Evaluating Leaf Photosynthesis and Stomatal Conductance Models against Diurnal and Seasonal Data from Two Contrasting Panamanian Tropical Forests

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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.

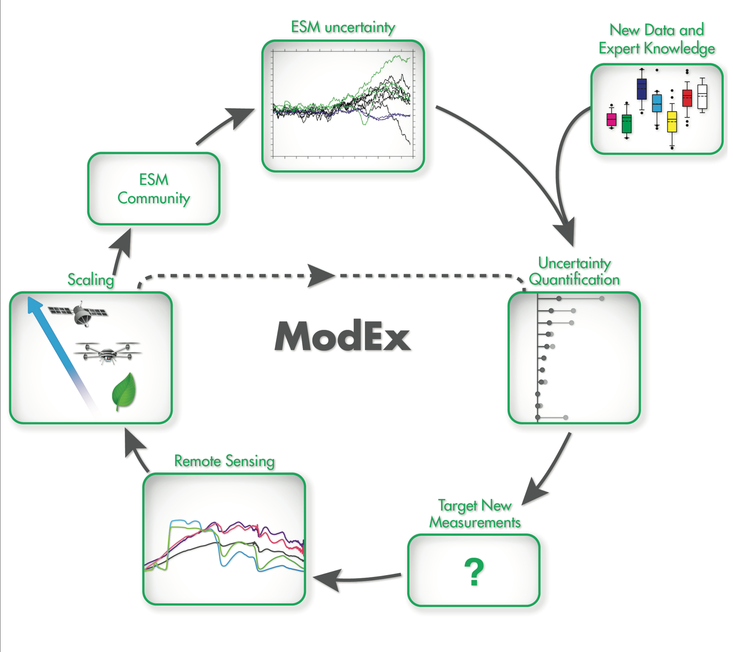


Figure 1. We are using a *ModEx* model-data integration approach to link models and data to test different assumptions and parameterizations

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 CO_2 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) canopy crane site sites in Panama. Our measurement suite included leaf-level gas exchange to derive diurnal photosynthesis and stomatal conductance, as well as CO_2 and light repsone curves, in addition to leaf functional traits and leaf optical properties

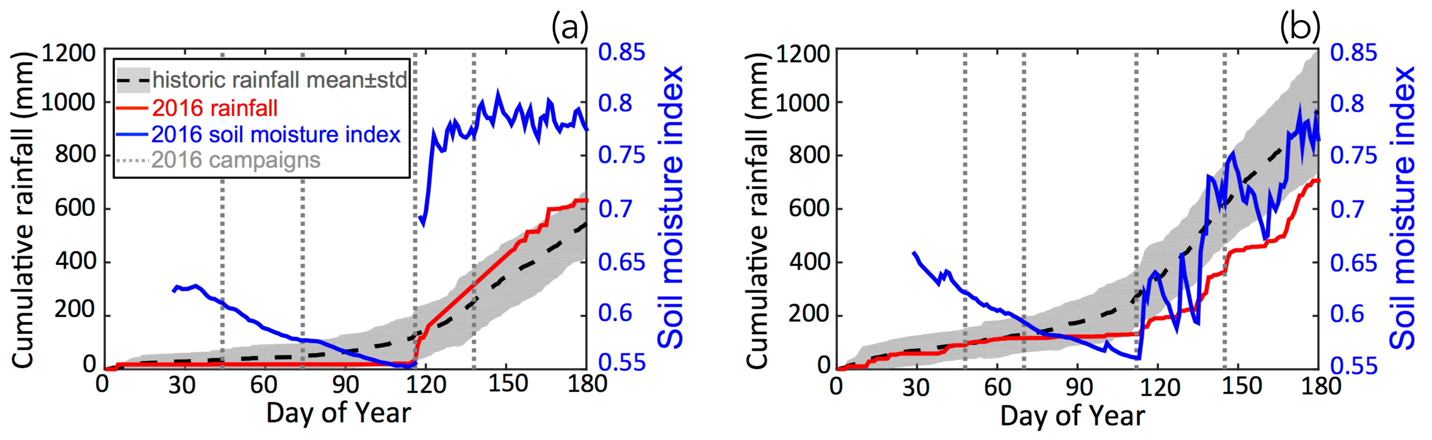


Figure 3. Climatology over the period of the four 2016 ENSO field campaigns (vertical grey dotted lines). Historical rainfall data is for the 1998-2015 period. From Wu et al., (in revision)

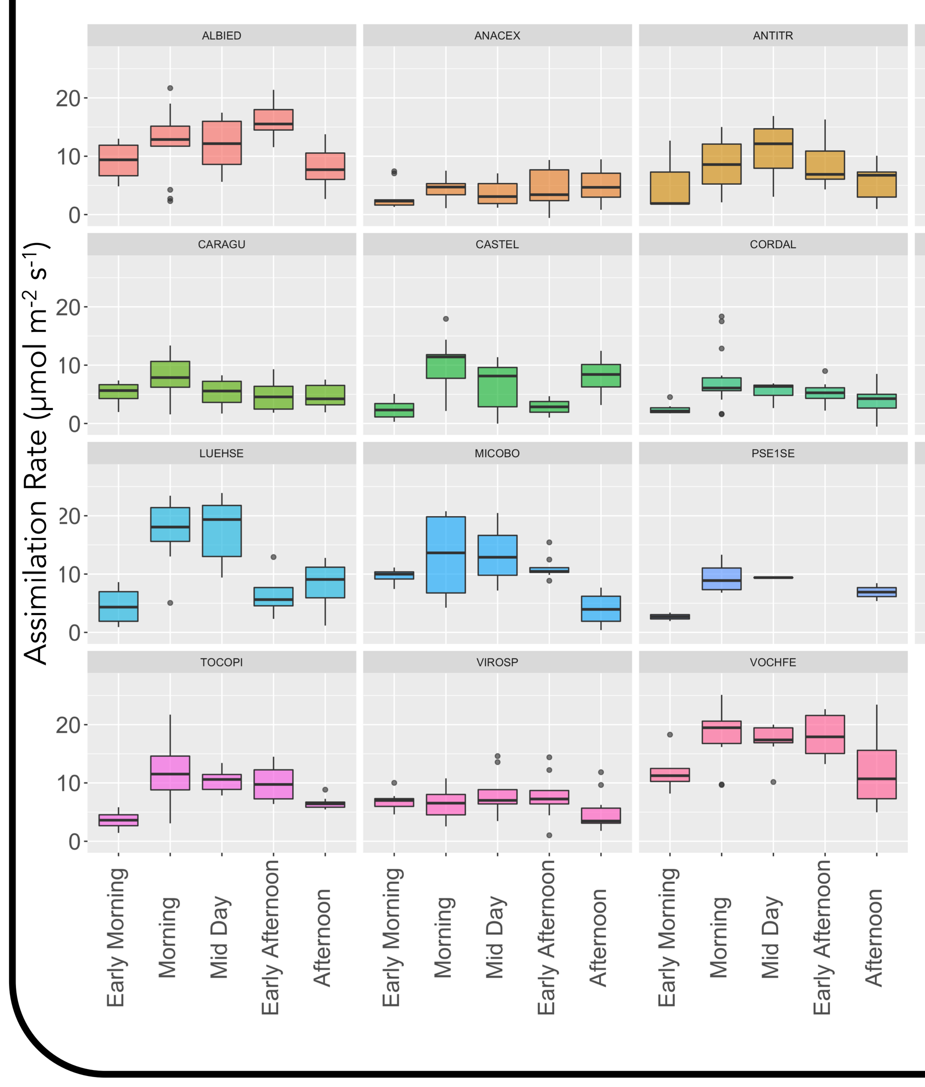


Figure 4. Summary of the measured diurnal leaf photosynthetic rates across our focal tree species located at the two crane sites (PNM and SLZ) during the 2016 dry season

3. Model-data Integration Framework

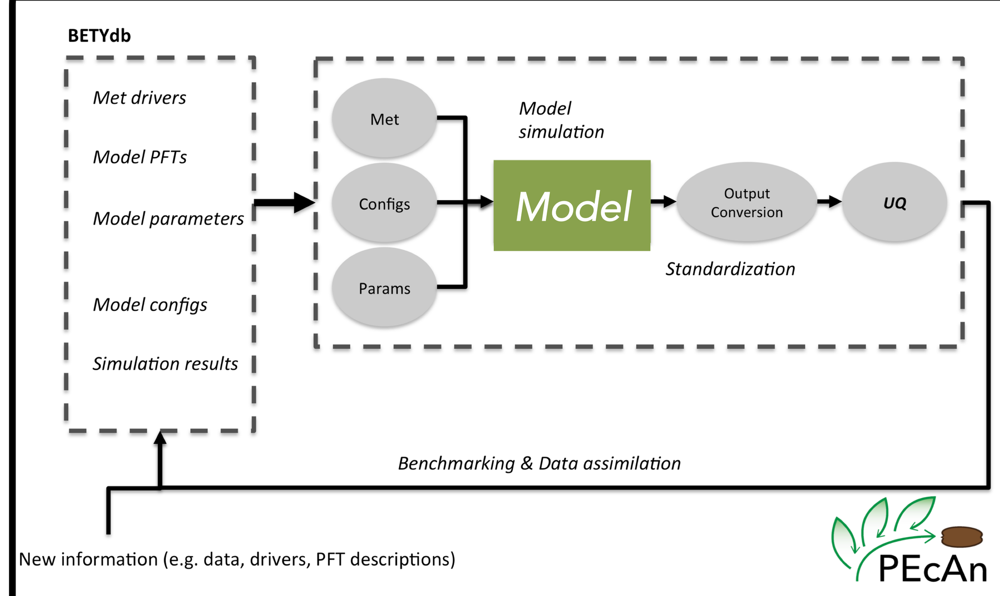
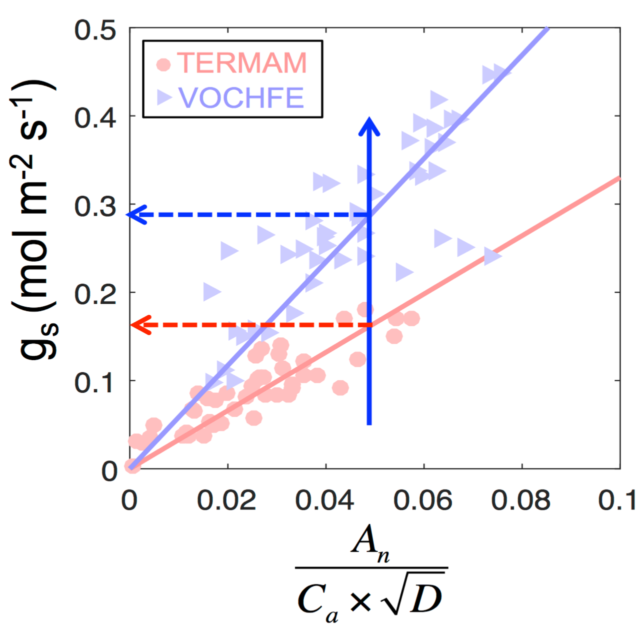


Figure 5. Our work uses the Predictive Ecosystem Analyzer (PEcAn) to link data with different models, processes and to evaluate the impacts of different plant functional type (PFT) descriptions and model parameterizations on the prediction of terrestrial carbon, water and energy.

Here we used PEcAn to assess different stomatal models and parameters.

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 (g_s, not shown)



Eq 1. Ball-Berry representation

$$g_s = g_0 + m\frac{A\ RH}{[CO_2]}$$

Eq 2. Unified Stomatal Optimization (USO or Medlyn) representation

$$g_s = 1.6\left(1 + \frac{g_1}{\sqrt{VPD}}\right)\frac{A}{[CO_2]}$$

Figure 6. Example of the stomatal slope (g_1) for two different species inferred from the measurement of leaf-level net photosynthesis (An) over a range of ambient CO_2 (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 g_s to keep the same photosynthetic rate, and is a measure of the intrinsic water use efficiency (iWUE), where a greater slope equates to a lower iWUE (from Wu et al., in revision)

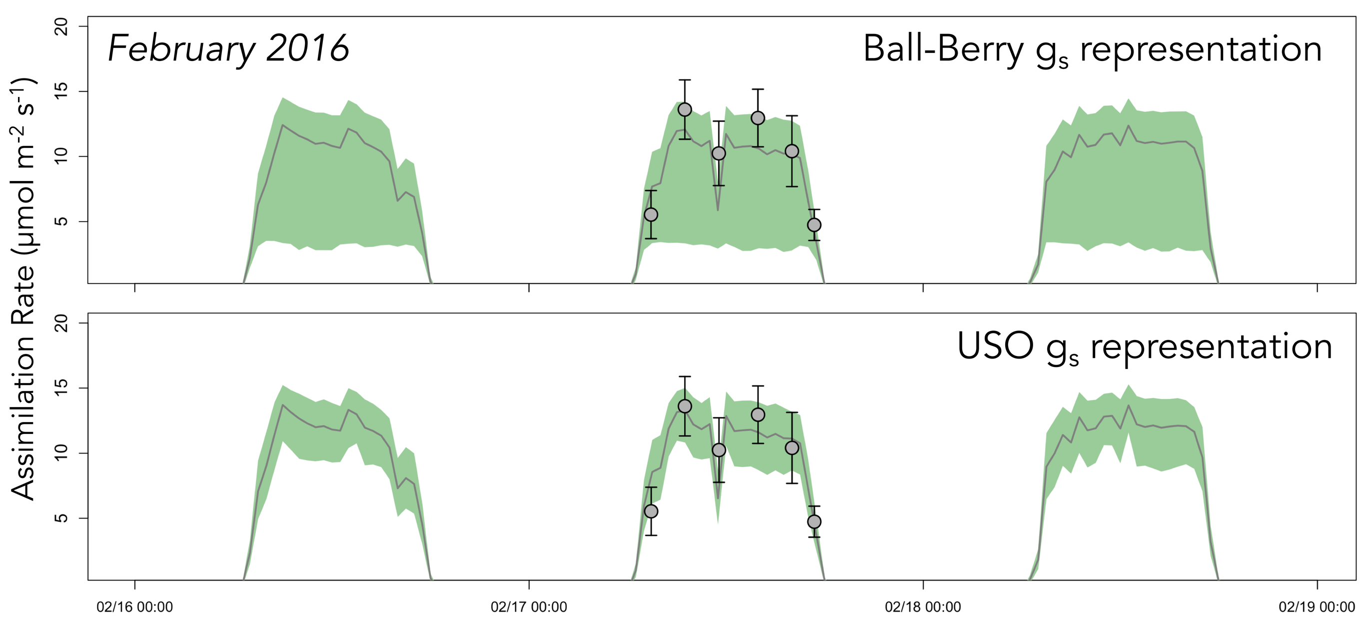


Figure 7. Measured versus MAAT modeled An during the February campaign a the SLZ crane site. Error bars for the measured data represent the 95% CI across species while the green shaded area represents the 95% ensemble CI of the MAAT results across different parameterizations for key photosynthesis parameters (e.g. V_{cmax}, J_{max}, R_d), including g_1 values

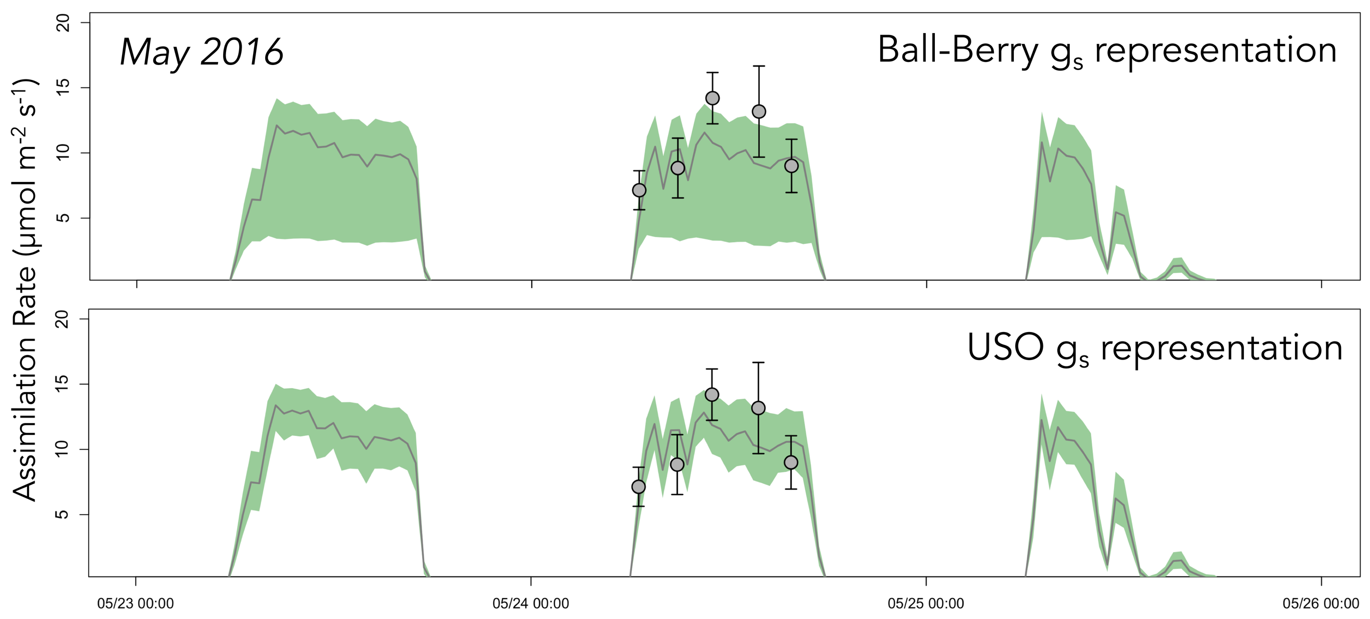


Figure 8. Similar to Fig. 7 except for start of the dry to wet season transition. Note in both February and May the Ball-Berry model tends to show larger variation during the diurnal period compared to the USO approach

5. FATES simulations: Diurnal Photosynthesis

The FATES model was run to evaluate the representation of diurnal photosynthesis and the impact of the Ball-Berry g_1 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 g_1 across measured ranges (Wu et al. in revision) to generate the FATES ensembles.

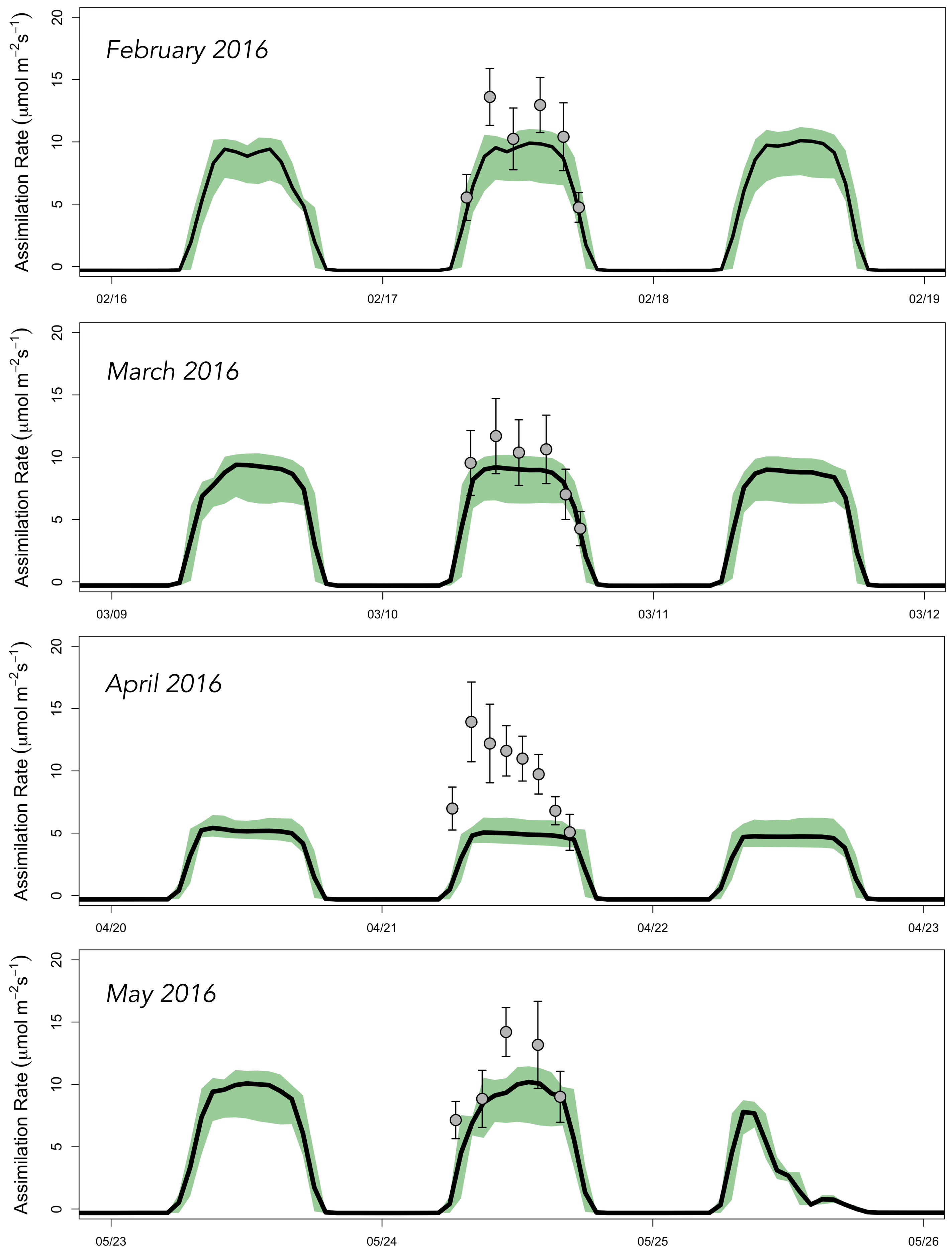
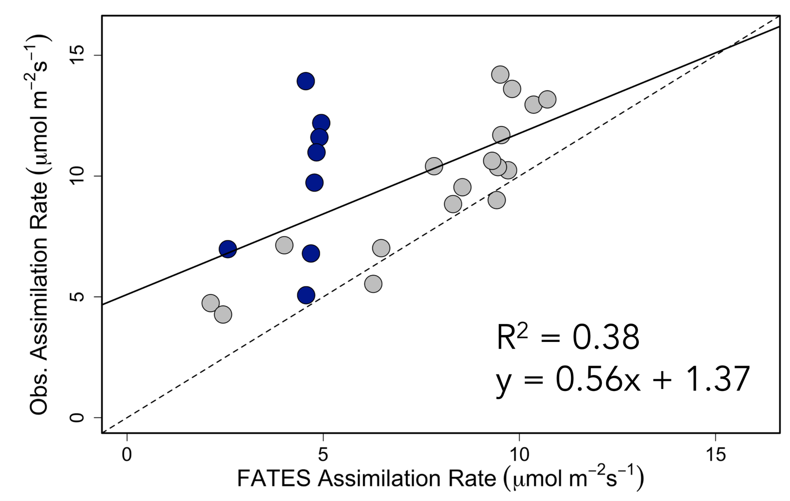


Figure 9. A preliminary analysis of the output An from ensemble FATES model simulations conducted at the SLZ crane site compared to measured diurnal photosynthesis. FATES model An represents the upper canopy, sunlit layer of leaves to correspond to the ENSO measurements

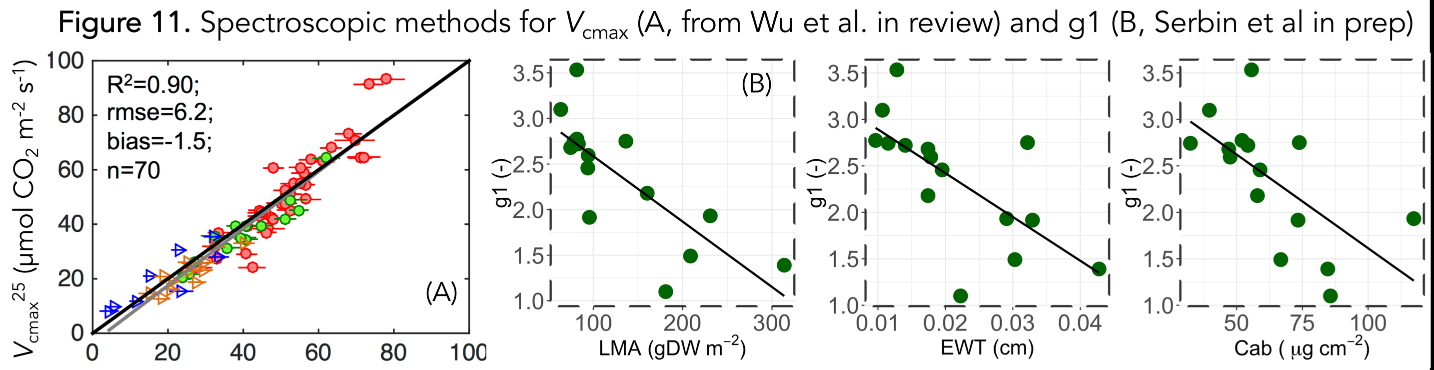
Figure 10. Comparison of FATES diurnal net photosynthetic rates (An) of upper canopy, sunlit leaves against measured values across the full 2016 ENSO campaign period. The blue dots represent April values where we observed the largest differences between modeled and observed An.



6. Conclusions & future plans

- Both parameterization and g_s 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
- 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 V_{cmax} (A, from Wu et al. in review) and g1 (B, Serbin et al in prep)



References: Walker, A. P., M. Ye, D. Lu, M. G. De Kauwe, L. Gu, B. E. Medlyn, A. Rogers, and S. P. Serbin. 2018. The multi-assumption architecture and testbed (MAAT v1.0): R code for generating ensembles with dynamic model structure and analysis of epistemic uncertainty from multiple sources. Geosci. Model Dev. 11:3159-3185; Wu, J. Serbin, S.P., Ely, K.S., Wolfe, B.T., Dickman, L.T., Grossiord, C., Michaeletz, S.T., Collins, A.D., Detto, M., McDowell, N.G., Wright, S.J., Rogers, A. The response of stomatal conductance to seasonal drought in tropical forests, Global Change Biology, in revision; Wu, J., Rogers, A., Albert, L., Ely, K., Prohaska, N., Wolfe, B.T., Raimundo, C.O., Saleska, S., Serbin, S.P. Leaf reflectance spectroscopy captures variation in carboxylation capacity across species, canopy environment, and leaf age in lowland moist tropical forests, New Phytologist