NGEE–TROPICS
NEXT-GENERATION ECOSYSTEM EXPERIMENTS–TROPICS

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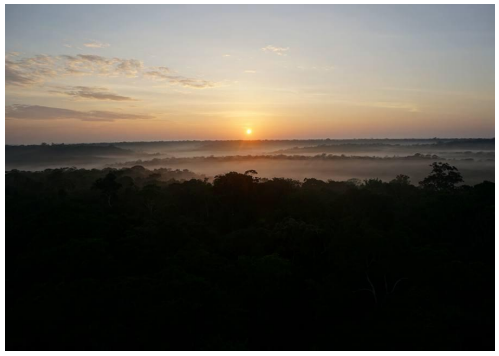

NGEE–Tropics

Abstract Package
2022 ESS PI Meeting

ENVIRONMENTAL SYSTEM SCIENCE

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Title: Do tropical forest trees have limited water sources? Plant water sourcing depth across the neotropics.

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Project: NGEE-Tropics (led by Berkeley Lab)
Project Website: https://ngee-tropics.lbl.gov/

Project Abstract:
Plant water availability and sourcing depth is central to understanding vegetation responses and coping mechanisms to water stress and increases in drought. Stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$) can be powerful tracers to investigate effective tree rooting depth when combined with site- and species-specific information like soil type, soil water and water table dynamics, and plant hydraulic traits. Yet, such studies are limited in the humid tropics, especially considering that it is difficult to time water isotope sampling with a significant dry-down which creates an isotopic separation of water sources across soil profile. Moreover, some of the foundational water isotope work conducted in the tropics generally relied on only one isotope tracer, which limits Bayesian and other mixing-model frameworks aimed at quantifying source water contributions. As a first step towards overcoming some of these challenges, we conducted repeated stem and soil water sample collections at several core NGEE-Tropics sites in the neotropics, which also have long-term hydrological or ecological data. These sites include the ZF2 ecological experiment station in the central Amazon, Brazil and Parque Natural Metropolitano and Barro Colorado Island in Panama. Other sites for which data has been collected opportunistically include the San Lorenzo site in Panama, and Mulehole in India. While it is thought that shallow soil water is sufficient to sustain forests during the dry season, here we summarize recent finding that for the ZF2 and BCI sites, the forest stand generally shifts to deeper soil water during periods with limited rainfall, suggesting that at least for some canopy-dominant species, which may drive ET patterns, deep soil water help trees cope with or all together avoid water stress. Other related work has reported that species across a rainfall gradient in Panama exhibit very little difference in leaf hydraulic traits within sites (see WP 1.2). We also report on preliminary data including the ecohydrological dynamics of soil moisture and groundwater for ZF2, soil moisture for BCI and ELM-FATES based modeling of soil moisture dynamics in Paracou, French Guiana. We discuss steps forward regarding water isotope analysis of samples collected across neotropical sites during dry periods in 2019-2022. This includes synergies with WP 1.3 linking leaf spectral and trait data to plant water isotope data, and MODEX efforts to validate inverse rooting-depth models of pantropical sites.

Title: Relationships between plant hydraulic traits, gas exchange, and species demography in Panama

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Project Abstract:
Climate change is impacting community demographics of tropical forests globally, but the underlying drivers and mechanisms of these responses are not understood. We investigated how species' physiological traits were associated with demographic trends and changes in climate over a 30-year monitoring period at Barro Colorado Island (BCI), and across an additional 71 sites with species composition inventories distributed along a moisture gradient across Panama. For all sites we collected associated species' trait data from published sources. The community dynamics of evergreen tropical tree species at BCI exhibited the expected life history trade-off of species having high mortality rates, fast growth rates, and high recruitment rates on one end of the continuum, and species on the other end of the continuum showing the opposite patterns. Xylem vulnerability to cavitation was the only tested trait that correlated with the life-history strategies, with fast-living species having more vulnerable xylem than slow-living species. The only significant relationship between demographic rates and climate variables was with temperature and mortality; hotter years exhibited higher mortality. However, despite substantial climate variability, there were no significant temporal changes in community weighted physiological traits at BCI over the monitoring period. Patterns across the regional transect, in contrast, exhibited large variation in response to local climate, with some particularly surprising hydraulic- and carbon-based trait trade-offs. These results suggest that forest communities adapt to local site conditions over longer-time scales than monitored at BCI, and indicate that for the forest at BCI, community-trait shifts may be slower than the rapid and variable changes in climate, potentially resulting in rising mortality as temperature increases.

Title: Survey Derived Gas Exchange Data Identify Diurnal Patterns in Leaf Level Water Use Efficiency and Improve Model Representation of Stomatal Function in Tropical Forests

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Project Abstract:
A primary source of uncertainty in Earth system model (ESM) projections of terrestrial carbon and water cycling is the relationship between CO_2 assimilation (A) and water loss via stomatal conductance (g_s). A common framework for modeling this relationship relates A to g_s over environmental conditions (temperature, CO_2, irradiance, and humidity) and is governed by two terms, the stomatal slope (g_1) and intercept (g_0). Given their importance in determining the relationship between forest productivity and climate, an accurate and mechanistic understanding of the g_1 and g_0 parameters is crucial. In this study, we assess possible physiological and mechanistic controls on the estimation of g_1 and g_0 using both diurnal gas exchange surveys and leaf level response curves for six tropical broadleaf evergreen tree species across a full range of leaf phenological stages. We found that g_1 estimated from curves was on average 50% less than g_1 estimated from survey data. We also show that while g_0 varied significantly between leaves of different phenological stages, this effect was generally not observed for g_1. While some species groups exhibited variable g_0 or g_1 with phenological stage, among species groups there was no consistent pattern of change in g_0 or g_1 with phenological stage. We also identified a diurnal trend associated with g_1 and g_0 that significantly improved model projections of diurnal trends in g_s. These results suggest that to improve the accuracy of modeled g_s in tropical forests, we should investigate the mechanism responsible for variation among species and across diurnal patterns.

Title: Stem Respiration and Growth in a Central Amazon Rainforest

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Project Abstract:
Tropical forests cycle a large amount of CO_2 between the land and atmosphere, with a substantial portion of the return flux due to tree respiratory processes. However, *in situ* estimates of woody tissue respiratory fluxes and carbon use efficiencies (CUE_W) and their dependencies on physiological processes including stem wood production (P_w) and transpiration in tropical forests remain scarce. Here, we synthesize monthly P_w and daytime stem CO_2 efflux (E_S) measurements over one year from 80 trees with variable biomass accumulation rates in the central Amazon. On average, carbon flux to woody tissues, expressed in the same stem area normalized units as E_S, averaged 0.90 ± 1.2 μmol m^{-2} s^{-1} for P_w, and 0.55 ± 0.33 μmol m^{-2} s^{-1} for daytime E_S. A positive linear correlation was found between stem growth rates and stem CO_2 efflux, with respiratory carbon loss equivalent to 15 ± 3% of stem carbon accrual. CUE_W of stems was non-linearly correlated with growth and was as high as 77-87% for a fast-growing tree. Diurnal measurements of stem CO_2 efflux for three individuals showed a daytime reduction of E_S by 15-50% during periods of high sap flow and transpiration. The results demonstrate that high daytime E_S fluxes are associated with high CUE_W during fast tree growth, reaching higher values than previously observed in the Amazon Basin (e.g. maximum CUE_W up to 77-87%, versus 30-56%). The observations are consistent with the emerging view that diurnal dynamics of stem water status influences growth processes and associated respiratory metabolism.

Reference: Jardine K, Cobello L, Teixeira L, East M, Levine S, Gimenez B, Robles E, Spanner G, Koven C, Xu C, Warren J, Higuchi N, McDowell N, Pastorello G, Chambers J (2022). Stem respiration and growth in a central Amazon rainforest, *Trees,* 20:1-4.

Title: Overlooked Aboveground Biomass Losses in Tropical Forests

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Project Abstract:
Tree mortality is typically considered as the only carbon output in forest systems. However, a pervasive but commonly neglected source of biomass loss is the damage to living trees (i.e., branch fall, trunk partial breakage, and/or standing wood decomposition). The dry, living, aboveground biomass (AGB) estimated from the trunk diameter of trees that are damaged but remain alive are not counted as losses in traditional forest inventories. Here we use 28 annual mortality and damage censuses to quantify AGB loss via damage on living trees and compare its relative contribution to total AGB loss (mortality + damage) in seven tropical forest plots of the ForestGEO network in the Neotropics (Amacayacu, Colombia; Barro Colorado Island, Panamá; Yasuní, Ecuador) and Asia (Fushan, Taiwan; Huai Kha Khaeng, Thailand; Khao Chong, Thailand; Pasoh, Malaysia). We found that almost half of total AGB losses were due to damage to living trees. The contribution of damaged trees to total AGB losses was highly variable across sites and over time, ranging from 13% in a lowland dipterocarp forest in Malaysia to 86% in a typhoon-prone forest in Taiwan. Our results show the importance of quantifying tree-level biomass loss through crown and trunk damage for obtaining more accurate estimates of tropical forest carbon stocks and fluxes.

Title: Simulating Environmentally Sensitive Tree Recruitment in Vegetation Demographic Models

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Project Abstract:
Vegetation demographic models (VDMs) endeavor to predict how global forests will respond to climate change. This requires simulating which trees, if any, are able to recruit under changing environmental conditions. We present a new recruitment scheme for VDMs in which functional-type-specific recruitment rates are sensitive to light, soil moisture, and the productivity of reproductive trees. We evaluate the scheme by predicting tree recruitment for four tropical tree functional types under varying meteorology and canopy structure at Barro Colorado Island, Panama. We compare predictions to those of a current VDM, quantitative observations, and ecological expectations. We find that the scheme improves the magnitude and rank order of recruitment rates among functional types and captures recruitment limitations in response to variable understory light, soil moisture, and changing precipitation regimes. Our results indicate that adopting this framework will improve VDM capacity to predict functional-type-specific tree recruitment in response to climate change, thereby improving predictions of future forest distribution, composition, and function.

Title: The Distribution of EcM Trees in Lowland Tropical Forests

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Project Abstract:
A lot has recently been written about the global distribution of plant nutrient acquisition strategies related to symbioses between fungi and trees, typically asserting that lowland tropical forests are dominated by plants with arbuscular mycorrhiza (AM) symbioses while ectomycorrhiza (EcM) symbioses are rare or absent. Climatic effects on decomposition rates and local variation in soil quality are considered the main drivers of the global and the local, fine-scale pattern of plant-fungi symbiotic distributions. AM is predicted to dominate at low latitudes and in areas with high soil quality while at high latitudes, and in areas with low soil quality, EcM is predicted to dominate. Using data from a pantropical network of forest dynamics plots, we show that the three major areas of lowland tropical forest differ in their plant-symbiont composition. Most lowland Asian rainforests are dominated by EcM, primarily species of the Dipterocarpaceae. African forests are dominated by mixtures of ectomycorrhizal species, including large expanses of monodominant forests. With the exception of small areas in the Guiana Shield and some white-sand habitats, South American lowland rainforests, including the Amazon Basin, are dominated by AM symbioses and are largely devoid of EcM species. These major differences in plant-symbiosis relationships are unrelated to soil fertility or climate at the pantropical scale. Historical biogeography and unique patterns of diversification within the three regions have resulted in dramatically different forest compositions and putative nutrient-acquisition strategies. Earth System Models treat lowland tropical forests as one biome. Differences in patterns of plant-fungi symbiosis across the lowland tropics have important consequences for carbon uptake and storage in response to global environmental change.

Title: Climate Warming Projected to Cause a Large Increase in Amazon Windthrow Disturbance This Century

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Project Abstract:
Forest mortality caused by convective storms (windthrow) are major disturbances in the Amazon, which shape forest structure and affect the regional carbon balance. However, the linkage between windthrow at the surface and convective storms in the atmosphere is poorly understood. In addition, the current Earth system models (ESMs) lack mechanistic links between convective wind events and tree mortality. Here we show that a simple proxy that is well simulated by global climate models (GCMs) – convective available potential energy (CAPE) – explains 57% of the variance in the spatial density of windthrow events encompassing 30 years in the Amazon. Using remote sensing and climate reanalysis data, this relationship builds connections between strong convective storms and forest dynamics for the first time in the Amazon. An analysis of 10 GCMs predicts a significant increase of CAPE with a warming climate, and our models using CAPE project a 65 ± 43% increase in windthrow density over this century. These results augur significant changes in tropical forest composition and carbon-cycle dynamics under climate warming.

Title: Key Parameters under Varying Phosphorus Supply in the Nutrient-enabled ELM-FATES

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Project Abstract:
Demographically structured vegetation models have a large number of input parameters, which complicates model development and calibration. Quantifying the impact of each parameter on model outputs and identifying key influential parameters are necessary to understand model behavior at various spatial-temporal scales. In this study, we conducted a comprehensive sensitivity analysis to diagnose influential parameters in the Energy Exascale Earth System Model (E3SM), land model (ELM) coupled to the nutrient-enabled Functionally Assembled Terrestrial Ecosystem Simulator (ELM-FATES). We used the Luquillo Experimental Forest site in Puerto Rico as a testbed to quantify the global sensitivities of model outputs (including carbon fluxes and above-ground biomass) to 43 model parameters. Since the phosphorus is generally limited in tropical forest ecosystems, we examined impacts of less phosphorus supply on the ELM-FATES parameter sensitivity. We designed two scenarios. In scenario 1, we used the climate data during the time period of 1995-2014 and high phosphorus supply to drive the model. In scenario 2, we used lower phosphorus supply together with the same climate data. We identified key parameters by using 1,000 model simulations of each scenario together with the Sobol' sensitivity indices from chaos. Overall, specific leaf area at the top of canopy and leaf N:C ratio were found to be the two most important parameters for simulated carbon stocks and fluxes. When phosphorus supply was low, the leaf C:P ratio became a more influential parameter for the above-ground biomass and gross primary production.

Title: Coupled Modeling of Hillslope Hydrology and Ecosystem Dynamics at Manaus and BCI

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Project Abstract:
Tropical forests play essential roles in the coupled land-atmosphere system by contributing to a large fraction of precipitation through evapotranspiration. Combined climate change and topography are likely to have considerable and diverse impacts on plant water availability, with consequential effects on vegetation dynamics and the regional and global water cycles. We have developed an integrated model that couples E3SM Land Model (ELM), an ecosystem dynamics model (FATES), and a three-dimensional hydrology model (ParFlow) to explicitly resolve hillslope topography and subsurface flow for a better understanding of the processes that drive plant water availability and tropical forest dynamics. Numerical experiments are conducted at Barro Colorado Island, Panama, and the Asu catchment, Manaus. Differing in terrain features and rainfall seasonality, the two sites provide useful testbeds for evaluating the coupled model. Machine learning-based surrogate models are built to help calibrate ELM–FATES–ParFlow based on multiple observations, including measured soil moisture, groundwater table, energy and carbon fluxes, and forest inventory data. Experiment results are analyzed to identify the main physical processes that drive the observed forest structure and dynamics and to study the modulation of hillslope processes on how drought affects plant water availability and vegetation.

Title: Soil moisture thresholds explain a shift from light-limited to water-limited sap velocity in the Central Amazon during the 2015-16 El Niño drought

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Project Abstract:
Transpiration is often considered to be light- but not water-limited in humid tropical rainforests due to abundant soil water, even during the dry seasons. The record-breaking 2015-16 El Niño drought provided a unique opportunity to examine whether transpiration is constrained by water under severe lack of rainfall. We measured sap velocity, soil water content, and meteorological variables in an old-growth upland forest in the Central Amazon throughout the 2015-16 drought. We found a rapid decline in sap velocity (-38% ± 21%, mean ± SD.) and in its temporal variability (-88%) during the drought compared to the wet season. Such changes were accompanied by a marked decline in soil moisture and an increase in temperature and vapor pressure deficit. Sap velocity was largely limited by net radiation during the wet season; however, it shifted to be primarily limited by soil moisture during the drought. The threshold in which sap velocity became dominated by soil moisture was at 0.33 m^3/m^3 (around -150 kPa in soil matric potential), below which sap velocity dropped steeply. Our study provides evidence for a soil water threshold on transpiration in a moist tropical forest, suggesting a shift from light limitation to water limitation under future climate characterized by increased temperature and an increased frequency, intensity, duration and extent of extreme drought events.

Title: Importance of fire for functional biogeography across tropics

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Project Abstract:
Fire regimes are changing over much of the world. Fire risk has already increased across much of the tropics. Projecting the impact of these changes in global scale simulation requires that we are able to capture and understand how fire acts as a driver of biogeography. Utilizing the Functionally Assembled Terrestrial Ecosystem Simulator (FATES), a size-structured Vegetation Demographic Model, with the fire behavior and effects module SPITFIRE, we test how various fire regimes and contrasting fire tolerance plant traits interact to determine tropical biogeography of forests and grasses. Observations demonstrate that geographic variability in bark thickness is explained in part by burned area, with frequently burned areas having trees adapted with thicker bark. Fire tolerance strategy in FATES is based on tree bark thickness, crown size and foliage resistance to heat, which are key fire-tolerance traits across woody plants. Simulations demonstrate reasonable productivity and capture observed patterns of aboveground biomass for the recent historical period. Burned fraction from the model is over predicted in areas with grass dominance, but resulting biogeography of fire-tolerant thick bark trees and -intolerant thin bark trees correspond to observations across the tropics. Comparisons of size-based fire mortality show that the fire-tolerant thick bark trees escape mortality through height and fire resistant traits more effectively than the thin bark trees. Drier fuels in simulation are shown to promote increased burning, an expansion of grass and thick bark tree area and loss of area for fire-intolerant thin bark trees. Conversely simulations without fire result in exclusive dominance of the thin bark tree, which is less resource expensive compared to the thick bark tree. These results suggest that thin bark forests are vulnerable to increased fire. Our ability to capture the connection between active fire and plant's fire tolerance strategies in determining biogeography provides an essential tool for assessing the vulnerability and resilience of these critical carbon storage areas under changing conditions across the tropics.

Title: A Nutrient Enabled Demographic Ecosystem Model - FATES-ELM-CNP - Evaluation and Parametric Sensitivity at a Tropical Testbed

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Project Website: https://ngee-tropics.lbl.gov/

Project Abstract:
Nitrogen and phosphorus play an important role in modulating global vegetation dynamics. Earth system models have shown that nutrient availability impacts projections of the global carbon sink. It has also been shown that terrestrial biosphere models that represent vegetation size, function and age structure, capture key processes that drive accurate and representative projections of forest demographics that traditional big-leaf models cannot. The Functionally Assembled Terrestrial Ecosystem Simulator (FATES) is a terrestrial vegetation model that is coupled with the Energy Exascale Earth System's Land Model (ELM). It can resolve plant growth, competition, mortality, recruitment and disturbance through a size, type and age structured scaling approximation. Until recently, these processes had been mediated solely through an evaluation of the plant's carbon balance. Here we present an updated version of the FATES-ELM model that accounts for the cycling of nitrogen and phosphorus between the vegetation and the soil microbiome, as well as the limitations that nutrient availability imparts on plant growth and dynamics. We evaluate the model at a tropical testbed site at Barro Colorado Island in Panama, using observations to constrain model parameters. We evaluate model hypotheses with a focus on the plant acquisition of mineralized nutrients, as well as their modulation of construction costs under nutrient limitations.

Title: The NGEE-Tropics Data Archive and Data Curation Activities

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BER Program: ESS
Project: NGEE-Tropics (led by Berkeley Lab)
Project Website: https://ngee-tropics.lbl.gov/

Project Abstract:
The NGEE-Tropics Data Archive supports and stores ecological, hydrological, micrometeorological, and remote sensing data from tropical forests used to advance scientific understanding and to improve model behavior for these ecosystems. This includes providing data access for current and future research teams, evaluation of data packages being published for completeness, generation of digital object identifiers (DOIs), and supporting results from data quality assurance and quality control (QA/QC) activities for the project. Since 2016, the NGEE-Tropics team has collected data from 21 sites across the tropics, data which was foundational to studies at site, regional, and pantropical scales. Current NGEE-Tropics Archive holdings include 96 public data packages, containing, for instance, leaf related data, including variables such as leaf mass area, leaf respiration, phenology, and water potential, and soil data encompassing soil chemical composition, water content, and temperature, and also includes data on related to sap flow, meteorological measurements, tree mortality, root data, and model codes and outputs. A review of the metadata quality is performed prior to publication, and whenever suitable, our metadata reporting templates (FRAMES) allow researchers to provide file-, measurement-, and experiment-level metadata to accompany their data. Data QA/QC activities are also an integral part of the data-related activities for NGEE-Tropics, including, for instance, micrometeorological datasets prepared and now available for sites in Panama, and more recently sites in the Brazilian and Peruvian Amazon, including collaborative work on data from the partner LBA Project. The NGEE-Tropics Archive provides a tailored user experience in creating and validating these datasets, while also synchronizing and making these datasets also available in the ESS-DIVE Archive, aiming at the long-term preservation of access to these data. Several of these datasets are already being used in empirical and synthesis studies of tropical forests and also for ecosystem modeling efforts through the NGEE-Tropics Functionally Assembled Terrestrial Ecosystem Simulator-FATES model.