Advective Heat Transport in Permafrost Landscapes: Biogeochemical Consequences

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When ice-rich permafrost thaws, the ground subsides, creating thermokarst features such as thaw bogs. These bogs are topographic low points in the landscape, and thus they receive and collect subsurface runoff from surrounding permafrost peat plateaus. The hydrologic connection between permafrost plateaus and thaw bogs has the ability to increase bog methane emissions by transporting thermal energy and nutrients from the plateau into the bog. On the time scale of interest for climate predictions (decades to centuries), radiative forcing associated with thermokarst bog formation is largely dictated by the amount of emitted methane.

Data previously collected by the research team from a thaw bog in Interior Alaska demonstrated that rainfall early in the growing season notably increased CO_2 uptake and CH_4. Water from the surrounding permafrost-peat-plateau flowed through the peat soils and penetrated into the bog, rapidly warming bog soils down to deep depths (~80 cm). The warm, deep bog soils early in the growing season supported microbial and plant processes that enhanced CO_2 uptake and CH_4 emissions. These results highlight how the plateau-bog hydrologic connection can influence methane. However, the hydrologic connection between bogs and the surrounding permafrost plateaus, and the ability of this connection to impact biogeochemical processes in the bog, is not traditionally recognized in field studies nor included in models.

Our project is advancing understanding of the bog-watershed connection, clarifying the conditions under which it results in the transport of thermal energy into bog and impacts land-atmosphere exchange of carbon. We are conducting fieldwork at a well-instrumented, thawing bog complex in Interior Alaska and performing Earth System modeling. Field data thus far indicate that bogs that receive proportionately more water from the surrounding watershed emit more methane. Through coupled modeling of lateral water and heat transport with Energy Exascale Earth System Model (E3SM) land model (ELMv1-ECA), we have confirmed the important role of advective heat transport in affecting bog soil temperatures and CH_4 emissions. Specifically, results show that incorporating lateral advective heat transport improved simulated soil-temperature and moisture profiles, active layer thickness (ALT), and bog inundation dynamics. Further, simulations that consider advective heat transport demonstrate deeper ALTs at bog edges than those without advective heat, suggesting advective heat transport facilitates faster thermokarst expansion.

Northern latitudes are expected to get warmer and wetter, and initiation and expansion of thermokarst thaw is expected to increase. In this context, the influence of the bog-watershed connection is likely to increase.