Dynamic Soil Columns Simulate Arctic Redox Biogeochemistry

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Arctic soil represents a large reservoir of organic carbon that is vulnerable to decomposition and release as carbon dioxide (CO_2) and methane (CH_4). Thawing permafrost landscapes are especially sensitive, with thermokarst formation dramatically changing Arctic hydrology and altering soil temperature regimes, oxygen availability, and biogeochemical redox cycling. There is limited understanding of how rapid redox transitions in Arctic soils will impact the magnitude and timing of CO_2 and CH_4 release. As ecosystem scale models advance to incorporate process-based soil redox biogeochemistry, improved mechanistic understanding of the links between hydrology, redox conditions, and microbial organic carbon decomposition will be required. This study identified shifts in Arctic soil microbial metabolisms due to changing oxygen availability during soil saturation and drainage. Dynamic soil column experiments were used to change the water level in soil and permafrost collected from an inundated thermokarst channel and the adjacent upland tundra near Council, Alaska. Soil columns (50 cm length, 7.5 cm diameter) were instrumented to continuously measure volumetric water content and oxygen concentrations and were operated at field-relevant temperatures and water contents. Discrete porewater samples were taken from MicroRhizon samplers and measured for ferrous and total iron, pH, dissolved organic carbon, and major cations, anions, and organic acids. Headspace samples were also taken to determine CO_2 and CH_4 soil fluxes. Relative to upland soils, thermokarst soils were expected to release more CH_4 and less CO_2 during draining and promote more efficient microbial iron reduction during saturation. Initial results indicate that thermokarst soil does release more CH_4 and less CO_2 during draining than upland soil, which is undoubtedly related to faster soil drainage (~3x initial drainage rate) in the upland soil. This trend could also be partially attributed to prior adaptation of upland and thermokarst microbial communities to more oxic and oxygen-depleted conditions, respectively. Iron cycling – from reduction during saturation to oxidation during draining – was observed in both soil types, and the links between carbon and iron cycling are being evaluated in terms of organic electron donors and iron mineral-associated organic carbon. This column study will help constrain the relative importance and timing of aerobic respiration, anaerobic respiration through iron oxidation/reduction, fermentation, and methanogenesis on carbon cycling in Arctic soils undergoing redox transitions. This dataset will also inform integration of redox processes impacted by transport and changing oxygen availability into reactive transport models, such as PFLOTRAN, which are being coupled to terrestrial components of Earth system models.