Royal Canadian Geographical Society 2010 Expedition of the Year

Permafrost and Climate Change

Background

Future climate warming is expected to have a profound impact on the infrastructure and ecology of northern Canada, both because climate change is expected to be enhanced in high latitudes compared to the globe as a whole, and because of its effect on permafrost. Thaw of permafrost will result in changes in basin hydrology and the runoff characteristics of rivers as the connections change between groundwater and surface water systems (Janowicz, 2008). Where ice-rich, permafrost degradation will result in the formation of thermokarst landforms. Linear infrastructure or structures built over thawing permafrost may suffer severe and irreversible settlement as the underlying substrate loses strength. On rock slopes, loss of ice bonding may result in more frequent rockslides and falls, potentially creating hazards in transportation corridors. Detachment failure (shallow landsliding) over degrading permafrost may become more frequent on slopes in unconsolidated deposits and the additional transfer of sediment into streams could be detrimental to fish habitat.

Objectives

The research covered in this grant proposal is part of a long-term program focusing on permafrost characteristics and persistence within the southern half of the Yukon Territory and northern BC. The goal of the Expedition of the Year research project is to obtain novel data on permafrost thickness and continuity at field sites along 1300 km of the Alaska Highway between Whitehorse YT and north of Fort St. John BC. These sites will be instrumented for long-term geophysical monitoring in August 2010 near the time of maximum thaw and will be revisited in March 2011 to measure the impacts of ground freezing. In addition, climate stations will be installed in the Atlin BC area in August 2010 in collaboration with the local community and the Taku River Tlingit First Nation to assist in a climate change adaptation study. Finally, some existing climate and permafrost monitoring sites in the mountains of the southern Yukon will be visited, the data downloaded, and data-loggers serviced.

Research plan and methods

Establishing geophysical monitoring at thin permafrost sites along the Alaska Highway

Five thin permafrost sites along the Alaska Highway started to be monitored during the Fourth International Polar Year in 2007-2008. At each site, air temperature, ground surface temperature and temperature at the top of permafrost, as well as snow depth are being measured. At two of the sites, one in Yukon and the other in northern BC, deeper ground temperatures are also being recorded in boreholes. All these sites were part of the survey along the Highway conducted by Roger Brown in 1964 (Brown, 1967) which was repeated in 2007-2008 (James, 2010). While permafrost has disappeared at half of Brown's sites, it has persisted at these ones while the climate has warmed by about 1.5°C (James, 2010). However, it is likely that the permafrost at these sites has both warmed and become thinner over the past four decades.

We plan to transform these five sites, plus five others along the Highway, into long-term stations to monitor climate change impacts. We will be experimenting with DC resistivity

profiling, a geophysical technique that generates an image of the electrical resistance of the ground in the form of a profile to a depth of 13 m over a length of 80 m (e.g. Hauck et al., 2008). We successfully conducted individual surveys at three of the sites in 2008 and now wish to undertake time-lapse surveys of the same sort over the next two years. This work will form part of the M.Sc. thesis of Christina Miceli.

Arrays of electrodes, consisting of 1.2 m long stainless steel rods, will be pushed into the ground and left with their ends extending 50-60 cm above surface. The ends will remain accessible to be connected to the DC resistivity apparatus even when a snow cover is present. It should be noted that this technique creates no disturbance of the terrain or the vegetation and that the rods will be left in place only until the end of the project.

The electrical resistivity of the ground (a measure of how difficult it is for electricity to pass through the soil or rock) depends mainly on the state and amount of moisture present. There is a great contrast between soil in which the moisture is present as ice (high resistivity) compared to where the moisture is unfrozen (low resistivity). However, the moisture in fine-grained soils changes state progressively between -10°C and 0°C, but particularly between -2°C and 0°C (Tice et al., 1978) and close to 0°C, permafrost can simultaneously contain moisture as ice and liquid water. The change of state requires energy, so that if the extra energy going into the ground due to climate warming is constant, ground warming slows down as the soil approaches 0°C because the surplus energy is used to thaw the ice rather than warm the soil mineral particles (Smith et al., 2010). These slow but very important changes in temperature are difficult to monitor given the accuracy of most data-loggers (typically ±0.1°C). For example, the borehole loggers at our site at MilePost 825.2 on the Alaska Highway indicate temperatures of +0.04°C when in fact probing shows that the ground is frozen. DC resistivity profiling is being tested as a means to detect changes in unfrozen moisture in these thin permafrost sites due to changes in temperature, something that has not previously been tried in North America. Changes are expected to occur due to the annual cycle of ground temperatures and also to develop progressively on a multi-year basis as the ground slowly warms.

The electrode arrays will be set up during site visits in August 2010 and DC resistivity profiling will be undertaken with an ABEM terrameter and a car battery as a power source. Subsequent visits to undertake profiling will be made in March 2011 to examine the effect of winter freezing and then more frequent visits will start in May 2011 through to freeze-up in 2011.

Establishing climate monitoring sites in the Atlin, BC area

Atlin, BC, is a small community that is accessible by road only through the Yukon. The community and local First Nation are in the process of undertaking climate adaptation planning but there are no records of climatic conditions other than from the Environment Canada weather station. In particular, conditions in the mountains that surround Atlin are unknown, and hence potential geohazards cannot be predicted. The goal of this part of the project is to set up two full automatic weather stations and several subsidiary air and ground temperature monitoring stations at various elevations through the area. Some of the sites will be high enough that permafrost should be present and observed trends in temperature with elevation will ultimately be used to develop a permafrost map of the area.

The community will provide the logistical support for the project and Indian and Northern Affairs Canada has provided funding for the equipment. One of the weather stations will be set up at the elementary school in the community and will be used for educational purposes as well as for research. Return visits to the community will be required in 2011 in order to train local community members on downloading and data-logger maintenance procedures.

Visits to existing air and ground temperature monitoring sites

Weather stations and other research monitoring sites in the mountains near the Alaska Highway and in the Wolf Creek hydrological research basin near Whitehorse will be visited to download the previous year's data and maintain the equipment. These stations have been in place for several years to almost a decade. Long-term data from high elevation sites are essential to understand climate change in this region. All the existing Environment Canada stations are in valley bottoms which constitute only a small part of the landscape. Our monitoring has revealed that annual air temperatures change much more slowly with elevation than the global average so that the mountains up to treeline are warmer than would be expected based on the Environment Canada data. Therefore, any permafrost present is closer to thawing than would be expected.

Significance of proposed project

All three elements of the Expedition of the Year project concern permafrost distribution and the impact of change in the environment. The existence of permafrost is of fundamental importance to northern hydrology, northern ecosystems, northern peoples and the northern economy. The proposed project will increase our understanding of the distribution and dynamics of permafrost in the Yukon and northern BC. Such knowledge is essential to make predictions about future ecological change, to support future infrastructure development in an environmentally sensitive manner, and to assist with climate adaptation studies for northerners.

References

Brown, R.J.E., 1967. Permafrost investigations in British Columbia and Yukon Territory. Technical Paper no. 253. National Research Council of Canada, Division of Building Research, Ottawa, 55 pp.

Kneisel, C., Hauck, C., Fortier, R. and Moorman, B., 2008. Advances in geophysical methods for permafrost investigations. Permafrost and Periglacial Processes, 19(2): 157-178.

James, M., 2010. Historic change in permafrost distribution in northern British Columbia and southern Yukon Territory, Canada. Unpublished M.Sc. thesis, Department of Geography, University of Ottawa.

Janowicz, J.R., 2008. Apparent recent trends in hydrologic response in permafrost regions of northwest Canada. Hydrology Research, 39(4): 267-275.

Smith, S.L. et al., 2010. Thermal state of permafrost in North America – a contribution to the International Polar Year. Permafrost and Periglacial Processes, 21(2): 117-135.

Tice, A.R., Burrous, C.M. and Anderson, D.M., 1978. Determination of unfrozen water in frozen soil by pulsed nuclear magnetic resonance, Proceedings of the Third International Conference on Permafrost, Volume 1. National Research Council of Canada, Ottawa, pp. 149-155.