1. Background

Tropical forests play a key role in regulating the global carbon (C), water, and energy cycles and stores, as well as influence climate through the exchanges of mass and energy with the atmosphere. However, projected changes in temperature and precipitation patterns are expected to impact the tropics and the strength of the tropical C sink, likely resulting in significant climate feedbacks. In addition, the impacts of more severe and extensive droughts are not well understood. The representation of the coupled photosynthetic and stomatal conductance processes in Earth System Models (ESMs) is critical for the accurate modeling of the tropical C and water cycling as well as how environmental and other drivers impact these processes across space and time.

We used multiple field campaigns and model-data integration methods to explore the impact of multiple mechanistic hypotheses of coupled photosynthesis and stomatal conductance, as well as the additional uncertainty related to model parameterization, on leaf-level CO₂ uptake and water fluxes during the 2015-2016 ENSO and 2017 dry season. We explored these questions within the MAAT and Functionally Assembled Terrestrial Ecosystem Simulator (FATES) model frameworks.

2. Field Campaigns

Figure 2. We conducted field work at the Smithsonian Parque Natural Metropolitano (PNM, a) and Fort San Lorenzo (SLZ, b) crane site in Panama. Our measurement suite included leaf-level gas exchange to derive diurnal photosynthesis and stomatal conductance, as well as CO₂ and light response curves, in addition to leaf functional traits and leaf optical properties.

Figure 3. Climatology over the period of the four 2016 ENSO field campaigns (vertical grey dotted lines). Historical rainfall data is for the 1998-2015 period. From Wu et al., (in revision)

3. Model-data Integration Framework

Figure 6. Example of the stomatal slope (gₛ) for two different species inferred from the measurement of leaf-level net photosynthesis (Aₚ) over a range of ambient CO₂ (CA), light, and leaf-to-air vapor pressure deficit (D), using the USO approach (eq. 2). The Ball-Berry method uses relative humidity (RH, eq. 1). A higher slope means the plant maintains a higher gₛ to keep the same photosynthetic rate, and is a measure of the intrinsic water use efficiency (WUE₊), where a greater slope equates to a lower WUE₊ (from Wu et al., in revision)

4. MAAT Simulations

To explore the impact of leaf-level process representation and parameterization we utilized the Multi-Assumption Architecture and Testbed (MAAT, Walker et al 2018) within PECAn. We conducted model simulation experiments at the SLZ and PNM (not shown here) crane sites using site-level meteorology with different formulations of stomatal conductance (e.g. equations 1 & 2) and model parameterizations based on field measurements. We focused on the impact of the stomatal slope parameter (Figure 6) on modeled diurnal photosynthesis (e.g. Fig. 7) and stomatal conductance (gₛ, not shown)

Figure 7. Measured versus MAAT modeled An during the February campaign at the SLZ crane site. Error bars for the measured data represent the 95% CI across species while the green shaded area represents the 95% ensemble CI of the MAAT results across different parameterizations for key photosynthesis parameters (e.g. Vₐₚ, Jₐₚ, R₂), including gₛ values

Figure 8. Similar to Fig. 7 except for start of the dry to wet season transition. Note in both February and May the Ball-Berry model tends to show larger variation during the diurnal period compared to the USO approach

5. FATES simulations: Diurnal Photosynthesis

The FATES model was run to evaluate the representation of diurnal photosynthesis and the impact of the Ball-Berry gₛ parameter. We spun-up the model to steady-state at the SLZ site using the same meteorology used in the MAAT simulations. We fixed photosynthesis parameters at the PECAn median values but varied gₛ across measured ranges (Wu et al. in revision) to generate the FATES ensembles.

Figure 9. A preliminary analysis of the output An from ensemble FATES model simulations conducted at the SLZ crane site compared to measured diurnal photosynthesis. FATES model An represents the upper canopy, sunlit layer of leaves to correspond to the ENSO measurements

Figure 10. Comparison of FATES diurnal net photosynthetic rates (An) of upper canopy, sunlit leaves against measured values across the full 2016 ENSO campaign period. The blue dots represent April values where we observed the largest differences between modeled and observed An.

6. Conclusions & future plans

- Both parameterization and gₛ representation impacted MAAT An, but ENSO measurements were effective at informing model predictions
- FATES generally captured the diurnal shape but not the magnitude of An in the 2016 ENSO campaign period. We plan to collect additional physiological data across vertical canopy profiles and leaf age to inform FATES parameterization using a combination of measurements and remote sensing (e.g. Fig 11)

Figure 11. Spectroscopic methods for Vₐₚ (A) from Wu et al. in revision) and gₛ (B, Serbin et al in prep)