Simulating Iron Reduction and Methanogenesis in Arctic Soils Using PFLOTRAN and ELM

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Biogeochemical cycles in thawing permafrost soils depend on interactions between carbon, nitrogen, microbial decomposers, and terminal electron acceptors. Redox cycling of iron (Fe) plays an important role in thawing permafrost soils. Reduction of Fe(III) to Fe(II) provides a preferential pathway to organic matter mineralization over methanogenesis, potentially decreasing methane production rates while Fe(III) is available. Fe(III) availability is dependent on soil minerals and pH as well as total dissolved Fe concentrations. Oxidation of Fe(II) at the oxic/anoxic interface and during cycles of inundation and oxygen exposure can play an important role in Fe(III) availability by replenishing reducible Fe. Land surface models such as the E3SM Land Model (ELM) currently do not simulate dynamics of either terminal electron acceptors or pH, instead assuming that water table and time since inundation can be used as proxies for controls on anaerobic decomposition pathways. We simulated organic matter degradation, Fe(III) reduction and Fe(II) oxidation, and methanogenesis in the reactive transport model PFLOTRAN and used an established interface to couple it to ELM. Model simulations were compared with measurements of Fe cycling and methane production from laboratory incubations. Simulations of inundation/oxygenation cycles showed that Fe availability and mineral properties drove the temporal dynamics of methanogenesis, with the onset of maximum methane production controlled by the rate of Fe(III) depletion. Incorporation of redox processes into ELM via PFLOTRAN will improve model simulations of CO_2 and CH_4 emissions from soil systems with dynamic hydrology and biogeochemistry, which are particularly important in the Arctic.