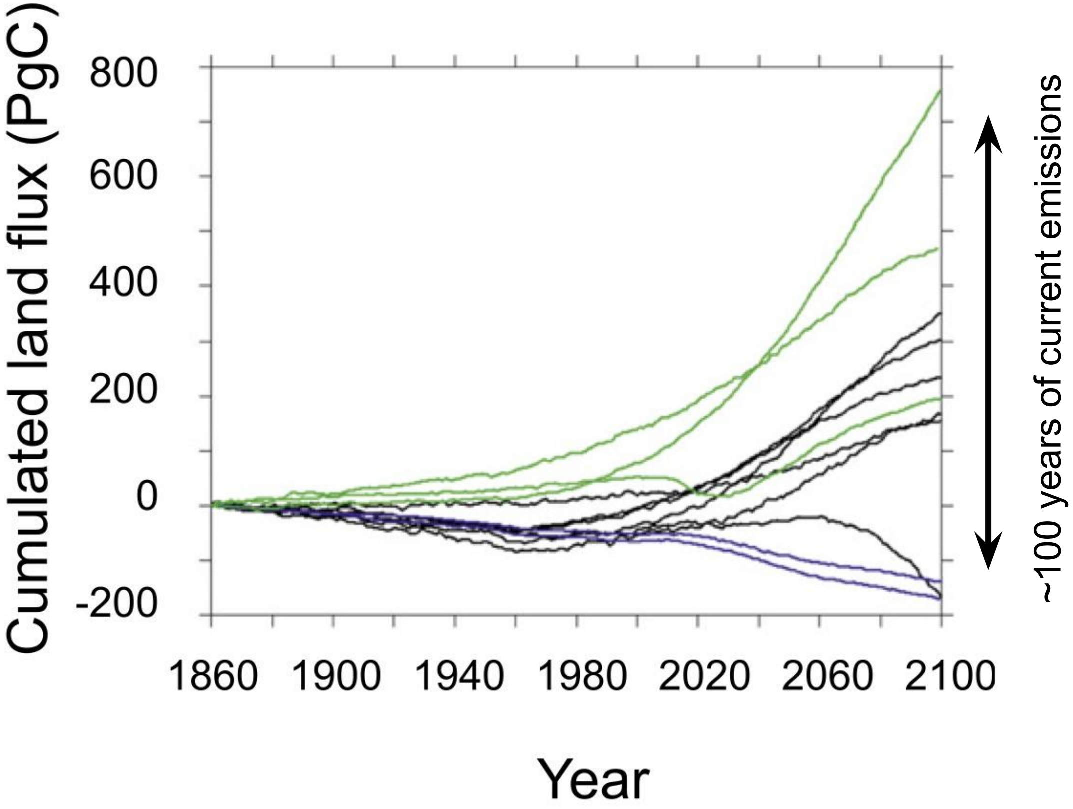
Stomatal trade-off

- Need to open pores to obtain CO_2
- But will lose water, which is often a limiting resource
- Plants can open and close stomatal pores in response to environmental conditions
- Different plants have developed different strategies



credit: University of California Museum of Paleontology

What do we expect going forward?



Look at projections from 11 Earth System Models

Forced by RCP8.5 emissions through 2100

Friedlingstein et al. 2014

How do models perform?

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL078131

Key Points:
- Most global vegetation models represent plant water limitation with a rarely tested empirical function based solely on soil moisture
- Carbon cycle uncertainty associated with such soil moisture stress functions is comparable to current

Soil Moisture Stress as a Major Driver of Carbon Cycle Uncertainty

A. T. Trugman[1], D. Medvigy[2], J. S. Mankin[3,4], and W. R. L. Anderegg[1]

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Dame, Notre Dame, IN, USA, [3]Division of Ocean and Climate Physics, Lamont-Doherty Earth Observa
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an increase in drought globally with climat
lant photosynthetic response to soil moisture
tic response where plant water potentials resp
ure stress may introduce significant uncertain
d the use of the soil moisture limitation functi
stem models. We found that soil moisture-limi
ertain component of the simulated carbon cy
proximately 40–80% of the intermodel variabil
alone. Our results highlight the importance of
odels and illuminate several avenues for impro

"40-80% of the intermodel variability [in the carbon cycle] due to the functional form of soil moisture limitation"

How do models perform?

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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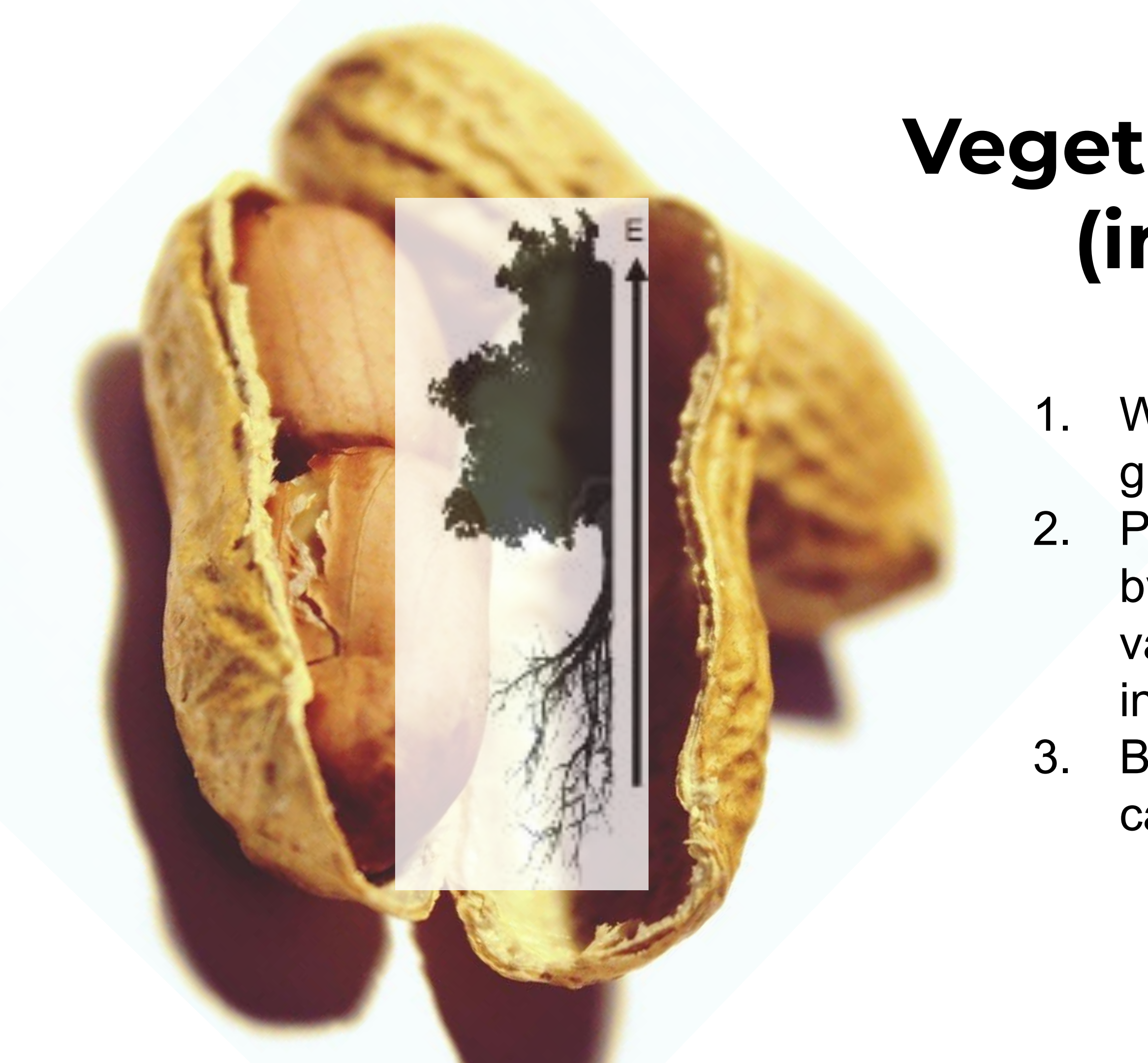
"Model predictions … poorly replicated the response to drought treatment"

te of Amazon rainforests in response to climate

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

Received: 12 February 2013
Accepted: 20 May 2013



Vegetation Water Use (in a nutshell)

1. Water flows down pressure gradients
2. Plants extract water from the soil by allowing the pressure in their vasculature to fall lower than it is in the soils.
3. But if the pressure gets too low, it can damage the vasculature

Some terminology

1. Water potential ≈ pressure
2. Units = Megapascals (MPa)

   1atm ≈ 0.1 MPa
3. Symbol: Ψ
4. Values are negative

Soil-plant-atmosphere continuum

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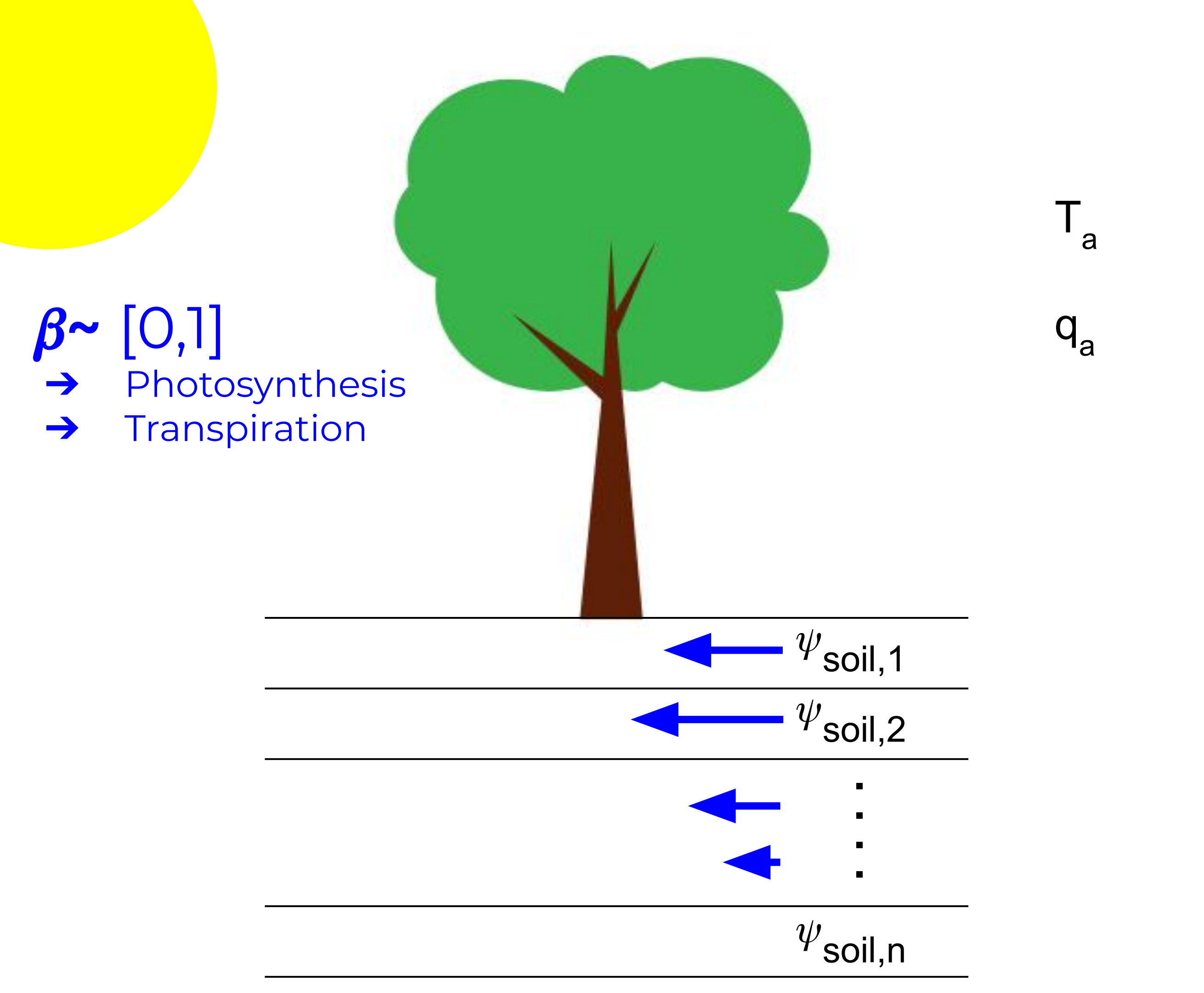
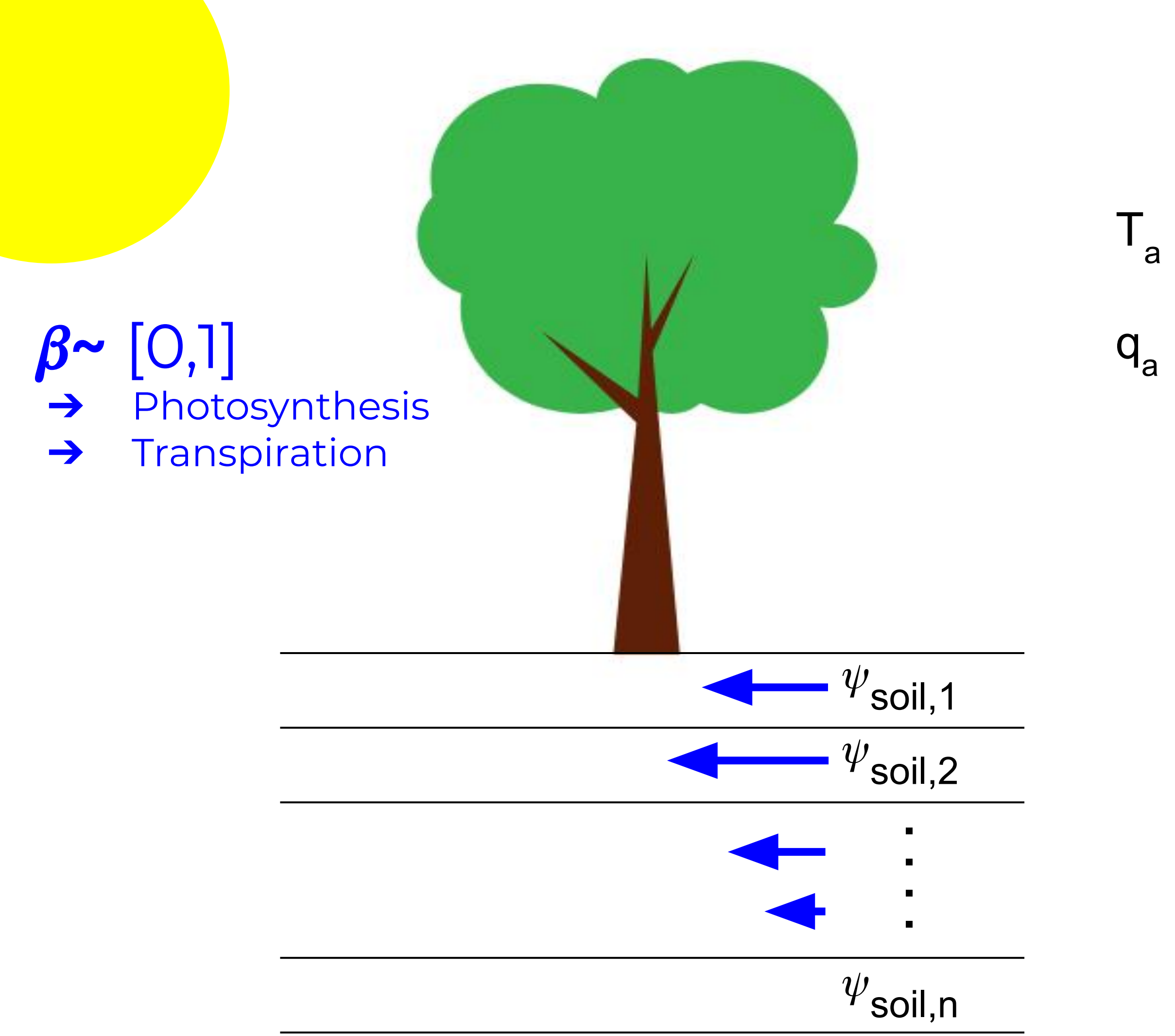
- where is the transpiration coming from?



Soil **M**oisture **S**tress

CLM4.5

- 2 parameters
- empirically derived
- calculates root water uptake from soil potentials
- calculates water stress from soil potentials



Soil **M**oisture **S**tress

CLM4.5

- 2 parameters
- empirically derived
- ca
  u
  s
- ca
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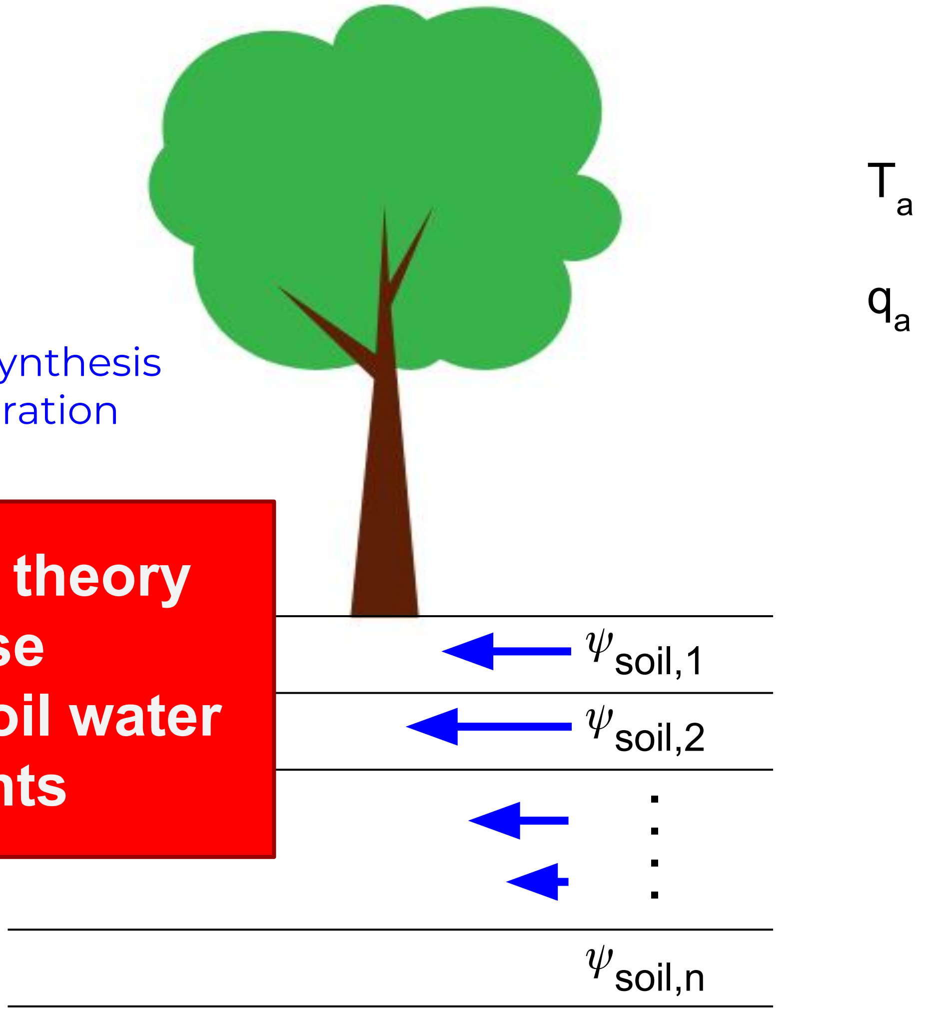
  s

$\beta \sim [0,1]$
- ➔ Photosynthesis
- ➔ Transpiration

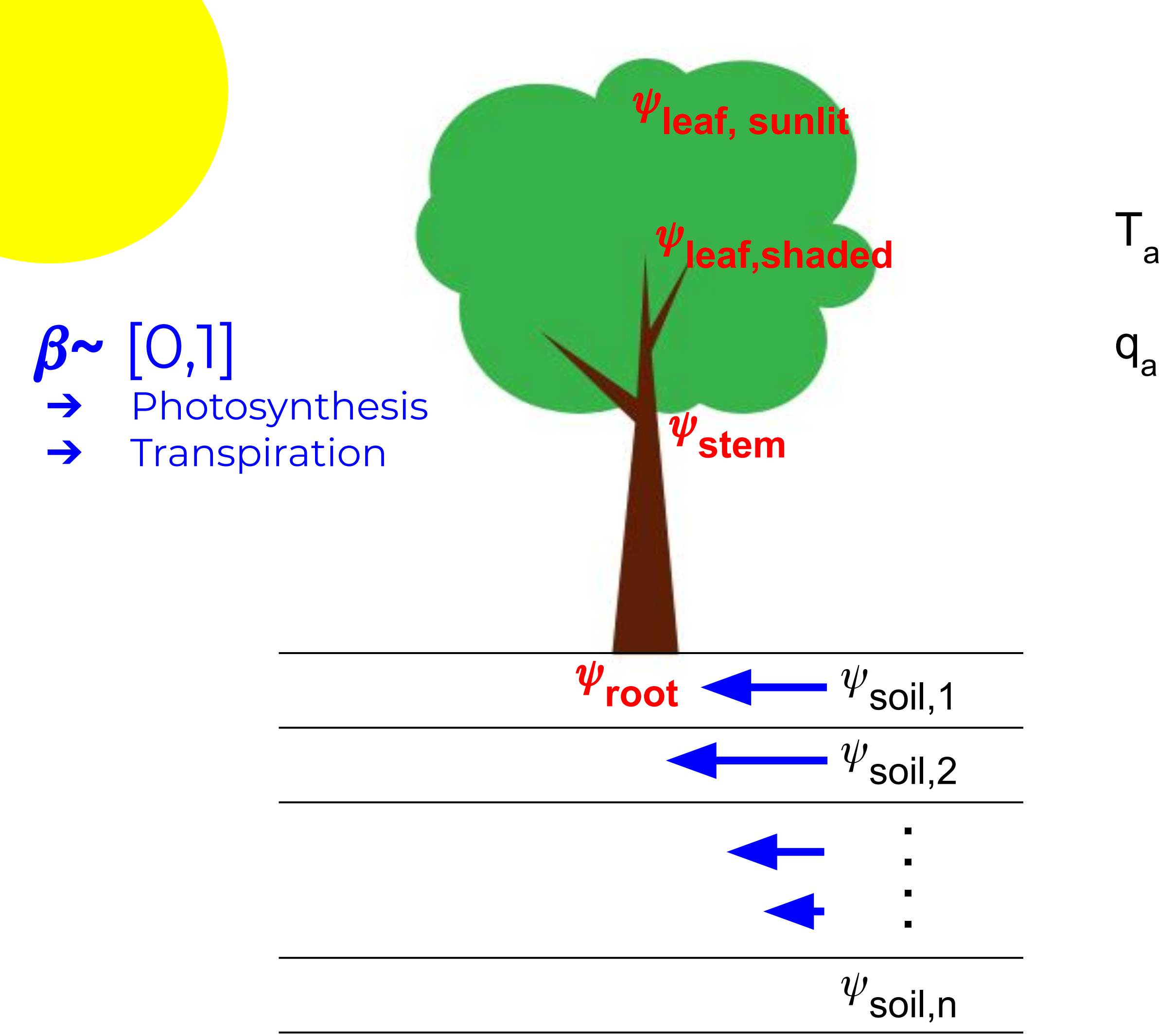
1. **Conflicts with current theory of vegetation water use**
2. **Extreme scarcity of soil water potential measurements**



Plant **H**ydraulic **S**tress

CLM5

- 4 parameters
- adds prognostic plant water potentials
- stronger physical basis
- calculates root water uptake from root water potential
- calculates water stress from leaf water potentials



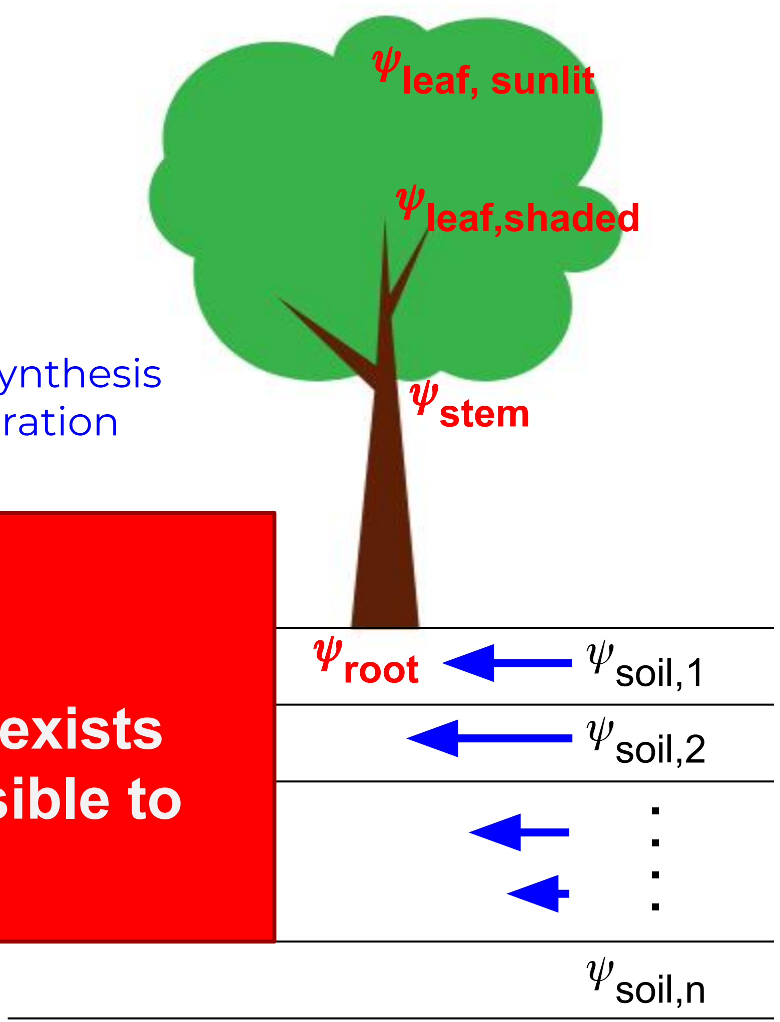
Plant **H**ydraulic **S**tress

CLM5

- 4 parameters
- adds prognostic plant w
- st
- ca u ro
- ca fr p

1. Better comports with hydraulic theory
2. Water stress variable exists above ground ➔ possible to validate

β~ [0,1]
➔ Photosynthesis
➔ Transpiration



T_a

q_a

Plant **H**ydraulic **S**tress

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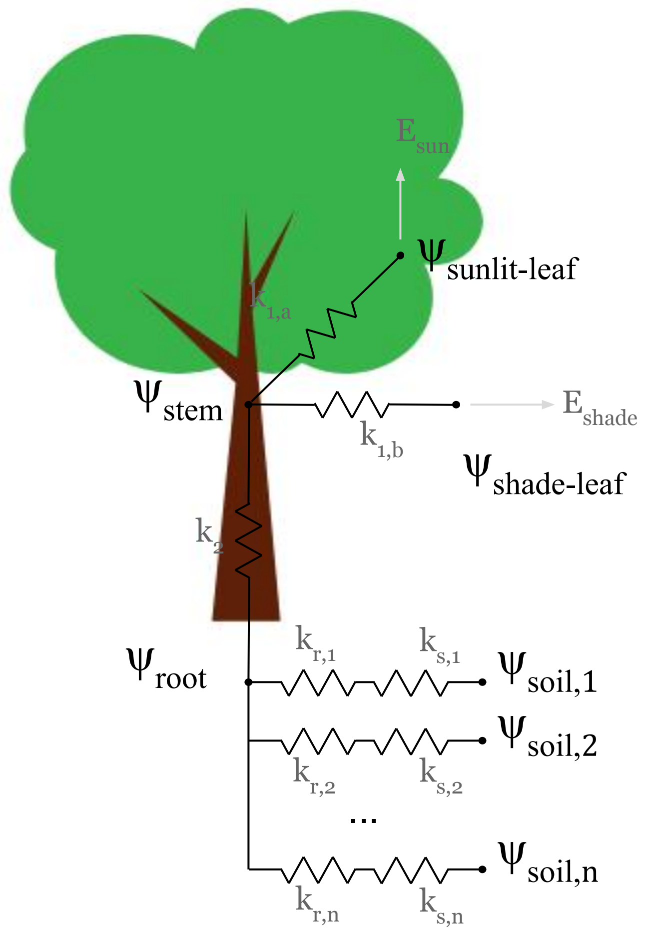


Experiment Description

Kennedy et al. 2019, *JAMES*

Caxiuanã, Brazil

- Critical biome
- Well-instrumented
- Highly studied
- Drought signal
  - Seasonally dry (Aug-Nov)
  - Experimental precip exclusion plot

Experiment Description

Results

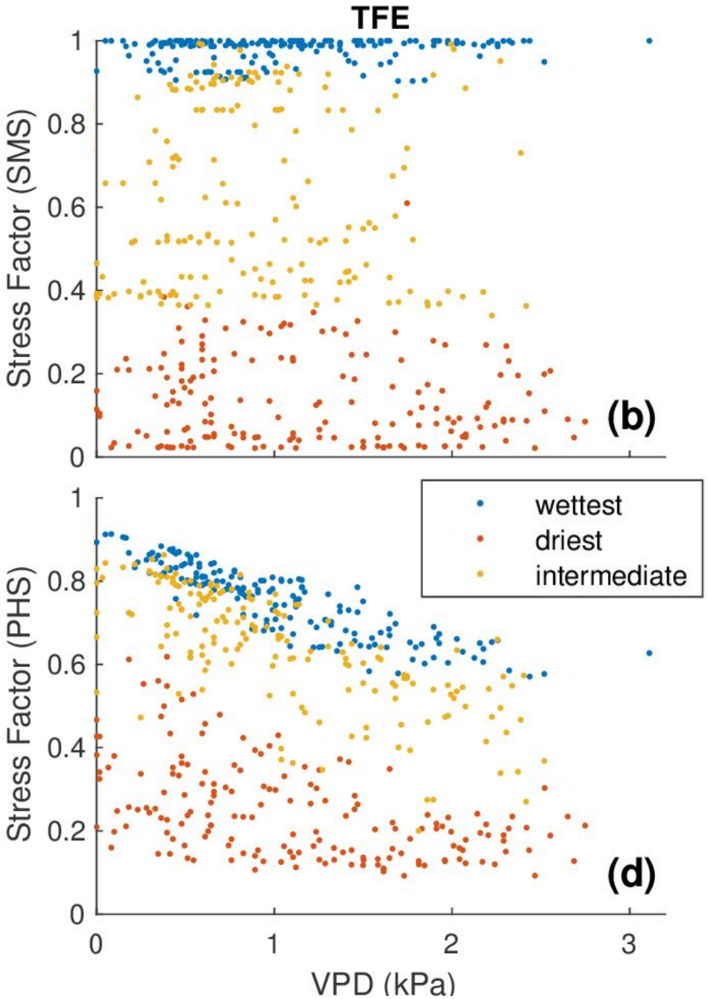
Is PHS functioning as expected?

Soil Moisture Stress

- driven only by soil moisture

Plant Hydraulic Stress

- responds to both:
  - soil moisture
  - VPD



Stress vs. VPD

(and soil moisture)

Subset for downwelling solar radiation between 400 and 425 W/m2 (~55th percentile)

Data subdivided by root-zone soil moisture

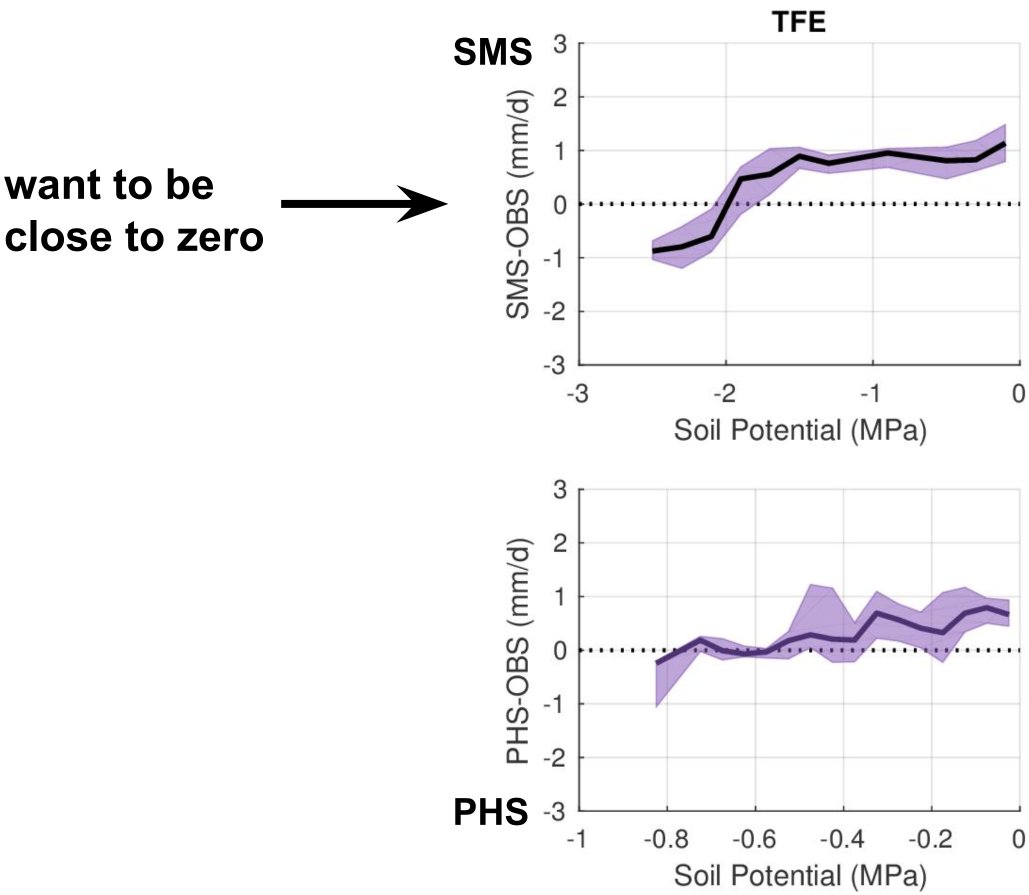
Results

How do we compare with field observations?

Transpiration: comparison with observations

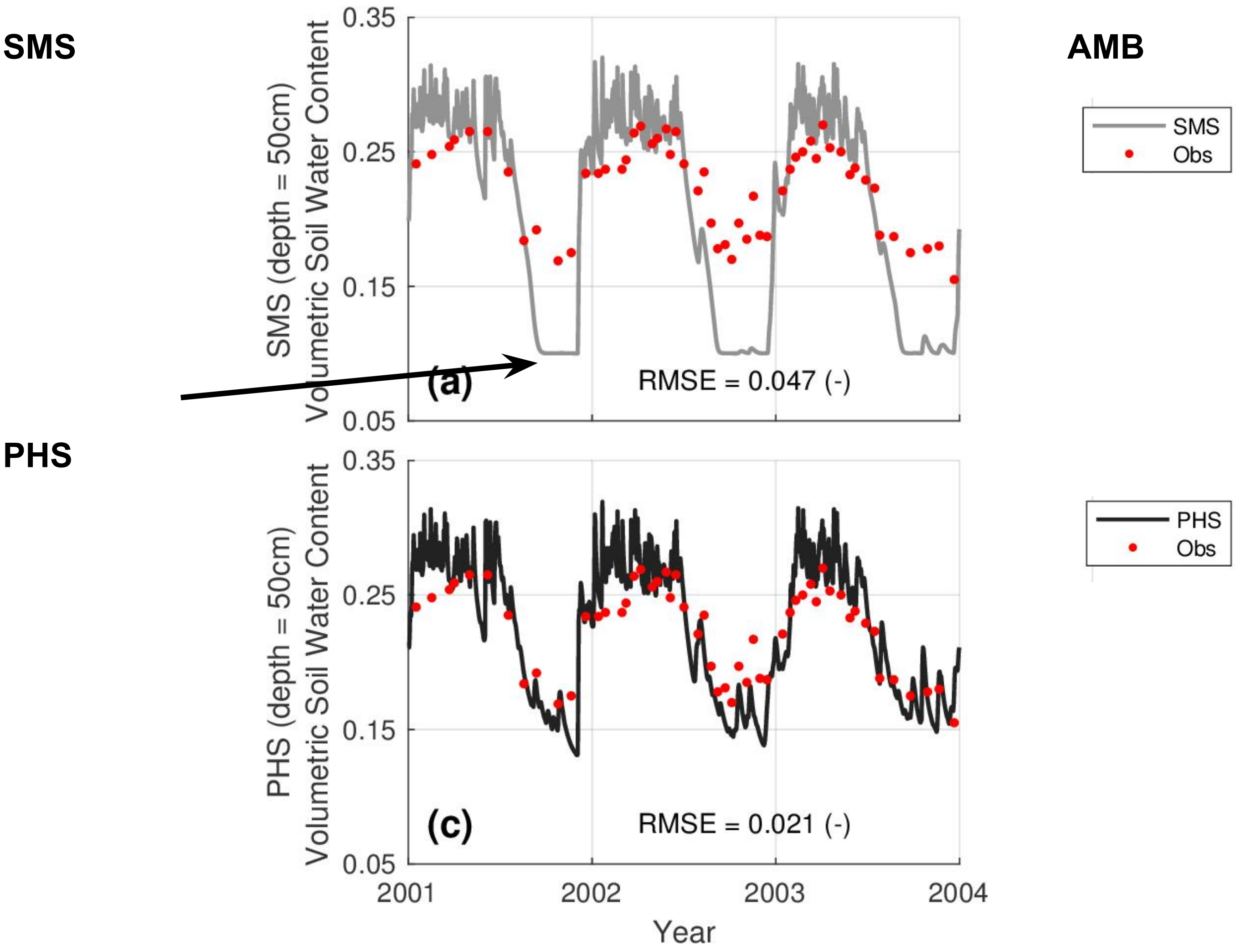
- Plotting error vs. soil water potential
- Line represents median
- Shading spans interquartile range

- PHS improvements derive from relationship between transpiration and soil potential



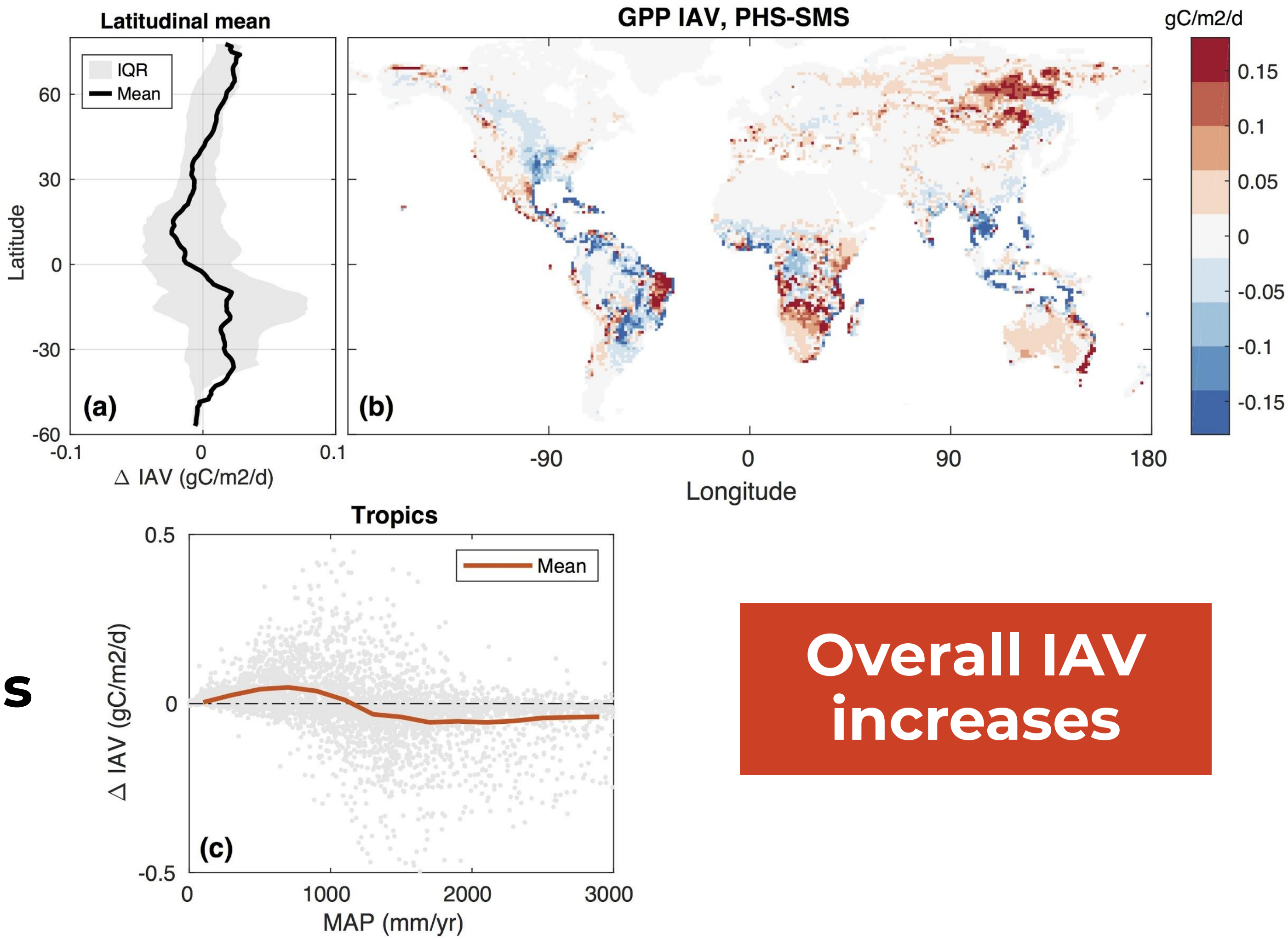
PHS yields improved soil moisture dynamics

SMS root zone is too dry during dry episodes



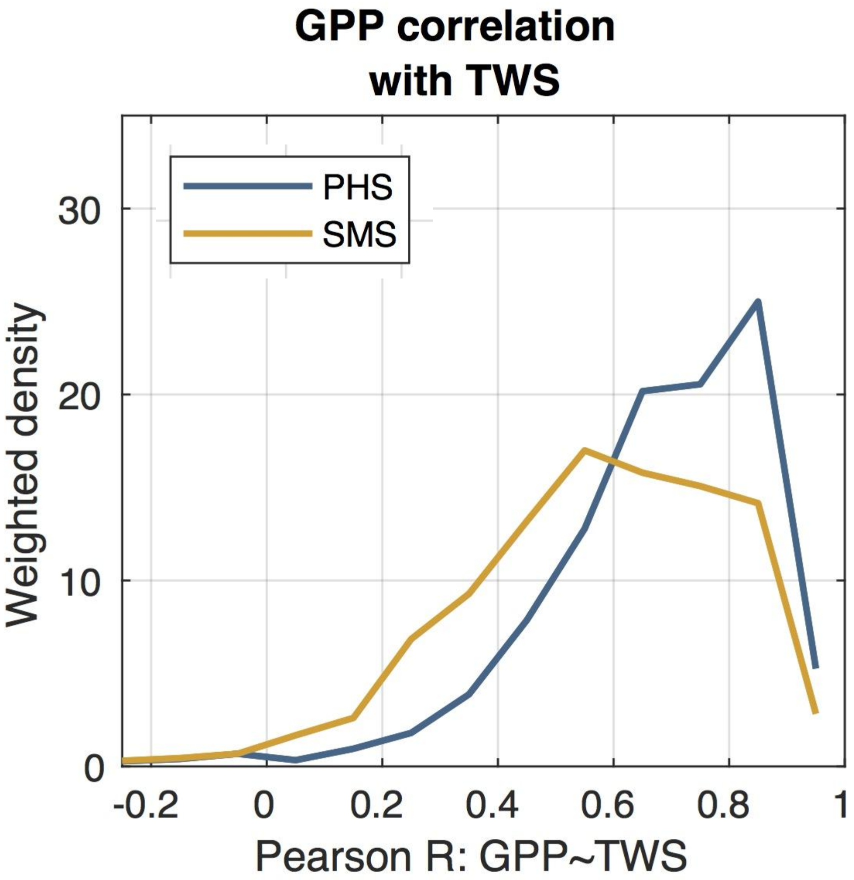
Global Results

Kennedy et al., *in prep*



How does PHS affect variability in Photosynthesis (GPP)?

Overall IAV increases



PHS shows stronger interannual correlations between GPP and terrestrial water storage (TWS)

- histograms represent the distribution of correlations across gridcells in a semi-arid domain
- see Humphrey et al. 2018, which suggests that ESMs significantly underestimate the GPP~TWS relationship

Conclusions:

- PHS is the default vegetation water use parameterization in CLM5/CESM2
- Better comports with hydraulic theory
- Exposes the model to a new suite of observations for validation and parameter estimation
- Creates an entry point for plant hydraulic researchers to test hypotheses on broader spatial scales

QUESTIONS?

photo: Aaron Ellison