MECHANISTIC LINKING OF STOMATA CONDUCTANCE TO SOIL MOISTURE USING A TREE LEVEL HYDRODYNAMIC MODEL

Ashley Matheny, The Ohio State University, 614-270-1825, matheny.44@buckeyemail.osu.edu

1. Ashley M. Matheny, The Ohio State University
2. Gil Bohrer, The Ohio State University

Hydraulic limitations are known to control transpiration in forest ecosystems when the soil is drying or when the vapor pressure deficit between the air and stomata (VPD) is very large, but they can also impact stomatal apertures under conditions of adequate soil moisture and lower evaporative demand. Current models for transpiration assume a coupling between stomatal conductance and soil moisture through empirical relationships that do not resolve the hydrodynamic process of water movement from the soil to the leaves. This approach does not take advantage of advances in our understanding of water flow and storage in the trees, or of tree and canopy structure. It has been suggested that stomata respond to water potential in the leaf and branch, and that this hydrodynamic response is a mechanism for hydraulic limitation of stomatal conductance. The lack of representation of the tree-hydrodynamic process should therefore lead to atypical intra-daily patterns of error in results of current models.

Among well calibrated land surface models we have analyzed, two general diurnal error patterns prevail: (1) a daytime underestimation followed by nighttime overestimation of latent heat exchange; and (2) an underestimation during the morning and an afternoon overestimation. Although model error patterns are site specific, there are models that are more likely to favor one pattern above the other based on the model's sensitivity to VPD and soil moisture. The second error pattern occurs more frequently in sites where non-limiting soil moisture conditions exist. We hypothesize that the afternoon overestimation of transpiration in these scenarios can be explained by the models' lack of a mechanism to handle midday stomata closure due to hydrodynamic stresses.

We introduce the Finite-Elements Tree-Crown Hydrodynamics model (FETCH) - a model that can resolve the fast dynamics of stomatal conductance. FETCH simulates water flow through the tree as a simplified system of porous media conduits. It explicitly resolves spatiotemporal hydraulic stresses throughout the tree's hydraulic system that cannot be easily represented using other stomatal-conductance models. By enabling mechanistic simulation of the effects of hydrological structural traits on stomata conductance, the FETCH modeling system enhances our understanding of the role of forest structure, growth and disturbance history in determining the tradeoffs between water and light in forest ecosystems. Though FETCH can simulate highly resolved individual tree structures, to the branch level, a simplified version of FETCH can rapidly represent a full forest patch using a small number of representative size/type trees. This type of simulation can be readily incorporated in a land-surface model, to dynamically resolve the effects of hydrodynamic stresses at short (minutes-hours) and long (days-seasons) time scales. We propose that coupling FETCH to other land-surface models would reduce intra-daily errors and improve the representation of canopy structure in atmospheric and hydrologic simulations.

We compare two sites: (1) the Forest Accelerated-Succession ExperimenT site (FASET) and its control plot, at the footprint of an Ameriflux tower at the University of Michigan Biological Station. By selectively girdling all Aspen and Birch trees in the treatment plot, the FASET experiment simulates the transition from mature early-successional forest to a heterogeneous late-successional mixed deciduous forest. The treatment occurred in 2008, and canopy structure has been drastically modified since. The FASET canopy is, on a verage, shorter, and more open and heterogeneous. We quantify the sensitivity to transpiration to hydrodynamic stress and its interaction with canopy structure by comparing the simulation results with eddy-flux observations.