Modeling the Pathways to Carbon Liberation: Microbiologically-Informed C-Cycle Modeling in a Thawing Permafrost Landscape, for Scaling from Molecules to the Earth System

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Project goals: Understanding the fate of C in thawing permafrost is a grand challenge in both the biological and earth sciences because of its importance to biogeochemistry and climate change. Permafrost C pools are large (~1700 PgC), and C dynamics of permafrost thaw are complex: old C decomposes to carbon dioxide (CO_2) and methane (CH_4) as it is mobilized from thawing permafrost peat, while new C accumulates as thaw initiates ecological succession in both plant and associated microbial communities. The IsoGenie project is working to combine measurements and modeling to improve understanding of historical C dynamics and prediction over the 21st century. Here we present results from four models participating in the project.

BioCrunch, a genome-informed trait-based model, emerged as part of continued improvements made to the reactive transport solver, Crunchflow. Its purpose is to explicitly represent microbes and microbial functions using ‘omics derived information. BioCrunch has been further extended to account for kinetic isotope fractionation in order to simulate how microbial feedbacks alter the isotopic signature of methane and other C species. Simulations allow for a faithful representation of the functional diversity of microbial populations, how microbial physiological traits impact fitness, how biogeochemical processes are impacted by emerging microbial composition, and how biogeochemistry feeds back to alter microbial fitness and community assembly. PRT (Peatland Reactive Transport) is a model of peat biochemistry and gas transport, whose purpose is to use observations of methane and CO_2 isotopes in the pore water to infer how carbon gas transport, production, and consumption rates vary with depth, allowing direct comparison to *in situ* ‘omic samples of microbial composition, potential, or activity. The DNDC biogeochemistry model was modified for IsoGenie to include a more detailed representation of acetotrophic and hydrogenotrophic methanogenesis, and associated ^{13}C isotopic signatures. Its purpose is to provide new means for testing model representations of these processes against observations of isotopic fluxes and methanogen community composition (acetoclasts vs hydrogenotrophs). The *ecosys* model is a mechanistic terrestrial ecosystem simulator that has been applied in many high-latitude studies. The model represents soil biogeochemistry with explicit microbial details, plant processes, and landscape-scale thermal and hydrological processes. Its purpose is to study (a) geomorphological dynamics and their effects on plant responses, (b) hydrological controls on site-level CO_2 and CH_4 emissions, and (c) landscape-scale soil biogeochemical and plant responses to expected climate changes.

These four modeling approaches provide a diverse toolkit for investigating, testing, and predicting the role of microbial communities in permafrost-thaw associated carbon dynamics.

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