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Ecosystem scale evapotranspiration is controlled by small scale processes and soil hydraulic properties

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The upscaling of hydrologic processes at catchment scale from small scale soil hydraulic parameterization has been met with limited success. For example, spatially variable attributes (topography, surface properties, preferential flow paths) affect infiltration and runoff rates, introducing uncertainties that mask the role of soil properties at catchment scales. In contrast, evidence suggests that evapotranspiration (ET) remains controlled by small scale processes (flow of water to roots, capillary pumping to drying surface) that are critically dependent on soil hydraulic properties. This scale invariance of ET offers opportunities for upscaling emergent ecosystem scale ET dynamics from basic soil information.

ET switches from being energy to water limited at a critical soil water threshold when the water flow through the soil matrix can no longer sustain the atmospheric water demand. This transition depends on the soil water characteristics and soil hydraulic conductivity curve (characterized by their nonlinearity and dependence on soil texture), on plant traits (root length density, leaf area, and xylem vulnerability), and on atmospheric conditions (e.g., vapor pressure deficit and wind velocity). Despite the importance of plant hydraulic traits and atmospheric conditions, the large variations in soil hydraulic properties as a function of soil texture, make small scale hydraulic properties the key in controlling ET during soil drying (Lehmann et al. 2008, Carminati and Javaux 2020). It follows that soil moisture thresholds of ET are controlled by water flow in soils and by the soil hydraulic conductivity. Accordingly, small-scale models of water flow to the soil surface and to the roots successfully predict soil moisture thresholds that have been measured at the ecosystem scale.

The question of why upscaling flow equations and properties derived from small sample and single plants to ecosystems proved to be successful is an important one. In contrast to water infiltration and run-off affected by the scale-dependent size of surface heterogeneities, the spatial scale of water flow from soils to roots does not increase with the scale of observation. It is the limiting flow through the soil matrix, with spatial scales of 0.01-0.1 m, which sets the point when plants downregulate transpiration and photosynthesis as the soil dries; a process that is similar to

the evaporation from the soil surface.

In conclusion, despite the challenges and uncertainties in applying soil physical laws to larger scale, the application of Buckingham-Darcy law to properly predict matrix flow and evapotranspiration at the ecosystem scale is doable and relevant for understanding drought effects on ecosystem water use and productivity.

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