Model-Inspired Science Priorities for Evaluating Tropical Ecosystem Response to Climate Change

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Scientific Significance

- Tropical forests contain 25% of the carbon in the terrestrial biosphere (Bonan, 2008).
- Tropical forests account for 34% of the total metabolic activity of Earth's land surface (Malhi, 2012; Beer et al., 2010).
- Earth System Models (ESMs) must demonstrate predictive skill for carbon budgets in critically important tropical biomes.
- ESMs currently disagree on the sign of the climate-carbon cycle feedback in tropical forests (Friedlingstein et al., 2006).
- Many processes unique to tropical forest ecosystems are absent or misrepresented in ESMs (Friedlingstein et al., 2010).
- State-of-the-science carbon cycle models, including the Community Land Model (CLM4), perform poorly in their prediction of tropical forest photosynthesis (Friedlingstein et al., 2006; Bonan et al., 2011).

To address the design needs of a new **Next Generation Ecosystem Experiment (NGEE)** for the tropics, we will integrate observations with models by obtaining new field measurements from which new model parameterizations will be developed, implemented, and tested. This project will help define critical science objectives and guide strategies for sampling and manipulative experiments for **NGEE Tropics** through the following four tasks:

Task 1: Observations for Improving Models and Guiding Experimental Design

Objective: Obtain measurements and develop new model parameterizations of P limitation to photosynthesis and mesophyll conductance in tropical trees, producing an improved CLM4 for tropical experiments.

Concepts:

- Tropical carbon and water cycles are sensitive to P limitation and mesophyll conductance.
- These physiological processes are not represented in CLM4 and are key model uncertainties.

Approach:

- Conduct an intensive field campaign of leaf gas exchange measurements at the Smithsonian Tropical Research Institute (STRI) in Panama in collaboration with Dr. Klaus Winter.
- We measured A/C_i curves for leaves of $\sim$100 tropical tree species growing in an outdoor laboratory and a closed canopy forest accessible by a canopy crane.
- After A/C_i measurements, these leaves will be brought into lab for P, N, and dry mass measurements.

Preliminary Results from First Field Measurements

Figure 1: ***A.*** *Lianhong Gu, Rich Norby, and Dave Weston preparing gas analyzers for leaf gas exchange measurements in Panama.* ***B, C.*** *Leaf gas exchange measurements being conducted on different tropical species at STRI in September 2012.*

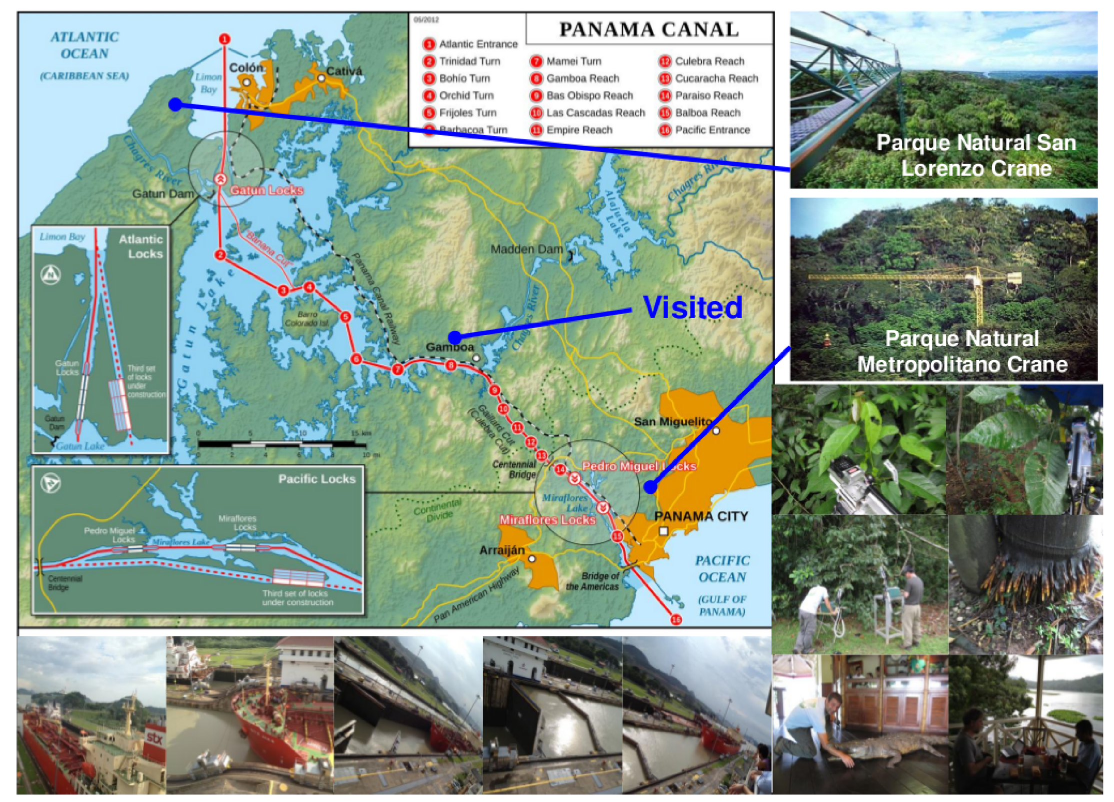


Figure 2: *Leaf gas exchange measurements were taken from Gamboa and Parque Natural Metropolitano in September 2012. During the second field campaign in January 2013, measurements were made from cranes used to access closed tree canopies at Parque Natural San Lorenzo and Parque Natural Metropolitano.*

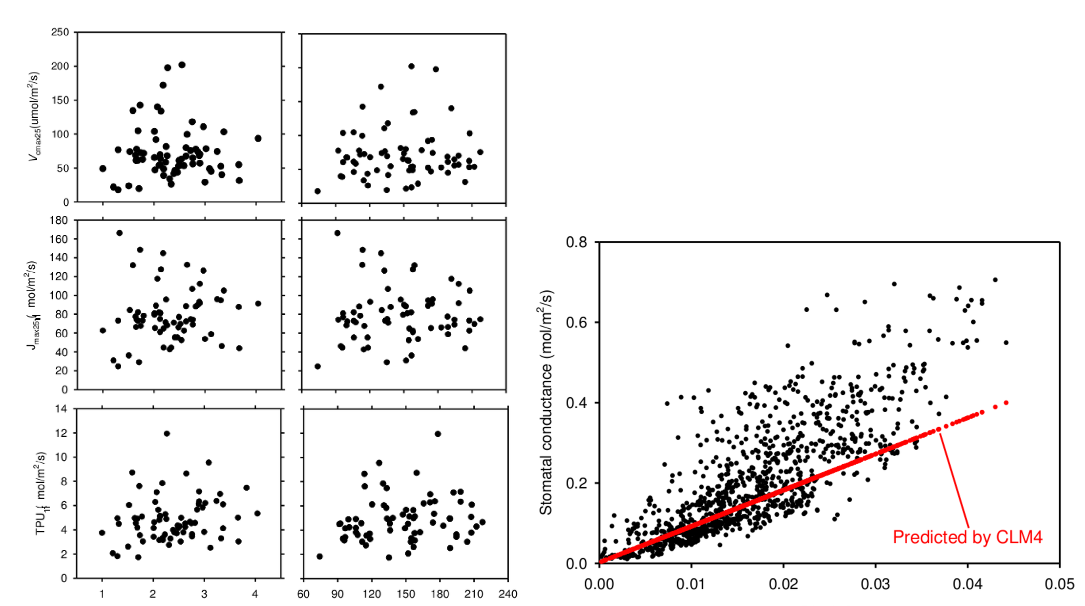


Figure 3: ***Left:*** *There are no clear control of leaf nitrogen on key photosynthetic parameters* ***across species****. Analysis on the role of phosphorous limitation is on-going.* ***Right:*** *The current parameterization for stomatal conductance in CLM4 may not be appropriate for tropical species.*

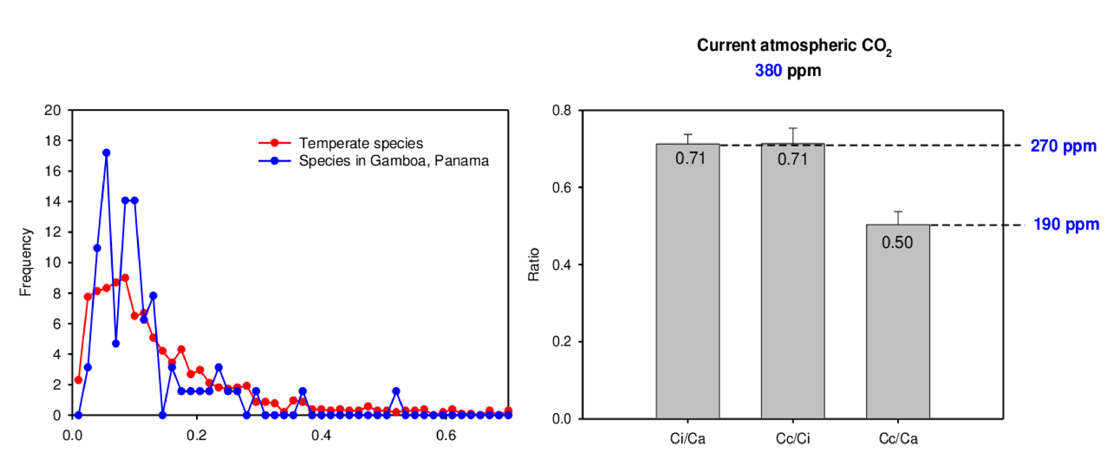


Figure 4: *As in temperate species, mesophyll conductance significantly limits photosynthesis in tropical species. More measurements are needed to determine whether tropical species have a higher percentage with low values of mesophyll conductance.*

Data obtained from these field campaigns will be used to establish models of P limitation and mesophyll conductance for use in a new verison of CLM4 enhanced for tropical experimental design.

Task 2: Global and Site-level Model Simulations for Guiding Experimental Design

Objective: Identify key uncertainties in model simulations, determine processes that need to be represented in models of tropical ecosystems, and provide guidance on the ecosystems and processes that need to be intensively measured.

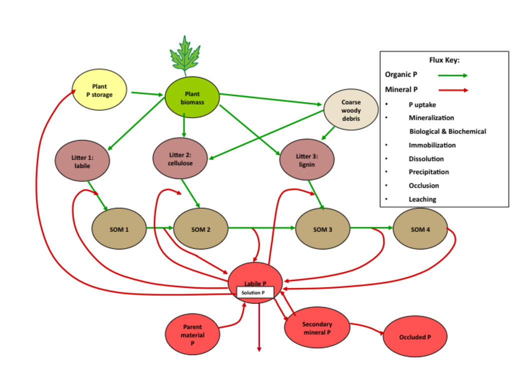
Concepts: Model simulations will answer important questions:

- What is the sensitivity of mesophyll conductance for modeling responses of tropical carbon and water cycles to increasing CO_2, warming, droughts?
- How do P dynamics and C-N-P interactions affect ecosystem responses to increasing CO_2, warming, and droughts?
- What are the relative effects of increasing CO_2, warming, and drought on GPP, soil respiration, and N availability in re-vegetating (gap phase) and mature tropical forests?

Task 2a Approach:

- Perform four global offline simulations with mesophyll conductance model between 1860 and 2010:
  - CO_2 only
  - Climate only
  - CO_2 + Climate only
  - CO_2 + Climate + N deposition + land use
- Evaluate model performance through comparison with observations in tropical regions.
- Identify the processes and tropical ecosystems that are most sensitive to changes in CO_2, climate, and N deposition to provide guidance for field experimental strategy.

Task 2b Approach:



Modules for P limitation and P dynamics in soil will be added to CLM4 and tested using site-level simulations. This will provide insights into how C-N-P interactions affect tropical ecosystem responses to changes in CO_2 and climate.

Task 3: Quantitative Delineation of Sampling Domains

Objective: Stratify the global pan-tropical region using climate and geophysical data to understand the representativeness of potential sampling locations and to provide a framework for scaling measurements and model parameters.

Concepts: Finite budgets limit the spatial extent of environmental measurements, necessitating a systematic strategy for objectively sampling environmental variability.

Approach:

- An extension of a k-means cluster analysis data mining technique will be applied to model results (Task 2) and observational data to define a hierarchy of ecoregions at multiple levels of division for the tropics.
- An ecoregion framework and data-space regressions offer quantitative methods for up-scaling and extrapolating measurements to the larger pan-tropical region.
- Maps of ecoregions, changing through time, will be produced, identifying optimal sampling locations.
- Ecoregion and representativeness maps will provide quantitative guidance on tropical regions most important for intensive observation and modeling.

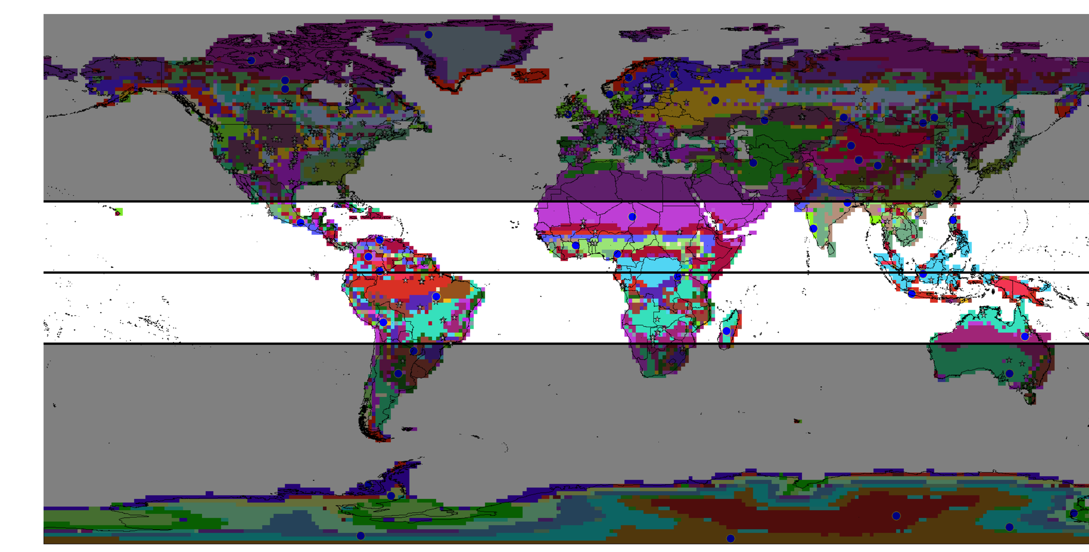


Figure 5: *An initial global analysis using 1° CESM1-BGC historical simulation, 10-y (1996–2005) averages of monthly surface temperature, precipitation, GPP, LAI, soil carbon, and elevation for* $k = 50$.

Task 4: Translating Model Insights into Experimental Strategy

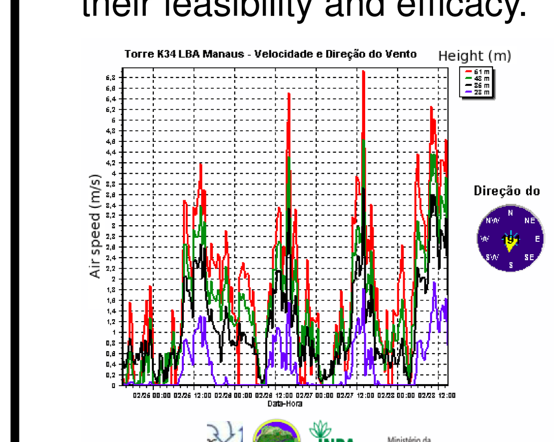
Objective: Evaluate the feasibility of alternative experimental campaigns to address the science priorities identified in Task 2.

Concepts: NGEE Tropics design must start with model-inspired science priorities, but an experimental campaign must also be designed with many critical issues of feasibility, engineering and cost constraints, and access to appropriate research sites.

Approach:

- Based on Task 2 modeling results we will evaluate the feasibility of experimental manipulations of atmospheric CO_2, air and soil temperature, or drought.
- The ecosystem of interest will be guided by model sensitivity and representativeness analysis (Task 3) and may include 1) tall, primary forest; 2) re-vegetating forest gap; 3) re-vegetating abandoned land; and 4) transitional forest edge.

Manipulative experiments in tropical forests will be especially challenging because of their size, diversity, and remoteness. We evaluated the prospects of an elevated CO_2 experiment in the Cuieiras Biological Reserve north of Manaus, Brazil. Data on air movement in the canopy (graph below) will be valuable for simulating different exposure regimes and evaluating their feasibility and efficacy.



Data from the National Institute of Amazonian Research (INPA)

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