3. What are the changes in the distribution and properties of permafrost in the ABR and what is controlling those changes?

Arctic tundra and boreal forests are unique from other biomes particularly because of the dominating influence of snow, ice and frozen ground. The role of the Cryosphere in the ABR makes this region especially sensitive to climate warming, and a shrinking Cryosphere is expected to have major and potentially irreversible consequences for ecosystems and society at multiple scales. A substantial portion of the ABR land area is underlain by permafrost, which directly influences the structure, nature, complexity and dynamics of its ecosystems. Many landscapes in the ABR have already experienced a marked degradation permafrost, which is expected to increase in the near future. Studying the forces driving changes in the state of permafrost and their consequences for ecosystems and society are therefore key research priorities.

Permafrost dynamics exert strong control on energy, water, and biogeochemical cycling, along with vegetation and disturbance processes, and are themselves driven by feedbacks in these ecosystem processes. Above permafrost, the seasonal active layer influences surface hydrology, vegetation cover and rooting zone depth, the frequency and severity of fire disturbances, and biogeochemical cycling. Permafrost and active layer characteristics are variable across spatial scales; while dominated by long-term climatic conditions, they are also regulated by a host of interacting local factors. Important feedbacks related to permafrost thaw and active layer changes include potential soil carbon release, increasing frequency and severity of wildfire, surface subsidence and hydrological change, changes in vegetation cover, and growing infrastructure vulnerability.

Permafrost thaw has significant consequences for society – both within and beyond the ABR – through impacts on ecosystem services. Permafrost strongly regulates surface water distribution and wildlife habitat, both of which are connected to key provisioning and subsistence services for the people of the ABR. Frozen ground supports infrastructure, transportation and other services that communities rely on. Pan-arctic permafrost stores an enormous quantity of frozen soil organic carbon that is protected from release to the atmosphere – thus providing a critical climate regulation service for global society. The fate of the thawing permafrost landscape, along with associated changes in ecosystem structure and function, represents a critical uncertainty in projecting greenhouse gas feedbacks to future climate.

Objectives for ABoVE permafrost research are focused on **understanding the drivers of permafrost degradation and loss**, **and the consequences that these changes have on ecosystems and society** within and beyond the ABR. These include:

1. Advance our scientific understanding of how landscape-scale variations in air temperature, snow cover, disturbance, surface hydrology, soil properties, and vegetation cover interact to control the distribution of permafrost and permafrost degradation across the ABR.

2. Acquire and analyze the observational and experimental data necessary to develop and validate model frameworks that accurately project distributions of permafrost and permafrost degradation at landscape to regional and broader scales.

The fundamental research strategy for addressing these objectives will leverage existing process studies and monitoring networks designed to observe and quantify changes in the key indicators of permafrost condition. Previous field studies and existing, ground-based permafrost and active layer monitoring networks have advanced our understanding of the basic processes regulating the local formation and degradation of permafrost. However, observations also show that the rates of permafrost warming have not been uniform in time and space. ABoVE should design a framework that integrates remote sensing and model development to scale this local-to-landscape information on key system drivers and indicators to a broader understanding of regional-to-global consequences.

During ABoVE, observations from satellite, airborne and ground-based remote sensing systems will be integrated to monitor and quantify 1) the fundamental environmental factors and land surface characteristics that regulate near-surface permafrost dynamics, and 2) the key indicators of permafrost thaw and associated landscape-scale impacts. Thawing permafrost is manifest as the long-term gradual, but widespread thickening of the seasonally thawed active layer (press disturbance) as well as the local and rapid occurrence of thermokarst features forming in ice-rich permafrost (pulse disturbance). Thaw processes along this press-pulse disturbance spectrum are primarily regulated by interactions of near-surface permafrost with local hydrology. The temporal and spatial variation in the major driving factors – such as freeze/thaw cycles, albedo, snow cover, patterns of vegetation cover and vegetation change, disturbance occurrence and severity, surface water coverage, and soil moisture – will be characterized over the ABR using satellite remote sensing data and products. Studies of the indicators and impacts of permafrost thaw across the landscape – including ground subsidence, mass wasting, and lake formation or drainage – will be carried out using high-resolution satellite and airborne remote sensing systems.

These remotely sensed observations will be used in conjunction with field-based measurements to understand driving processes and aid in the development of inputs for physical models projecting spatial and temporal patterns and future conditions of permafrost and active layer dynamics. Improving the representation of fundamental processes in these models will require integration, synthesis and scaling of field-based studies strategically sampled from different land-cover types located across the major permafrost zones and encompassing variation in ice content and disturbances. The field-based studies will include static and dynamic measurement of depths and bulk densities of organic and mineral soils (in both the active layer and frozen ground), permafrost temperature and other physical properties, ground ice and liquid water content, seasonal active layer depths, vertical and lateral ground temperature and moisture profiles, seasonal and long-term thaw subsidence and frost heave, as well as vegetation cover, seasonal snow depths and snow water equivalent. While for some of these variables snapshot observations are sufficient others will require repeated or continuous observations. The permafrost models will be validated using existing longer-term records of permafrost temperature, as well as new observations of ground temperature and moisture.