BIOGEOMON 2024: Session 3 (Soil carbon stabilization and C sequestration)

Modeling temperature sensitivity of soil carbon loss from a lowland tropical forest

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Soils represent the largest terrestrial carbon (C) pool, and the flux of carbon dioxide (CO_2) from soils to the atmosphere is ~ 6-10 times more than anthropogenic emissions. Understanding responses of soil CO_2 emissions to warming is crucial for evaluating feedbacks to climate change. The relationship between microbial respiration and temperature is typically modeled using a Q_{10} function. Generally, observations of the apparent Q_{10} of soil respiration are higher for cool vs. warm-climate ecosystems, reflecting expected biophysical controls of Arrhenius kinetics. However, results from two field warming experiments in the tropics contradict this expectation, both observing extraordinarily high soil respiration responses to in situ warming.

Here we systematically represent the potentially confounding effects of temperature sensitivity of enzymatic reactions, changes in the microbial enzymatic capacity, and substrate supply as they affect microbial decomposition of soil C in tropical forests under warming. The DAMM (Dual Arrhenius Michaelis-Menten) model was optimized using data generated from the Soil Warming Experiment in Lowland Tropical Forest in Panama. By including simple representations of measured warming-induced changes in microbial biomass and changes in soil moisture that affect substrate diffusion, we show that the observed increased soil respiration with warming does not reflect a change in activation energy, which remained at reasonable values (Ea: ~62-65 kJ mol^{-1}) for both warmed and control plots in optimized model parameterization. In contrast, optimization of the model without representation of changing microbial biomass required a higher activation energy (Ea: ~84-85 kJ mol^{-1}) in the warmed plots, which is inconsistent with kinetic theory. Hence, the higher soil respiration observed under warming could be explained by the increased enzymatic capacity of the microbial biomass rather than an increased activation energy of the enzymatic reactions.

Our parsimonious modular approach allows us to attribute agreement or disagreement of model outputs with measured respiration rates and specific model functions, as well as identify model structures necessary for representing soil temperature responses in broader Earth System Models. This will enable us to increase both the sophistication and capability of models to represent these processes from individual to Earth-System scales.