Q7: What are the changes in the distribution of surface and subsurface water storages and the amount and timing of water discharge in the ABR, what is controlling those changes, and how are they affecting ecosystem structure and function and materials export in the ABR?

Scientific Rationale

The terrestrial water cycle across the high northern latitudes (HNL) is dominated by the seasonal storage in snow, which leads to relatively high runoff rates and subsequent river flows. In many areas, including the ABoVE Study Region (ASR) precipitation (P) is nearly equally partitioned between rain and snow, with excess above evapotranspiration (ET) stored as snow, surface water, soil and groundwater or exported as runoff, river flow to the Arctic Ocean. Under this regime of generally positive net precipitation (P-ET) but relatively low precipitation amounts, permafrost contributes uniquely to surface storage and surface to groundwater interactions. Permafrost creates an effective barrier to subsurface fluid movement and its dynamic distribution exerts strong controls on the length and distribution of subsurface flow paths. While precipitation rates tend to be low relative to midlatitude and tropical regions, low evaporation and ET rates due to low temperatures and solar illumination lead to positive net precipitation most months. This excess water, the presence of permafrost and seasonally frozen ground, poorly drained soils, and vast areas with low relief has produced extensive areas with ponds, small lakes, wetlands, and peatlands. The unique hydrology influences land-atmosphere interactions and feedbacks including water, carbon and energy exchange, vegetation dynamics and a host of other ecosystem processes. Data point to intensification in fluxes of P, ET, and runoff, at the pan-Arctic scale, and expected manifestation of a warming climate. Warming is also projected to lead to a shift from a surface to a more groundwater dominated system, a transition that may potentially dampen any intensification in runoff from increased net precipitation.

Much of the ABR is underlain by permafrost that is spatially contiguous across the landscape. Permafrost is discontinuous or sporadic in other areas depending on local factors. The presence or absence of permafrost and the seasonal change in thawing of the soil active layer in summer both strongly influence vertical and lateral runoff and groundwater flows and associated soil and groundwater storages. Connections between surface and subsurface flow paths are limited during the winter months, with the exception of taliks that effectively connect the supra-permafrost to underlying aquifers and flow systems. It is hypothesized that thawing permafrost will increase hydrologic flow paths and residence times, thus effecting water and materials exports and biogeochemical processing of carbon, nutrients, and contaminants. Recent measurements across the region of major organic matter constituents and major ions suggest that permafrost is degrading and flow paths are lengthening. Decreased permafrost extent has been linked with increased organic carbon mineralization (carbon dioxide production), decreased organic carbon export, and increased inorganic carbon export across boreal and arctic regions. Classically, we think of flow paths as being surface and sub-surface flow, with residence times essentially the travel times along those paths. However, the HNL and the ASR are unusual in having a long winter season during which standing stocks of water (in the form of river and lake ice, snow, and frozen soil moisture) become key components of the system. These also have a residence time, albeit measured in months, and an impact, if not on the total export, at least the timing of the export. These cryospheric components introduce another timing mechanism into the material export system which is only poorly understood, and which is potentially critical in ecosystem structure.

One of the unusual things about the ASR is that the spatial distribution of water has a thermal as well as hydrologic aspect. Throughout the ASR, snow covers the ground from about October through April or May. Thus the snow is not only half of the annual surface runoff, but it is also a superb insulator and reflector that controls the surface energy balance during much of the year. The insulating properties vary with depth and character of the snow (wind-packed or not), and have a major impact on winter soil freezing and permafrost temperature. The reflecting properties of the snow (usually stated as albedo) are the highest of any natural material (albedo approx. 0.8) and reflect significant solar energy. The distribution of snow, however, is complicated. In the boreal forest, the snow can be in or below the canopy with radically different results for energy exchange. Likewise the depth of snow is heavily influenced by the vegetation and the linkage between the vegetation and wind. When the snow falls, how it falls, and how long it stays has profound implications for the HNL, as well as ecosystem state and function in the HNL.

While precipitation inputs and permafrost state are key controls on the spatial distribution and timing of water movement, other more local controls operating across the ASR, and how they may be modified due to warming, are less clear. Characterizing the spatial distribution of water, and the amount and timing of water discharge is a major challenge, as the water cycle across the HNL is tightly coupled with ecosystem structure and function. For example, the timing and magnitude of surface runoff and river flows control the amount and concentration of materials exported from a given watershed. Cold and wet surface conditions control the accumulation and decomposition of soil organic matter. Surface waters also influence the carbon cycle through the exchange of gases between the land and atmosphere. Unlike terrestrial ecosystems that are spatially and temporally variable sources or sinks of carbon dioxide and methane, lakes, streams, and rivers are all net sources of these greenhouse gases (GHG) to the atmosphere, and commonly exhibit gas flux densities that far exceed terrestrial GHG fluxes.

Surface water extent and soil moisture can be estimated using a number of different sensors and approaches, but estimates at finer spatial and temporal resolutions are needed. Understanding changes in hydrologic fluxes and storages and the primary controls on these changes will require observations and modeling targeted at P, ET, river discharge, snowfall and snowpack accumulation and duration, soil moisture, and surface water storages. Other observations such as permafrost extent, vegetation type, and soil carbon content are needed as well. Observations of active-layer thickness (ALT) and groundwater flow paths from in situ measurements are sparse. Remote sensing approaches are limited but emerging. There is a key need to characterize flow pathways within relatively flat boreal and tundra landscapes.

Research Approach

Understanding the spatial distribution of water, and the amount and timing of discharge will require measurements of several key quantities at a range of spatial scales. Critical measurements to answer Q7 will include soil moisture, precipitation, snow depth and snow water equivalent, stream flow, and the extent and temporal variability of surface water distribution. A critical part of the approach is the need to observe the state and distribution of the hydrologic system (and water in its various phases) year round, with particular attention to the shoulder seasons when snow and ice are either melting, or forming/being deposited. Research will be carried out in a number of Primary and Secondary Research Areas that provide the needed gradients to understand how surface and groundwater hydrology are controlled by a number of critical factors, including climate, permafrost, and land cover type, ecosystem dynamics and disturbance. Water chemistry and stable isotope measurements will be needed. Hydrologic observations at research sites should include baseline residence time estimates for soil and ground water pools. Water isotope measurements across targeted catchments should include observations from precipitation, snowpack, surface water, and ground water to facilitate the development of models. High-resolution satellite imagery and airborne LIDAR will be used to investigate effects of thermokarst and thermal erosion on subsurface flows. Other measurements including concentrations and exports of organic matter, major ions,and sediment load will be made to quantify bulk materials exports. High resolution measurements from aircraft and satellite-based instruments will be used to quantify areas of saturated surfaces and inundation, particularly along riparian zones near rivers and streams. Tower eddy covariance measurements will constrain land-atmosphere water and energy fluxes at research sites. Water isotope measurements will be made to diagnose water sources, rates of transfer and storage residence times. Fine scale topography and landcover data will be other key observations. This data will come from ongoing research and additional efforts funded by ABoVE. Surface hydrological characteristics available through the processing of satellite remote sensing data include longer-term patterns of the number of small ponds and lakes and their area (using Landsat TM), mapping of surface water extent and inundation (using data from spaceborne SARs, MODIS, AMSR-E), detection and mapping of floods (using MODIS and SAR data), and mapping of soil moisture (using data from airborne and spaceborne SARs, microwave radiometers, and SMAP). The satellite observations will be used as inputs for or a means to validate models of the distribution and runoff of surface water. At research sites with flux towers, measurement of ET will help close the water budget. Measurements of snow depth, density, and water equivalent will be made by direct measurement and remote sensing where feasible.

Objectives

1) Quantify the storage and export of water across the ABR, investigate the processes and factors controlling the spatial and temporal patterns of surface and subsurface storage and export, understand the ramifications of the spatial temporal patterns of storage and phase (liquid/solid), and improve understanding the nature of recent changes (i.e. permafrost degradation, disturbances due to fire and land use change).

2) Quantify the impact of changes in hydrologic connectivity on ecosystem structure (i.e.species composition?) and function and dissolved and particulate materials export in the ABR.