Initial results from the first year of the Permafrost Outreach Program, Yukon, Canada

***Panya S. Lipovsky*[1]**
Yukon Geological Survey

***Kenji Yoshikawa*[2]**
University of Alaska Fairbanks

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ABSTRACT

In 2007, a permafrost outreach program was initiated in Yukon, Canada by installing long-term permafrost monitoring stations near public schools in Whitehorse, Faro, Ross River, Dawson, Old Crow and Beaver Creek. Shallow boreholes were drilled near participating schools, and data loggers were installed to measure hourly air and ground temperatures at a variety of depths. Frost tubes were also installed in fall 2008 to start monitoring seasonal freezing and thawing trends in the active layer. School students are actively engaged with field data collection and interpretation of results posted on a central website. The program also provides baseline data that can be used to characterize local permafrost conditions and detect long-term changes. A snapshot of current permafrost conditions is provided for each monitoring station, based on the first year of data collection.

RÉSUMÉ

En 2007, un programme de sensibilisation au pergélisol a été lancé au Yukon en établissant des stations de surveillance à long terme du pergélisol près d'écoles publiques à Whitehorse, Faro, Ross River, Dawson, Old Crow et Beaver Creek. Des puits de forage peu profonds ont été creusés près des écoles participantes, et des enregistreurs de données ont été installés pour mesurer la température de l'air à chaque heure ainsi que la température du sol à diverses profondeurs. Des tubes de contrôle du gel ont également été installés à l'automne 2008 afin de commencer à surveiller les tendances saisonnières en matière de gel et de dégel dans la couche active. Le programme donne aux élèves la possibilité de participer à la collecte de données sur le terrain et à l'interprétation des résultats affichés sur un site Web central. De plus, le programme fournit des données de référence qui caractérisent les conditions locales du pergélisol et qui, à long terme, rendront possible la détection de toute variation de ces conditions. Un aperçu des conditions actuelles du pergélisol est fourni pour chaque station de surveillance, en fonction des données recueillies au cours de la première année de collecte.

[1]*Panya.Lipovsky@gov.yk.ca*

[2]*ffky@uaf.edu*

INTRODUCTION

The Permafrost Outreach Program (POP) was implemented in Yukon in 2007. Long-term permafrost monitoring equipment was installed in shallow boreholes drilled near six public schools in the communities of Beaver Creek, Whitehorse, Ross River, Faro, Dawson and Old Crow. The program is part of a larger circumpolar network of permafrost monitoring stations that have been set up by the University of Alaska Fairbanks at over 100 schools throughout Alaska, Yukon, Greenland, Mongolia, China, Russia, Norway and Finland.

The project has both scientific and educational components. Scientific data is collected at the monitoring sites to measure permafrost temperature and determine the thickness of the active layer (the layer above the permafrost that thaws during summer and refreezes during winter). The program is generating baseline data that will be useful for detecting long-term changes with respect to these permafrost characteristics, and in the seasonal timing of freezing and thawing within the active layer. Changes in these permafrost characteristics will potentially influence local ecosystems, hydrological regimes, terrain stability (landslides and thermokarst) and infrastructure integrity. Data from the program will also be made available to support academic research that seeks to investigate these relationships.

In addition to expanding our knowledge of the permafrost environment, the primary objective of the program is to engage school students, with the ultimate goal of inspiring a new generation of scientists to pursue similar research. Local students are actively involved in the monitoring program by assisting with equipment installation and data collection. The data are regularly uploaded to a central website (http://www.uaf.edu/permafrost/) where students are encouraged to explore a variety of educational resources, as well as data collected at other schools. Ongoing outreach activities are also conducted at participating schools to explain important permafrost concepts and discuss the significance of locally collected data.

The purpose of this paper is to: (1) outline the equipment and methodology used to set up the monitoring stations; (2) describe the site conditions at each station; and (3) provide a snapshot of current permafrost conditions at each station, based on the first year of air and ground temperature measurements.

EQUIPMENT AND METHODOLOGY

In spring and fall 2007, ground temperature sensors were installed in shallow (2-28 m) boreholes that were drilled at schools in Beaver Creek, Whitehorse, Faro, Ross River, Dawson and Old Crow (Table 1). In fall 2008, water-filled tubes (frost tubes) were installed within smaller boreholes that were drilled near schools in Beaver Creek, Whitehorse, Faro, Ross River, Dawson and Carmacks. Further details outlining the drilling and installation methodology and apparatus is described in the remainder of this section.

DRILLING

Ground temperature boreholes measuring 51 mm (2 inches) in diameter were augered using a variety of portable drilling equipment. An electric Bosch hammer drill with a 14A motor was used at all sites with custom-built auger stems (in 1 m lengths) and carbide drill bits (Fig. 1a). A portable (dolly-mounted), gasoline-powered, Minuteman® drill (Foremost Mobile) with a hollow stem auger attached to a water swivel was also used to perform water-jet drilling at the Robert Service School site in Dawson (Fig. 1b). At a second, forested site near Dawson, a simple percussion drill was used to drive a shaft (18 mm in diameter) into the ground by manually dropping a 30 lb weight onto it repeatedly (Fig. 1c). Smaller boreholes measuring 25 mm (1 inch) in diameter were also drilled at each site with the electric hammer drill; these smaller boreholes were used for installing either frost tubes or air temperature monitoring apparatus.

The portability of these drilling systems makes them a very cost-effective tool for performing shallow drilling in vehicle-accessible locations. However, these drilling systems cannot effectively penetrate soil containing any coarse fragments, therefore all sites were drilled in fine-grained sediments. It is also difficult to precisely log sediment characteristics such as texture and ice-content because the auger disturbs and mixes the sediment as it is brought to the surface. Despite these limitations, an experienced driller can still determine relative ice-content and general soil texture based on the speed and ease of drilling progress. For these reasons, the stratigraphic descriptions provided in the following section are considered to be approximate, with the exception of the Beaver Creek and Ross River sites, where geotechnical drilling and detailed logging was performed by professional engineering contractors.

Table 1. *Summary of key parameters that characterize permafrost conditions, based on a year of data collected between 2007 and 2008.*

Municipality	Beaver Creek	Whitehorse	Ross River	Faro	Dawson	Old Crow	Carmacks
School	**Nelnah Bessie John School**	**Golden Horn Elementary**	**Ross River School**	**Del Van Gorder School**	**Robert Service School**	**Chief Zzeh Gittlit School**	**Tantalus School**
GROUND TEMPERATURE BOREHOLES					school site/ natural forest site		
latitude	62°20'16"N	60°35'35"N	61°58'46.5"N	62°13'24.5"N	64°03'40.0"N/ 64°01'54.7"N	67°34'34.8"N	N/A
longitude	140°50'9"W	134°54'18"W	132°27'9.5"W	133°20'31.3"W	139°25'49.1"W/ 139°17'41.1" W	139°49'33.8"W	N/A
elevation (m)	700	712	659	720	320/344	255	N/A
disturbed site?	no	no	yes	no	yes/no	no	
borehole depth (m)	5.8	5.0	27.7	3.9	3.4/2.0	3.15	N/A
depth of lowest temperature sensor (m)	5.0	5.0	13.0	3.9	3.4/2.0	3.0	N/A
data logger installation date	May 2, 2007	May 7, 2007	Jun. 13, 2007	May 8, 2007	Oct. 1, 2007/ Nov. 16, 2008	Oct. 2, 2007	none installed
THERMAL REGIME					(for school site only)		
active layer thickness (m) - D_{AL}	1.0	2.0	9.5	2.4	2.0	<2.0	N/A
depth of zero annual amplitude (m) - D_0	>5.0	2.0	13.0	>4.0	>3.4	>3.0	N/A
measured mean annual air temperature (°C) - T_A	-4.1	-2.2		-3.1	-3.1	N/A	N/A
mean annual ground temperature (°C)							N/A
at ground surface - T_S	-1.7	-1.0	1.0	0.5	2.7		
at top of permafrost - T_{PT}	-3.6	-0.2	-0.1	-0.9	-0.2	<-3.4	
at 3m depth - T_{3m}	-3.3	-0.1	0.9	-0.8	-0.3	-3.3	
at depth of zero annual amplitude - T_0	>-3.1	-0.2	-0.3	<-0.8	<-0.5	>-3.3	
surface offset (T_A - T_S)(°C)	-2.4	-1.2		-3.6	-5.8	N/A	N/A
thermal offset (T_S - T_{PT}) (°C)	1.9	-0.8	1.1	1.4	2.9	N/A	N/A
FROST TUBES							
latitude	N/A	60°36'22.4"N	61°58'46.5"N	62°13'36.2"N	64°03'40.0"N	N/A	62°05'19.1"N
longitude	N/A	134°52'16.9"W	132°27'9.5"W	133°21'01.4"W	139°25'49.1"W	N/A	136°17'30.0"W
elevation (m)	N/A	741	659	712	320	N/A	537
depth (m)	N/A	2.3	2.0	2.1	1.0	N/A	1.8
installation date	none installed	Nov. 19, 2008	Nov. 18, 2008	Nov. 18, 2008	Nov. 16, 2008	none installed	Nov. 16, 2008

Figure 1. *Portable apparatus used for drilling shallow boreholes:* ***(a)*** *electric hammer drill;* ***(b)*** *gasoline-powered Minuteman water jet drill; and* ***(c)*** *manual percussion drill.*

GROUND AND AIR TEMPERATURE DATA LOGGERS

The ground temperature boreholes were cased with a PVC pipe which measured 25 mm (1 inch) in diameter. This pipe was capped and sealed on the bottom end and it extended approximately 50 cm above ground. Up to seven soil temperature sensor cables ("Onset" brand TMCx-HD series thermistor probes) were positioned inside the borehole casing, starting at the ground surface and extending down in 50 cm or 100 cm increments. These temperature sensors have a reported accuracy of ±0.25 °C at 0°C, without calibration.

To monitor air temperature, a shallow (~50 cm) hole 25 mm (1 inch) in diameter was also drilled into the ground approximately 1 m from each ground temperature borehole. A piece of thin PVC tube (3/4 inch or 19 mm in diameter) was inserted into this hole and positioned to extend 1 m above the ground surface. An additional temperature sensor cable was inserted through this tube, and mounted at a height of 1 m above the ground surface. The air temperature sensor was shielded beneath a 4 inch (10.2 cm) PVC cap mounted at the top of the tube (Fig. 2a).

The air and ground temperature sensors were connected to Onset HOBO® U12 data loggers (model number U12-006) with 12-bit resolution and four external channels. The loggers were housed inside a piece of capped 4 inch (10.2 cm) PVC pipe placed above the main borehole (Fig. 2b). The data loggers were set to collect hourly data from each sensor, which allowed them to run continuously for up to 450 days without requiring downloading.

FROST TUBES

Frost tubes (Fig. 3) were constructed by filling a length of 6-8 mm (1/4 - 5/16 inch) clear flexible plastic tube with

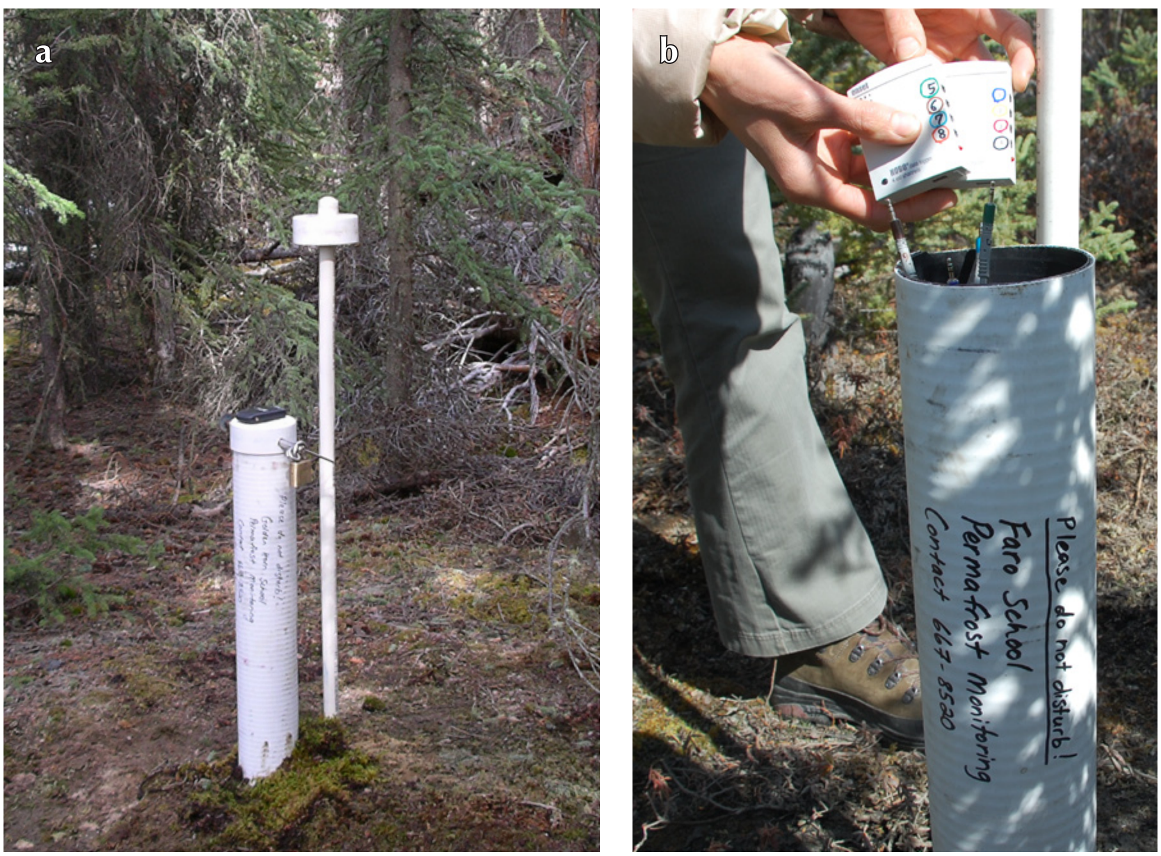

__Figure 2.__ Typical permafrost monitoring station apparatus and configuration. __(a)__ The larger PVC pipe houses the ground temperature sensors and data loggers. The thinner PVC pipe houses an air temperature sensor mounted at 1 m above the ground surface. __(b)__ Four-channel Onset data loggers store hourly temperature measurements for up to 15 months.

water. The water was tinted with a small amount of food colouring to make the boundary between frozen and unfrozen liquid in the tube more distinct. The ends of the tube were sealed shut by melting them with a blow torch.

A shallow borehole, 25 mm (1 inch) in diameter, was drilled up to approximately 2 m depth, depending on site conditions. The borehole was cased with 12 mm (1/2 inch; inside diameter) PVC pipe which was open on the bottom end. This casing pipe served primarily to protect the inner tubes from physical damage and frost heaving. The casing extended above ground approximately 1 m so that the top would still be accessible under peak snow accumulation conditions. An inner casing of flexible plastic tubing (10-12 mm or 1/2 - 3/8 inch outside diameter) sealed on the bottom end with epoxy putty, was inserted into the PVC casing to prevent convection, as well as house the actual frost tube. Once the frost tube was inserted securely inside the inner casing pipe, the entire installation was closed with a 12 mm (1/2 inch) PVC cap.

Figure 3. *Typical frost tube apparatus. At weekly intervals, students briefly remove the clear tube from the white PVC casing. The depth of freezing in the active layer is indicated by the lowest depth of frozen water in the clear tube.*

Graduations were marked on the tube every 5 cm below the ground surface level. This allows the depth of ground freezing to be read directly from the tube when it is briefly pulled out of the inner casing. This activity is currently performed on a weekly basis by local school students and teachers, who regularly report their measurements to Yukon Geological Survey by email. A graph depicting the progression of ground freezing and thawing in each community is continually updated on the POP's central website as new data is reported (http://spreadsheets.google.com/pub?key=pM4dgm3fEG1FIs33iUMLjDA&oid=10&output=image).

SITE DESCRIPTIONS

BEAVER CREEK

The Beaver Creek Permafrost Outreach Program monitoring station is located in a muskeg plain adjacent to the Alaska Highway at kilometre-post 1928.5 (Table 1). The site is approximately 5 km south of Beaver Creek and 40 m west of the Alaska Highway embankment margin. The station is located in a cluster of black spruce trees where the ground surface is slightly raised above the level of the surrounding plain. The vegetation immediately surrounding the station consists of undisturbed muskeg with scattered clusters of black spruce trees that form an unusual and distinctive polka-dot pattern when viewed on aerial photographs. The microtopography surrounding the clusters of black spruce trees is heavily tussocked.

A ground temperature borehole was drilled to 5.8 m depth using a portable electric Bosch drill on May 2, 2007 (Table 1). The ground surface at the borehole location was covered by 10-15 cm of moss, and the entire borehole was drilled through silty materials assumed to be of eolian origin, with some clay-rich layers. A thin, extremely ice-rich layer, assumed to represent the bottom of the active layer, was encountered at a depth of 1.2 m. Between 1.2 and 3 m depth, very ice-rich silt was encountered; clay-rich silt with low ice content was encountered from 3 to 3.5 m depth; and very ice-rich silt was encountered below 3.5 m depth. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3, 4 and 5 m depths, and an air temperature sensor was placed at 1 m above the ground surface.

The highway was constructed at this location in the early 1990s and the road embankment was built up to approximately 6 m above the level of the surrounding muskeg. Local permafrost degradation beneath, and immediately adjacent to, the highway has caused ongoing settlement and longitudinal cracking of the road surface at this location. Geotechnical boreholes were drilled approximately 70 m east and southeast of the POP borehole in 1991 (Yukon Highways and Public Works (YHPW), unpublished data). Massive ice was encountered in these boreholes between 2.7 m and 3.5 m below the surface in YHPW borehole number 157-190, and between 3.6 m and 4.6 m below the surface in YHPW borehole number 157-191. Additional geotechnical drilling completed adjacent to the highway in 1997 (approximately 20 m east of the POP borehole) revealed 5.5 m of massive ice with <5% silt inclusions between 1.8 m and 7.3 m below the ground surface (Paine and Associates, 1997).

Yukon Highways and Public Works has been monitoring ground temperatures at this location down to a depth of 8-10 m since 1997. Thermistor strings were installed by YHPW beneath the highway centre line, in the stabilization berm, and adjacent to the highway in undisturbed ground (approximately 20 m from the edge of the highway embankment).

Using this data, the thermal regime of the area was analyzed in detail by Dore (2005). He reported that ground temperatures were rising beneath the highway centre line and berm as a result of highway construction, despite local cooling climatic trends in the area between 1997 and 2003. Dore also determined that warming was greater beneath the berm than beneath the centre line, which appears to induce thawing of the underlying ice-rich ground. This may also explain why longitudinal cracks continue to develop in the road surface at this location each year.

Unpublished data from the YHPW thermistor strings between March 2006 and March 2007 reveal that the active layer was 1 m thick at the natural control site, located 20 m east of the POP borehole. They also show that ground temperatures at 8 m depth at that location fluctuate between -1.9°C and -2.7°C, with a mean annual ground temperature of -2.2 °C.

Other recent permafrost research at this site includes a satellite monitoring pilot study which attempted to use RadarSat interferometry to detect subtle ground displacement of the road and adjacent ground surface resulting from permafrost thaw during the summer of 2006 (C-CORE, 2007).

WHITEHORSE

On May 7, 2007, a ground temperature borehole was drilled in Cowley Creek Subdivision, 2.2 km southwest of Golden Horn Elementary School. The borehole was drilled to 5 m depth approximately 40 m east of Cowley Creek and about 40 m southeast of Salmon Trail (Table 1). The site is located in a mature white spruce forest with feather moss ground cover and slightly mounded microtopography. Numerous 'drunken' trees are leaning in random directions along both sides of the creek at this site, indicating the presence of degrading ice-rich permafrost in the local area.

The surface organic layer is 10 cm thick, and this is underlain by approximately 4 m of dark grey frozen silt and fine sand containing wood fragments and organics and no visible ice. A layer of ice-rich, light grey clay was encountered between 4 and 5 m depth. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3, 4 and 4.95 m depths, and an air temperature sensor was situated 1 m above the ground surface.

A frost tube was also installed near Golden Horn Elementary School on November 19, 2008. The frost tube is located approximately 100 m north of the school (Table 1). The site is located adjacent to a mature white spruce forest, amidst willow shrubs that fringe a grassy meadow and shallow pond. Between November 26 and December 17, 2008, the frost tube indicated that the depth of freezing progressed from 30.5 to 40 cm below the ground surface.

FARO

On May 8, 2007, a ground temperature borehole was drilled to 3.9 m depth approximately 600 m southeast of Del Van Gorder School in Faro (Table 1). This site is of particular interest because permafrost degradation has caused settlement problems beneath the school gymnasium in the past.

The borehole site is located 50 m southeast of a small track that cuts between Douglas Drive and Blind Creek

Road. The site is located in a young white spruce forest with scattered birch, thick moss and Labrador tea shrubs. Old slash piles from past logging activities are found nearby, and a peat excavation pit is located approximately 200 m northwest of the site.

Soil stratigraphy at the site is composed of 10 cm of moss, underlain by 10 cm of ash, which is in turn underlain by fine sand and silt with occasional stones to a depth of 3.5 m. Higher clay contents were encountered in the sandy silt layer at 3.5 m depth, and the borehole terminated in a gravelly layer at 3.8 m depth. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3 and 3.9 m depths within the borehole, and an air temperature sensor was placed at 1 m above the ground surface.

On November 18, 2008, a frost tube borehole was drilled to 2.1 m depth in a forested area just behind the Del Van Gorder School. The site is approximately 25 m east of the northeastern corner of the swimming pool building (Table 1). A frost tube was installed within this borehole, and weekly measurements will be made over the upcoming winter and spring by local students.

ROSS RIVER

On June 13, 2007, a deep ground temperature borehole was drilled at Ross River School to a depth of 27.7 m. The borehole was drilled by EBA Engineering Consultants using a CME75 hollow stem auger rig. The site is located inside the school yard approximately 15 m west of the school gymnasium doors (Table 1).

This site is of particular interest because permafrost degradation resulting from site disturbance has caused differential ground displacement beneath Ross River School since it was constructed in 2000. Consequently, substantial cracks continue to develop in the foundation, walls and floors of the building, despite the fact that thermosiphons have been installed around the perimeter of the school to promote ground cooling.

A simplified log of the borehole (#W14101031-BH01) is as follows: unfrozen sand from 0-4 m depth; unfrozen gravel from 4-6 m depth; silt and clay from 6-20 m depth (frozen and ice-rich below 7 m, and ice lenses up to 20 cm thick); frozen sand and clay from 20-24.5 m depth; and unfrozen, wet silt and clay with a high pore pressure below 24.5 m (EBA Engineering Consultants, 2007, unpublished data). The site has been cleared of natural organic cover and is covered with patchy grass and partly exposed mineral soil. The borehole was lined with a steel casing, which was heaved 50 cm upward immediately following installation due to the high pore water pressures in the unfrozen silt and clay at depth. A precision thermistor string was installed in the borehole casing by EBA Engineering Consultants for engineering purposes. A 25 mm (1-inch) PVC pipe was also inserted into the casing and POP ground temperature sensors were placed within the pipe at 0.5, 1.5, 2.5, 3.5, 4.5, 9.5 and 13 m below the ground surface.

A frost tube was also installed to 200 cm depth at the same site on November 18, 2008. Between November 21 and December 9, 2008, the frost tube indicated that the depth of freezing progressed from 87 to 143 cm below the ground surface.

DAWSON

A ground temperature borehole was drilled to 3.4 m depth at Robert Service School on October 1, 2007. The borehole is located just outside the school about 5 m south of Queen Street and mid-way between 4th and 5th avenues (Table 1). Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3 and 3.4 m depths, and an air temperature sensor was placed at 1 m above the ground surface.

The soil stratigraphy in the borehole includes: topsoil and bark mulch from 0-0.3 m depth; gravel fill from 0.3-0.7 m depth; and organic-rich silt from 0.7-3.4 m depth. The drill could not penetrate below 3.4 m depth due to the presence of gravel. Previous studies have noted near-surface segregated ice lenses in trenches dug along 4th and 5th avenues (EBA Engineering Consultants, 1977, 1983).

On November 16, 2008, a frost tube was installed to 100 cm depth adjacent to the ground temperature monitoring station. Between November 18 and December 2, 2008, the frost tube indicated that the depth of freezing progressed from 27 to 34 cm below the ground surface.

Because the Dawson School permafrost monitoring station is located in an ‘unnatural’ setting immediately adjacent to the school, on November 16, 2008, an additional ‘natural’ station was installed at an undisturbed forested site. This station is located about 500 m south of the Klondike Highway and 6 km east of the Klondike River bridge. The station is located approximately 600 m along, and 25 m north of, the road leading to the municipal dump from the Klondike Highway (Table 1).

The local vegetation at the forested site consists of black spruce, tussocks, Labrador tea and blueberry. Soil stratigraphy includes 70 cm of peat overlying fine sand and silt which extends down to 2 m depth. Gravel was encountered below 2 m depth, forcing the borehole to be terminated. A distinct ice-rich layer was also noted at 1.5 m depth, which likely represents the bottom of the active layer. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1 and 2 m depth.

OLD CROW

On October 2, 2007, a ground temperature borehole was drilled to 3.15 m depth near the Chief Zzeh Gittlit School. The site is located in a muskeg plain across the road from the school entrance, about 10 m north of the road (Table 1). Surrounding vegetation includes Labrador tea, blueberry, alder, willow and scattered black spruce trees 2-3 m tall. Ground temperature sensors were positioned at 0, 0.5, 1, 2 and 3 m depths within the borehole and an air temperature sensor was placed at 1 m above the ground surface.

Surficial materials encountered in the borehole include: 15 cm of moss at the ground surface, underlain by 2 m of organic-rich dark brown silt. Dark brown clay was encountered between 2 and 3.15 m depth, at which point the auger stem broke and the borehole was terminated.

The site was vandalized on July 14, 2008 and the site has not been resurrected since then. All data from the site were lost with the exception of data collected at 2 and 3 m depths (Fig. 4f) up to July 14.

CARMACKS

Because permafrost has not been documented in the area immediately surrounding the community of Carmacks, no ground temperature sensors were installed there. However, a frost tube was installed to 1.8 m depth near Tantalus School on November 16, 2008. The site (Table 1) is located near Prospector Road in a stand of aspen trees behind the baseball diamond. Soil stratigraphy in the frost tube borehole consists of fine sandy and silty alluvial sediment from 0-1.8 m depth, underlain by gravelly materials which prevented further drilling. Between November 19 and December 10, 2008, the frost tube indicated that the depth of freezing progressed from 25 to 35 cm below the ground surface.

PRELIMINARY RESULTS

Results from the first year of ground temperature monitoring are presented in Table 1 and Figure 4. A variety of key parameters that are commonly used to describe permafrost conditions are highlighted for each site. All parameters were calculated as a mean of hourly data collected over a period of one year. These data are summarized below.

Mean annual air temperature (T_A) ranged between -4.1°C in Beaver Creek and -2.2°C in Whitehorse. While the mean annual air temperature in Old Crow could not be calculated for the borehole site due to missing data, Environment Canada estimated the mean annual air temperature to be -3.4°C in 2004.

Mean annual ground surface temperature (T_S) varied between -1.7°C in Beaver Creek and 2.7°C in Dawson. The high mean annual ground surface temperature in Dawson is likely related to the fact that the ground cover at the borehole site consists of dark-coloured bark mulch.

Active layer thicknesses (D_{AL}) were interpolated from the ground temperature envelope curves (Fig. 4). At sites with natural organic cover, active layer thickness varied between 1.0 m in Beaver Creek to 2.4 m in Faro. Active layer thickness extended up to 9.5 m in Ross River, where no natural organic ground cover was present due to site disturbance.

Mean annual ground temperatures at the permafrost table (T_{PT}), that is at the top of permafrost, were -0.2°C in Whitehorse and Dawson, -0.1°C in Ross River, -0.9°C in Faro and -3.6°C in Beaver Creek (Fig. 4).

Mean annual ground temperatures at 3 m depth (T_{3m}) were -3.3°C in Beaver Creek, -0.1°C in Whitehorse, -0.8°C in Faro, -0.3°C in Dawson and 0.9°C in Ross River (Fig. 4). The anomalously warm permafrost temperature in Whitehorse is typical of marginal permafrost temperatures in the sporadic discontinuous permafrost zone.

Depth of zero annual amplitude (D_0), where seasonal temperature variation is <0.1°C, was only intersected by the boreholes in two locations: D_0 occurred at 2.0 m in Whitehorse (Fig. 4b) and 13 m in Ross River (Fig. 4d). Mean annual ground temperature at the depth of zero annual amplitude (T_0) was -0.2°C at the Whitehorse site and -0.3°C at the Ross River site (Figs. 4b and 4d, respectively).

Frost tube data collected to date indicate that by early to mid-December 2008, seasonal frost depths ranged from

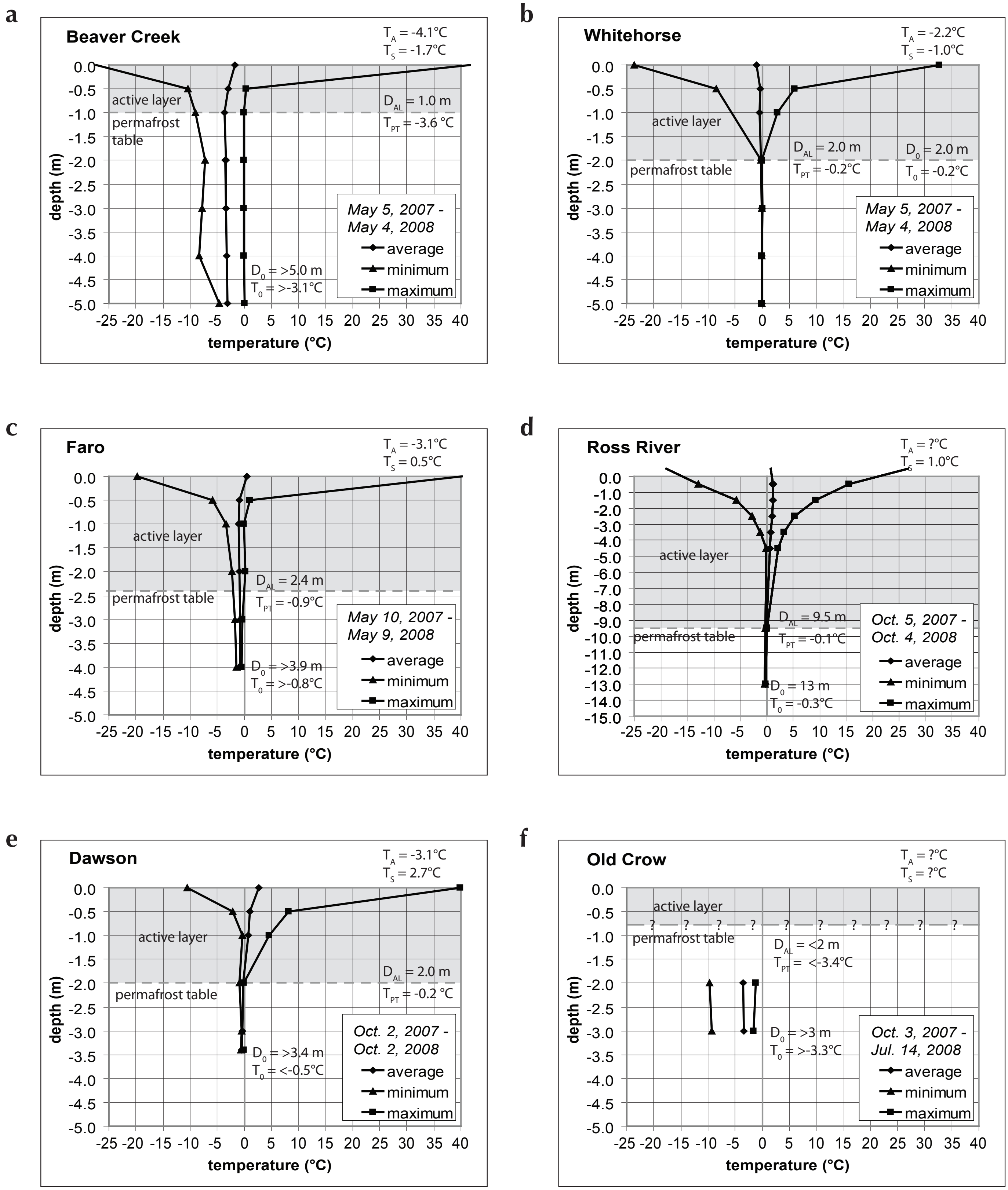

Figure 4. *Ground temperature envelope curves summarize the first year of data collected at each of the six permafrost monitoring stations established near schools in 2007.*

33.5 to 40 cm at the Carmacks, Dawson and Whitehorse sites. However, where no surface organic material exists and dry coarse-grained material is found near the surface, the depth of frost penetration is much higher. This condition was observed at the Ross River School site, where seasonal freezing extended down to 143 cm depth by early December 2008. More detailed seasonal freezing patterns within the active layer will be determined in winter 2009 after a year of data has been collected.

DISCUSSION

The data show that mean annual ground temperatures in permafrost at all monitoring sites are very warm (>-1°C), with the exception of the Beaver Creek and Old Crow sites, where it is >-4°C. It is also interesting to note that at all sites, except Old Crow, the maximum annual permafrost temperatures are at, or very close to, the thawing point (Fig. 4) which suggests the presence of degrading ice-rich permafrost. Conductive heat penetrating into the ground during these periods provides latent heat energy (which is used to thaw ground ice rather than raise the ground temperature). Recent surface disturbance near several of the POP sites has caused permafrost degradation which has produced serious consequences for nearby infrastructure. This is illustrated by ongoing subsidence problems on the Alaska Highway near Beaver Creek, and beneath the schools in Faro and Ross River.

It is important to note that due to the variation in site conditions at each borehole, significant comparisons of permafrost conditions between sites can not be made. In addition, the strong influence and variability of slope, aspect, ground cover, surficial materials and soil moisture make it difficult to extrapolate the reported permafrost conditions beyond the immediate vicinity of each borehole. The first year of data will, however, be very useful in the future for evaluating and detecting any changes in local permafrost conditions.

Public school students assisted with the installation of the air and ground temperature sensor strings and data loggers, and annual downloading of the data loggers. The data from each monitoring site were used to construct ground temperature profiles and time series graphs to illustrate temperature variations with depth at the site throughout the year. These figures were useful for demonstrating several important concepts to students, including: the thickness of the active layer, permafrost temperature, ground temperature variations with depth on any given day, seasonal air temperature variations, and seasonal ground temperature variations at any given depth.

These temperature variation patterns have important implications for infrastructure design and maintenance, and slope stability in permafrost terrain. Permafrost plays a strong role in slope stability in south and central Yukon with respect to its influence on soil moisture (Huscroft *et al.*, 2004; Lipovsky *et al.*, 2006, 2008; Lipovsky and Huscroft, 2007; Lyle, 2006). Any changes in active layer thickness or thawing of ice-rich permafrost on slopes would therefore directly influence landslide susceptibility.

The frost tubes are a simple apparatus students of all ages can use to monitor seasonal freezing variations within the local active layer. Seasonal frost depth depends on near-surface ground conditions such as snow depth, surface organic layer character, soil texture, soil moisture content and antecedent air temperature. Compilation and analysis of circumpolar frost tube data will allow students and scientists to better understand both local and global seasonal freezing patterns.

It is important to monitor changes in frost depth, timing of freezing and thawing, and the total length of the freezing period, since these factors can potentially affect buried municipal infrastructure, building construction timelines, terrain stability and plant growth. The frost tube data will also be useful for testing and running computer models of soil and ecosystem dynamics. For example, the frost tube data can be incorporated into hydrologic computer models used for flood forecasting by regional weather service providers.

The relationships between permafrost, climate and the physical environment are complex and vary spatially and temporally. Northern climatic systems and physical environments also have a particularly important influence on global climate. Monitoring the thermal state of permafrost by measuring ground temperatures in a wide network of boreholes is one method that can be used to understand global climatic trends. Recent reports on climate change highlight the need for establishing and maintaining long-term observation networks to support this work (ACIA, 2004, 2005). The Permafrost Outreach Program is a simple and effective method of developing a sustainable scientific infrastructure to support both local and global-scale permafrost and climate change research in the future.

SUMMARY

The Permafrost Outreach Program (POP) was implemented in 2007 to engage local school students in local permafrost research, and to begin collecting long-term baseline permafrost data around the territory. The program provides opportunities for elementary and high school students to participate with field research, and in doing so, allows them the opportunity to learn about the complex relationships between permafrost, the active layer, global climate, and the physical environment.

Shallow boreholes were drilled in 2007 and 2008 near six Yukon schools. The boreholes were drilled up to 6 m depth, primarily using an electric hammer drill, which is a very cost-effective tool for shallow drilling in fine-grained soils. At each site, frost tubes, temperature sensors and data loggers were installed to monitor permafrost temperatures, air temperatures and seasonal freezing patterns in the active layer.

Data collected for POP in 2007 and 2008 provide a snapshot of current permafrost conditions which will be useful for detecting and characterizing future changes in permafrost conditions. These data will be a valuable resource for both local and global scientific research efforts, and will also have important implications for a variety of land use activities in the territory, including infrastructure design and maintenance.

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