Taming fine-root systems complexity to reduce Earth System Model uncertainty

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Terrestrial biosphere models are confronted with huge structural and parameter uncertainty. Improving leaf and canopy processes has been the focus since the 1980s. However, the rudimentary representation of fine-root systems forms another large model-data discrepancy. Theoretical and empirical advances in the last two decades have revealed structural and functional differentiation and cooperation within fine-root systems underlying their functioning of nutrients and water acquisition and transport. To close this model-data gap, we propose a 3-pool structure of TAM (Transport, Absorptive, and Mycorrhizal fungi) to model vertically resolved explicit fine-root systems. We hypothesize that TAM will contribute to reducing uncertainty in terrestrial biosphere models. We discuss realization of this TAM structure using an APD scheme (Allocation, Partitioning, and Distribution) in the context of Energy Exascale Earth System Model (E3SM) Land Model (ELM). ELM is representative of existing land surface models grouping heterogeneous fine roots into a single homogeneous pool. Accounting for parametric and structural uncertainty, a demonstration of TAM at two temperate forests (evergreen and deciduous) shows robust impacts of dampening GPP, heterotrophic respiration, and soil carbon stock but of increasing fine-root biomass. TAM captures structural and functional heterogeneity within fine-root systems and provides a framework that can best leverage increasingly explicit root and fungal traits data (e.g., FRED: Fine Root Ecology Database). Though with challenges for a full test of the uncertainty reduction hypothesis, TAM holds promise to guide empirical root ecology, advance understanding of ecosystem functioning, and improve ESMs accuracy. We advocate for its embrace by both modelers and empiricists.