



Quantifying cross-scale hydrodynamic effects of root ecophysiology

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Mechanistic representation of soil-root hydrodynamics is necessary to make robust predictions of canopy fluxes (transpiration, photosynthesis) under water limitation. Soil water limitation can arise at a range of characteristic scales down to millimetres but its effects can be felt across entire landscapes. This mismatch between the scales of cause and effect makes representing water limitation a central challenge in Earth System Models (ESM) and a key source of uncertainty in the terrestrial carbon cycle. We aim to unify the description of soil-root water flows across scales to bridge this gap and to demonstrate cross-scale effects of root ecophysiological mechanisms on the water and carbon cycles.

We developed a new model formulation from analytical solutions to the differential equations for flows on root networks. By formulating the integrals in terms of mean water potentials over arbitrary root segments, we obtain a linear system directly without introducing a numerical approximation. Partial Gaussian elimination then yields a system of exact equations for mean water potentials in the absorbing roots at any chosen scale.

The upscaled equations reproduce exact solutions for water potentials and flows on a single plant at any scale under set boundary conditions. Fitted to explicit stand-scale simulations, the model shows non-increasing error with the addition of further plants to the explicit simulation set. Proof-of-concept results show improved agreement with field data during a seasonal drought over previous models. The computational cost of these calculations is lower or equal to methods present in ESM and other upscaling methods. Code for producing the upscaled equations for any root hydraulic architecture is available online for beta testing.

We will use this model formulation to connect observations of plant hydrodynamic functioning across scales. We are currently collecting data on root growth, turnover, and soil-plant hydrodynamics at six instrumented forest sites. We will supplement these observations with lab-based measurements at root and plant scale. By using the model to bridge across the scales of observation, we expect to quantify the cross-scale effects of individual mechanisms, such as the effect of root phenology on the seasonal variation in land-atmosphere hydrodynamics. This will be an important step towards reducing uncertainties in the plant-mediated processes that link the terrestrial carbon and water cycles.

