How is the magnitude and fate of soil organic carbon pools in the ABR changing, and what are the processes controlling the rates of those changes?

Changes in the climate are destabilizing pools of soil organic carbon (SOC) in the ABR that have resided in soil profiles for hundreds to thousands of years, in addition to accelerating the turnover of more labile SOC pools. This is particularly relevant in regions of permafrost degradation, where SOC has remained stable due to low temperatures. However, destabilization of slow-turnover SOC is also an important feature of non-permafrost profiles, where stabilization mechanisms of SOC may be more strongly linked to processes of SOC formation. Simultaneous with enhanced SOC destabilization, the changing climactic regime is driving shifts in vegetation and hydrological cycle that can alter rates of SOC production. Which of these phenomena dominates, what the processes are that drive their importance, and over what timescales they are most relevant to ABR C cycling remain unclear. Because these dynamics and their interactions ultimately drive ABR feedbacks to climate, ABoVE must promote a greater understanding of the production, transformations, and fate of ABR SOC.

Research questions addressing SOC stabilization and destabilization must invoke multiple temporal and spatial scales. The penultimate drivers of soil organic matter decay, exo-enzymes, are secreted by microorganisms and function in accordance with the biochemical properties of substrates and enzymes. The microbes that demand the resources liberated upon substrate decay produce exo-enzymes in response to their stoichiometric constraints and competitive dynamics among microbial populations. A fraction of the C they take up can then be allocated to CO_2 or CH_4, two important greenhouse gases. The fluxes resulting from this complex interplay of biochemistry and ecology generate the biogeochemical fluxes investigators typically measure at the mesocosm- to plot-scale, and then scale up using models and remote sensing to the landscape or regional level. CO_2 and CH_4 fluxes frequently correlate with soil temperature and moisture, prompting efforts to estimate soil respiration and CH_4 dynamics using remotely sensed data. However, a key challenge currently hindering progress in more accurate predictions of soil microbial gas fluxes is the lack of mechanistic models validated against large scale measurements which piece together highly heterogeneous spatial length scales found in the ABR. In addition to gaseous efflux of C to the atmosphere, C also can be liberated from these ecosystems into water and transported as POC, DIC, dissolved CH_4 and DOC to streams, ponds, lakes and eventually to the coastal ocean where it can be buried, available for decomposition to a different microbial community and potentially emitted to the atmosphere. Only recently have modelers begun to incorporate critical drivers of microbial activity such as nutrient availability and substrate stoichiometry into their work. Any research strategy thus must promote the development of empirical and modeling studies that link disciplines as diverse as biochemistry, microbial ecology, and biogeochemistry to broader-scale, remote sensing efforts.

Objectives for ABoVE research addressing SOC stabilization and destabilization are to:

1) Quantify destabilization rates of slow- to fast-turnover SOC pools in permafrost and non-permafrost profiles of the ABR, and link these rates with mechanistically linked biogeochemical and ecological data from spatially disparate scales;
2) Assess contributions of changes in above ground biomass, microbial activity, permafrost and hydrology to SOC in a diversity of soil profiles in the ABR to aid in understanding how SOC stabilization may function in a future climate, and link these data to biogeochemical fluxes and land cover at disparate scales; and

3) Integrate empirical approaches with theoretical and process modeling efforts to improve accuracy of SOC destabilization predictions and scalability.

Research addressing these objectives will employ landscape and regional scale observations of land cover classes, hydrological and C cycles, and other physical observations, and may invoke space-for-time substitutions as a means of predicting future SOC stabilization and destabilization trends. Biogeochemical and ecological data from spatially disparate scales include availability of critical microbial resources and edaphic features at the plot scale (i.e. nutrients, quantity and stoichiometry of soil inputs, moisture, pH, stable isotopes of SOC, dissolved species and trace gases, hydrologic connectivity or transport); flux tower data describing meso-scale energy and fluxes of CO_2 and CH_4 and isotopologues of these gases' fluxes; large scale observations of CO_2 and CH_4 and isotopologues of these gases fluxes using aircraft and tall towers; and remotely-sensed data at the landscape to regional scale to understand patterns of biogeochemical fluxes among land cover age and classes. Modeling activities should consider on-going developments by NGEE Arctic with particular attention paid to scaling with remote sensing. A robust spatial representation of the ABR is critical to this study. This is a particularly valuable approach given apparent, recent boreal forest encroachment northward, and shrub encroachment into tussock tundra. This approach can help us understand consequences of land cover changes induced directly or indirectly by future climatic regimes. Remotely-sensed data can also be employed to characterize seasonal patterns of soil moisture and freeze-thaw dynamics, permitting investigators to develop linkages among abiotic conditions, land cover, microbial resource availability, and SOC transformations.