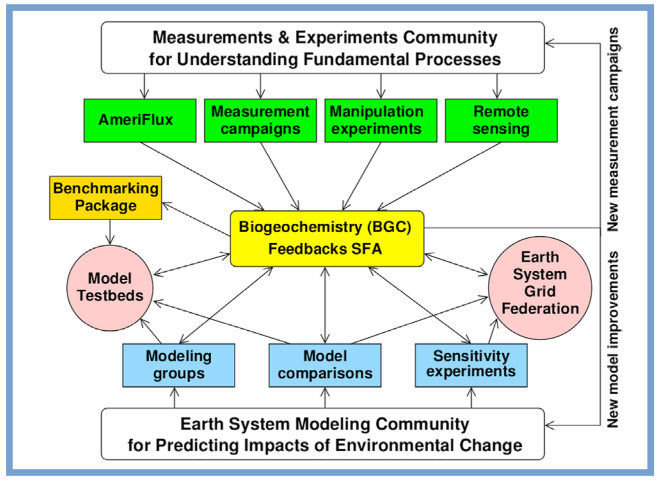
OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Climate and Earth System Modeling

U.S. DEPARTMENT OF ENERGY | Office of Science

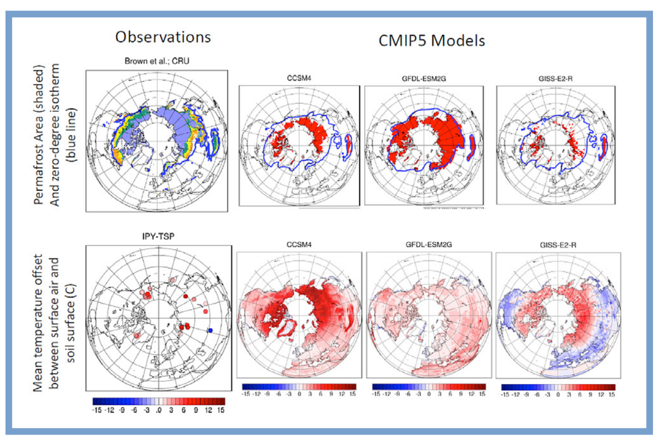
QUANTIFYING FEEDBACKS AND UNCERTAINTIES OF BIOGEOCHEMICAL PROCESSES IN EARTH SYSTEM MODELS

As Earth system models (ESMs) become increasingly complex, there is a growing need for comprehensive and multi-faceted evaluation of model predictions. To advance our understanding of biogeochemical processes and their interactions with climate under conditions of increasing atmospheric carbon dioxide (CO_2), we need to develop new ways to use observations to constrain model results and inform model development. Better representation of biogeochemistry–climate feedbacks and ecosystem processes is essential for reducing uncertainties associated with projections of climate change during the remainder of the 21st century.

In an effort sponsored by the U.S. Department of Energy's Office of Science through the Regional and Global Climate Modeling Program, a diverse team from Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, University of California at Irvine, University of Michigan, Los Alamos National Laboratory, and Argonne National Laboratory is developing new diagnostic approaches for evaluating ESM biogeochemical process representations. Called the *Biogeochemistry (BGC) Feedbacks Scientific Focus Area*, this research effort supports the *International Land Model Benchmarking (ILAMB) Project* by creating an open source benchmarking system that leverages a growing collection of laboratory, field, and remote sensing data. This benchmarking system, which will be extended to include ocean biogeochemistry, is expected to contribute model analysis and evaluation capabilities to phase 6 of the *Coupled Model Intercomparison Project (CMIP6)* and future modeling experiments. In addition, the researchers will use this system to engage experimentalists, including those in DOE's Terrestrial Ecosystem Science Program, in identifying model weaknesses and needed measurements and field experiments.



The Biogeochemistry (BGC) Feedbacks Scientific Focus Area (SFA) brings together the modeling and the measurements communities to systematically assess model fidelity using best available observations through an open source benchmarking package.

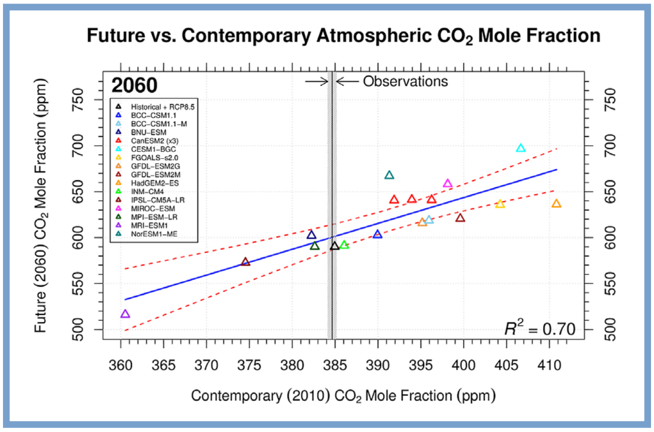


CMIP5 models exhibit a large inter-model spread in permafrost properties, including permafrost area and mean temperature across the atmosphere-soil interface. However, none of these individual variations was strongly related to modeled permafrost susceptibility to warming. Figure adapted from Koven et al. (2013).

SCIENTIFIC FOCUS

The overarching goals of this activity are to identify and quantify the feedbacks between biogeochemical cycles and the climate system, and to quantify and reduce the uncertainties in ESMs associated with these feedbacks. Through a comprehensive program of hypothesis-driven research, these goals will be accomplished by performing multi-model sensitivity analyses and comparisons with best-available observations and derived metrics. Investigations will focus on biogeochemistry–climate feedbacks associated with changes on interannual to decadal timescales (including ecological impacts of changes in disturbance regimes and climate extremes) and longer-term trends (including potential tipping points).

Important classes of observations used in the effort include observations of energy, carbon, and water from U.S. Department of Energy Ameriflux and Next Generation Ecosystem Experiments, National Aeronautics and Space Administration remote sensing observations of land and ocean ecosystem characteristics, National Oceanic and Atmospheric Administration and National Science Foundation atmospheric trace gas observations from aircraft and surface sites, above- and below-ground carbon inventories, atlases of three-dimensional ocean carbon and nutrient distributions compiled from shipboard observations, and syntheses and meta-analyses of terrestrial ecosystem manipulations of carbon dioxide, warming, nutrients, soil moisture, and tree cover.

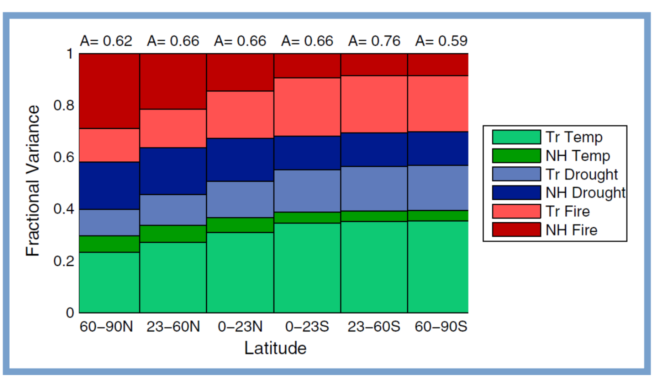


Future (2060) vs. contemporary (2010) atmospheric CO_2 mole fraction fit for CMIP5 emissions-forced simulations of RCP 8.5. Models that had positive biases in contemporary CO_2 tended to predict higher levels of CO_2 during the middle and end of the 21st century as a consequence of weak carbon–concentration feedbacks. Figure adapted from Hoffman et al. (2014).

OBJECTIVES

Four objectives define the research focus of this activity:

1. development of new hypothesis-driven approaches for evaluating ESM biogeochemical processes using observations from site, regional, and global scales;
2. investigation of the degree to which contemporary observations can be used to reduce uncertainties in future scenarios, using an “emergent constraint” approach;
3. creation of an open source benchmarking software system that leverages the growing collection of laboratory, field, and remote sensing data sets for systematic evaluation of ESM biogeochemical processes; and
4. evaluation of the performance of biogeochemical processes and feedbacks in different ESMs participating in model intercomparison projects, including CMIP5 and CMIP6.



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. While temperature was the largest single driver of atmospheric CO_2 variability (except north of 23°N), drought and fire collectively contributed more to that variability than temperature. The amplitude factor (A), calculated as the ratio of the standard deviation of the simulated CO_2 relative to the standard deviation of the observations, is shown for each latitudinal band. Figure adapted from Keppel-Aleks et al. (2014).

Another important objective is to contribute to ILAMB Project by providing new analysis approaches, benchmarking tools, and scientific leadership. The goal of ILAMB is to assess and improve the performance of land models through international cooperation and to inform the design of new measurement campaigns and field studies to reduce uncertainties associated with key biogeochemical processes and feedbacks. ILAMB is expected to be a primary analysis tool for CMIP6 and future model–data intercomparison experiments. This team developed an initial prototype benchmarking system for ILAMB, which will be improved and extended to include ocean model metrics and diagnostics.

ACCOMPLISHMENTS

Over the past 4 years, the Carbon–Climate Feedbacks Project, which preceded this activity, pioneered the development and application of new diagnostic approaches for carbon cycle and ecosystem processes, resulting in 37 peer-reviewed literature publications, plus additional manuscripts in press or in review. Several of these publications focused on benchmarking and analysis of biogeochemistry and land surface processes in the set of phase 5 Coupled Model Intercomparison Project (CMIP5) models available on the Earth System Grid Federation (ESGF). The team also contributed significantly to the development and evaluation of the Community Earth System Model (CESM), focusing on areas of critical uncertainties associated with tropical forest nutrient dynamics, trajectories for forest disturbance, and the state and fate of permafrost carbon.

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BGC Feedbacks Website:
http://www.bgc-feedbacks.org/

International Land Model Benchmarking Website:
http://www.ilamb.org/