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

II: Model simulations and the implications for field experiments

Forrest M. Hoffman, Richard Norby, Xiaojuan Yang, Lianhong Gu, Anna M. Jensen, Jitendra Kumar, Damian M. Maddalena, Ying Sun (U. Texas), Anthony P. Walker, Jeffrey M. Warren, and David Weston

Climate Change Science Institute (CCSI), Oak Ridge National Laboratory (ORNL)

Significance and Objectives

- Develop model representations of breakthrough / bottleneck processes for predictive understanding of tropical ecosystem responses to climate change as identified in Part I of the Project
- Translate insights from an improved Community Land Model (CLM) tropical simulations into guidance for a DOE NGEE-Tropics experimental design plan
- Understand the representativeness and therefore strategic importance of potential experimental locations in the pan-tropical domain by integrating model simulations, ecosystem and climate, and geophysical data

To address the design needs of a new **Next Generation Ecosystem Experiment (NGEE)** for the tropics, we integrated observations with models and new field measurements from which new model parameterizations were developed, implemented, and tested. This project was designed to define critical science objectives and guide strategies for sampling and manipulative experiments for **NGEE Tropics**.

Global and Site-level Model Simulations for Guiding Experimental Design

What is the sensitivity of mesophyll conductance for modeling terrestrial responses to increasing CO_2?

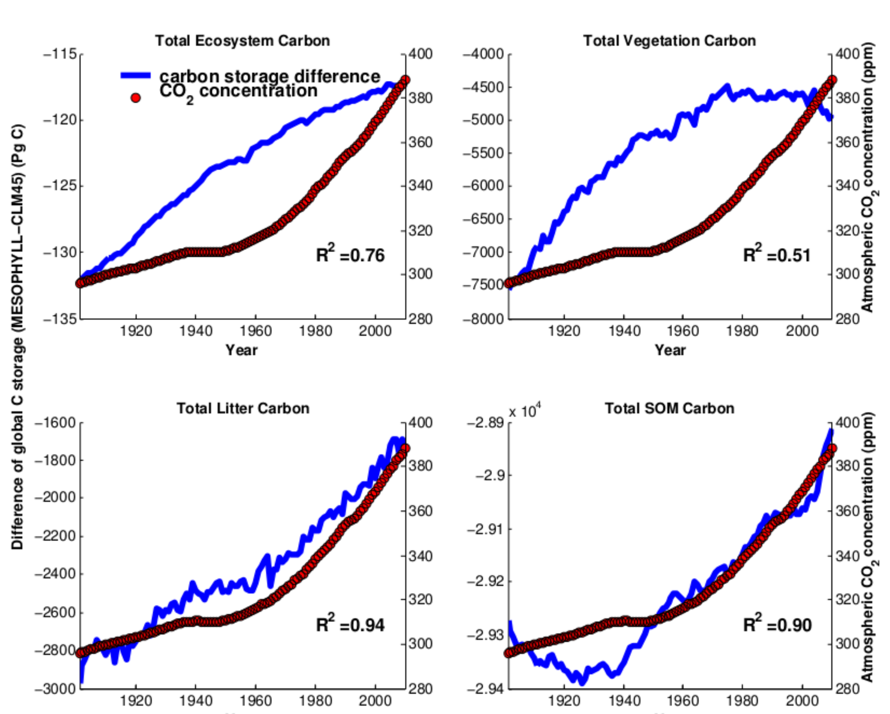

Figure 1: *Time series of the difference in the simulated carbon stocks (blue lines) of global total ecosystem, vegetation, litter and soil organic matter between models with and without mesophyll conductance representations since 1900. In each plot, the temporal variations in atmospheric CO_2 concentrations (red lines) are also shown. Of importance is the temporal trend of the carbon stock difference between the two model simulations, not the absolute values in a particular year.*

- From 1900 to present, existing global carbon cycle models may underestimate the CO_2 fertilization effect on global photosynthesis by a cumulative total of 113 to 148 Pg C, a magnitude equivalent to one full year's gross primary production by the global terrestrial biosphere, or to the entire global fossil CO_2 emissions from 1850 to the 1970s.
- The terrestrial biosphere may be more CO_2-limited and absorb more carbon with increased atmospheric CO_2 concentrations than previously thought. Further, coupled carbon-climate models may have over-predicted future growth rates of atmospheric CO_2 concentrations.

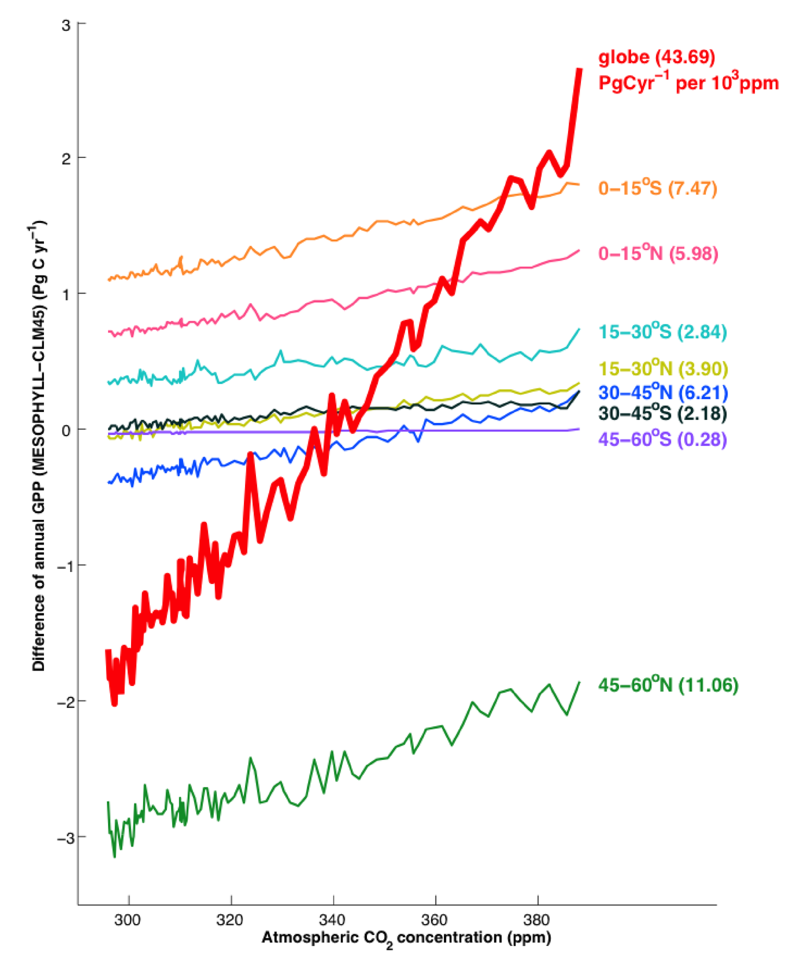

Figure 2: *Differences of annual total GPP between MESOPHYLL and CONTROL simulations versus atmospheric CO_2 concentration (ppm) for the globe (red) and individual 15° latitudinal bands: 0–15°N (orange), 0–15°S (pink), 15–30°N (dark yellow), 15–30°S (cyan), 30–45°N (blue), 30–45°S (dark green), 45–60°N (green), and 45–60°S (purple). The numbers in parentheses associated with each band are the changes of GPP sensitivity to CO_2 resulting from mesophyll conductance (Pg C/yr per 1000 ppm). All simulations here are offline simulations with CLM4.5, without biogeochemical (BGC) model coupling.*

How do P dynamics and C-N-P interactions affect ecosystem responses to increasing CO_2, warming, and droughts?

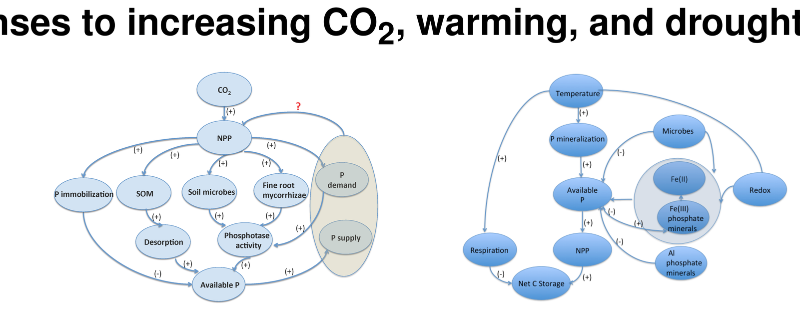

Figure 3: *Feedback loops between C and P cycles that affect tropical ecosystem responses to (a) CO_2 and (b) warming.*

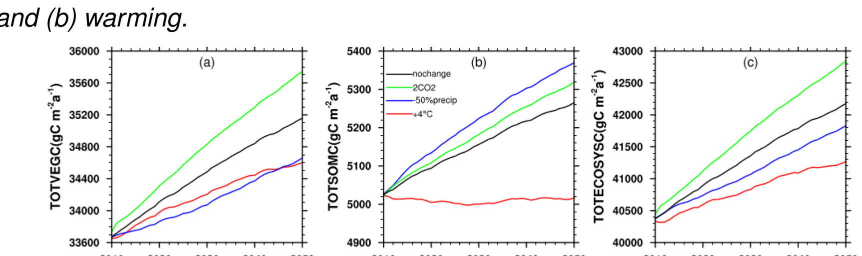

Figure 4: *Changes in carbon stocks, 2010–2050.*

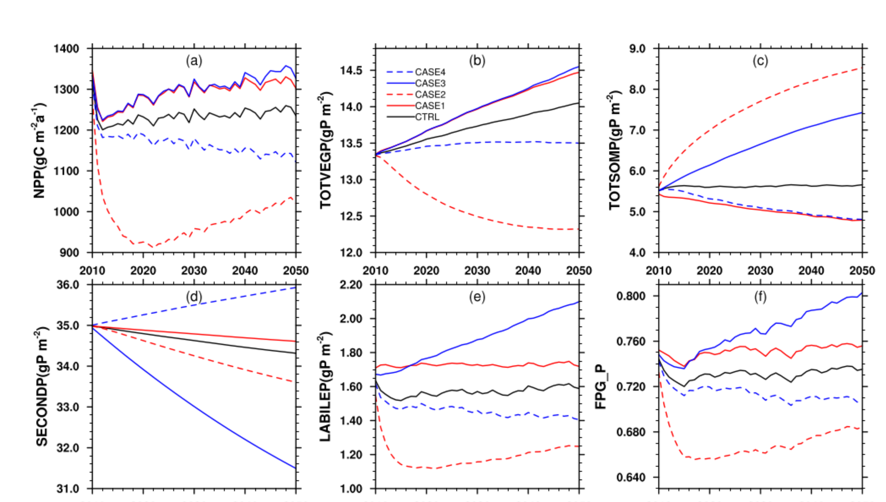

Figure 5: *Simulated time course of (a) net primary production, (b) vegetation P, (c) soil organic P, (d) secondary mineral P, (e) labile P, (f) the degree of P limitation for five simulation cases with doubling of CO_2. Control: default parameters (desorption rate and specific biochemical mineralization rate kept unchanged), Case 1: enhanced biochemical mineralization (biochemical mineralization rate doubled), Case 2: reduced biochemical mineralization (biochemical mineralization rate zero), Case 3: enhanced desorption (desorption rate doubled), Case 4: reduced desorption (desorption rate reduced by half).*

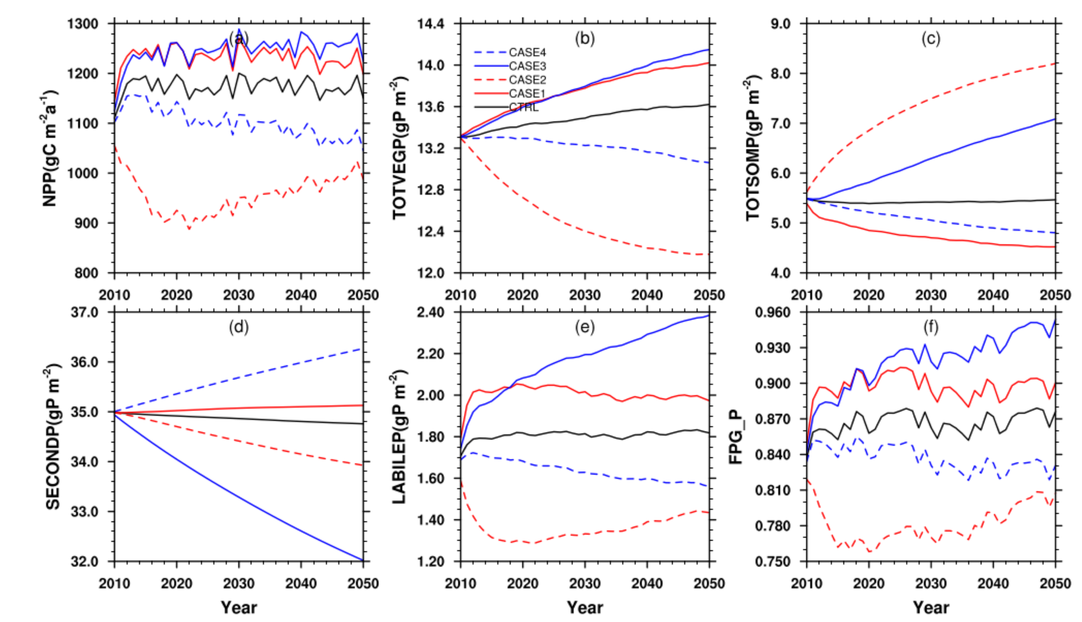

Figure 6: *Same as Figure 5 but with 4°C increase of temperature.*

- Model simulations suggest that tropical forest responses to increasing CO_2, warming, and drought interact strongly with changes in nutrient cycles, particularly the P cycle.
- Growth-chamber or free-air CO_2 enrichment (FACE) experiments, warming experiments, and drought experiments in tropical forest ecosystems are needed to help quantify P cycle processes and the interactions between C, N, and P in response to changes.

Quantitative Delineation of Sampling Domains

- The Multivariate Spatiotemporal Clustering (MSTC) method was applied using 12 variables (Table 1) to define global ecoregions at various levels of divisions.

Table 1: *The 12 characteristics from 0.5° CLM historical simulation, averaged for 1991–2000, used in Multivariate Spatiotemporal Clustering (MSTC).*

Description	Number	Units
Monthly mean air temperature	12	°K
Monthly std. dev. air temperature	12	°K
Monthly mean total precipitation	12	mm
Monthly std. dev. total precipitation	12	mm
Monthly mean atmospheric incident solar radiation	12	W/m^2
Monthly std. dev. atmospheric incident solar radiation	12	W/m^2
Monthly mean relative humidity	12	%
Monthly std. relative humidity	12	%
Monthly mean total canopy transpiration	12	mm/s
Monthly std. dev. total canopy transpiration	12	mm/s
Monthly mean total respiration	12	gC/m^2/s
Monthly std. dev. total respiration	12	gC/m^2/s
Monthly mean net ecosystem productivity	12	gC/m^2/s
Monthly std. dev. net ecosystem productivity	12	gC/m^2/s
Monthly mean gross primary productivity	12	gC/m^2/s
Monthly std. dev. gross primary productivity	12	gC/m^2/s
Monthly mean leaf area index	12	–
Monthly std. dev. leaf area index	12	–
Monthly mean above ground net primary productivity	12	gC/m^2/s
Monthly std. dev. above ground net primary productivity	12	gC/m^2/s
Monthly mean below ground net primary productivity	12	gC/m^2/s
Monthly std. dev. below ground net primary productivity	12	gC/m^2/s
Total phosphorous	1	gP/m^2

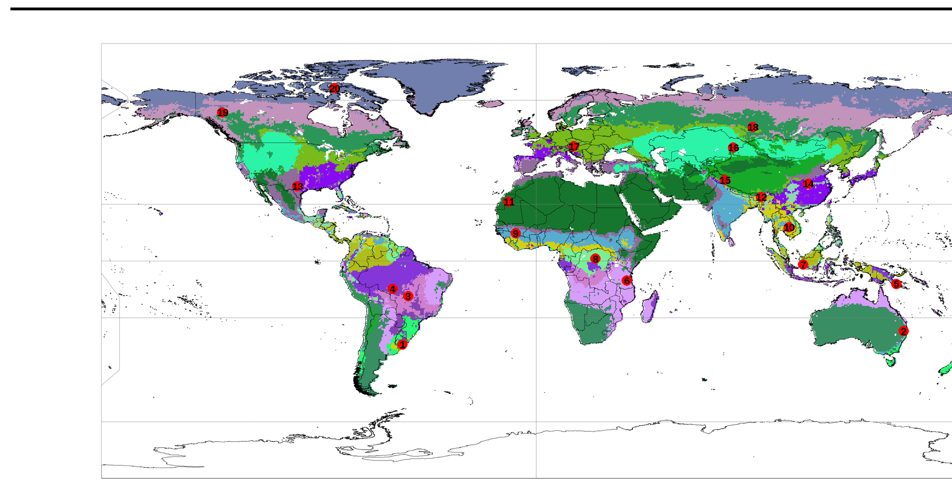

Figure 7: *The map of 20 ecoregions resulting from MSTC.*

- Statistically derived *realized* centroid (red circles in Figure 7) represent the optimal sampling location for each ecoregion.
- Table 2 shows the mean characteristics of the ecoregions represented by the centroids.

Table 2: *A subset of the seasonal mean characteristics for each of the 20 global ecoregions and the area contained within and outside the tropics.*

	Temperature (°C)		Precipitation ($\times 10^6$ mm/s)		LAI (m^2/m^2)		GPP ($\times 10^6$ gC/m^2/s)		Global	Extra-Tropical	Tropical
	DJF	JJA	DJF	JJA	DJF	JJA	DJF	JJA	Area	Area	Area
1	-23.7	11.2	11.3	22.0	0.6	1.5	0.3	28.3	7.7%	12.2%	0.0%
2	-12.7	11.9	5.7	19.0	0.2	1.0	0.7	13.7	4.0%	6.1%	0.4%
3	13.7	30.2	3.0	5.7	0.0	0.0	0.7	0.7	15.1%	12.7%	19.1%
4	4.5	22.8	24.7	54.0	5.0	6.7	41.3	103.0	3.4%	5.2%	0.4%
5	22.8	21.3	83.7	27.3	7.3	7.5	107.7	90.3	1.9%	0.8%	3.7%
6	24.5	12.4	19.0	6.0	0.4	0.3	7.3	3.7	8.7%	9.3%	7.8%
7	23.5	23.3	42.7	59.3	7.8	7.6	117.7	131.3	2.2%	0.0%	5.9%
8	15.4	24.7	21.3	98.3	7.1	7.1	78.3	111.3	1.6%	1.0%	2.6%
9	24.6	20.1	65.3	4.0	1.6	1.1	35.0	16.7	6.4%	1.3%	15.1%
10	23.7	23.9	77.3	104.3	9.6	9.6	155.0	162.3	2.7%	0.1%	7.1%
11	-33.8	2.1	7.3	13.3	0.0	0.2	0.3	3.7	7.4%	11.7%	0.0%
12	-16.8	14.0	14.3	29.3	3.5	4.7	2.3	82.3	7.0%	11.1%	0.0%
13	22.3	26.4	2.7	74.7	1.3	1.8	19.7	45.3	4.4%	0.9%	10.6%
14	24.7	24.0	98.3	34.0	8.3	8.5	147.0	134.3	3.7%	0.1%	9.8%
15	-7.4	18.2	14.3	31.7	1.2	3.6	3.7	62.7	5.5%	8.7%	0.0%
16	-10.6	20.5	7.0	13.3	0.2	0.6	0.7	13.0	7.2%	11.4%	0.0%
17	10.9	25.2	12.3	24.0	0.9	0.8	10.7	17.3	4.7%	4.9%	4.4%
18	18.9	9.9	49.3	47.3	6.0	5.3	88.3	52.3	1.2%	1.7%	0.3%
19	21.6	24.1	7.0	95.3	3.7	4.9	46.7	93.3	2.5%	0.4%	6.2%
20	23.6	22.8	82.0	6.7	5.2	3.6	94.3	44.0	2.5%	0.2%	6.6%

- Representativeness of the entire globe with respect to individual sampling points can be quantified in data space to produce grayscale maps (Figures 8, 9), where well represented areas shown in lighter shades of gray and poorly represented areas shown in darker shades of gray.

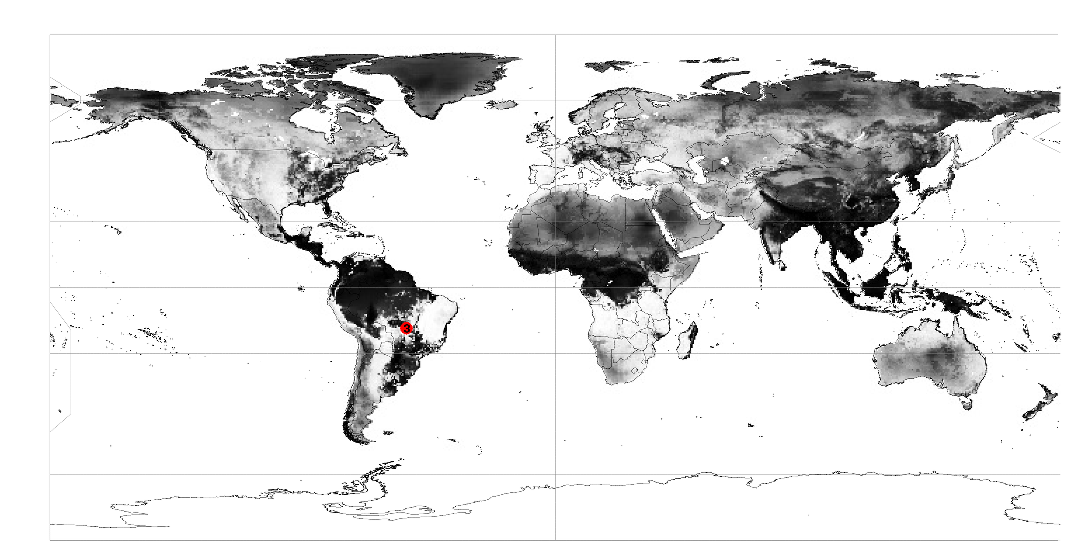

Figure 8: *Representativeness map for ecoregion 3, a low productivity region covering about 19% of the tropics, with the realized centroid shown in South America.*

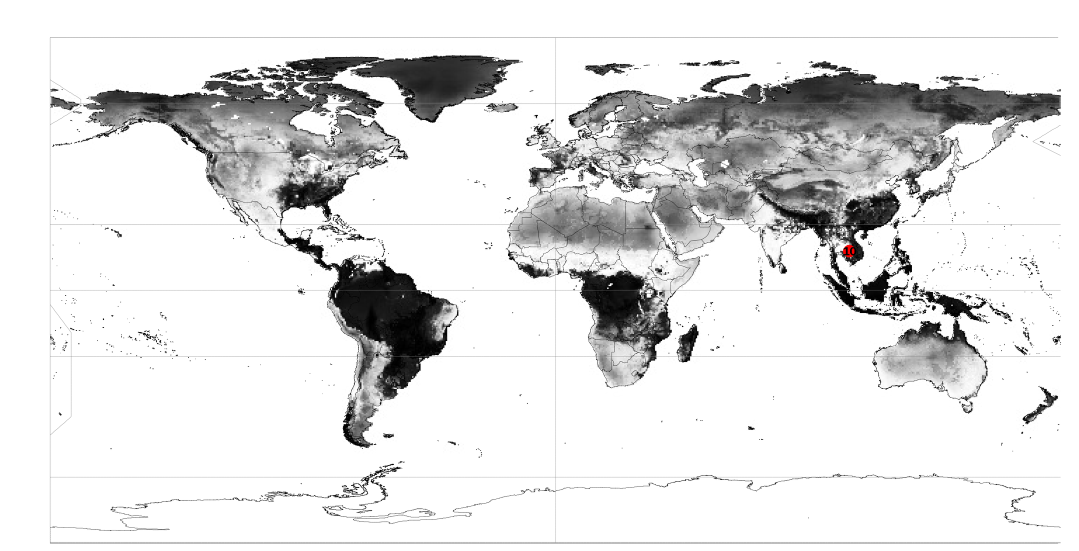

Figure 9: *Representativeness map for ecoregion 10, a high productivity region covering about 7% of the tropics, with the realized centroid shown in Southeast Asia.*

Annual LDRD Poster Session (September 23–25, 2013), Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Oak Ridge National Laboratory (ORNL) is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC005-00OR22725.