Adapting to Permafrost Change: A Science Framework

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Permafrost is a defining feature of the circumpolar north, and with climate change already affecting its range and behavior, understanding the fate of northern environments is a pressing concern. The Canadian Arctic Development and Adaptation to Permafrost in Transition (ADAPT) project is bringing together researchers from within and outside Canada to study the mechanisms and consequences of permafrost degradation and to place this information within an interdisciplinary systems framework.

Permafrost lands are home to many northern communities, including aboriginal peoples such as the Inuit, who have lived in the Arctic for millennia, and increasingly are the adopted home of many people who have moved from the south. The infrastructure and resources for all of these settlements, from drinking water and exploited wildlife to industry, runways, roads, and housing, critically depend on the state of the permafrost.

At a broad level, changes in the temperature of permafrost over time and depth define the physical and biogeochemical stability of the landscape. Small climate- or human-induced changes in temperature can weaken the ability of permafrost to serve its various functions, such as being a stable foundation for transportation infrastructure, sequestering carbon, or retaining freshwater in permafrost-bound lakes. Globally significant quantities of organic carbon are stored in permafrost soils. If the permafrost thawed fully, this would substantially raise atmospheric carbon dioxide concentrations [*Schuur et al.,* 2009].

The ADAPT project is designed to provide an improved understanding of the effects on engineered infrastructure such as roads and runways and of the physical and biogeochemical links between the land, freshwater, vegetation, and the atmosphere. For several of these aspects, ADAPT is collaborating with the European Seventh Framework project Changing Permafrost in the Arctic and its Global Effects in the 21st Century (PAGE21; http://www.page21.org). Snowfall and the duration of snow cover are also changing in the Arctic [*Callaghan et al.,* 2011], and ADAPT is addressing the implications of such changes on permafrost, lakes, vegetation, and wildlife.

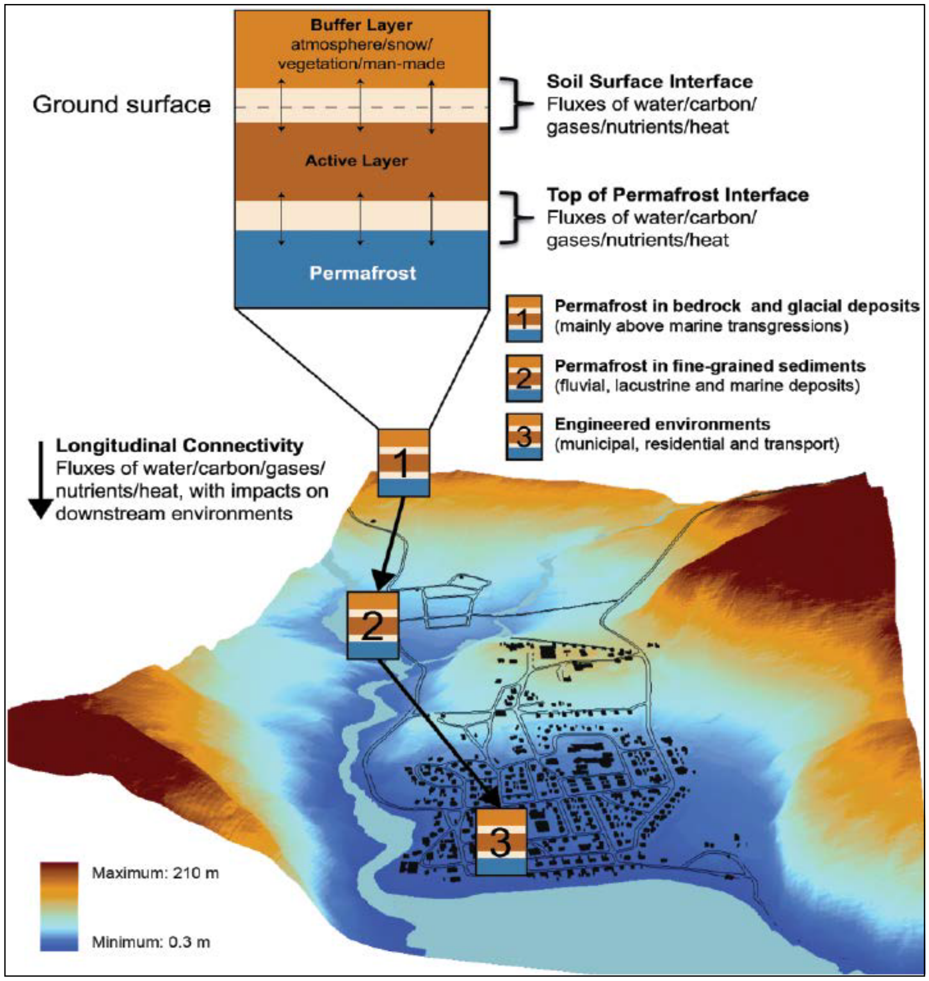

Fig. 1. The project Arctic Development and Adaptation to Permafrost in Transition (ADAPT) is applying an interdisciplinary framework to northern landscapes and communities, such as here in Salluit, northern Quebec, Canada. The ADAPT conceptual model considers the ground at each site as a three-layer system in which the bottom perennially frozen "permafrost layer" extends from beneath the "active layer" (the seasonal thaw zone) into bedrock (profile 1 in the diagram) or sediments (profile 2), here depending on altitude (color scale, meters above sea level). The uppermost "buffer layer" contains air; snow; vegetation; and, within the village, engineered infrastructure such as roads and houses (profile 3). Fluxes of water, heat, carbon, gases, and nutrients occur across the two interfaces within each profile and longitudinally via downstream flow (arrow), eventually to the ocean. The thickness of the layers varies in the landscape depending on site conditions and soil thermal properties.

Permafrost in Decline

Permafrost is ground that stays at or below 0°C for 2 or more years, and throughout the north, much of this frozen terrain is on the brink of massive change [*Rowland et al.,* 2010]. In Russia, thawing has been pronounced at many sites, especially in the discontinuous permafrost zone, a region where 50% to 90% of the land is permafrost [*Romanovsky et al.,* 2010]. In Alaska, slumping and drainage due to permafrost thawing have caused major landscape change [*Bowden,* 2010] and have damaged certain types of vegetation, including the complete destruction of some forest ecosystems [*Jorgenson and Osterkamp,* 2005]. In low Arctic Canada, the southern limit of discontinuous permafrost has moved northward by 130 kilometers over the past few decades, and thermokarst lakes—ponds that form in thawed depressions in the permafrost—have become larger and more abundant [*Thibault and Payette,* 2009]. Throughout the North American Arctic, a deepening of the active layer, the surface layer of the ground that thaws and freezes back every year, has accompanied increasing air temperatures since the end of the 20th century [*Burn and Kokelj,* 2009; *Smith et al.,* 2010].

Civil engineers are increasingly called upon in the Canadian north to respond to the effects of thawing permafrost on buildings, mining sites, roads, airports, and seaports, but an improved understanding of permafrost geophysics is needed to guide their actions. There is an immediate need for new adaptive strategies in resource management and infrastructure to adjust to these ongoing changes in the permafrost landscape and to mitigate or avoid the resultant effects.

Interdisciplinary Permafrost Modeling

ADAPT aims to integrate a broad spectrum of disciplines, including geomorphology, geophysics, biogeochemistry, microbiology, ecology, and civil engineering, to identify the processes that couple environmental change to the rate and state variables of permafrost geosystems and ecosystems. ADAPT places emphasis on identifying the critical places and periods of rapid change in permafrost and snow characteristics that have amplified effects on the Arctic's natural infrastructure and on its ability to provide geosystem and ecosystem services. These services include wildlife habitat availability, biodiversity (including microbial diversity), plant and animal production for harvesting, water quality and supply, carbon and nitrogen cycling, greenhouse gas consumption, flood and erosion control, and ground stability for infrastructure and communities.

The individual studies within ADAPT are all linked to an overarching hypothesis that liquid water and snow cover control heat, sediment, carbon, and microbial transport and thereby affect thermodynamic stability; geomorphological processes; and the ecology, biogeochemistry, and human use of permafrost landscapes. The ADAPT approach is based on a conceptual model of the permafrost system that, from top to bottom, represents permafrost with three layers and two interfaces as shown in Figure 1: the atmosphere-snow-vegetation layer (the "buffer layer"), the soil surface interface, the active layer, the interface between the active and the permafrost layers, and the permafrost layer itself. This three-layer depiction is also relevant in engineered environments, where the buffer layer contains human infrastructure.

Applying ADAPT

The ADAPT team is applying this conceptual model at 15 sites across northern Canada, using the framework to develop statistical and numerical models that represent permafrost behavior at multiple space and time scales, including downstream effects on connected environments [e.g., *Jolivel and Allard,* 2013].

The ultimate goal of ADAPT is to model permafrost, vegetation, and associated carbon fluxes at a pan-Canadian scale. A set of standardized methods for permafrost characterization and data compilation has been developed to provide inputs to these regional models and to help integrate across sites. The regional data sets, along with continuous air and borehole temperature records, are being made available via the digital object identifier (DOI)-referenced, open access data publication series Nordicana D (http://www.cen.ulaval.ca/nordicanad).

ADAPT runs from 2011 to 2016, and new collaborations are welcome. Further details can be found at http://www.cen.ulaval.ca/adapt/.

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