U.S. DEPARTMENT OF ENERGY | Office of Science

UNDERSTANDING UNCERTAINTIES ASSOCIATED WITH CARBON CYCLE-CLIMATE SYSTEM FEEDBACKS

In a project sponsored by the U.S. Department of Energy's Office of Science through the Regional and Global Climate Modeling program, a team of researchers at three National Laboratories—Oak Ridge, Lawrence Berkeley, and Los Alamos—and the University of California, Irvine, are working towards answering the following major questions:

- What limits the growth of tropical forests?
- How does a forest harvest 100 years ago influence the climate today?
- How much permafrost carbon might be released under a warming climate?
- How reliable are the models used to predict these and other connections between the global climate system and the global carbon cycle?

The team has identified four major task areas to focus these questions:

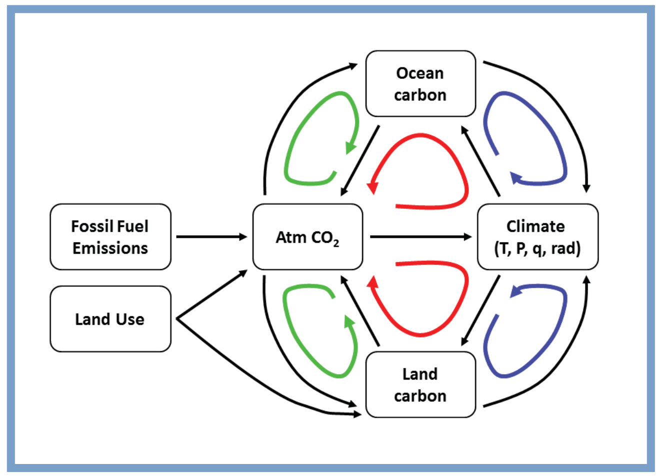
Task 1 – tropical forest nutrient dynamics

Task 2 – trajectories of forest disturbance

Task 3 – state and fate of permafrost carbon

Task 4 – a comprehensive analysis system to quantify the performance of models against multiple observational benchmarks.

Tasks 1-3 have been identified as areas of critical uncertainty in our ability to understand and predict current and future global climate system behavior and Task 4 will improve the mechanistic treatment for these carbon-climate feedbacks in Earth System Models.



The carbon cycle-climate system is characterized by multiple interconnected feedback loops, shown here by colored arrows. Land and ocean carbon pools respond to and cause changes in atmospheric CO_2 concentration (green arrows). Atmospheric CO_2 imposes radiative forcing on climate, resulting in changes in temperature (T), precipitation (P), humidity (q), and radiation (rad) which in turn affect land and ocean carbon pools with feedback to atmospheric CO_2 (red arrows). Changes in climate also cause changes to land and ocean ecosystems which in turn have direct influence on climate (blue arrows). Humans impact this coupled system, in part, through combustion of fossil fuels and through land use and land cover change.

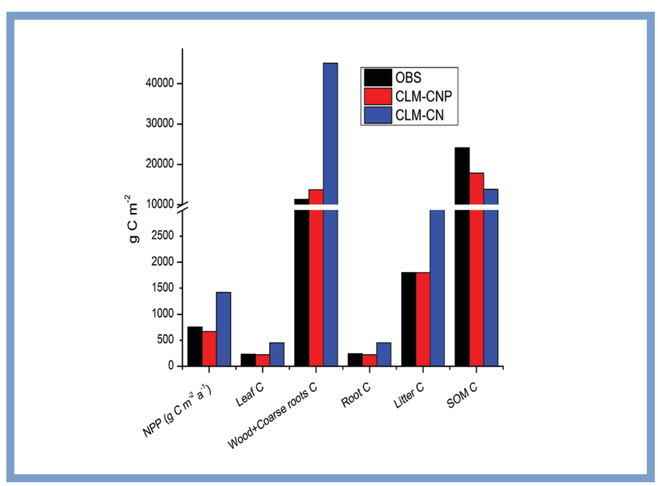
TASK 1: TROPICAL FOREST PHOSPHORUS CYCLING, CARBON-NITROGEN PHOSPHORUS COUPLING, AND NUTRIENT-CLIMATE FEEDBACKS

Led by: Peter Thornton, Oak Ridge National Laboratory.

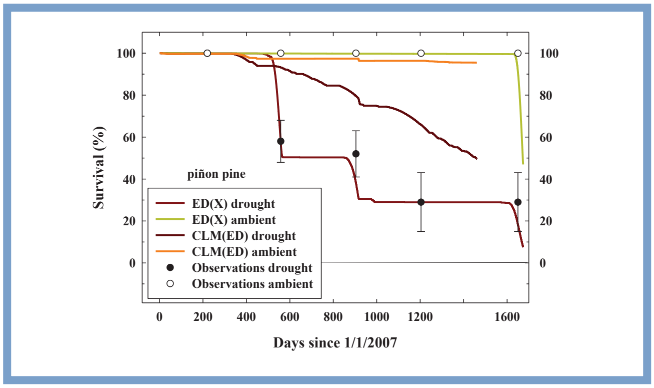
Phosphorus (P) is considered to be the most limiting nutrient in lowland tropical forest ecosystems, and may be co-limiting with nitrogen in the upland tropics and some temperate forests.

The P-cycle and carbon-nitrogen-phosphorus interactions into the Community Land Model (CLM-CNP) have been incorporated, and the data sets necessary to run at the global scale have been developed. Extensive diagnostics and evaluation of the new model are being performed, compared with multiple observational and experimental data sources.

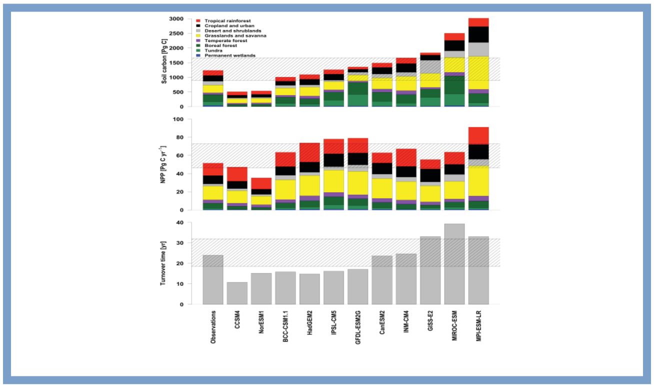
Earlier work demonstrated that carbon-nitrogen coupling plays a fundamental role in regulating carbon-climate feedbacks, and the team is finding that phosphorus limitation in the tropics is an important additional regulating mechanism.



Task 1: At a P-limited site in Hawaii, introducing P-limitation into the CLM-CN model improves estimate of net primary production (NPP) and estimated carbon stocks in vegetation and litter pools. (Yang et al., in prep.)



Task 2: Observations and simulations of piñon pine drought survival and ambient plots by ED(X) and CLM(ED) in central New Mexico. (McDowell et al.)



Task 4: Soil carbon stocks, net primary production, and turnover times for a collection of Earth System Models.

TASK 2: TEMPERATE FOREST DISTURBANCE TRAJECTORIES, MORTALITY, AND ASSOCIATED CLIMATE SYSTEM FEEDBACKS

Led by: Nathan McDowell, Los Alamos National Laboratory.

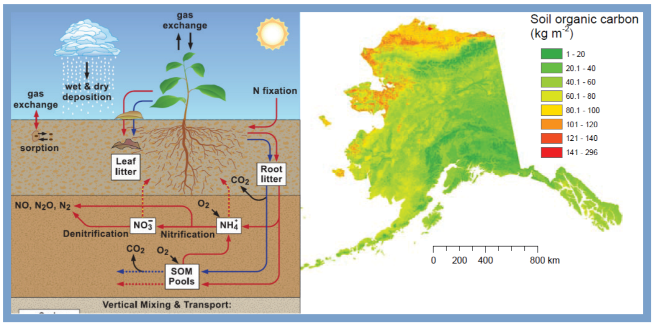
The response of woody ecosystems to disturbance, and associated tree mortality, are known to exert strong controls on net carbon fluxes and on carbon-nutrient interactions. The performance of an ecosystem demography (ED) model has been analyzed, with evaluation against observations of piñon pine mortality in a controlled drought experiment.

The model is able to capture many of the observed details of tree mortality during a long, severe drought. We have incorporated ED into the Community Land Model, and that model performs nearly as well, though lacking competition between piñon pine and juniper.

TASK 3: ANALYZING AND PREDICTING THE STATE AND FATE OF PERMAFROST CARBON IN HIGH LATITUDE ECOSYSTEMS

Led by: William Riley, Lawrence Berkeley National Laboratory.

Large stocks of carbon in permafrost soils at high latitudes could play an important role in future carbon-climate system feedbacks, depending on the amount of new carbon exposed to microbial activity under a warming climate, and the fractions released as methane or carbon dioxide.



Task 3: New process representation in CLM4.5 (left). Analysis of soil organic carbon for Alaska (right).

The team is improving permafrost carbon representation in the Community Land Model by adding vertical resolution and improved process representation. In addition, they are developing metrics to evaluate model predictions of high latitude carbon stocks and fluxes.

TASK 4: ANALYSIS OF CARBON-CLIMATE FEEDBACK AND PERFORMANCE BENCHMARKING FOR EARTH SYSTEM MODELS

Co-led by: Forrest Hoffman, Oak Ridge National Laboratory and James Randerson, University of California - Irvine.

Systematic evaluation of carbon cycle processes is needed to build confidence in future scenarios, quantify model improvements, and reduce uncertainties associated with carbon dioxide-induced climate change.

Here we are developing new approaches for benchmarking the carbon cycle in Earth System Models. These include: 1) new ways to use atmospheric CO_2 observations to evaluate the distribution of land and ocean carbon sinks in the Community Earth System Model, 2) development of emergent constraints based on atmospheric CO_2 biases from an ensemble of Earth System Models from different modeling centers, 3) evaluation of soil carbon pools, turnover times, and climate sensitivities in Earth System Models, and 4) assessment of the climate impacts of seasonal phasing biases in photosynthesis in Earth System Models. An important next step is to build an integrated model scoring system.

SUMMARY OF ACCOMPLISHMENTS

Since its inception in 2010, the project has resulted in 14 papers published or in press, with an additional nine papers submitted or in review. Team members have made over 60 presentations on results at national and international science meetings; more than half have been invited talks. Each task has generated new software modules for CLM.

CONTACT

Renu Joseph, Ph.D.
DOE Program Manager
Regional and Global Climate Modeling
renu.joseph@science.doe.gov