Establishment of Community-based Permafrost Monitoring Sites, Baffin Region, Nunavut

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ABSTRACT
The Geological Survey of Canada collaborated with communities and the Nunavut Departments of Environment and Community and Government Services to establish six new permafrost monitoring sites in communities in the Baffin Region. The new monitoring sites provide information to improve the characterization of permafrost thermal state and terrain sensitivity in the communities. Initial data are now available from the monitoring sites that indicate that mean annual ground temperatures range from -5.2°C in the southern Baffin Region at Pangnirtung to -12.3°C at Resolute.

RÉSUMÉ
La commission géologique du Canada a collaboré avec des communautés et avec les Ministères de l'Environnement et des Services communautaires et gouvernementaux afin d'établir six nouveaux sites de détection et de surveillance du pergélisol dans des communautés de la région de Baffin. Les nouveaux sites de surveillance aideront à améliorer la caractérisation de l'état thermique du pergélisol et de la sensibilité des terrains dans les communautés. Les données initiales des sites de surveillance sont maintenant disponibles et indiquent que les températures moyennes du sol varient entre -5.2°C à Pangnirtung, au sud de la région de Baffin, et -12.3°C à Resolute.

1 INTRODUCTION

Permafrost is an important component of the northern landscape and underlies communities throughout Nunavut. Permafrost, and the ground ice it contains, present challenges to engineering design in these communities as techniques must be utilized to prevent or avoid thawing of ice-rich soil during construction and operation of infrastructure in order to ensure stability (e.g. Brown 1970; Smith et al. 2001). Climate change presents an additional challenge and may lead to further thawing of the ground over time having implications for infrastructure performance. This is particularly important for structures that may have a long operating life or where there are high consequences of failure as could be the case with waste containment facilities and linear structures such as runways (e.g. Hayley and Horne 2008; Prowse et al. 2009). Knowledge of permafrost conditions including its thermal state is therefore essential for informed land use planning decisions, engineering design and the development of adaptation strategies to respond to the impacts of climate change.

An important objective of the International Polar Year (IPY) project on the thermal state of permafrost was to increase the number of permafrost monitoring sites to address geographical gaps in the existing network (Smith et al. 2008). Although permafrost temperature data have been collected for a number of years in Nunavut at a few sites, such as Alert and Iqaluit, there were large areas where no recent data were available. The IPY project presented the opportunity to establish permafrost monitoring sites in the eastern Arctic to address a gap between the monitoring network in northern Quebec operated by Université Laval and the site maintained by the Geological Survey of Canada (GSC) at Alert.

In 2008, GSC collaborated with the Government of Nunavut and individual communities to establish permafrost monitoring sites in 6 communities in the Baffin Region of Nunavut (Figure 1. One of the goals of the project was to provide information on permafrost conditions to aid the communities in the development of climate change adaptation plans. In addition, these sites contribute to the larger national permafrost monitoring network and improve our knowledge of current conditions across the Canadian permafrost region providing an improved baseline against which to measure change (Smith et al. 2010).

This paper describes the nature of the collaborative project to establish the permafrost monitoring sites in communities across the Baffin region. The initial ground temperature data collected from the first year of monitoring are presented, providing a snapshot of the current permafrost conditions in the region.

2 NATURE OF TERRITORIAL AND COMMUNITY PARTNERSHIPS

Collaboration with the Government of Nunavut as well as Baffin region communities was crucial to the success of the project. Through collaboration with Community and Government Services (CGS) and the Nunavut Department of Environment, GSC gained access to their extensive knowledge and experience working within the target communities. CGS was able to establish connections between the GSC and community councils and leaders. This was essential as support was required from each town council. The councils were asked if they were willing to support the initiative and to provide a representative to assist with establishment of the community monitoring site as well as maintenance and annual data collection. This ensured that communities were directly involved in the monitoring activities and also provided the opportunity to build local capacity. In all cases the councils recognized the importance of learning about the permafrost characteristics in their communities and agreed to support the project.

The consultation process was facilitated through a permafrost monitoring workshop in Pond Inlet in June 2008, which was jointly organized by the GSC, CGS and Department of Environment. The workshop was designed to educate selected members of the target communities on the methods and procedures for preservation and instrumentation of boreholes for ground thermal monitoring. The discussion included critical feedback on the proposed methods from the community perspective. Documents were distributed to all participating communities that outlined in detail the procedure for installing and monitoring the permafrost network boreholes. These documents were designed to reside within the office of the Senior Administrative Officer (SAO) so institutional memory of the project would be retained.

Collaboration with CGS was required in order share logistics and costs associated with drilling a borehole in each community. Borehole drilling was coordinated with CGS and utilized drilling equipment and personnel already engaged by CGS for construction related work. The availability of the drill and crew on-site in each community reduced mobilization cost and therefore the overall cost of the project.

3 ESTABLISHMENT OF MONITORING SITES

In collaboration with CGS, a 15 m borehole was drilled in each of six communities in the Baffin region of Nunavut in summer 2008 (Figure 1, Table 1). The hamlets of Arctic Bay, Clyde River, Igloolik, Pangnirtung, Pond Inlet, and Resolute Bay formed a rough north-south transect in the eastern Arctic between northern Quebec and the high Arctic (Figure 1). Locations of monitoring sites within each Hamlet were selected in collaboration with the local community leaders, most often the Senior Administrative Officer (SAO). The SAO identified locations that met the required criteria which were: a relatively undisturbed area, closeness to the community for easy access and a safe distance from major travel routes for snowmobiles and ATV's.

Borehole drilling was conducted between June and September 2008. An air rotary type drill was used to drill through gravel and bedrock sub-surface material. Due to the nature of the drilling process, samples of the underlying materials were not collected. All boreholes were completed to the desired depth of 15m in about 3-5 hours. The short drilling time and the lack of fluid

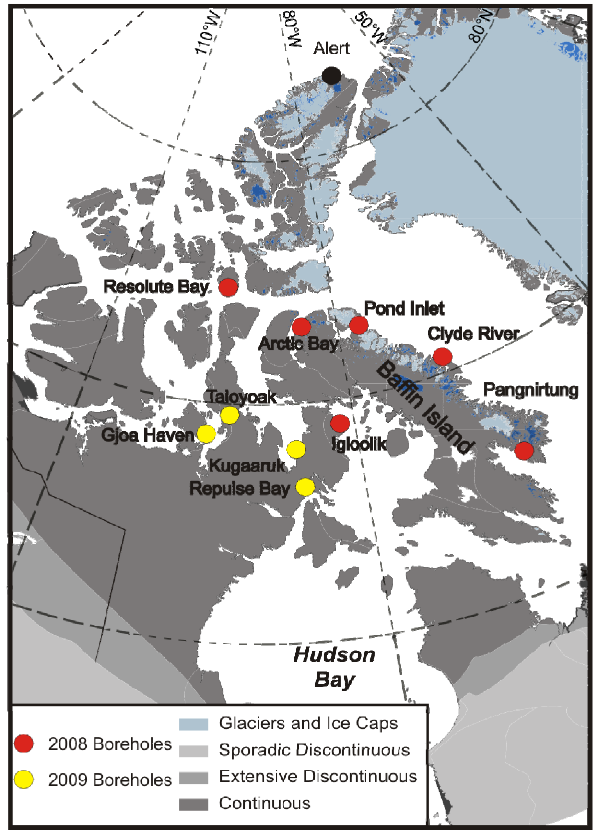

Figure 1. Location of new permafrost monitoring sites in Nunavut superimposed on permafrost map of Canada (from Heginbottom et al. 1995). The long-term monitoring site at Alert is also shown.

circulation in the borehole during drilling meant there was minimal disturbance to the ground thermal regime.

Preservation and instrumentation of boreholes follows procedures utilized by the GSC for recent establishment of monitoring sites in the Mackenzie Valley (e.g. Smith et al. 2007). Boreholes were preserved for temperature measurement through the installation of PVC casing 1-1.5" in diameter. Drill cuttings were used to backfill the space between the casing and the borehole wall. A multi-sensor temperature cable was installed in the casing. Thermistors utilised are YSI 46004, which have an accuracy of ±0.1°C. An eight-channel data logger

Table 1. Characteristics of monitoring sites.

Community	Latitude (ºN)	Longitude (ºW)	MAAT (ºC)[1]	Mean ground temperature (ºC)[2]	Thaw depth (m)	Depth to zero annual amplitude (m)
Resolute Bay	74.7	94.9	-16.4	-12.3	0.8	26.5
Pond Inlet	72.7	77.9	-15.1	-8.5	0.8	17.6
Arctic Bay	73.0	85.2	-15.2	-10.6	1.3	17.4
Clyde River	70.4	38.6	-12.8	-7.2	1.0	16.6
Igloolik	69.4	81.8	-13.2	-8.5	1.2	18.2
Pangnirtung	65.7	68.1	n/a	-5.2	1.9	12.3

[1]Normal mean annual air temperature (MAAT) from Environment Canada 2009
[2]Mean ground temperature at 15 m depth

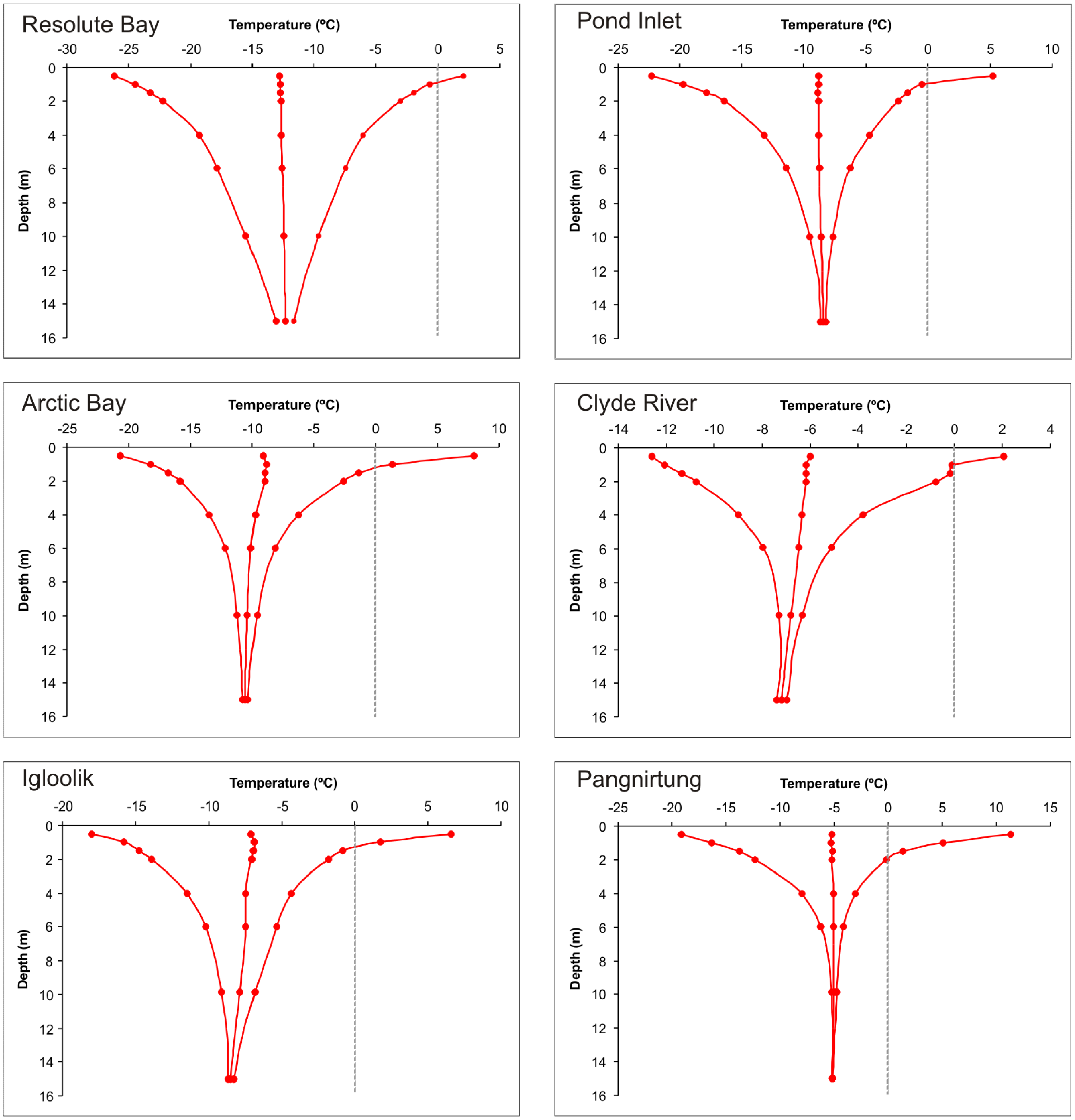

Figure 2. Annual mean, maximum and minimum ground temperatures from first year of data collection (2008-2009).

manufactured by RBR Ltd. was attached to the cable to collect data at eight hour intervals and to provide a continuous record of ground temperatures. The measurement system allows for a resolution of ±0.01℃. A protective cover was placed over the exposed casing and data logger.

Although the loggers are able to collect data for periods of 2 years or longer, it is desirable to acquire data on an annual basis in order to update databases and also to check data logger function. Pre-programmed replacement loggers are provided annually to the community representatives to be exchanged with that presently on the cable. Loggers are returned to GSC for data retrieval, processing and compilation in a database. The processed data is disseminated back to the community and Government of Nunavut. Data were successfully acquired from all six sites in late summer 2009. During the annual site visits, community representatives can also take a manual temperature reading and check the condition of equipment.

4 GROUND THERMAL REGIME

4.1 Data collection and analysis

At least one complete year of continuous data from 2008 through 2009, was collected from each site with the exception of Clyde River, for which an eleven month record was available. Based on visual inspection, any irregular temperature data were removed from the data set. There were also slight effects related to warming of the ground that accompanied the drilling process which resulted in elevated temperatures at the beginning of the record. However, ground temperatures returned to their natural states quickly as there were no latent heat effects to delay the cooling process. Data in the first part of the record were therefore removed from the data set and analysis.

Annual maximum and minimum temperatures were determined for each measurement depth to define the ground temperature envelope for each site (Figure 2). The mean annual ground temperature was also determined for each depth. The maximum annual temperature profile was utilized to determine the maximum summer thaw depth following the procedure described by Riseborough (2008). Depth to zero annual amplitude (depth at which seasonal variation is negligible) was also calculated (Williams and Smith 1989).

4.2 Thermal Data

All six communities are located within the continuous permafrost zones and the Arctic ecozone. All are subject to cold conditions, with mean annual air temperatures for most sites below -10°C (Table 1). Information obtained from deep exploration wells drilled in the 1970s indicates that permafrost in the area of the Baffin Region encompassed by the six communities may be 300 to 600 m thick (Smith and Burgess 2002). The characteristics of the ground thermal regime are shown in Table 1 and Figure 2. Mean annual ground temperatures (at 15 m depth) reflect the cold climate conditions and range from -12 to -5°C (Figure 2 and Table1). A more detailed description of the ground thermal conditions for each of the sites is provided below.

The permafrost monitoring site at Resolute Bay is located adjacent to Environment Canada's weather station. This site is the furthest north of the six with the lowest ground temperature recorded. The surficial material at the site consists mainly of gravel and frost-shattered bedrock and no organic material. After the first year of measurements the average ground temperature is -12.3ºC compared to a 30 year normal mean annual air temperature (MAAT) of -16.4ºC (Table 1). Similar ground temperature ranges between -12 and -15ºC were observed in the Resolute Bay area in exploration wells drilled in the 1970s (see for e.g. Smith and Burgess 2000). The active layer at Resolute Bay is thin (0.8 m). The annual range in ground temperature at a depth of 0.5 m is 28°C and at 15 m the range is about 1.5°C. Seasonal variations therefore propagate to below the deepest sensor and the estimated depth to zero annual amplitude is 26.5 m which is the deepest of all the sites.

The borehole in Pond Inlet is located south of the airport in a flat vegetated area. The ground surface is covered by grasses and is slightly hummocky. Hummocky moraine has been mapped in the area and the glacial till is likely more than 5 m thick (Hodgson and Haselton 1968; Hyatt 1998a). The average ground temperature is
-8.5ºC with a MAAT of -15.1ºC (Table 1). The observed ground temperatures are slightly lower than average ground temperatures recorded (1989-1992) at depths of 7.5 m by Hyatt (1993) at a site located further inland near the water supply lake. The estimated active layer thickness for Pond Inlet is 0.8 m. The annual range in ground temperature at 0.5 m is 27.5°C and there is still an annual range of greater than 0.5°C at 15 m. The estimated depth to zero annual amplitude is 17.6 m.

The Arctic Bay borehole is located less than one kilometre northwest of town next to the road leading to the community water supply on a south-east facing slope. The ground surface immediately surrounding the borehole is non-vegetated and is composed of gravel. A blanket of till covers this area that may be up to 10 m thick (Dyke 2000). The wider area surrounding the borehole is covered by grasses. The closest Environment Canada weather station is at the Nanasivik airport, 8 km from the community of Arctic Bay. The normal MAAT for Nanasivik is -15.2ºC. The average ground temperature at the site is -10.6ºC. The annual range at 0.5 m is 28.6°C and at 15 m it is 0.4°C with the level of zero annual amplitude occurring at a greater depth estimated to be 17.4 m. Deep thaw penetration of about 1.3 m was observed at the site.

The permafrost monitoring site in Clyde River is adjacent to the airport. Surficial materials in the area consist of glacial till. The MAAT is -12.8ºC and the average ground temperature is -7.2ºC. The estimated thaw penetration is 1 m. The annual range in temperature at 0.5 m is 14.6°C and there is still significant variation (0.5°C) at a depth of 15 m and seasonal variation becomes negligible at a depth of 16.6 m.

The location of the borehole in Igloolik is unique due to its position relative to the community. The borehole is located in the center of the hamlet in a fenced off grassy section. The surface is a mix of short grasses and bare soil. Marine deposits cover the area (Dredge et al. 1998). The average ground temperature is -8.5ºC and the MAAT is -13.2ºC. A large annual range in ground temperature (24.6 °C at 0.5 m) in the upper part of the ground is also observed at this site with annual variation extending to greater than 15 m, and an estimated depth to zero annual amplitude of 18.2 m. The active layer is estimated to be 1.2 m thick.

The permafrost monitoring site at Pangnirtung is located close to airport. Surficial materials in this area consist of glacial till greater than 3 m thick which overlies bedrock (Smith et al. 1989). There is no continuous air temperature record from the Environment Canada station in Pangnirtung. Hyatt et al. (2003) reports a mean annual air temperature of -8.9°C but the time period of observations is not provided. The MAAT, based on the most recent Environment Canada data (1996-2009) available from the weather station, is -7.6°C. This is considerably higher than that reported by Hyatt et al. (2003) and the normal MAAT reported for Iqaluit (-9.8°C) which is the closest weather station with a continuous record. Examination of the recent air temperature record suggests that MAAT at Pangnirtung is generally higher than that at Iqaluit. However, the MAAT for 1996-2009 is likely not representative of the 30 year average as warming in the eastern Arctic has occurred since the early 1990s (e.g. Smith et al. 2005). Mean annual ground temperatures at Pangnirtung are warm compared to other sites with an average temperature at 15 m depth of -5.2ºC and an active layer of 1.9 m. This is comparable but higher than average (1988-1991) ground temperatures of -7.5 to -6.5℃ at 15 m depth recorded by Hyatt (1993, 1998b) for sites about 2 km away near the town reservoir. Although the annual range in temperature is still large in the near surface (30℃ at 0.5 m) the annual wave decreases more rapidly with depth compared to other sites (Figure 2) and the depth of the level of zero annual amplitude is 12.3 m.

5 DISCUSSION

Figure 3 shows mean annual ground temperature (MAGT) profiles for the six communities ranging from -5.2℃ in the southern Baffin, Region to -12.3 at Resolute Bay. This falls within the range of -6.5 to -15℃, previously recorded in the 1970s and 1980s for the area encompassed by the six communities (see for example Smith and Burgess 2000). In northern Baffin, conditions are colder where mean ground temperatures at CFS Alert for example are below -13℃ (Figure 3) (Smith et al. 2003; Smith et al. 2010). Ground temperatures show a general decrease with increasing latitude (Figure 4) which reflects the general decrease in air temperature with latitude. Scatter in the latitudinal relationship reflects differences in climatology related to location and site characteristics. However there is less scatter than for the relationship in the discontinuous permafrost zone in the Mackenzie Valley for example (Smith et al. 2010), where ground thermal conditions are strongly influenced by the variability in snow cover and vegetation conditions. Also, the range in ground temperatures observed for the continuous permafrost zone of the Baffin Region (Figure 3) is much greater than that for the discontinuous permafrost zone where temperatures of frozen ground are generally greater than -2.5℃ (Smith et al. 2010).

The large annual range in near surface temperature (Figure 2) reflects the lack of a surface buffer layer at these sites associated with the tundra conditions and likely thin snow cover. The smaller annual range in near surface ground temperatures at Clyde River compared to other sites could be related to a thicker snow cover which would reduce the cooling of the ground in winter. The annual temperature wave propagates to depths below the deepest temperature measurement (15 m) at 5 of the 6 sites (Table 1). The cold permafrost conditions and the lack of latent heat effects associated with phase change result in high apparent thermal diffusivities and deeper penetration of the annual temperature wave. In contrast, in the warmer permafrost of the discontinuous permafrost zone where latent heat effects are more important the annual temperature wave in sediments generally does not penetrate to depths greater than 10 m (Smith et al. 2010). In bedrock, where thermal conductivity is higher, the annual temperature wave can penetrate to depths greater than 20 m as is the case at Resolute Bay. The cold permafrost in the Baffin communities therefore would be expected to be very responsive to changes in climate.

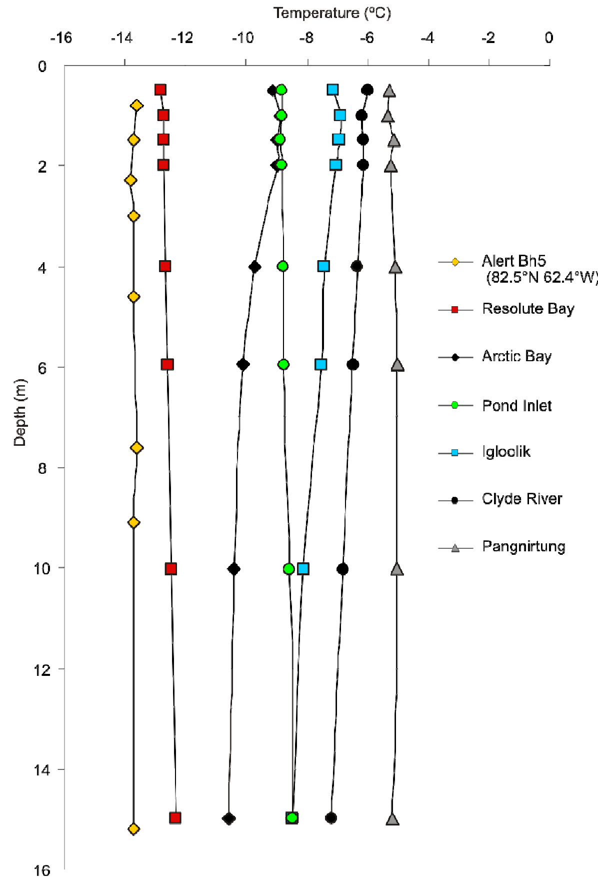

Figure 3. Mean annual ground temperature profiles for the six communities in the Baffin Region and the long-term monitoring site at CFS Alert.

The mean annual ground temperature profiles for Arctic Bay, Clyde River and Igloolik (Figures 2 and 3) indicate that temperatures decrease with depth and are on average 1.3ºC warmer near the surface than at 15 m. This may indicate a recent warming at the surface which could be related to recent increases in air temperature, snow cover or both. Recent increases in ground temperature have been observed in the eastern Canadian Arctic at other sites (Smith et al. 2010). However, only one year of data is available for these community sites and data will needed to be collected for a few years to adequately characterize the current ground thermal conditions and to determine whether there is a general warming of the ground.

6 SUMMARY AND NEXT STEPS

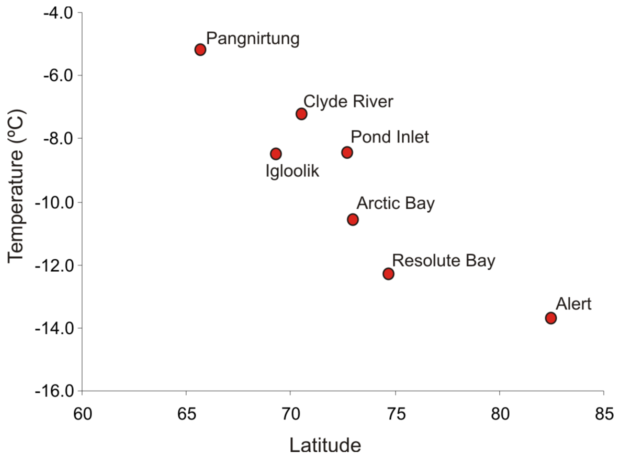

Figure 4. Relationship between MAGT and latitude.

In a region that can only be reached by aircraft making travel expensive, difficult and time consuming, the collaboration with the Government of Nunavut and local communities proved to be an essential tool in developing and maintaining a permafrost monitoring network. Without the sharing of logistics and drilling resources the installation cost of the monitoring sites would have been significantly greater which would have resulted in fewer boreholes and a smaller network. Direct involvement of the community through collaboration with community leaders and members ensures ongoing data collection and maintenance of the monitoring sites while in return providing valuable information about permafrost thermal conditions back to the Government of Nunavut and the communities.

The successful instrumentation of boreholes in the six communities has resulted in the generation of new information on ground thermal conditions where little recent data are available. Only one year of data are available and data will need to be collected for a few more years to adequately characterize the baseline ground thermal conditions. The establishment of these monitoring sites in the Baffin region has filled a gap in our current knowledge of regional permafrost thermal state. The ongoing collection will provide important data that can be used for community infrastructure design and development of climate change adaptation plans. The improved knowledge of the regional conditions is also useful for other purposes such as infrastructure design associated with resource development projects and related land management activities.

Other efforts are currently underway to better characterize permafrost conditions in Nunavut. In 2009, a study was initiated in Pangnirtung which included instrumentation of additional boreholes and collection of soil samples to better characterize the terrain sensitivity in the community (see Leblanc et al. 2010). The permafrost monitoring network was further expanded west into the Kitikmeot and Kivalliq regions of Nunavut (Figure 1) in 2009 following the methods described in this paper. Four more sites were established in Repulse Bay, Kugaaruk (Pelly Bay), Gjoa Haven and Taloyoak (Spence Bay). Collaboration with community planners at the regional level was again essential to establish connections with local SAOs and community leaders. The first data will be collected from these four communities in summer 2010 and will improve our knowledge of regional permafrost conditions in the central Arctic.

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