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Permafrost temperature data 2008-2014 from community based monitoring sites in Nunavut

M. Ednie and S.L. Smith

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Canada

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ABSTRACT

The Geological Survey of Canada collaborated with Nunavut communities and the territorial government to establish ten permafrost monitoring sites between 2008 and 2009. A summary of ground temperature data collected over a five year period is presented as a digital database. This information improves the characterization of permafrost thermal state and support climate change adaptation planning in Nunavut communities. Records of permafrost temperature indicate that mean annual temperatures at 15 m depth range from -5.06 °C in Pangnirtung to -11.93 °C in Resolute Bay. In the approximately 5 years since site establishment, ground temperatures at 15 m depth have increased between 0.04 ºC/year and 0.25 ºC/year with an average increase of 0.17 ºC/year for all sites.

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INTRODUCTION

Knowledge of permafrost thermal state is essential for sound design of infrastructure in the Canadian North and for ensuring its integrity under a warming climate. As part of an International Polar Year project, the Geological Survey of Canada collaborated with Nunavut communities and the territorial government to establish six permafrost monitoring sites in 2008 in the Baffin Region communities of Pangnirtung, Clyde River, Igloolik, Pond Inlet, Arctic Bay, and Resolute Bay (Figure 1, Ednie and Smith, 2010). In 2009, four monitoring sites were established in Kivalliq (Repulse Bay) and the Kitikmeot (Taloyoak, Gjoa Haven and Kugaaruk) regions of Nunavut. These monitoring sites were a key enhancement to the existing national permafrost monitoring network (Smith et al., 2010a). Baseline permafrost information provided to community planners and engineers facilitates the design and the development of adaptation strategies to cope with the impacts of climate change on community infrastructure and lifestyles. This Open File presents a summary of the ground temperature data collected from the monitoring sites over the past five years as well as a digital database of monthly ground temperatures. A poster describing the permafrost monitoring network in Nunavut is included in appendix A. A full size high resolution Portable Document Format (.PDF) version of the poster also accompanies the Open File.

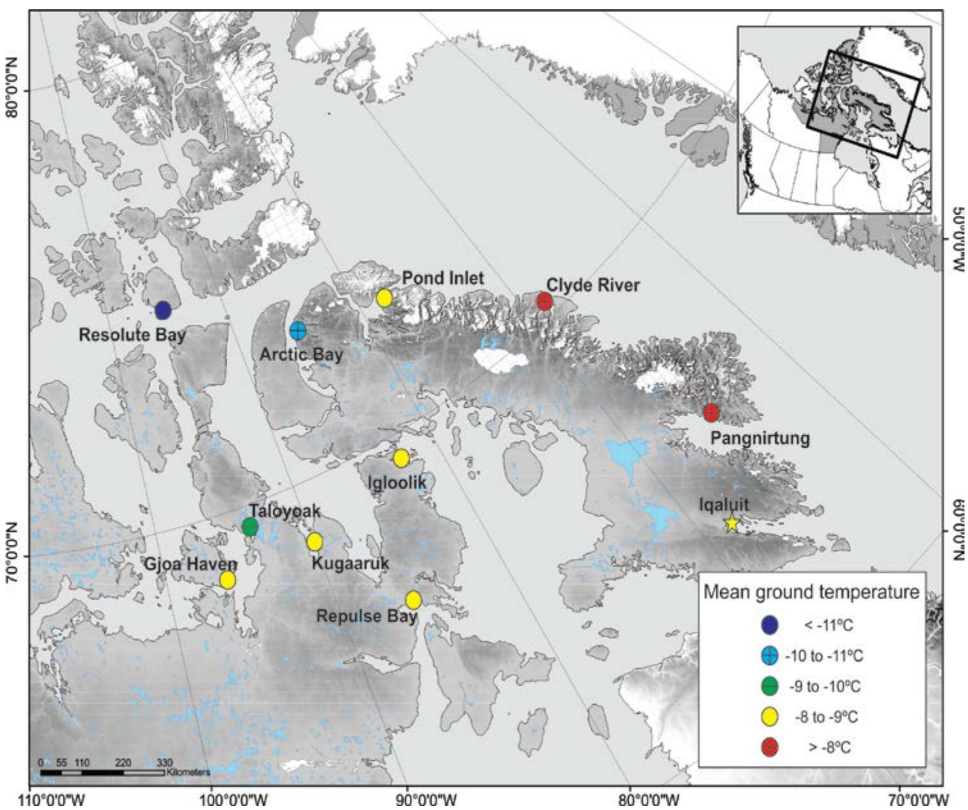

Figure 1. Mean ground temperature at 15 m depth for Nunavut community monitoring sites.

SITE DESCRIPTION AND INSTRUMENTATION

The ten communities (Figure 1) are all located within the continuous permafrost zone and Arctic ecozone with mean annual air temperature generally below -10 °C with the exception of Pangnirtung (Table 1). A borehole (15 m deep) was drilled in each community in collaboration with the Nunavut Department of Community and Government Services (Ednie and Smith 2010, 2011). The boreholes are located within Hamlet administrative boundaries and/or near airport weather stations (Environment Canada's weather stations). The close proximity of the permafrost monitoring sites to the hamlets facilitates the collection of data from these monitoring sites by community members.

The majority of the boreholes were drilled in relatively undisturbed terrain consisting of sparse vegetation over a thin layer of mineral soil and/or bare surface (natural terrain or gravel pad) underlain by till or fractured bedrock. A summary of regional surficial material in the vicinity of each borehole is presented in Table 2.

Ground temperatures are measured to depths of 15 m using a multi-thermistor (YSI 44033) temperature cable deployed in a borehole casing. A multi-channel datalogger (RBR Ltd.) connected to the cable collects data every eight hours, providing continuous data collection. The measurement system allows for a resolution of ±0.01 °C. For a more detailed description of equipment and data collection methodology see Ednie and Smith (2010, 2011). Data collection periods for each site are summarized in Table 1.

Table 1. Characteristics of permafrost monitoring sites.

Community	Latitude (°N)	Longitude (°W)	Mean Annual Air Temperature (MAAT)[1]	Ground temperature (°C)[2]	Active layer thickness (m)[3]	Data collection period
Resolute Bay	74.72	94.97	-15.7	-11.93	1.02	June 2008-Sept 2012
Arctic Bay	73.04	85.15	-14.8	-10.21	1.19	Aug 2008-Aug 2013
Pond Inlet	72.69	77.97	-14.6	-8.20	1.04	July 2008-Aug 2013
Clyde River	70.49	68.52	-12.6	-6.90	0.95	Nov 2008-Aug 2009 / Dec 2010-Oct 2012
Taloyoak	69.49	93.58	-14.3	-9.68	1.84	Jan 2010-Nov 2011
Igloolik	69.38	81.80	-13.3	-8.42	1.39	July 2008-Sept 2011
Gjoa Haven	68.63	95.88	-14.4	-8.70	n/a, failed sensors	Jan 2012-Dec 2012
Kugaaruk	68.54	89.80	-13.5	-8.22	1.49	Nov 2009-Apr 2012
Repulse Bay	66.52	86.24	-12.1	-8.24	1.19	Oct 2009-Aug 2013 Cable destroyed
Pangnirtung	66.14	65.71	-7.6[4]	-5.06	1.90	July 2008-Oct 2010 / Mar 2012-Mar 2014

1 Mean annual air temperature from 1981-2010 climate normal (Environment Canada, 2015).

2 Average ground temperature at 15 m depth for the entire data collection period.

3 Mean active layer thickness for entire data collection period.

4 Mean annual air temperature available only for 1996-2009; In comparison, Iqaluit 1981-2010 climate normal is -9.3ºC (Environment Canada, 2015). Air temperatures records suggest that Iqaluit MAAT is general lower than Pangnirtung (Ednie and Smith, 2010).

Table 2. Summary of regional surficial materials and surface characteristics of boreholes.

Hamlet	**Surficial Geology**	**Source**	**Surface characteristics**
Resolute Bay	Gravel and frost shattered limestone and dolomite bedrock of Ordovician to Devonian age.	Edlund, 1991	Frost shattered bedrock surface with no vegetation.
Arctic Bay	Till ≤ 10 m thick.	Dyke, 2000	Surface consists of gravel and short grasses. The borehole is located on a south facing slope.
Pond Inlet	Glacial till consisting of sands and silts >5 m in thickness with some boulder sized material.	Haselton and Hodgson, 1974	Hummocky grassy plain.
Clyde River	Glacial marine deltaic material consisting of sands, silts and gravels.	Smith et al., 2012	Ice wedge polygons are present.
Taloyoak	Till veneer between 0.5 to 2 m in thickness.	Boydell et al., 1984	Located at Environment Canada's weather station at airport.
Igloolik	Marine littoral deposits consisting of gravels and sands.	Dredge et al., 1998; Dredge, 1992	Surface consists of a combination of short grasses and bare soil.
Gjoe Haven	Exposed beach ridges composed of sands and gravels.	Helie, 1984	Located at Environment Canada's weather station at airport (gravel surface).
Kugaaruk	Pelly Bay uplands formation consisting of exposed igneous and metamorphic bedrock of Precambrian age	Boydell et al., 1984	Located at Environment Canada's weather station at airport (gravel surface).
Repulse Bay	Offshore and sub-littoral deposits of stratified sands and silts ranging from 1-10 m in thickness.	Dredge, 1994	Located at Environment Canada's weather station at airport (gravel surface).
Pangnirtung	Colluvial blanket (sands and gravels up to 4 m in thickness) over littoral to nearshore sediments (gravels, sands and silts 2-15 m in thickness).	Dyke, 2011; Carbonneau et al., 2012; Leblanc et al., 2011	Located at Environment Canada's weather station at airport (gravel surface).

DATA PROCESSING AND PRESENTATION

Data were acquired for the period 2008-2014 for the Baffin boreholes and 2009-2013 for the Kivaliq and Kitikmeot boreholes (Table 1). Some temperature records have gaps due to datalogger or thermistor cable malfunction. The datasets were visually inspected and irregular temperature data were removed. Daily average temperatures were calculated for each measurement depth and monthly average permafrost temperatures were determined using the daily averages. For each site, annual maximum, minimum and mean temperatures were determined for each depth. The annual maximum temperature profile was utilized to determine the maximum summer thaw depth (active layer thickness) using the method described by Riseborough (2008).

Average monthly ground temperatures are compiled in the accompanying MS Excel spreadsheet titled "Nunavut mean monthly ground temperatures.xlsx". A separate worksheet is provided for each community within the single spreadsheet. For each sensor depth the average monthly ground temperature (°C) is provided.

RESULTS AND DISCUSSION

Ground temperature envelopes (Figure 2) indicate that there is considerable annual variation in shallow ground temperatures due to the lack of a surface buffer layer such as organic material and snow cover. The annual temperature wave propagates below (i.e. below the depth of the zero annual amplitude, ZAA) the maximum measurement depth for all sites except Pangnirtung where the ZAA depth is close to 15 m. Mean annual ground temperature (MAGT) at 15 m depth ranges from -5.06 °C in Pangnirtung to -11.93 °C in Resolute Bay (Figure 2, Table 1) and generally decreases northward (Figure 3a).

Active layer thicknesses were calculated for all permafrost monitoring sites with the exception of Gjoa Haven, where the top 4 sensors failed. Active layer thickness ranges from 1.90 m in Pangnirtung to 0.95 m in Clyde River (Table 1), with considerable inter annual variability at some sites (Figure 3b) especially in Resolute Bay. Active layers are thinner at the more northerly sites (Figure 3b).

There can be considerable variability in permafrost temperatures across Nunavut, at both regional and local scales. At a local scale, observed MAGTs can range from -3.6 °C to -9.5 °C over ~ 40 km^2 area (Smith et al., 2013). Leblanc et al. (2011) found that MAGTs around Pangnirtung varied between -2.8 °C and -7.1 °C depending on surficial geology and snow thickness. Active layer thickness was similarly variable, ranging from 0.75 to 2.5 m. Local ground temperature variations are attributed to a number of factors which include proximity of water bodies, topography, vegetation cover and snow cover thickness (Smith et al., 2010b).

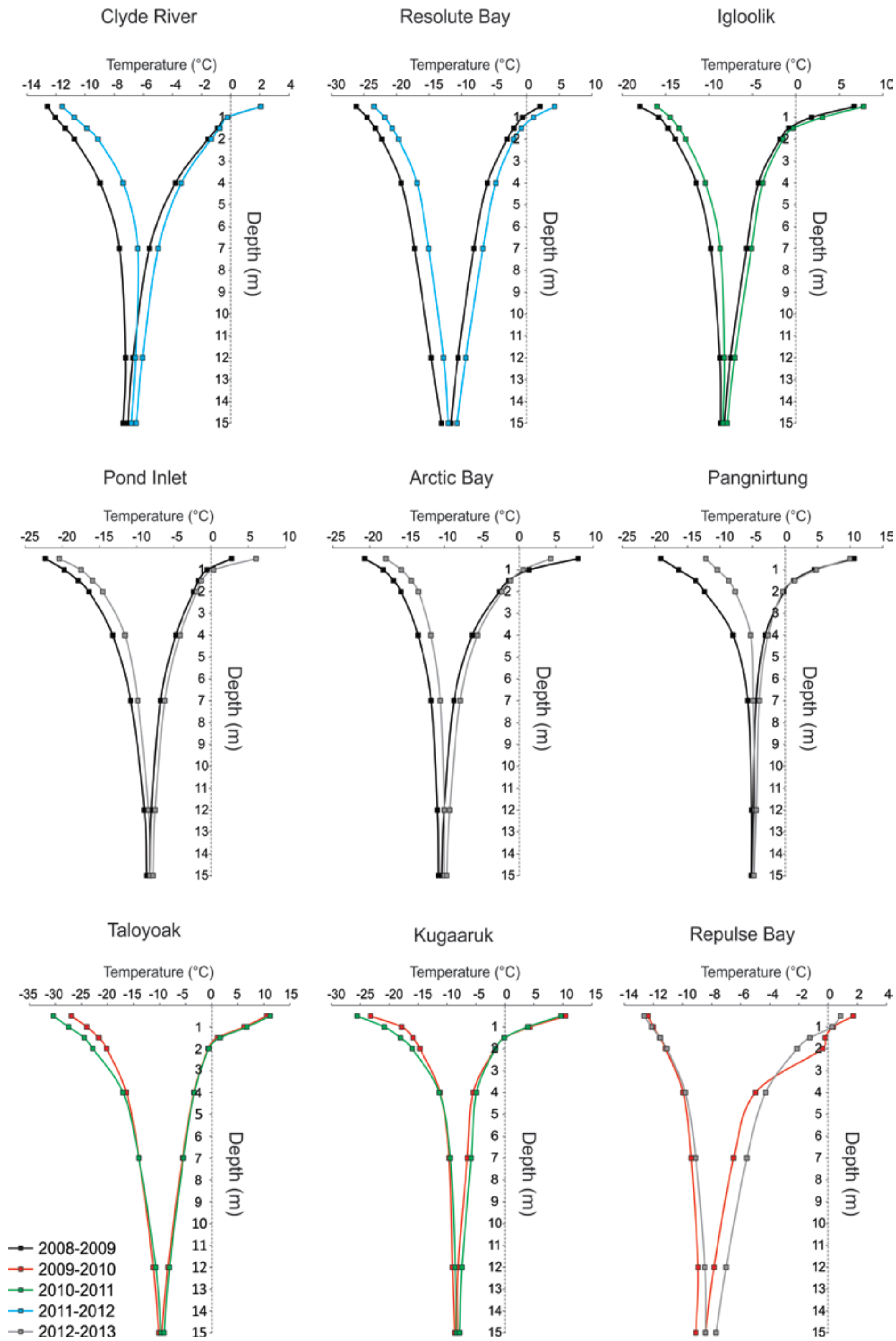

Figure 2. Annual ground temperature envelopes for 9 boreholes in Nunavut. The envelope for the first and last year of available record is shown. The envelope for Gjoa Haven is not shown due to incomplete data series.

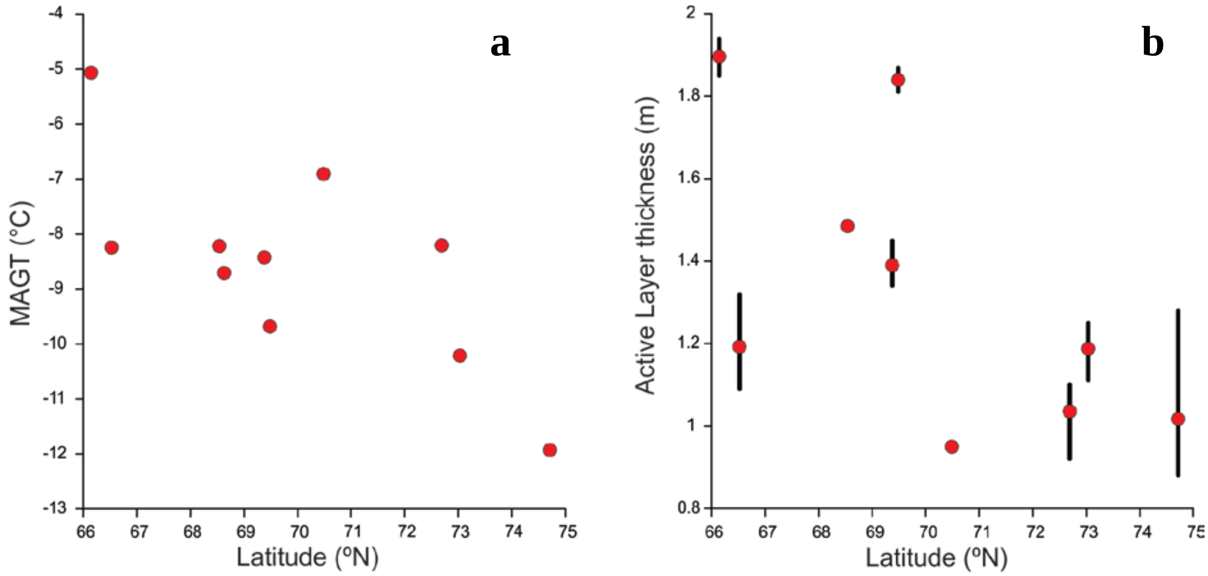

Figure 3. a) MAGT at 15 m depth and b) average of maximum active layer thickness and range (inter annual variability) for the period of record.

Permafrost temperatures at 15 m depth have increased since boreholes were instrumented in 2008 and 2009 (Figure 4). At 15 m depth, the rate of permafrost warming varies from 0.04 °C/year in Igloolik to 0.25 °C/year in Resolute Bay with an average of about 0.17 °C/year for all 10 sites. The observed permafrost warming is consistent with the changes in air temperature for the region. In recent years, air temperatures have increased with some of the warmest temperatures occurring since 2008 (Figure 5). The recent rapid changes in permafrost temperature in some communities may be attributed to the lack of a ground surface buffer from changes in air temperature i.e. lack of vegetation and/or lack of ice bearing fine grain sediments (Throop et al., 2012). Although long-term records are limited, information available from other boreholes indicates that there is a general warming of permafrost in the eastern and high Arctic (Smith et al., 2010a,b; Romanovsky et al., 2014).

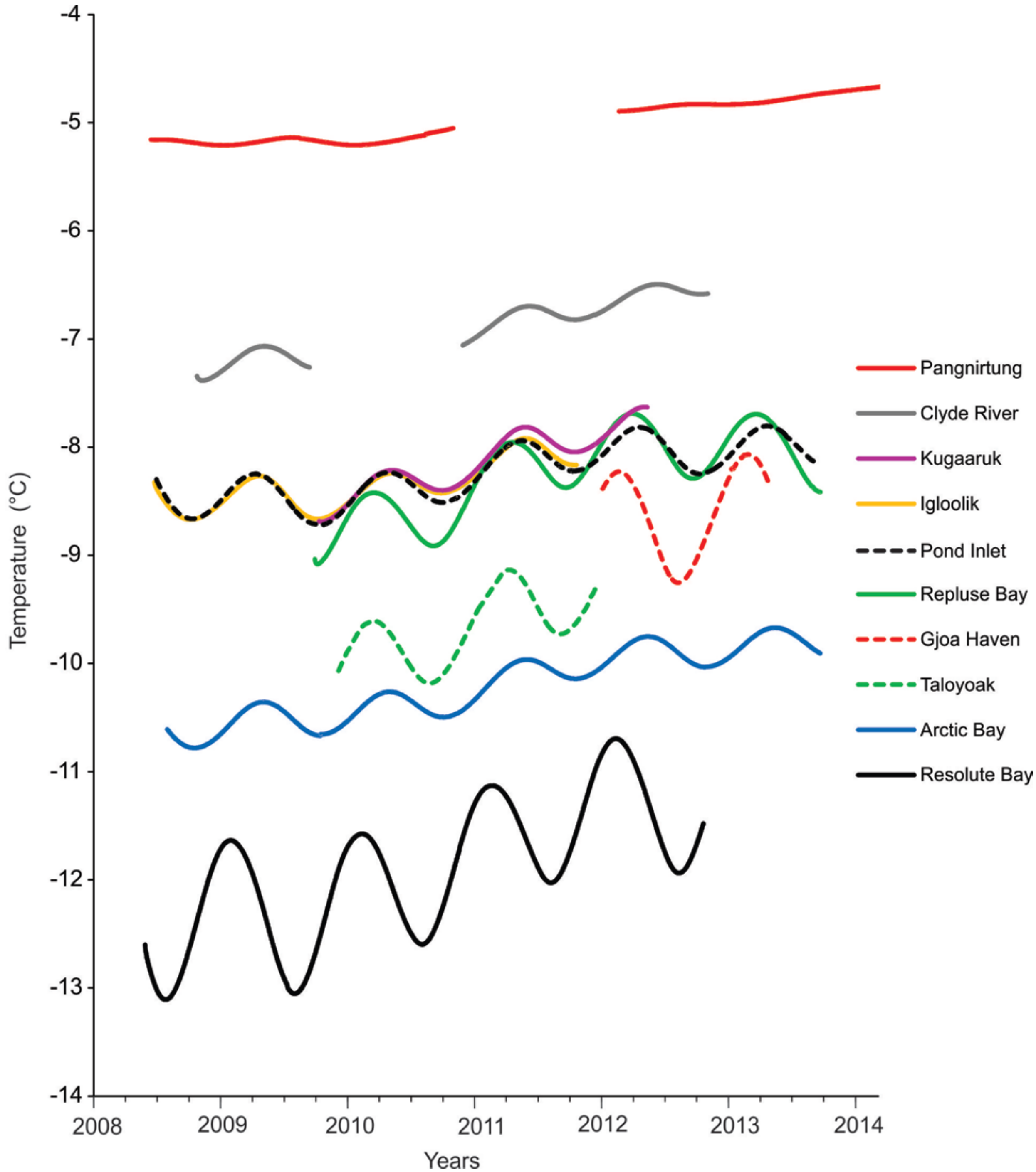

Figure 4. Continuous ground temperatures measured at 15 m depth for 10 communities in Nunavut.

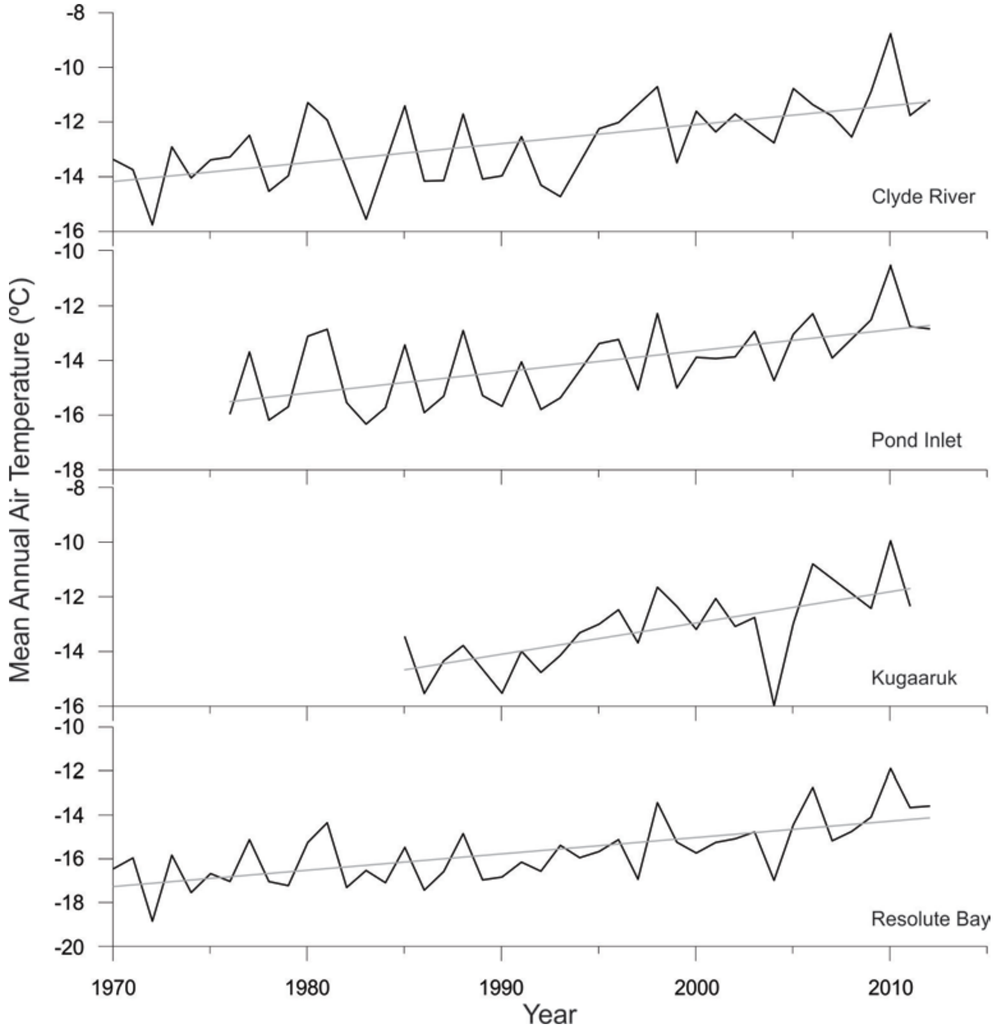

Figure 5. MAAT (1970-2012) for Clyde River, Pond Inlet, Kugaaruk and Resolute Bay (Environment Canada, 2015). The gray line represents the best fit (linear regression) line (significant to a 95% confidence interval).

SUMMARY

The community permafrost monitoring sites have generated information on permafrost thermal conditions, contributing to a better understanding of regional permafrost conditions in Nunavut. The ground temperature records indicate that permafrost is warming in the region. Continued data collection, with the help of our community partners, will facilitate better assessments of climate change impacts. The publicly available database provides essential baseline information to community planners and decision makers and facilitates the development of adaptation strategies to cope with impacts of climate change on community infrastructure and lifestyles.

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APPENDIX A

Poster presented at Arctic Change 2014 Conference, Ottawa, December 8-12 2014