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Upscaled exact solutions to root water uptake equations for earth system modelling

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Earth system models struggle to accurately predict soil-root water flows, especially under drying or heterogeneous soil moisture conditions, resulting in inaccurate description of water limitation of terrestrial fluxes. Recent descriptions of plant hydraulics address this by applying Ohm's law analogues to the soil-plant-atmosphere hydraulic continuum.

While adequate for stems, this formulation linearises soil-root and within-root resistances by assumption, neglecting the nonlinearity of pressure gradients in absorbing roots. The resulting discretisation error is known to depend strongly on model spatial resolution. At coarse resolution, substantial errors arise in a form depending on the assumed configuration of resistances. In simulations of a drought at the Wind River Crane (WRC) flux site, a parallel Ohm model based on the rooting profile overpredicted hydraulic redistribution, while a series model overpredicted uptake in shallow layers at the expense of deep ones.

A conceptual alternative is to upscale exact solutions to the hyperbolic differential equation that describes root water uptake, by solving for the mean root water potential in each soil subdomain. Upscaled solutions show that multiple soil water potentials affect pressure gradients in each root segment, producing the nonlinearities absent in Ohm models. This upscaled model gave better predictions of WRC drought data and was significantly less prone to over-fitting than the two Ohm models, with more robust predictions beyond calibration conditions.

Analysis reveals classes of root systems of differing architectural complexity that yield a common upscaled model. In numerical experiments, using a simple upscaled model in situations of increasing complexity (e.g., adding individual plants), resulted in bounded errors that decreased asymptotically with increased complexity. The approach is thus a viable candidate for upscaling the effects of heterogenous soil moisture distributions on root water uptake.