Proceedings of the 7th International Conference on Functional-Structural Plant Models, Saariselkä, Finland, 9 - 14 June 2013. Eds. Risto Sievänen, Eero Nikinmaa, Christophe Godin, Anna Lintunen & Pekka Nygren. http://www.metla.fi/fspm2013/proceedings. ISBN 978-951-651-408-9.

Simulated interaction between tree structure and xylem and phloem transport in 3D tree crowns using model LIGNUM

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Highlights: We have implemented xylem and phloem transport model (Hölttä et al. 2006) with 3D tree model LIGNUM to study how structural traits in tree crown influence the transport in branched architecture with observed transpiration and photosynthetic response to driving environmental variables. We study how structural traits in tree crown influence the xylem and phloem transport and associated pressure gradients when observed transpiration and photosynthetic response to driving environmental variables are applied in branched architecture.

Keywords: phloem translocation, sap flow, photosynthesis, transpiration, tree architecture

Transpiration of tree crowns is directly connected to xylem pathway conductivity from soil to transpiring leaves. Assimilate transport in phloem is closely connected to xylem transport (Hölttä et al. 2006). Low water potential in leaves will slow down phloem transport or cause even reversal of flow (Hölttä et al. 2006). The environmental variables that drive photosynthesis and transpiration vary a lot within tree crowns and canopies influencing the attainable photosynthetic and transpiration rates. The hydraulic architecture of a tree crown along with the environmental conditions at each site within the canopy will influence local (and thus global) assimilation and transpiration rates (Nikinmaa et al. 2012).

We combined the assimilation and transpiration model (Mäkelä et al. 2006), xylem and phloem transport model (Hölttä et al. 2006) with 3D tree model LIGNUM (Sievänen et al. 2008) for Scots pine trees. The xylem and phloem transport model deals with water pressure in xylem (P_x) and phloem (P_p) and the amount of sugar solute in phloem (N_p). In LIGNUM, the woody parts of trees consist of internodes. We formulate the transport model as differential equations for each internode as

$$\frac{dP_i}{dt} = a_i\left(Q_{i,ax,in} - Q_{i,ax,out}\right) + E_{xp} - S_i \;\; (i = x, p) \qquad \frac{dN_p}{dt} = a_n\left(Q_{i,ax,in} - Q_{i,ax,out}\right)N_p + L - U$$

where $Q_{i,ax,in}$ and $Q_{i,ax,out}$ are axial inflow and outflow of water, E_{xp} is accounting for flow of water between xylem and phloem in the internode, S_i is sink of water depending on transpiration rate of the internode, a_i and a_n are coefficients depending on physical conditions and the properties of the internodes (including volume and elastic modulus), and L and U are rates of loading and uploading of sugars. L is proportional to photosynthetic rate and U is proportional to growth and respiration rates of the internode. We solve the equations using fourth order Runge-Kutta method with time step of order of seconds and follow daily patterns of environmental drivers (radiation, temperature and water vapor deficit).

We study how vertical variation in xylem conductivity, variation in leaf-area vs. sapwood area relation in different branching orders and variation in phloem cross-sectional area reflect to diurnal within crown water and assimilate transport rates and water potentials and discuss the results against know features of tree transport. We use the results to evaluate feasible crown structure and its ecological significance.

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