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Modelling the impact of the light regime on single tree transpiration based on 3D representations of plant architecture

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We apply a functional-structural model of tree water flow to single old-growth trees in a temperate broad-leaved forest stand. Roots, stems and branches are represented by connected porous cylinder elements further divided into the inner heartwood cylinders surrounded by xylem and phloem.

Xylem water flow is simulated by applying a non-linear Darcy flow in porous media driven by the water potential gradient according to the cohesion-tension theory. The flow model is based on physiological input parameters such as the hydraulic conductivity, stomatal response to leaf water potential and root water uptake capability and, thus, can reflect the different properties of tree species. The actual root water uptake is calculated using also a non-linear Darcy law based on the gradient between root xylem water potential and rhizosphere soil water potential and by the simulation of soil water flow applying Richards equation.

A leaf stomatal conductance model is combined with the hydrological tree and soil water flow model and a spatially explicit three-dimensional canopy light model. The structure of the canopy and the tree architectures are derived by applying an automatic tree skeleton extraction algorithm from point clouds obtained by use of a terrestrial laser scanner allowing an explicit representation of the water flow path in the stem and branches. The high spatial resolution of the root and branch geometry and their connectivity makes the detailed modelling of the water use of single trees possible and allows for the analysis of the interaction between single trees and the influence of the canopy light regime (including different fractions of direct sunlight and diffuse skylight) on the simulated sap flow and transpiration.

The model can be applied at various sites and to different tree species, enabling the up-scaling of the water usage of single trees to the total transpiration of mixed stands. Examples are given to reveal differences between diffuse- and ring-porous tree species and to simulate the diurnal dynamics of transpiration, stem sap flux, and root water uptake observed during the vegetation period in the year 2009.