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The Importance of Deep Roots and Hydraulic Redistribution on Vegetation and Soil Responses to Hydro-Climatic Variability: A Simulation Analysis

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Vegetation is fundamentally coupled to the soil through the uptake of moisture and nutrients that regulate carbon, water and energy exchange with the atmosphere. Along with the biological and physical characteristics of the above-ground vegetation, rooting depth and the vertical distribution of root biomass play a critical role in vegetation functioning by controlling access to resources. Hydraulic redistribution (HR), the passive redistribution of moisture across soil potential gradients by the root system, has been widely observed and provides plants the ability to modify resource distributions through the depth of the root zone. Amongst the potential consequences of HR are greater resiliency to drought during dry seasons and more efficient transport of moisture to deep soil layers for storage during wet seasons. At longer timescales the redistribution of moisture through the top several meters of the soil column has the potential to modify soil moisture persistence with implications for long-term weather and climate prediction. Here we examine the roles of deep roots and HR in modulating mass and energy exchange at a site in Eastern Amazonia over decadal timescales. Recent studies using remotely-sensed indices of canopy functioning (ie. canopy greeness, canopy water storage and photosynthetic capacity) have raised questions regarding the response of deep-rooted Amazonian vegetation functioning to short-term hydro-climatic forcing anomalies. Climate model predictions show an increase in ENSO-driven drought for eastern Amazonia in the coming decades, leaving open the question of how the climatologically important rain forest vegetation in this region will respond to more frequent and deeper droughts. Our analysis is conducted utilizing a multi-layer process-based model that represents the complex set of interactions and feedbacks between the canopy, soil and root subsystems. The model canopy is partitioned into several layers, allowing for resolution of the shortwave and longwave radiation regimes that drive photosynthesis, stomatal conductance and leaf energy balance in each layer, along with the canopy microclimate. The canopy component of the model is coupled to a multi-layer soil-root model that computes soil moisture and heat transport, root water uptake, and the passive redistribution of moisture across soil potential gradients by the root system. The below-ground model is based on a novel mechanistic formulation coupling soil moisture transport by the Richards' equation to root water uptake and hydraulic redistribution. Model skill in capturing the diurnal variability in canopy-atmosphere exchange is validated using eddy-covariance flux observations from a tower site in the Tapajos National Forest. A climate forcing record for the region provides a basis for simulating vegetation and soil responses to ENSO-driven drought conditions over the last several decades. Particular focus is placed on the impacts of deep rooting and HR on soil moisture persistence through the root zone and its role in regulating carbon uptake and energy partitioning by the vegetated land surface.