QUANTIFYING FOREST DROUGHT RESISTANCE

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EXECUTIVE SUMMARY

Changing patterns of precipitation and rising temperatures have highlighted the vulnerability of tropical rainforests to water limitation. Current land surface models are unable to fully capture the plasticity of the forest to water limitation caused by El Niño-induced droughts. This work focuses on examining the role of root water uptake to individual and community drought resilience. Using a modified version of the PFOTRAN model, we simulated root water uptake for more than 3,000 individuals located within the eastern Amazon River basin. Because the below-ground nature of root systems prevents *in situ* observation, an ensemble of simulations has been developed that test various plant traits including various structures and hydraulic functions. Analysis is ongoing, but preliminary data have highlighted the ability of root systems to dynamically shift uptake when shallow layers of the soil water supply have been exhausted.

RESEARCH CHALLENGE

Cases of heat- and drought-induced mortality have been documented in every biome of the world, indicating that changes in global temperatures and precipitation patterns are pushing the world's forests beyond current thresholds of stress resilience [1]. The Amazon Basin region, home to the world's largest area of undisturbed tropical biomass, is critical to global energy, water, and carbon cycles. Over the past two decades, the region has been hit with multiple drought events that were triggered by strong shifts in sea surface temperature caused by the El Niño–Southern Oscillation. The increased frequency and severity of droughts and their regional consequences have highlighted the potential vulnerability of the Amazon to heat- and drought-induced stress. To adequately capture the response of tropical rainforests to water limitation, mechanistic models that incorporate diverse plant morphology and hydraulic function are needed.

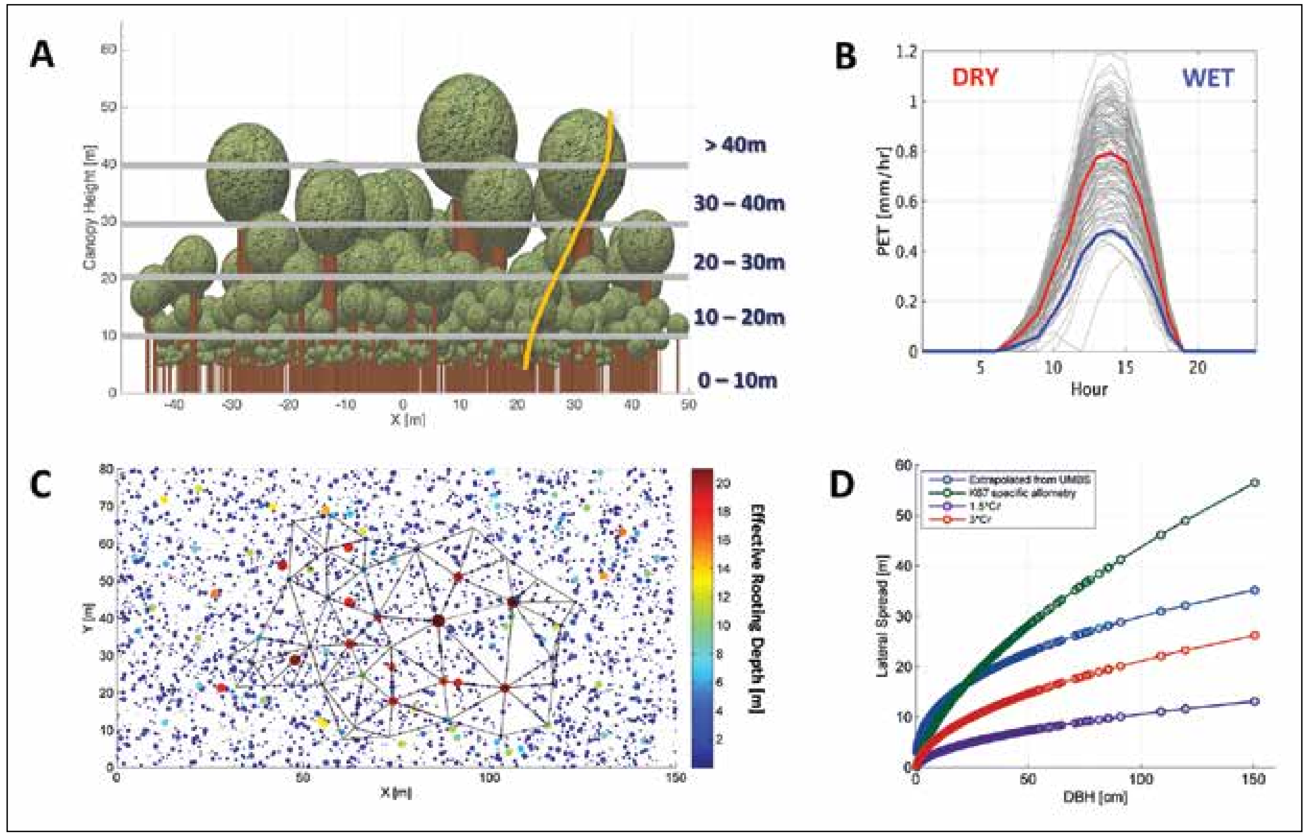

Figure 1: Canopy structure of monitored trees within the Tapajós National Forest. (b) Mean daily potential evapotranspiration for both wet (blue) and dry (red) seasons. (c) Dots represent individual trees in the domain with color indicating rooting depth. (d) Scenarios of lateral spread, which vary with tree diameter at breast height (DBH).

METHODS & CODES

The computational complexity of single-plant models has previously limited incorporation into hydrological models at the forest-plot or ecosystem scale, but recent developments in microscale hybridization of root hydraulic architecture has opened the door to coupled models of three-dimensional root water uptake and soil water physics. We modeled root architectures that represent the structural and spatial distribution of roots using the open source RootBox model [3]. Each tree system was assigned hydraulic parameterization (e.g., root hydraulic conductivity and water potential thresholds) based on statistically generated water usage strategies. Water usage strategies may range from risky, which favor carbon assimilation over hydraulic integrity, to conservative, which will limit carbon assimilation and, therefore, water uptake to protect hydraulic pathways from damage. Root water uptake was coupled with the massively parallel flow and transport model, PFLOTRAN [4], using hybridization techniques [5].

Using these tools, we are exploring how tree roots contribute to forest drought resilience in areas of the Amazon rainforest, during the recent 2015–2016 El Niño drought event. To tease apart the contributions of various ecophysiological properties, we employed ensemble modeling approaches that test a multitude of risk configurations and root distributions. Each of these approaches uses spatial distributions from and is validated with data collected from our field site in the Tapajós National Forest, located in the eastern Amazon River Basin.

RESULTS & IMPACT

We have crafted several different model scenarios that explore the contributions of various root system traits. Because root systems are obscured by the soil from direct observation, we relied on ensemble modeling techniques that allowed us to test various combinations of traits. For example, we tested the response of water uptake to various scenarios of rooting depth and lateral spread. Rooting depth is the maximum depth the root system grows, and lateral spread is its horizontal extent from the base of the tree. Both traits affect the volume of soil trees can extract resources from, but they also incur construction and maintenance costs. Benefits gained from increasing lateral extent can be limited by competition from neighboring trees. Fig. 1 highlights the canopy structure (a) and examples of different rooting depths and lateral spreads tested (c and d). These traits are modeled individually and concurrently for both wet and dry seasons (b) to highlight shifts in water uptake during water limitation.

Simulations encompass more than 3,000 individuals of varying size and water demands. Preliminary results highlight the contribution of root traits to both individual and community integrity. Analysis is ongoing, but this work represents one of the largest modeling studies of three-dimensional root water uptake ever attempted. Results from this work can enhance next-generation earth system models by identifying key traits for water uptake processes.

WHY BLUE WATERS

Blue Waters is critical to the ongoing success of this project. Simulations of this complexity and scale require the computational power of this system to make meaningful analyses. Not only are the simulation domains complex, multiple simulations are needed to account for system uncertainty. The enormous biodiversity and harsh environmental conditions of tropical forests hinder data collection needed for model parameterization. Scalable, physically based models provide a necessary tool with which to explore modes of uncertainty and help target data collection efforts.

Elizabeth Agee is a fifth-year PhD student studying environmental engineering. She is working under Dr. Valeriy Ivanov at the University of Michigan and plans to graduate in the summer of 2019.