FETCH3: A Tree-Level Hydrodynamic Modeling Approach for Examining Species-Specific Stomatal Regulation at AmeriFlux Sites

Justine Missik[1], Gil Bohrer[2], Edoardo Daly[3], Marcela Silva[3], Ashley Matheny[4], and Ana Maria Restrepo Acevedo[4]

[1]The Ohio State University
[2]Ohio State University
[3]Monash University
[4]University of Texas at Austin

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Abstract

Improving the representation of plant hydraulic behavior in vegetation and land-surface models is critical for improving our predictions of the impacts of drought stress on ecosystem carbon and water fluxes. Species-specific hydraulic traits play an important role in determining the response of ecosystem carbon and water fluxes to water stress. Here, we present plans for the development of the Finite-difference Ecosystem-scale Tree Crown Hydrodynamics model version 3 (FETCH3), a tree hydrodynamic model which builds upon its predecessors FETCH and FETCH2. FETCH3 simulates water transport through the soil, roots, and xylem as flow through porous media. The model resolves water potentials along the vertical dimension, and stomatal response is linked to xylem water potential. The tree-level model is scaled to the plot scale based on the species composition and canopy structure of the plot, allowing the model to be validated using both tree-level observations (sap flux) and plot-level observations (eddy covariance). We will collect data from multiple sites that have both sap flux and eddy covariance measurements for analysis. The Predictive Ecosystem Analyzer (PEcAn) will be used for optimization of the hydraulic parameters in FETCH3 for different plant types in multiple sites. We plan to use this new modeling framework to examine the interactions among water stress, species-specific hydraulic strategies, and stomatal regulation across different species and ecosystem types.

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Justine Missik[1], Gil Bohrer[1], Edoardo Daly[2], Marcela Silva[2], Ashley Matheny[3], Ana Maria Restrepo[3]

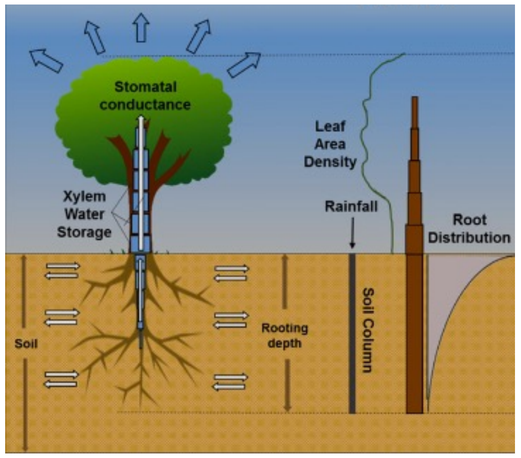
[1] Department of Civil, Environmental and Geodetic Engineering, The Ohio State University, OH, USA, [2] Department of Civil Engineering, Monash University, Clayton, VIC, Australia, [3] Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, TX, USA

BACKGROUND

- Improving the representation of plant hydraulic behavior in vegetation and land-surface models is critical for improving our predictions of the impacts of drought stress on ecosystem carbon and water fluxes.
- Species-specific hydraulic traits play an important role in determining the response of ecosystem carbon and water fluxes to water stress

APPROACH

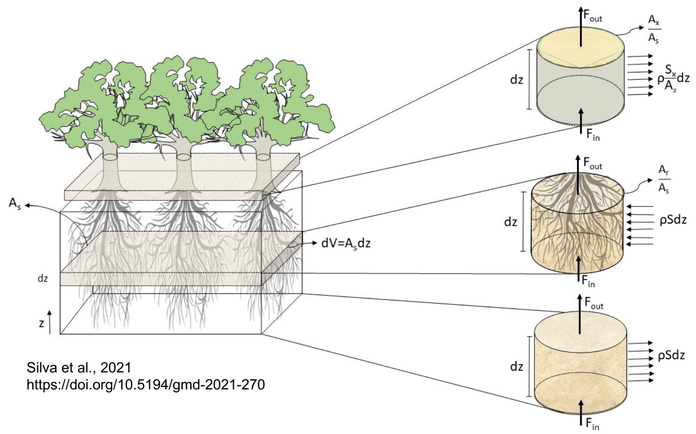
Finite-difference Ecosystem-scale Tree Crown Hydrodynamics model version 3 (FETCH3)



Mirfenderesgi et al., 2019

- Tree represented as simplified 1-D conduit with realistic vertical leaf area distribution
- Stomatal response is linked to xylem water potential (rather than directly to soil moisture)

Water transport through soil, roots, and xylem as porous media flow



Silva et al., 2021
https://doi.org/10.5194/gmd-2021-270

- Resolves water potentials along the vertical dimension
- Accounts for water storage in plant

water potential; hydraulic conductivity

$$C_s \frac{\partial \Phi_s}{\partial t} = \frac{d\theta_s}{d\Phi_s}\frac{\partial \Phi_s}{\partial t} = \frac{\partial}{\partial z}\left[K_s\left(\frac{\partial \Phi_s}{\partial z} + \rho g\right)\right] - S \quad \text{Soil}$$

root water uptake

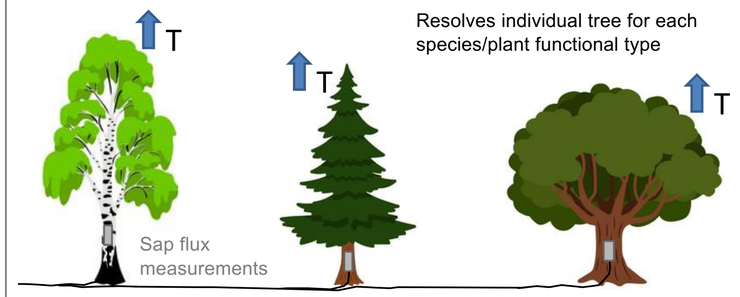
$$C_r \frac{\partial \Phi_r}{\partial t} = \frac{d}{d\Phi_r}\left(\frac{\theta_r A_r}{A_s}\right)\frac{\partial \Phi_r}{\partial t} = \frac{\partial}{\partial z}\left[K_r \frac{A_r}{A_s}\left(\frac{\partial \Phi_r}{\partial z} + \rho g\right)\right] + S \quad \text{Roots}$$

root cross-sectional area index

$$C_x \frac{\partial \Phi_x}{\partial t} = \frac{d}{d\Phi_x}\left(\frac{\theta_x A_x}{A_s}\right)\frac{\partial \Phi_x}{\partial t} = \frac{\partial}{\partial z}\left[K_x \frac{A_x}{A_s}\left(\frac{\partial \Phi_x}{\partial z} + \rho g\right)\right] - \frac{S_x}{A_s} \quad \text{Xylem}$$

capacitance; volumetric water content; hydroactive stem xylem cross-sectional area index; transpiration

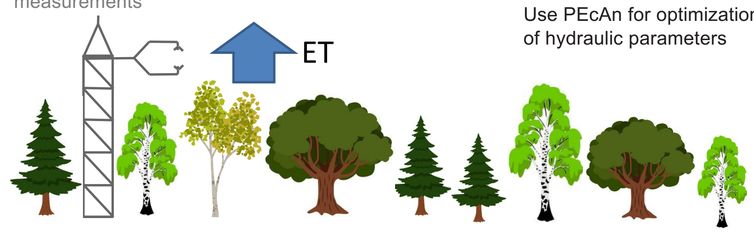
Scaling



Resolves individual tree for each species/plant functional type

Scale representative single trees to plot scale based on species composition and canopy structure

Can be validated using both tree-level observations (sap flow) and plot-level observations (eddy covariance)



PEcAn

Use PEcAn for optimization of hydraulic parameters

PLANS

- Use FETCH3 to examine interactions among water stress, species-specific hydraulic strategies, and stomatal regulation across different species and ecosystem types
- Use multiple sites that have both sap flux and eddy covariance data

THE OHIO STATE UNIVERSITY

AMERIFLUX