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A general approach for analytically upscaling the exact root water uptake equations despite heterogeneous soil moisture at the soil-root interface

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Recent advances in scaling up water flows on root system networks hold promise for improving predictions of water uptake at large scales. These developments are particularly timely, as persistent difficulties in getting Earth system models to accurately represent soil-root water flows, especially under drying or heterogeneous soil moisture conditions, are now a major obstacle describing the water limitation of terrestrial fluxes.

One recently developed upscaling formalism has been shown to be both free of discretisation error in flow predictions regardless of scale and with computational cost linearly diminishing with the number of soil subdomains considered. What has been missing from this approach, however, is a proven method to apply it generally – i.e. to an arbitrary root system architecture discretised on an arbitrary grid.

The work presented here demonstrates a general algorithm that can be applied to a wide range of root system architectures (the only assumption being that only one lateral root originates at one point along a parent root) discretised on a grid consisting of a series of soil layers of variable thickness, as is common in Earth system models. It is further shown theoretically that both of these restrictions can in principle be relaxed and that this approach can in principle be extended to conditions of soil moisture heterogeneity – i.e. situations where each root segment in a soil grid cell faces a different water potential at the soil-root interface.

This work represents both a practical advance bringing broad applicability to this upscaling approach and a major theoretical advance as exact solutions for water uptake under conditions of soil moisture heterogeneity within grid cells were previously unknown. While obtaining exact solutions despite heterogeneity within the grid cell requires a way of finding the overall mean soil water potential faced by the plant, this advance nevertheless points to possible directions of future research for overcoming the major hurdle of soil moisture heterogeneity.

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