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RESOLVING PLANT FUNCTIONAL BIODIVERSITY TO QUANTIFY FOREST DROUGHT RESISTANCE IN THE AMAZON

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EXECUTIVE SUMMARY

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. The increased frequency and severity of droughts and their regional consequences have highlighted the potential vulnerability of the Amazon Basin region to heat- and drought-induced stress. To adequately capture the response of tropical rainforests to water limitation, mechanistic models that incorporate three-dimensional plant morphology and traits are needed. Three-dimensional root water uptake is modeled for a forest plot in the Tapajós National Forest for the 2015–2016 El Nino drought. Results confirm the model's ability to capture differential response of individual species to standard diurnal cycles and water limitation. Using Blue Waters, future work will model whole-forest response to water limitation and the contribution of root systems to drought resilience.

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 triggered by strong shifts in sea surface temperature cause by the El Niño–Southern Oscillation (ENSO). 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 [2]. To adequately capture the response of tropical rainforests to water limitation, mechanistic models that incorporate diverse plant morphology and hydraulic function are needed.

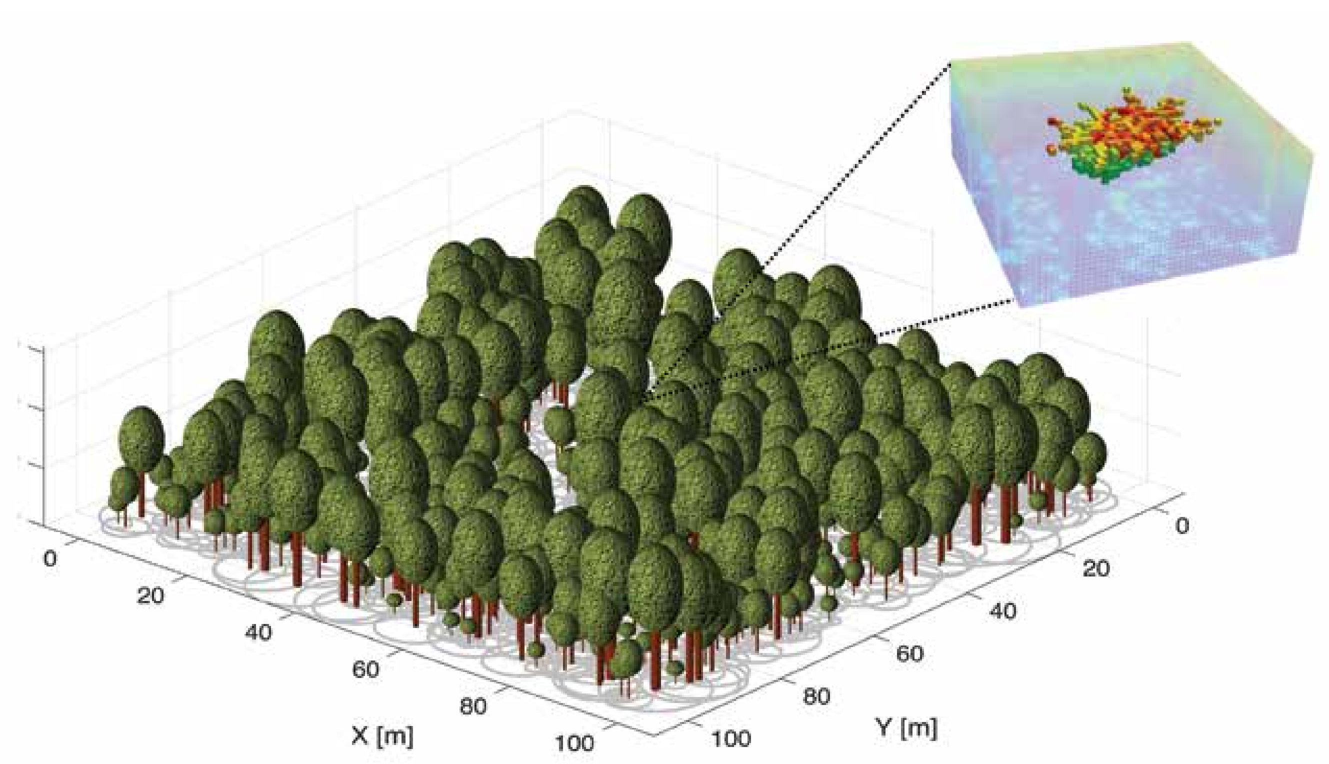

Figure 1: Root water uptake was modeled for individuals within the canopy. This representation shows the spatial distribution of trees and their relative heights. Grey circles indicate the lateral spread of root systems. Root systems overlap (inset), pulling water from shared soil water reserves.

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. Root architectures that represent the structural and spatial distribution of roots were modeled using the open source RootBox model [3]. Each tree system is assigned hydraulic parameterization (e.g., root hydraulic conductivity, water potential thresholds) based on statistically generated water-usage strategies. These 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 has been coupled with the massively parallel flow and transport model, PFLOTRAN [4], using hybridization techniques from [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, ensemble modeling approaches are employed 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 (K67), located in the eastern Amazon River Basin.

RESULTS & IMPACT

Preliminary simulations focused on canopy-dominant species. Representing the largest individuals in the forest, canopy trees have the greatest water demand and are thus susceptible to stress or damage during water limitation. Initial results confirm the model's capacity to model water uptake for individual trees at the forest scale. Individuals show differential response to water limitation based on both their size and physical traits such as tissue conductivity and stomatal response. Furthermore, intrinsic properties are not the only driver of an individual tree's response. Social position, the relative location of a tree to its peers, is an important factor in determining where in the soil water column uptake occurs. As soils continue to dry, uptake will be shifted away from the center of mass and into deeper soil layers.

Future simulations will include all canopy layers—upwards of 1500 trees per hectare—comprising the largest simulations of three-dimensional root water uptake ever attempted. It is expected that the additional root density and root-zone overlap will further tune individual response as competition increases in soil-water reservoirs. Individual and community drought resilience will be assessed, elucidating the contributions of root systems to forest drought resilience in the Amazon rain forest.

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 fourth-year Ph.D. student in environmental engineering at the University of Michigan. She is working under the supervision of Valeriy Ivanov, and hopes to graduate in April 2019.