Implementing Plant Hydraulics in the Community Land Model

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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 Hydraulic Stress fundamentally has two jobs:

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

Soil-plant-atmosphere continuum model
Stomatal trade-off

- Need to open pores to obtain $\text{CO}_2$
- 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?

“40-80% of the intermodel variability [in the carbon cycle] due to the functional form of soil moisture limitation”
Confronting model predictions of carbon fluxes with measurements of Amazon forests subjected to experimental drought

Thomas L. Powell¹, David R. Galbraith²,³, Bradley O. Christoffersen⁴, Anna Harper⁵,⁶, Hewlley M. A. Imbuzeiro⁷, Lucy Rowland⁸, Samuel Almeida⁹, Paulo M. Brando¹⁰, Antonio Carlos Lola da Costa¹¹, Marcos Heil Costa⁷, Naomi M. Levine¹, Yadvinder Malhi³, Scott R. Saleska⁴, Eleneide Sotta¹², Mathew Williams⁸, Patrick Meir⁸ and Paul R. Moorcroft¹

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“Model predictions ... poorly replicated the response to drought treatment”
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)
   \[1\text{atm} \approx 0.1 \text{ MPa}\]
3. Symbol: \(\psi\)
4. Values are negative
Soil-plant-atmosphere continuum fundamentally has two jobs:

- how much water stress ($\beta$)?
- where is the transpiration coming from?

$\beta \sim [0,1] \rightarrow$ Photosynthesis \rightarrow Transpiration
CLM4.5

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

\[ \beta \sim [0,1] \]

\[ \Rightarrow \text{Photosynthesis} \]
\[ \Rightarrow \text{Transpiration} \]
CLM4.5

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

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

\[ \beta \sim [0, 1] \]

\[ \rightarrow \text{Photosynthesis} \]

\[ \rightarrow \text{Transpiration} \]
Plant Hydraulic Stress

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

\[ \beta \sim [0,1] \]

\[ \rightarrow \text{Photosynthesis} \]

\[ \rightarrow \text{Transpiration} \]

\[ \psi_{\text{root}} \leftarrow \psi_{\text{soil},1} \]

\[ \leftarrow \psi_{\text{soil},2} \]

\[ \vdots \]

\[ \leftarrow \psi_{\text{soil},n} \]
Plant Hydraulic Stress

CLM5

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

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

\[ \beta \sim [0,1] \]

\[ \rightarrow \text{Photosynthesis} \]

\[ \rightarrow \text{Transpiration} \]
Plant Hydraulic Stress

fundamentally has two jobs:

- how much water stress ($\beta$)?
- where in the soil column is the transpiration coming from?
Experiment Description

Kennedy et al. 2019, JAMES
Caxiuana, Brazil

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

Is PHS functioning as expected?
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

Soil Moisture Stress
- driven only by soil moisture

Plant Hydraulic Stress
- responds to both:
  - soil moisture
  - VPD
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

want to be close to zero
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?