Biogeochemistry–Climate Feedbacks Scientific Focus Area

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Biogeochemistry–Climate Feedbacks Goals & Objectives

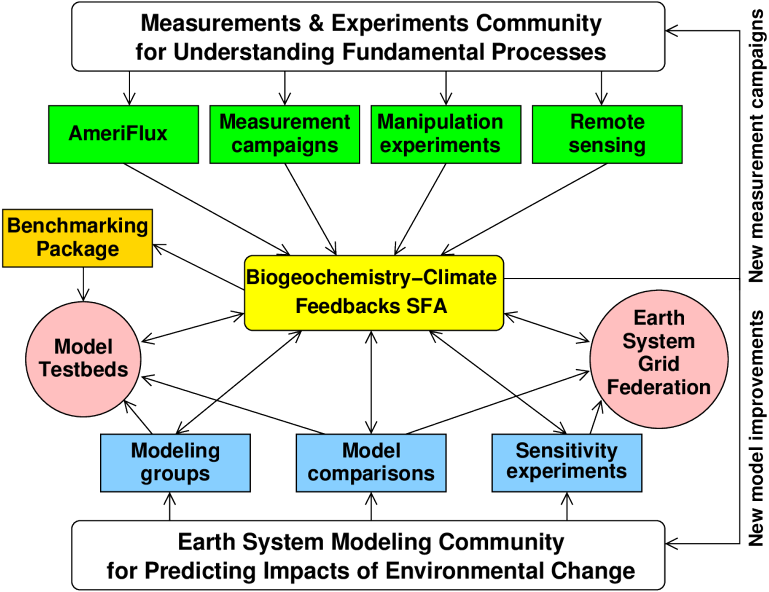
BGC Feedbacks SFA Goals

The overarching goals of the BGC Feedbacks SFA are to identify and quantify the feedbacks between biogeochemical cycles and the climate system, and to quantify and reduce the uncertainties in Earth system models (ESMs) associated with those feedbacks.

In particular, we are

- developing new hypothesis-driven approaches for evaluating ESM process representations at site, regional and global scales;
- investigating the degree to which contemporary observations can be used to reduce uncertainties in future scenarios (e.g., emergent constraints);
- developing open source benchmarking software tools that leverage laboratory, field, and remote sensing data sets for systematic evaluation of ESM biogeochemical processes; and
- evaluating performance of biogeochemical processes and feedbacks in different ESMs using benchmarking tools.

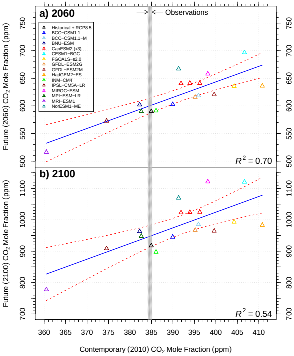
Biogeochemistry–Climate Feedbacks SFA Diagram



Biogeochemistry–Climate Feedbacks SFA Highlights (1)

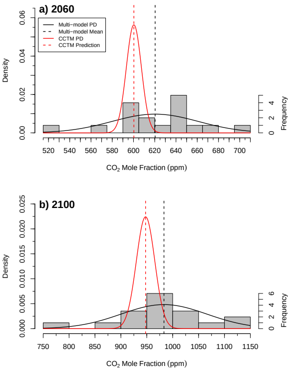
An emergent constraint based on carbon inventories was applied to constrain future atmospheric CO_2 projections from CMIP5 ESMs.

Future vs. Contemporary Atmospheric CO_2 Mole Fraction



- Much of the model-to-model variation in projected CO_2 during the 21st century is tied to biases that existed during the observational era.
- Model differences in the representation of concetration–carbon feedbacks and other slowly changing carbon cycle processes appear to be the primary driver of this variability.
- Range of temperature increases at 2100 slightly reduced, from $5.1 \pm 2.2^\circ C$ for the full ensemble, to $5.0 \pm 1.9^\circ C$ after applying the emergent constraint.

Probability Density of Atmospheric CO_2 Mole Fraction



Best estimate using Mauna Loa CO_2

At 2060: 600 ± 14 ppm, 21 ppm below the multi-model mean

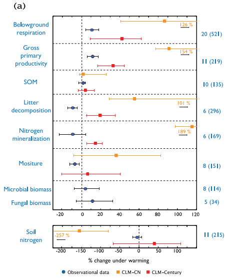
At 2100: 947 ± 35 ppm, 32 ppm below the multi-model mean

Hoffman, Forrest M., James T. Randerson, Vivek K. Arora, Qing Bao, Patricia Cadule, Duoying Ji, Chris D. Jones, Michio Kawamiya, Samar Khatiwala, Keith Lindsay, Atsushi Obata, Elena Shevliakova, Katharina D. Six, Jerry F. Tjiputra, Evgeny M. Volodin, and Tongwen Wu. February 2014. "Causes and Implications of Persistent Atmospheric Carbon Dioxide Biases in Earth System Models." *J. Geophys. Res. Biogeosci.*, 119(2):141–162. doi:10.1002/2013JG002381. *Most downloaded JGR-B paper for February 2014!*

Biogeochemistry–Climate Feedbacks SFA Highlights (2)

Objective

We describe an observational and modeling meta-analysis to benchmark land models and identify needed improvement. We applied the method to CLM with two versions of belowground biogeochemistry (CN and Century).



Carbon cycle responses to warming in observations (blue) and two versions of CLM. CLM performed poorly against many of these observations.

Research

- We extracted benchmark metrics (e.g., belowground respiration, soil organic matter content) from 53 manipulation experiments studies across 17 high-latitude ecosystems.
- We calculated a response ratio of a metric relative to the control.
- We performed complimentary CLM4.5 simulation and analyzed discrepancies.

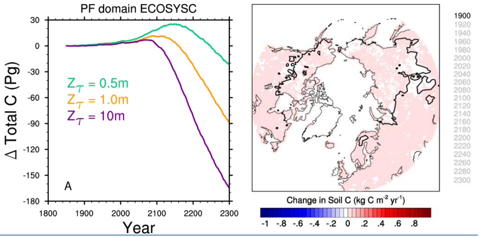
Impacts

- We identified poor representation of microbial activity, above- and belowground coupling, and nutrient cycling as the primary reasons for the discrepancies.
- Identifying deficiencies in the model structure can motivate future experiments and focus model development efforts.

Reference: Bouskill NJ, Riley WJ, Tang J (2014) Meta-analysis of high-latitude nitrogen-addition and warming studies implies ecological mechanisms overlooked by land models. Biogeosciences. 11:1-15.

Biogeochemistry–Climate Feedbacks SFA Highlights (3)

Objective:
Quantify the carbon cycle dynamics of the permafrost region under a warming climate, and understand the roles of deep C lability and carbon–nitrogen interactions in determining the magnitude of the permafrost carbon–climate feedback.



Research:
Use CLM4.5-BGC, which allows for interactions between thawing permafrost, mineralization of C and N from decomposing permafrost soil and vegetation feedbacks, under a transient, offline, RCP 8.5 warming experiment to 2300. Identify N controls by comparing C–N and C-only versions of the model; and quantify role of deep C dynamics by varying a parameter that controls role of depth on decomposition.

Impact:
Permafrost soils are a potentially large component of the terrestrial carbon cycle response to warming, which are only recently available for understanding their dynamics in ESMs. Including these processes allows CLM4.5-BGC to predict the magnitude of the permafrost carbon–climate feedback, which is a potentially large fraction of global feedbacks on long timescales.

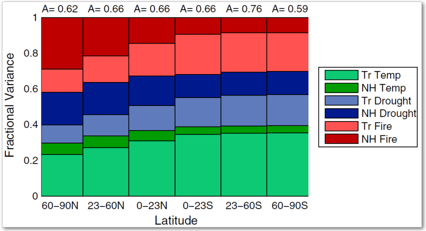
Reference: Koven, C. D., D. M. Lawrence, and W. J. Riley (2014), Permafrost carbon−climate feedback is sensitive to deep soil carbon decomposability but not deep soil nitrogen dynamics, *Proc. Nat. Acad. Sci.*, 112(12):3752–3757, doi:10.1073/pnas.1415123112.

Biogeochemistry–Climate Feedbacks SFA Highlights (4)

Objective:
Quantify the contributions of known drivers of interannual variability in the growth rate of atmospheric carbon dioxide (CO_2).

Approach:
We examined how the temporal evolution of CO_2 in different latitude bands may be used to separate contributions from temperature stress, drought stress, and fire emissions to CO_2 variability.

Results/Impacts:

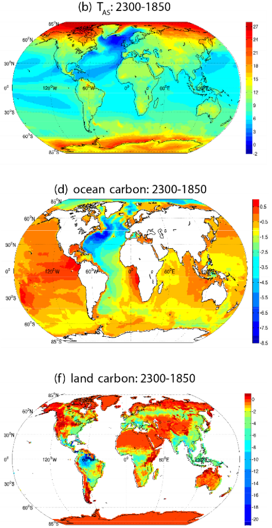


Relative contributions to the simulated variability in atmospheric CO_2 in different latitude bands (x axis) from net ecosystem exchange responses to temperature, drought stress, and fire emissions originating from the tropics and Northern Hemisphere.

- Net ecosystem exchange (NEE) responses to temperature, drought, and fire emissions all contributed significantly to CO_2 variability; no single mechanism was dominant.
- Combined, drought and fire contributions to CO_2 variability exceeded direct NEE responses to temperature in both the Northern and Southern Hemispheres.
- Accounting for fires, the sensitivity of tropical NEE to temperature stress decreased by 25% to 2.9 ± 0.4 Pg C yr^{-1} K^{-1}.
- Results will inform the improvement of the representation of terrestrial ecosystem processes in Earth system models.

Keppel-Aleks, Gretchen, Aaron S. Wolf, **Mingquan Mu**, Scott C. Doney, Douglas C. Morton, Prasad S. Kasibhatla, John B. Miller, Edward J. Dlugokencky, and **James T. Randerson** (2014), Separating the Influence of Temperature, Drought, and Fire on Interannual Variability in Atmospheric CO_2. *Global Biogeochem. Cycles*, 28(11):1295–1310. doi:10.1002/2014GB004890.

Biogeochemistry–Climate Feedbacks SFA Highlights (5)



Objective:

Understand how land and ocean contributions to climate–carbon feedbacks evolve over time from 1850 to 2300.

Research:

- Use CESM1(BGC) to assess carbon cycle dynamics for the Representative Concentration Pathway 8.5 and its extension.
- Three simulations with different levels of radiative coupling allowed us to diagnose parameters describing the gain of the climate–carbon feedback.

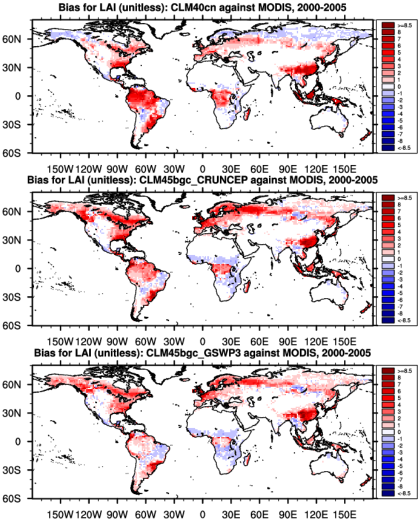
Impact:

- We found that the gain of the climate–carbon feedback increased almost 3-fold from 2100 to 2300.
- Ocean carbon sensitivity to climate change was proportional to increases in heat content.
- Climate influence on carbon largest in the Atlantic Ocean and in Central and South American forests.

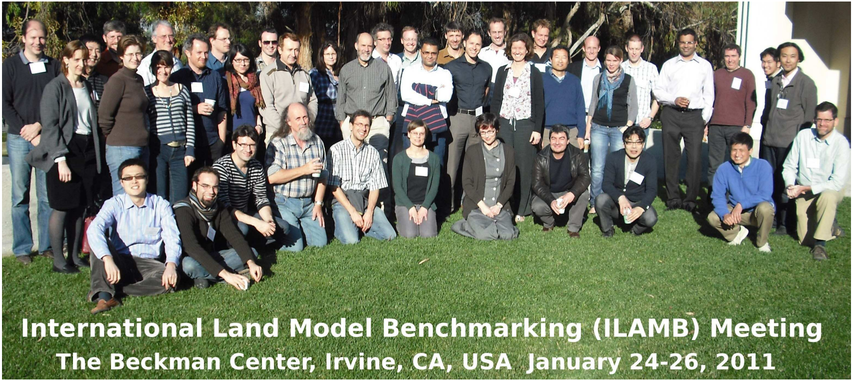
Reference: Randerson, J. T., K. Lindsay, E. Munoz, W. Fu, J. K. Moore, F. M. Hoffman, N. M. Mahowald, and S. C. Doney (2015), Multicentury Changes in Ocean and Land Contributions to Climate–Carbon Feedbacks, *Global Biogeochem. Cycles*, 29(6):744–759, doi:10.1002/2014GB005079.

What is ILAMB?

- The **International Land Model Benchmarking (ILAMB)** project seeks to develop internationally accepted standards for land model evaluation.
- Model **benchmarking** can diagnose impacts of model development and guide synthesis efforts like IPCC.
- **Effective benchmarks** must draw upon a broad set of independent observations to evaluate model performance on multiple temporal and spatial scales.
- A free, **open source analysis and diagnostics software package** for community use will enhance model intercomparison projects.



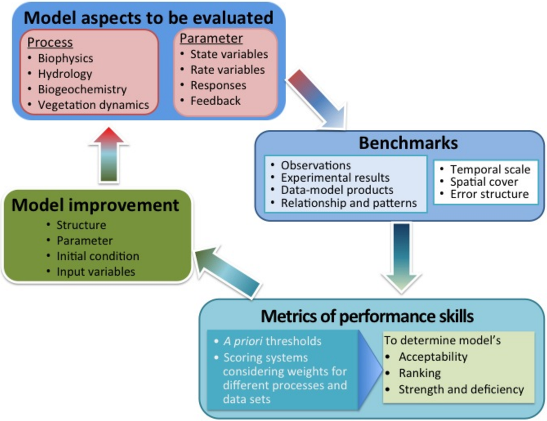
Bias in mean annual leaf area index from comparison of three versions CLM with MODIS.



- We co-organized inaugural meeting and ~45 researchers participated from the United States, Canada, the United Kingdom, the Netherlands, France, Germany, Switzerland, China, Japan, and Australia.
- **ILAMB Goals:** Develop an internationally accepted set of benchmarks for model performance; advocate for design of open source software system; and strengthen linkages between experimental, monitoring, remote sensing, and climate modeling communities.
- Methodology for model–data comparison and baseline standard for performance of land model process representations (Luo et al., 2012).

Benchmarking Methodology (Luo et al., 2012)

- Based on this methodology and prior work in C-LAMP, we developed a new model benchmarking package for ILAMB.
- Prototype is ready for use in NCL and a new version is under development using python.



(Luo et al., 2012)

Future ILAMB Developent and Application

- Current ILAMB Prototype was applied to:
  - Model development of the Community Land Model (CLM)
  - CMIP5 Historical and esmHistorical simulations
  - ACME Land Model evaluation
- Within U.S. Department of Energy projects:
  - NGEE Arctic, NGEE Tropics, and SPRUCE are adopting the framework for evaluating process parameterizations & integrating field observations
  - ACME is developing metrics for evaluation of new land model features
  - BGC Feedbacks is developing the framework and benchmarking MIPs
- Future projects where we hope to apply ILAMB:
  - CMIP6, including C^4MIP, LS3MIP, and LUMIP
  - TRENDY
  - PLUME-MIP

Acknowledgments

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