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Ground thermal data collection along the Alaska Highway easement (KP 1559-1895) Yukon, summer 2014

S.L. Smith and M. Ednie

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Canada

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ABSTRACT

Ground temperature data were acquired in summer 2014 from eight boreholes instrumented in summer 2013 along the Alaska Highway easement between KP1559 and the Alaska border. Permafrost was found to be present at six boreholes and was generally at temperatures above -0.7°C except near the Alaska border where permafrost temperature was -3°C. Summer thaw depths at permafrost sites range from 0.8 to 2.4 m. A warm period in January 2014, during which air temperatures rose above 0°C, appears to have had an impact on shallow winter ground temperatures at most sites. The information provided contributes to the characterization of regional permafrost conditions and supports decisions regarding development projects in the region, climate change assessments and adaptation planning.

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INTRODUCTION

The Alaska Highway Corridor traverses the discontinuous permafrost zone of the southern Yukon from the Alaska border to northern British Columbia. Proposals for a natural gas pipeline and the need to develop climate change adaptation options for infrastructure such as the highway have stimulated the need for up to date information on permafrost and terrain conditions within the corridor. Construction and operation of infrastructure associated with development projects can result in changes to the ground thermal regime resulting in thaw settlement, frost heave, drainage alteration and landscape instability which may affect infrastructure integrity and have consequences for terrestrial and aquatic ecosystems. Knowledge of current permafrost conditions in the corridor is essential to characterize terrain response to construction and operation of infrastructure and to ensure the integrity of both the infrastructure and the environment is maintained. Although a great deal of information on permafrost conditions including its thermal state was collected in the late 1970s to support a previous pipeline proposal (e.g. Burgess et al. 1982), there is limited information on current ground temperature conditions in the corridor. Changes in permafrost conditions over the last three to four decades have been documented along the Alaska Highway corridor between Whitehorse YT and Fort St. John BC (e.g. James et al., 2013) and elsewhere in northern Canada (e.g. Smith et al., 2010). Therefore, improved knowledge of current permafrost conditions and how they may change over time is required to ensure that development projects and infrastructure in this region are designed appropriately for current and future conditions.

The Geological Survey of Canada (GSC) acquired, from TransCanada Pipeline Ltd., a suite of cased boreholes located on the Alaska Highway easement between the Alaska border and KP1559 near Haines Junction (Figure 1). Boreholes were instrumented, to measure ground temperatures, in July 2013 by GSC in collaboration with the Yukon Department of Highways and Public Works, Yukon Research Centre and Yukon Geological Survey. In late July and early August 2014, field sites were visited to acquire data from the loggers. This report describes the fieldwork conducted in summer 2014, and provides a summary of the ground thermal data collected from the field sites.

STUDY SITES AND INSTRUMENTATION

The field sites are located on the highway easement between approximately KP1559 and KP1895 (Figure 1). The study area is located within the Western Cordillera and the highway corridor crosses (east to west) the Teslin and Kluane Plateau over the Shakwak Trench and follows the Kluane Ranges (Mathews, 1986). Elevation in the region is variable reflecting the numerous mountains, valleys and plateaus. However the highway corridor itself is less variable in elevation than the surrounding area with elevation of the study sites ranging from approximately 600 to about 850 m a.s.l. Most of the area has been glaciated although some areas around Beaver Creek remained ice free (Duk-Rodkin 1999; Rampton 1969, 1971). The glacial history of the region is described by Bond (2004), Duk-Rodkin (1999), Fulton (1989), Jackson et al., (1991), Rampton (1969, 1971) and summarized in Smith and Ednie (2013).

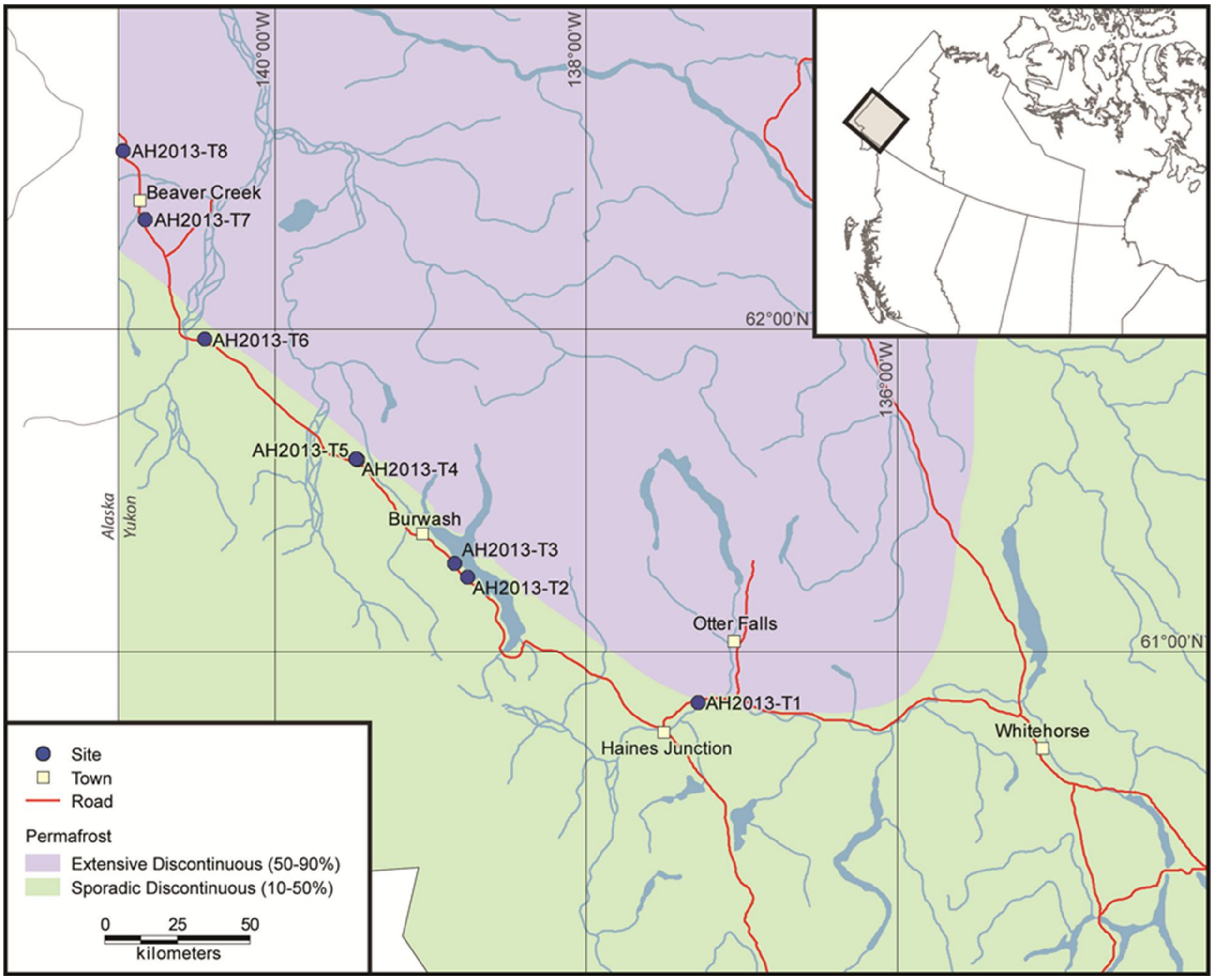

Figure 1. Location of boreholes along Alaska Highway easement instrumented for ground temperature measurement in summer 2013. Permafrost zones (from Heginbottom et al. 1995) are also shown.

Surficial materials in the study area vary from coarse-grained sands, gravels and tills, associated largely with moraine and outwash deposits, to fine-grained silts and clays associated with alluvial and lacustrine deposits (Fuller and Jackson, 2009; Clague, 1989). Peat, generally less than 5 m thick is found in large areas that are poorly drained (Clague, 1989; Foothills Pipe Lines, 1979). Sediment thickness generally exceeds 10 m in the section of the corridor where the boreholes are located (Foothills Pipe Lines, 1979). According to terrain analysis presented in the Environmental Impact Statement for the original pipeline application (Foothills Pipe Lines, 1979), peat was observed in about 35% of the terrain in the section of the corridor within about 370 km of the Alaska border where the study sites are located.

The climate in the southern Yukon is subarctic continental, with cold winters and short mild summers (Jackson et al., 1991). Climate data for Environment Canada weather stations between Whitehorse and the Alaska border (Whitehorse, Haines Junction, Burwash and Beaver Creek) can be used to characterize the climate in the Alaska Highway Corridor. Mean annual air temperature (based on 1981-2010 Normals, Environment Canada, 2015) ranges from -0.07°C at Whitehorse to -4.87°C at Beaver Creek. Mean January air temperature ranges from -15.5°C at

Whitehorse to -25.21°C at Beaver Creek. Mean July temperatures are lower at Haines Junction and Burwash (7.24°C and 13.06°C respectively) compared to Whitehorse and Beaver Creek where they are about 14°C. Mean total annual precipitation is greater in the western portion of the corridor, where it exceeds 400 mm, compared to Whitehorse which receives 262 mm. The proportion of total precipitation that falls as snow is 30-40%. Monthly mean air temperature for the July 2013 to July 2014 period is shown in Figure 2 for the Environment Canada weather stations at Whitehorse, Haines Junction and Burwash Landing. Of note is the increase in air temperature during January 2014 for all stations. Daily air temperature records indicate that temperatures during January 2014 rose above 0°C with maximum temperatures of 11°C, 16.5°C and 13°C at Beaver Creek, Burwash and Haines Junction respectively. Temperatures were above 0°C for 3 days in January 2014 at Beaver Creek and for 12 days at Burwash and Haines Junction.

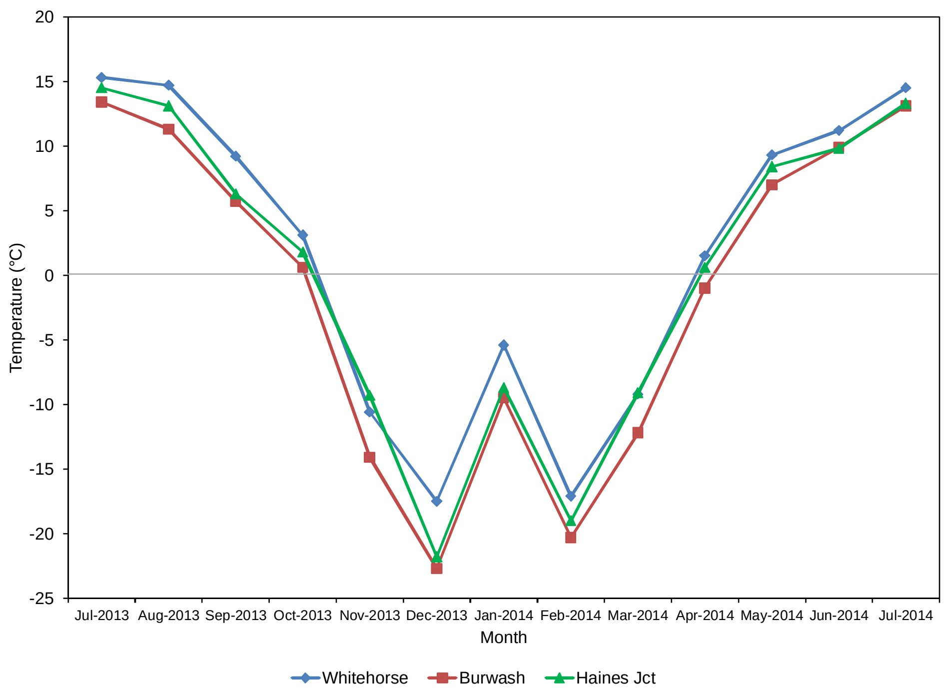

Figure 2. Mean monthly air temperatures July 2013 to July 2014 for Environment Canada stations at Whitehorse, Haines Junction and Burwash Landing (data from Environment Canada, 2015).

The highway corridor is located largely within the sporadic discontinuous permafrost zone (Figure 1, Heginbottom et al., 1995), except for the portion that is within about 50 km of the Alaska border which falls within the extensive discontinuous zone. Studies done in the 1970s for the Environmental Impact Statement for the proposed pipeline indicate that north of Kluane Lake, permafrost is nearly continuous with taliks present under major streams and lakes and isolated south facing slopes (Foothills Pipelines, 1979). Modelling studies by Bonnaventure et al. (2012) also predict continuous permafrost in this area. South of Kluane Lake permafrost is less abundant, becoming patchy near Whitehorse where it is largely limited to organic terrain (James et al, 2013; Lewkowicz et al., 2011). Observations from geotechnical investigations and ground temperature measurements in the 1970s, indicate that permafrost is generally less than 20 m thick in the corridor and in many places it is less than 10 m thick (Burgess et al., 1982; Smith and Burgess, 2002) although Foothills Pipelines (1979) reported that permafrost thickness exceeds 45 m near the Alaska border. Recent surveys utilizing Electrical Resistivity Tomography in the corridor indicate that permafrost is thicker than 20 m in sections of the corridor between Burwash Landing and the Alaska Border (Duguay, 2013). Shallow temperature measurements made within the corridor between 1978 and 1981 indicate that mean annual ground temperatures are generally above -3°C (Burgess et al., 1982). More recent temperature information along the corridor (2011-12) as well as regional data (2008-09) for the southern Yukon, including that from higher elevations, also indicates warm permafrost conditions with temperatures approaching 0°C for the section of the corridor between Whitehorse and the BC border (Blais-Stevens et al., 2013; Duguay, 2013; Duguay et al., 2012; Lewkowciz et al., 2011; Smith et al., 2010).

Locations of the eight boreholes are shown in Figure 1 and a brief site description is provided in Table 1. Boreholes are located on the highway easement, 10 to more than 30 m from the existing highway, with many located in or near previously disturbed areas. Photos of sites as well as air photos showing borehole location are provided by Smith and Ednie (2013).

Table 1. Site description and location.

Site	Latitude (°N)	Longitude (°W)	Approx. KP	Site Description	Soil description	Instrumentation
AH2013-T1	60.840	137.278	1559.6	Disturbed area between highway and old road	Silt (<1m) underlain by sand	HOBO logger with sensors installed to 4.95 m
AH2013-T2	61.232	138.762	1681.4	Open area with shrubs on edge of conifer forest	Organic silt (~1 m) over sandy till	RBR logger and Multi-thermistor cable installed to 9.67 m
AH2013-T3	61.273	138.847	1687.7	10-15 m from embankment, open area with shrubs, ground cover, hummocky, edge of conifer (black spruce) forest	Organic silt (~1 m) underlain by silt	RBR logger and Multi-thermistor cable installed to 7.43 m
AH2013-T4	61.595	139.468	1741.9	Shrub and grass covered area adjacent to open forest	Sand (some gravel) underlain by ice rich silt at 8.5 m depth	RBR logger and Multi-thermistor cable installed to 8.36 m iButton (Snow depth measurement).
AH2013-T5	61.598	139.477	1742.6	Shrub and grass covered area on edge of forested area	Organic silt (~1 m) underlain by sand	HOBO logger with sensors installed to 4.85 m
AH2013-T6	61.970	140.452	1812.5	Open area with small conifers, shrubs (re-growth)	Surface organic layer (0.1m) Ice-rich silt underlain by sand at 4 m depth	RBR logger and Multi-thermistor cable installed to 8.82 m
AH2013-T7	62.340	140.833	1865.3	Open mixed forest	Surface organic layer (5 cm) Organic silt to ~1 m depth, Ice-rich silt underlain by till at 6 m depth	RBR logger and Multi-thermistor cable installed to 9 m iButton (Snow depth measurement)
AH2013-T8	62.554	140.974	1894.5	Hummocky with small spruce, shrub, willow	Organic layer (0.1 m) Peat and ice-rich silt extends to borehole bottom	RBR logger and Multi-thermistor cable installed to 9.94 m

Cased boreholes up to 10 m in depth, were instrumented in summer 2013 with thermistor cables (see Smith and Ednie, 2013 for more details). At six of the boreholes (Table 1), cables with eight sensors (accuracy better than ±0.1°C) were attached to eight channel data loggers manufactured by RBR Ltd (resolution better than ±0.01°C) to record temperature measurements at eight hour intervals. Two of the shallower boreholes (AH2013-T1, AH2013-T5) were instrumented with 4-channel HOBO Microstation loggers (manufactured by Onset Corp.) connected to HOBO 12-bit temperature sensors to measure temperatures at four hour intervals. The accuracy and resolution of this system is better than ±0.2°C and ±0.03°C respectively.

At two sites (AH2013-T4 and AH2013-T7) a series of nine Thermochron iButton temperature loggers (accuracy ±1°C) mounted on a wooden stake were installed to measure snow depth (Table 1). The iButton sensors were spaced at 5, 10, 20, 30, 40, 50, 60, 80 and 100 cm above the ground surface. Snow depths are inferred through analysis of temperature patterns at each height as described by Lewkowicz (2008). Resolution of the system depends on the sensor spacing.

FIELD WORK CONDUCTED IN SUMMER 2014

Field sites were visited between July 30 and August 1 2014. At the six boreholes instrumented with RBR loggers, manual measurements of resistance at multi-sensor cables were made using a Fluke Multimeter and later converted to temperatures (system resolution 0.01 – 0.02 K). Live readings of ground temperatures were also made at the two HOBO Microstations. Manual readings are utilized to check operation of sensors and loggers and supplement the logger readings (and ensure that at least one record is available if the logger fails). RBR loggers were removed in order to download data and replaced with programmed loggers. HOBO Microstations were downloaded in the field. The iButton loggers were also removed to extract data and replaced with pre-programmed loggers.

DATA PROCESSING AND PRESENTATION

Data were acquired from all loggers and a one year record of ground thermal data is now available for all eight boreholes. Data records were visually inspected and erroneous data were removed. Daily mean temperatures were calculated and utilized to determine the annual maximum, minimum and mean temperature for each depth for the July 15, 2013 – July 14, 2014 period. The annual maximum and minimum temperature profiles define the ground temperature envelope. At permafrost sites the maximum temperature profile may be utilized to determine the summer thaw depth while the depth of winter frost penetration can be determined from the minimum annual temperature profile for non permafrost sites. Monthly mean ground temperatures at each measurement depth were also calculated for each borehole.

The temperature records obtained from the iButton loggers were analysed to determine the daily snow depth at AH2013-T4 and AH2013-T7. The method is based on comparison of temperatures measured in the atmosphere and beneath the snow surface as described by Lewkowicz (2008).

Detailed graphical and tabular presentation of the data collected for each site including ground temperature envelopes, monthly mean temperature and summer thaw depth or frost depth are provided in the Appendix. A summary of the data collected is provided below.

RESULTS

Ground temperatures determined from the manual readings during the site visit are shown in Figure 3. Unfrozen conditions were observed at T1 and a thin frozen layer, corresponding to the base of the seasonal frost layer (about 1.5 m) was still present at T2. Frozen conditions were found at all other boreholes. Mean annual ground temperature profiles for 2013-14 are presented in Figure 4 and indicate unfrozen conditions exist at T1 and T2 with permafrost existing at the other six sites (Table 2). At sites where permafrost exists, the base of permafrost is deeper than the borehole depth except at T4 where the base of permafrost is about 8 m (Figure 4).

Ground temperature envelopes for each site are presented in the Appendix and define the range in temperature at each measurement depth. These data can be utilized to determine the depth of zero annual amplitude (ZAA) which for practical purposes can be defined as the depth where the annual temperature variation is less than 0.1°C (Williams and Smith, 1989). The ZAA depth is greater than the deepest measurement depth for T1, T2, T5, T8 and ranges from 1.93 m (T3) to 6.0 m (T7) at the other boreholes (Table 2). The depth to ZAA is generally shallower where permafrost is at temperatures close to 0°C.

Annual mean ground temperature at the depth of ZAA or the deepest measurement depth ranges from 4.38°C to -3°C (Figure 4, Table 2). Generally colder conditions are found closer to the Alaska Border (Figure 5) with the lowest mean ground temperature found at T8. Following installation of the temperature cable at T8 in 2013, a ditch was excavated, by the Department of Highways, adjacent to the embankment about 3 m from the borehole (Figure 6). It is not clear from the available data whether the excavation had any impact on the ground temperatures at this site. The temperature measured at 9.9 m depth in July 2014 (-3.27°C) is slightly lower than that measured during cable installation in July 2013 (-3.01°C, Smith and Ednie 2013) but there is an annual range in temperature at that depth of about 0.4°C.

Table 2. Summary of ground thermal conditions at instrumented sites. Annual mean ground temperature is near the depth of zero annual amplitude (ZAA) or at deepest measurement depth (indicated by "*" for measurement depth) if depth of ZAA is not reached. Maximum summer thaw depth for permafrost sites or depth of winter frost penetration for non-permafrost sites is also provided.

Borehole	Annual Mean Temperature (°C)	Measurement Depth (m)	Permafrost Y(es) or N(o)	Thaw Depth or Frost Depth (m)
AH2013-T1	4.38	4.95 *	N	1.74
AH2013-T2	1.97	9.67*	N	1.54
AH2013-T3	-0.19	1.93	Y	1.45
AH2013-T4	-0.37	4.36	Y	2.36
AH2013-T5	-0.31	4.95*	Y	1.80
AH2013-T6	-0.33	3.82	Y	2.40
AH2013-T7	-0.67	6.0	Y	0.86
AH2013-T8	-3.0	9.94*	Y	0.88

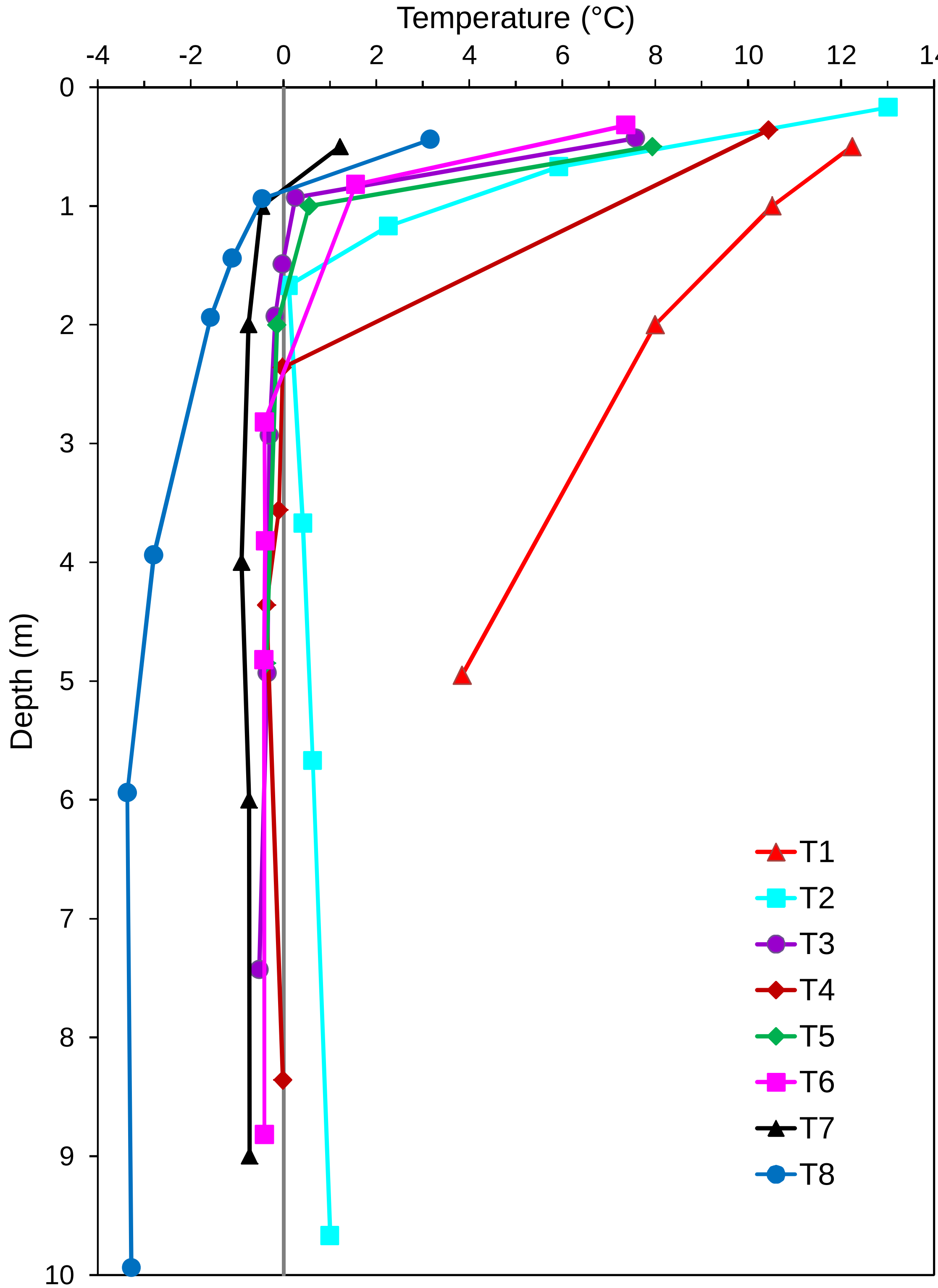

Figure 3. Ground temperatures measured during sites visits between July 30 and August 1, 2014.

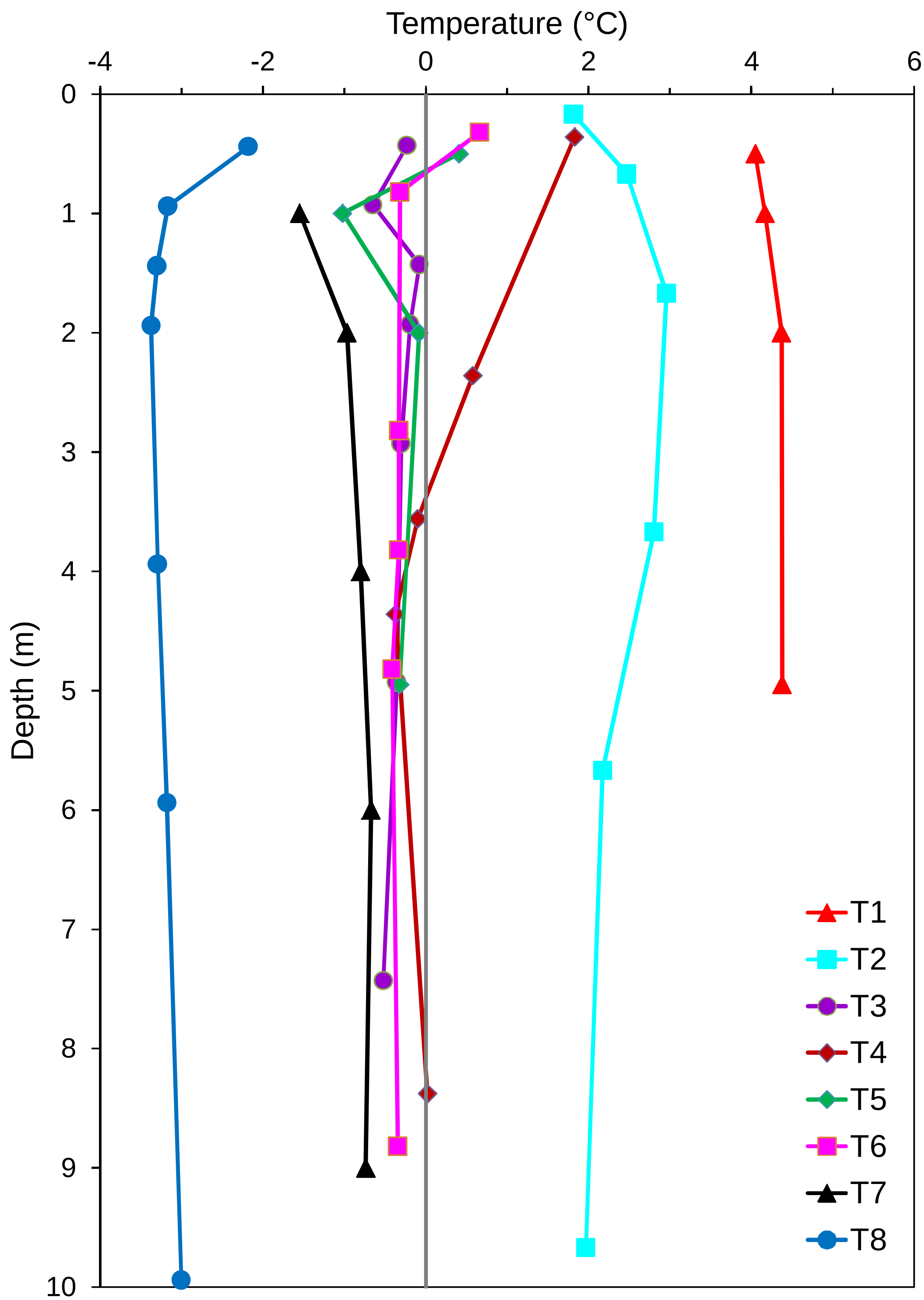

Figure 4. Annual mean ground temperature profiles for 2013-14 (July 15 2013 to July 14 2014).

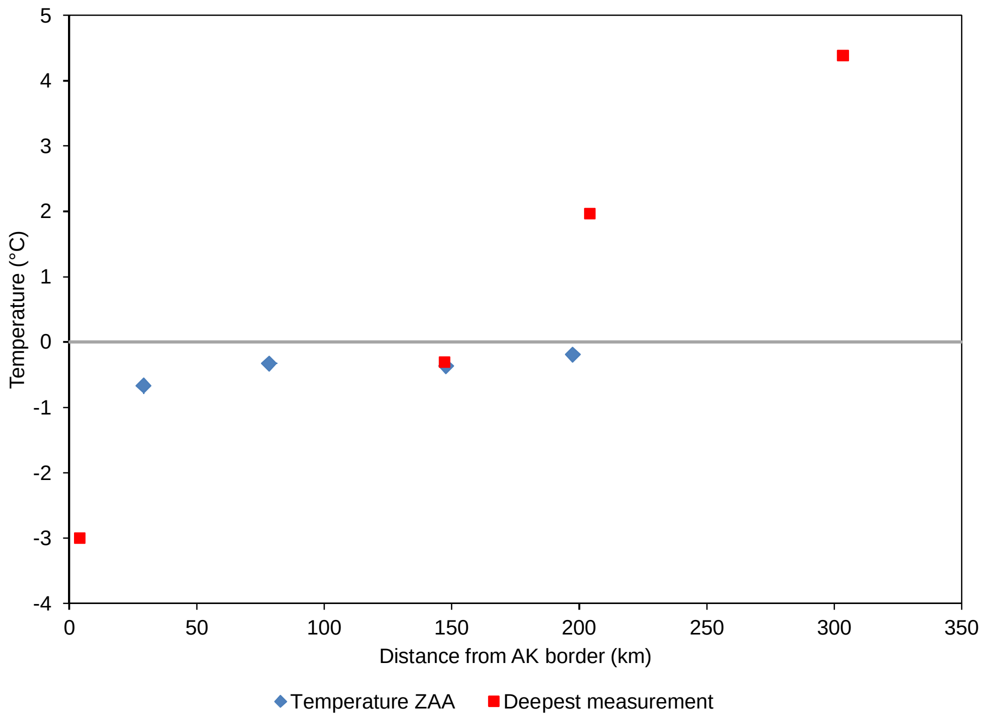

Figure 5. Mean ground temperature for 2013-14 along the corridor (distance given from Alaska border). Mean temperature is determined for the depth of zero annual amplitude (ZAA) or deepest measurement depth.

Ground temperature envelopes were also utilized to determine the depth of seasonal frost at unfrozen sites and the depth of maximum summer thaw at permafrost sites. Seasonal frost depth during the winter of 2013-14 at unfrozen sites was found to be 1.7 and 1.5 m for T1 and T2 respectively (Table 2). Maximum summer thaw depths range between 0.8 and 2.4 m (Table 2) with the shallower thaw depths found at the sites closest to the Alaska border.

Monthly maximum snow depths determined from the iButtons at T4 and T7 are shown in Figure 7. Maximum winter snow depth was 50 cm at T4 and 40 cm at T7 (resolution ±10cm). Snow on ground measurements for the Environment Canada station at Beaver Creek for November 2013 to January 2014 indicated a maximum snow depth of 45 cm which is comparable to those measured at T4 and T7. At T7 snow had accumulated to a depth of 40 cm by December but the snow depth was less during January with deeper snow cover observed in February and March. Warmer conditions in January (Figure 2), including a period during which air temperatures rose above 0°C, likely resulted in some melting of the snow pack. A similar decrease in maximum snow depth is not observed for T4 where January snow depth was similar to that in December. Greater snow depths however, were observed at T4 in February.

The warmer conditions in January 2014 had some impact on shallow ground temperatures during the winter. For some sites, monthly mean ground temperature measured in the upper 1 m was higher in January 2014 than December 2013. For example at T2, T3, T5 and T6, January mean ground temperatures at depths of 0.2 to 0.5 m were between 0.9 and 4.5°C higher than the mean for December (see Appendix). At other sites the impact of the January warming was less noticeable but resulted in a delay in cooling of the ground. The impact of shorter term fluctuations in air temperature on shallow ground temperature will be dependent on snow cover and the thermal properties of the ground.

Figure 6. Photo of AH2013-T8 in July 2014. Note the ditch beside the embankment.

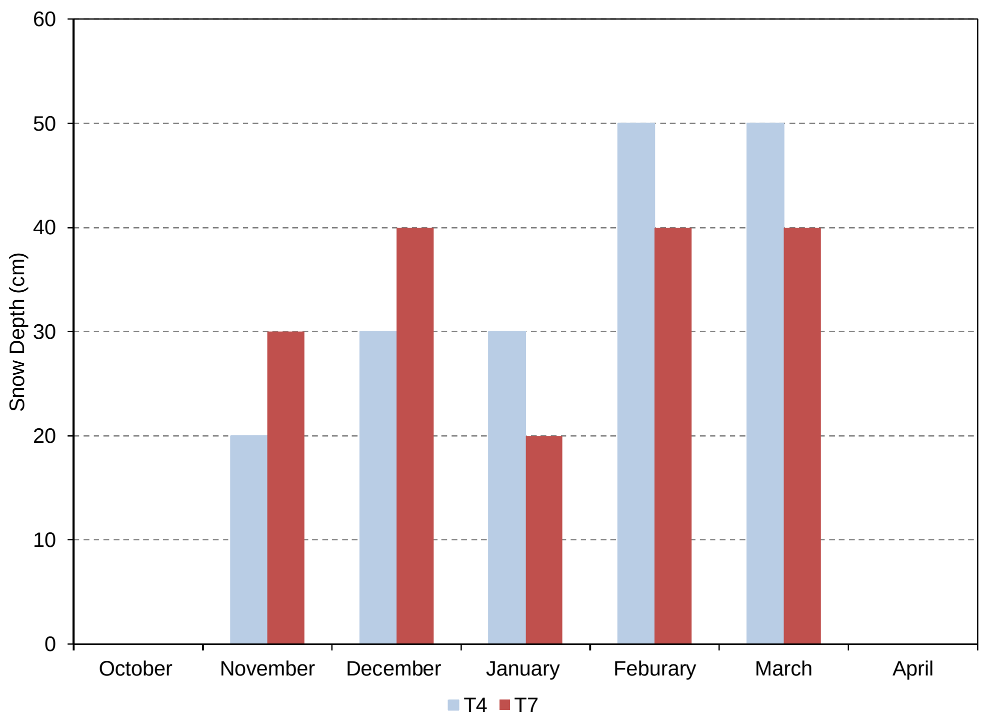

Figure 7. Maximum monthly snow depth determined from iButtons at AH2013-T4 and AH2013-T7 between October 2013 and April 2014 (resolution ±10 cm).

SUMMARY

A one year record of ground temperatures to depths of 10 m has been acquired for eight boreholes along the Alaska Highway easement in the southern Yukon. These data facilitate a characterization of the ground thermal regime for the section of the corridor between highway KP1559 and the Alaska border. Permafrost exists at six of the borehole sites. Frozen conditions extend beyond the bottom of the borehole for five of these sites while the base of permafrost is at about 8 m depth at a site to the northwest of Burwash. Results indicate that where present, permafrost is generally warm with annual mean ground temperatures, measured at or near the level of zero annual amplitude, above -0.7°C except near the Alaska border where the temperature is about -3°C. Maximum summer thaw depths at permafrost sites range from 0.8 to 2.4 m while winter frost depths for unfrozen sites are between 1.5 and 1.7 m. Warm conditions in January, including a period during which maximum daily air temperatures rose above 0°C, appear to have had an impact on shallow winter ground temperatures at several sites.

Further data collection is planned for these sites in order to better characterize the current ground thermal conditions. Ongoing measurements over the long-term will facilitate detection of trends in permafrost thermal state and support assessments of the impact of climate change on permafrost environments. These data will be compiled into a publicly available digital data base along with data acquired elsewhere in the corridor and in the central and southern Yukon. This will provide information on regional permafrost conditions to support decisions regarding development in the region and climate change adaptation planning.

ACKNOWLEDGEMENTS

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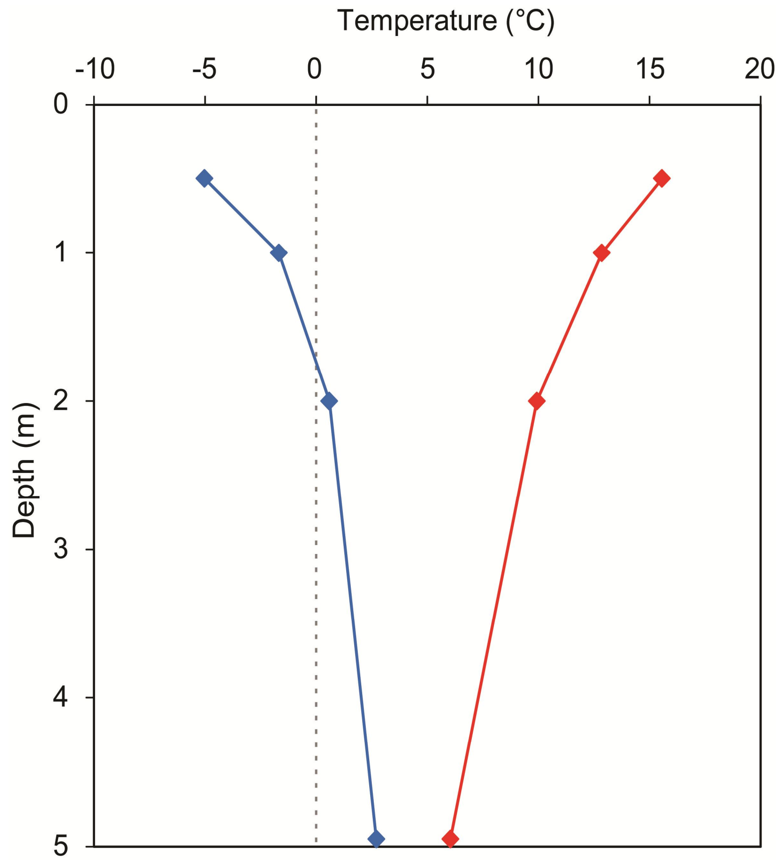
APPENDIX

For each site the following are provided:

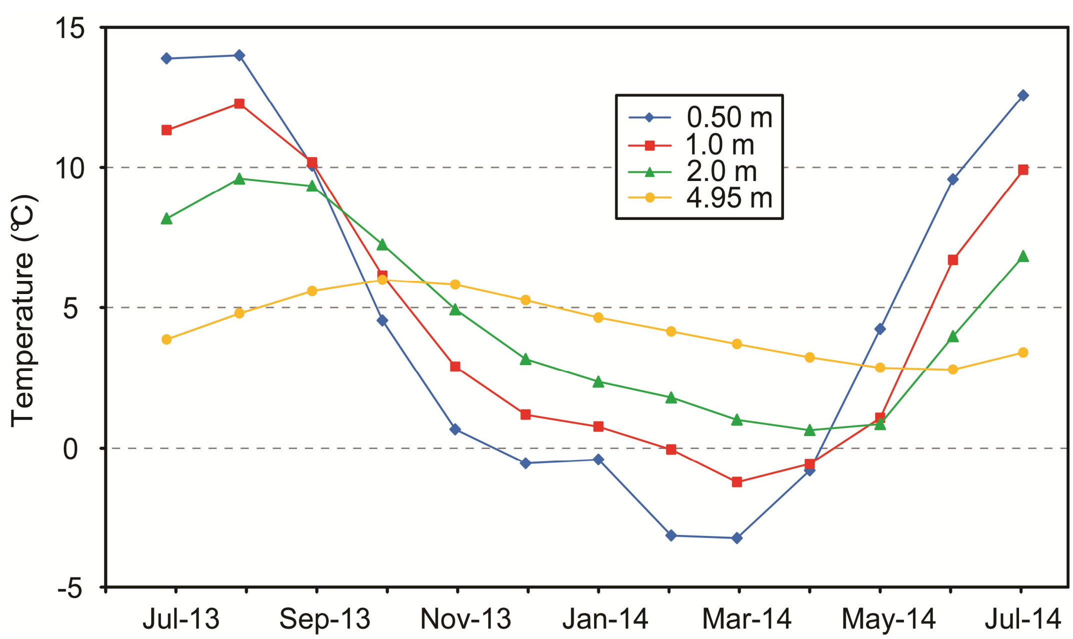
- Graphical and tabular presentation of ground temperature envelopes (annual maximum and minimum temperature at each measurement depth) for July 15, 2013 to July 14, 2014
- Graphical presentation of monthly mean ground temperature for 2013-14

AH2013-T1

Latitude: 60.840 N   Longitude: 137.278 W
Elevation: 686 m a.s.l.
Max Frost Depth: 1.74 m

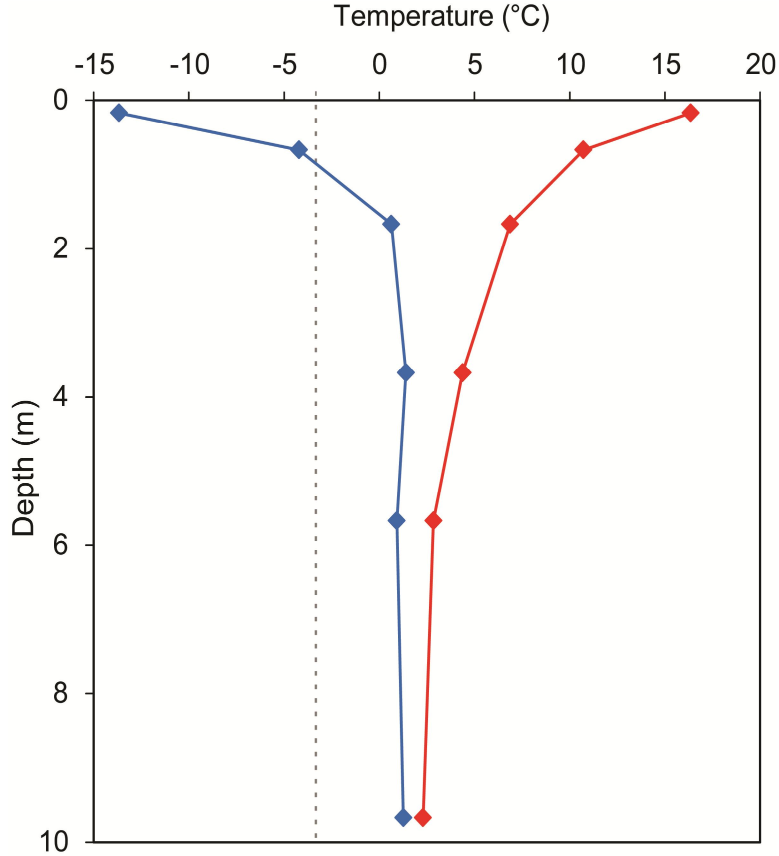


Depth (m)	Temperature (°C) Max	Min
0.5	15.57	-5.02
1.0	12.86	-1.68
2.0	9.93	0.59
4.95	6.05	2.71

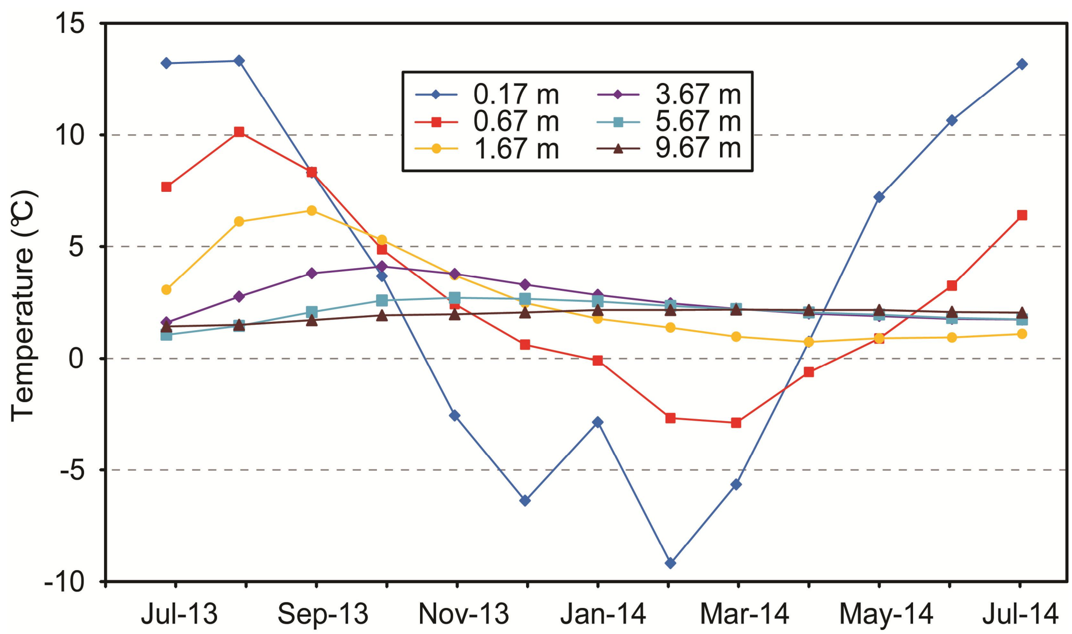


AH2013-T2

Latitude: 61.232 N   Longitude: 138.762 W
Elevation: 841 m a.s.l.
Max Frost Depth: 1.54 m

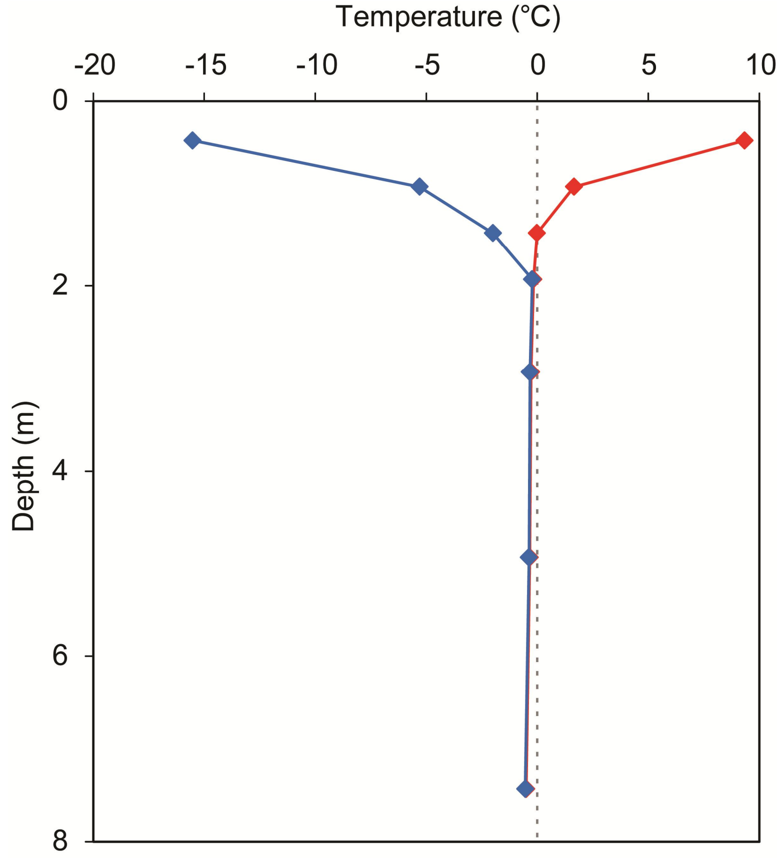


Depth (m)	Temperature (°C)	
	Max	Min
0.17	16.35	-13.66
0.67	10.72	-4.22
1.67	6.87	0.64
3.67	4.37	1.40
5.67	2.85	0.92
9.67	2.30	1.27

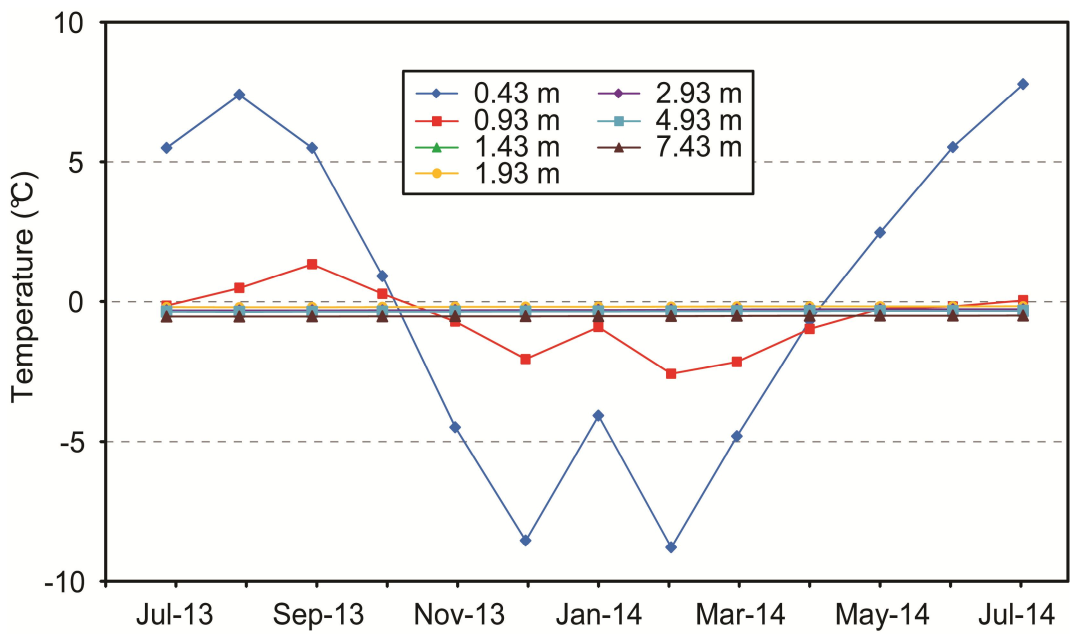


AH2013-T3

Latitude: 61.273 N Longitude: 138.847 W
Elevation: 833 m a.s.l.
Max Thaw Depth: 1.45 m

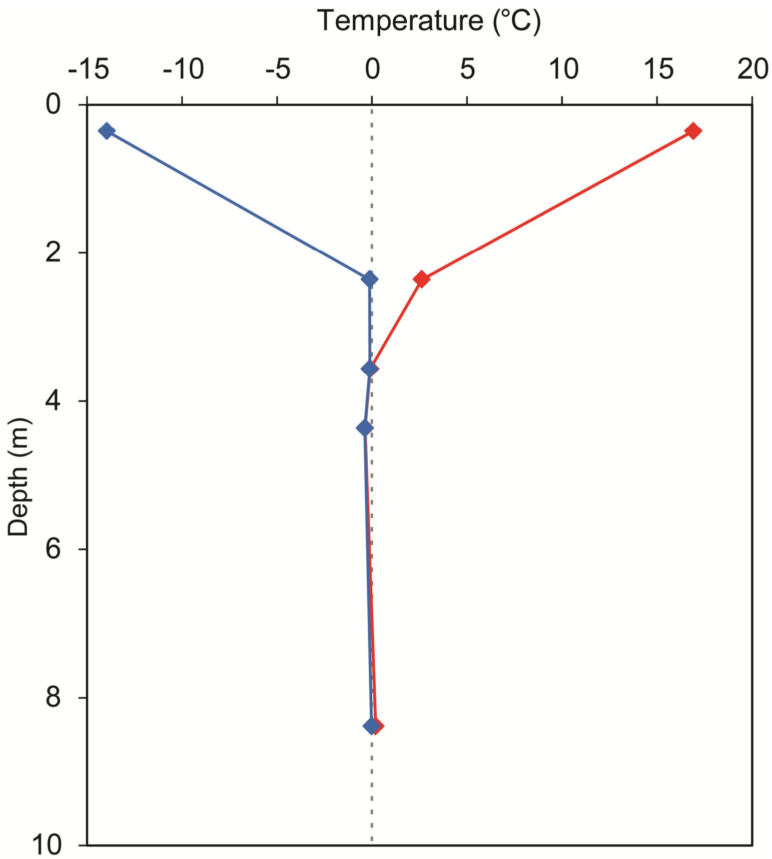


Depth (m)	Temperature (°C) Max	Min
0.43	9.35	-15.52
0.93	1.66	-5.30
1.43	-0.01	-2.00
1.93	-0.17	-0.22
2.93	-0.28	-0.33
4.93	-0.34	-0.38
7.43	-0.50	-0.54

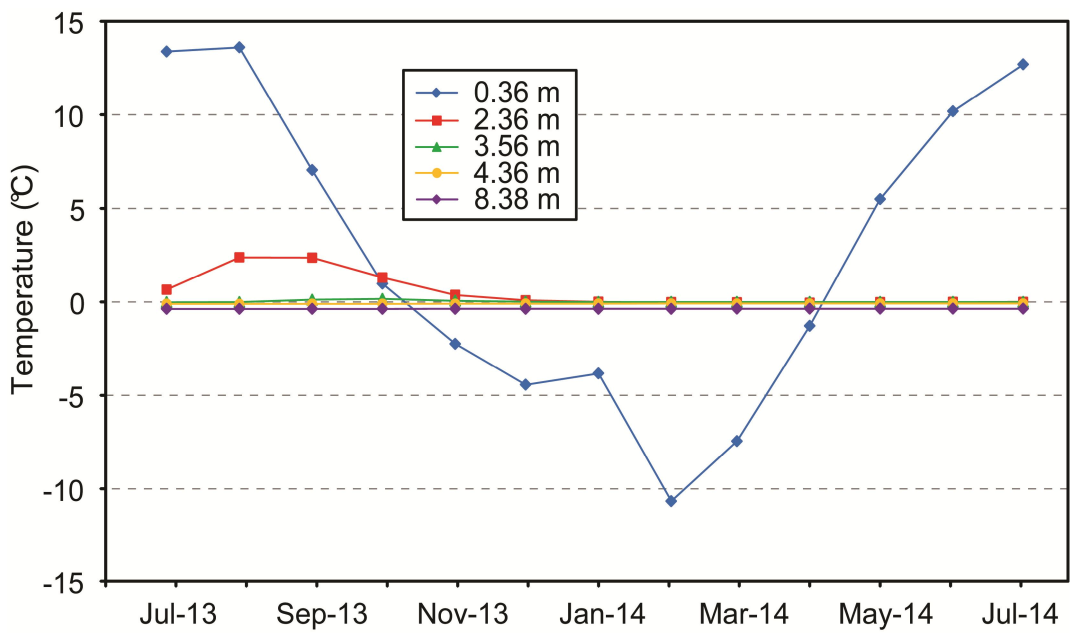


AH2013-T4

Latitude: 61.595 N Longitude: 139.468 W
Elevation: 783 m a.s.l.
Max Thaw Depth: 2.356 m

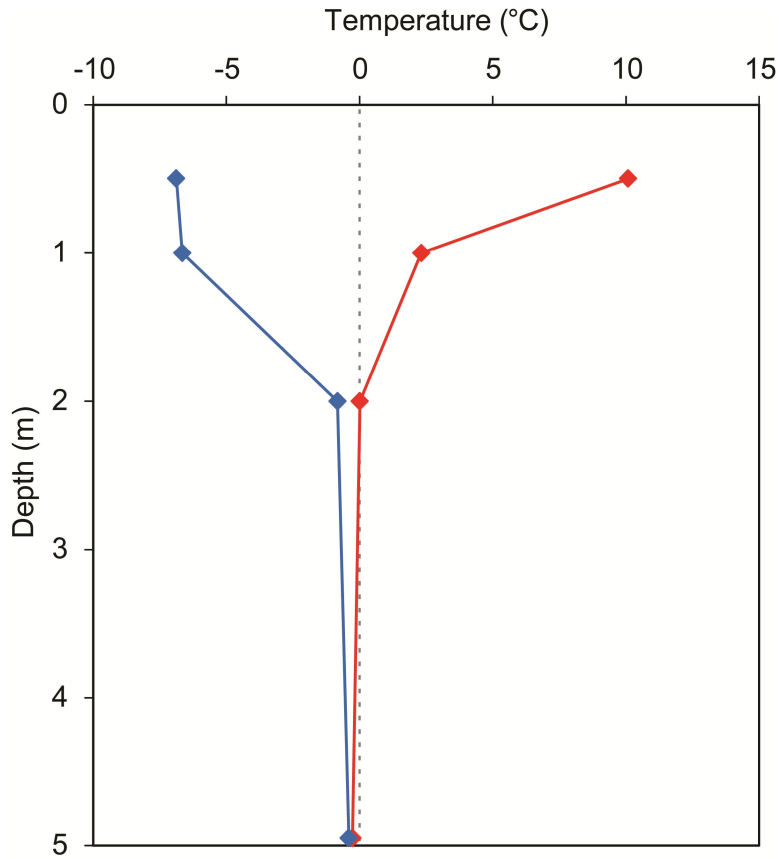


Depth (m)	Temperature (°C) Max	Temperature (°C) Min
0.36	16.91	-13.95
2.36	2.63	-0.12
3.56	-0.09	-0.11
4.36	-0.36	-0.38
8.38	0.19	-0.02

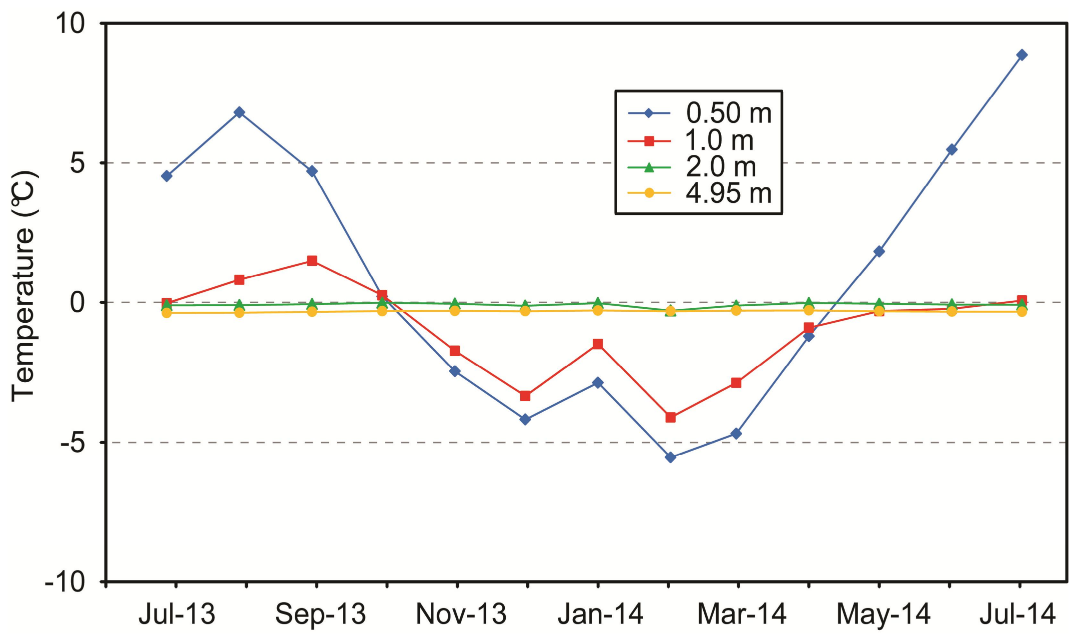


AH2013-T5

Latitude: 61.598 N   Longitude: 139.477 W
Elevation: 747 m a.s.l.
Max Thaw Depth: 1.797 m

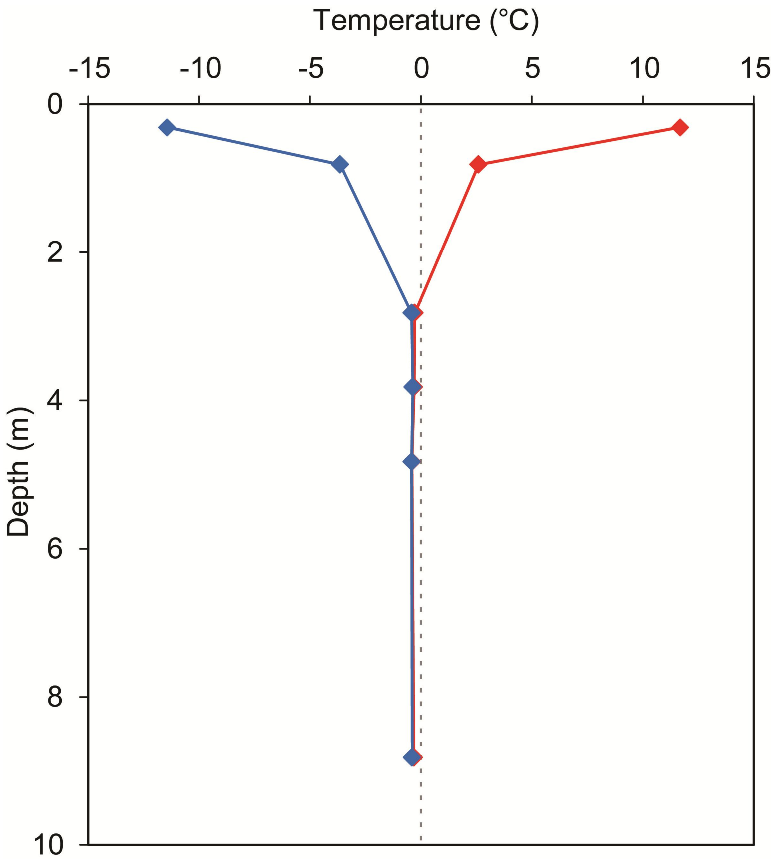


Depth (m)	Temperature (°C)	
	Max	Min
0.5	10.09	-6.88
1.0	2.32	-6.65
2.0	0.01	-0.82
4.95	-0.26	-0.40

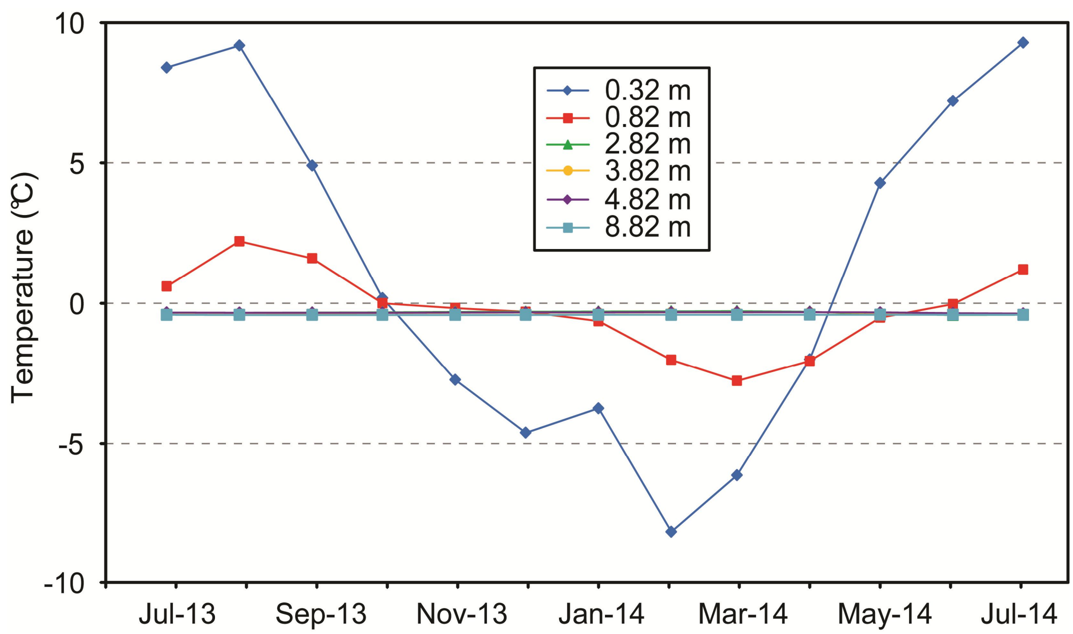


AH2013-T6

Latitude: 61.970 N Longitude: 140.452 W
Elevation: 672 m a.s.l.
Max Thaw Depth: 2.404 m

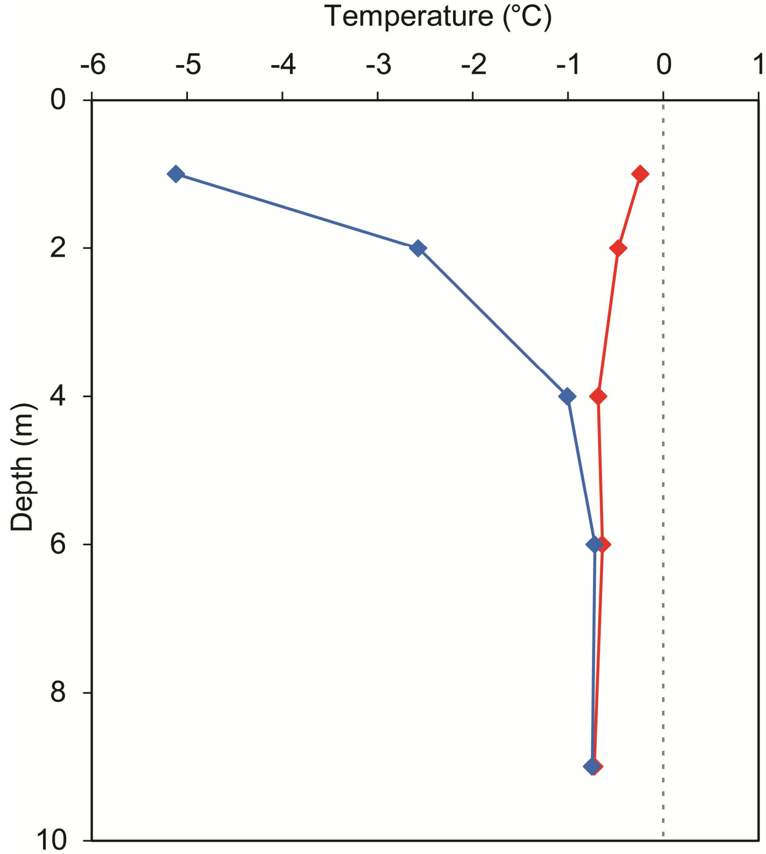


Depth (m)	Temperature (°C) Max	Min
0.32	11.68	-11.43
0.82	2.60	-3.64
2.82	-0.28	-0.42
3.82	-0.31	-0.37
4.82	-0.41	-0.42
8.82	-0.32	-0.40

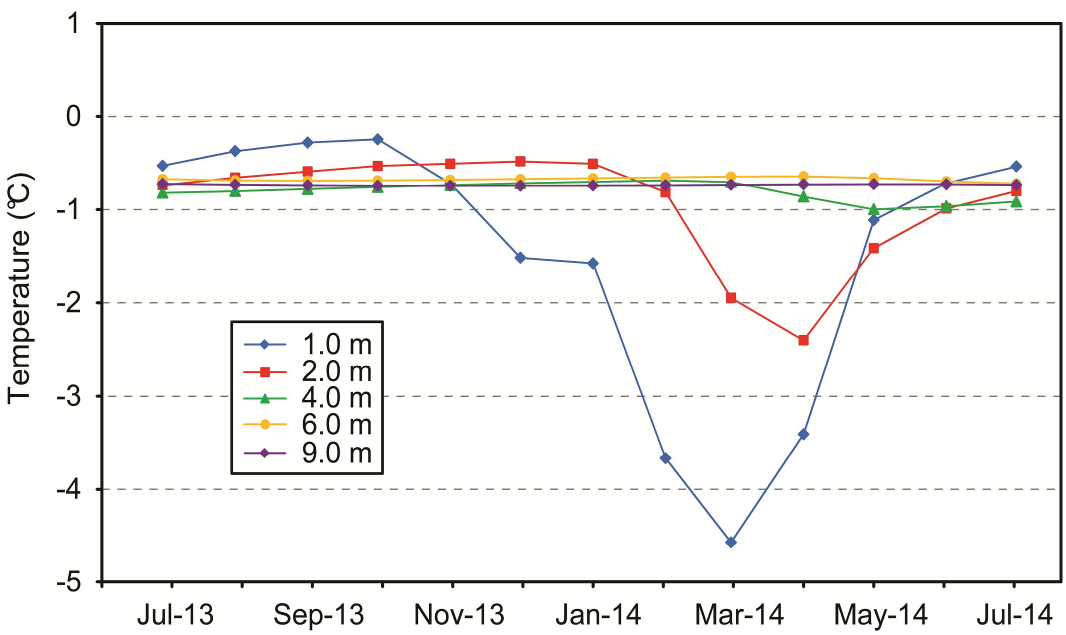


AH2013-T7

Latitude: 62.340 N Longitude: 140.833 W
Elevation: 701 m a.s.l.
Max Thaw Depth: 0.861 m

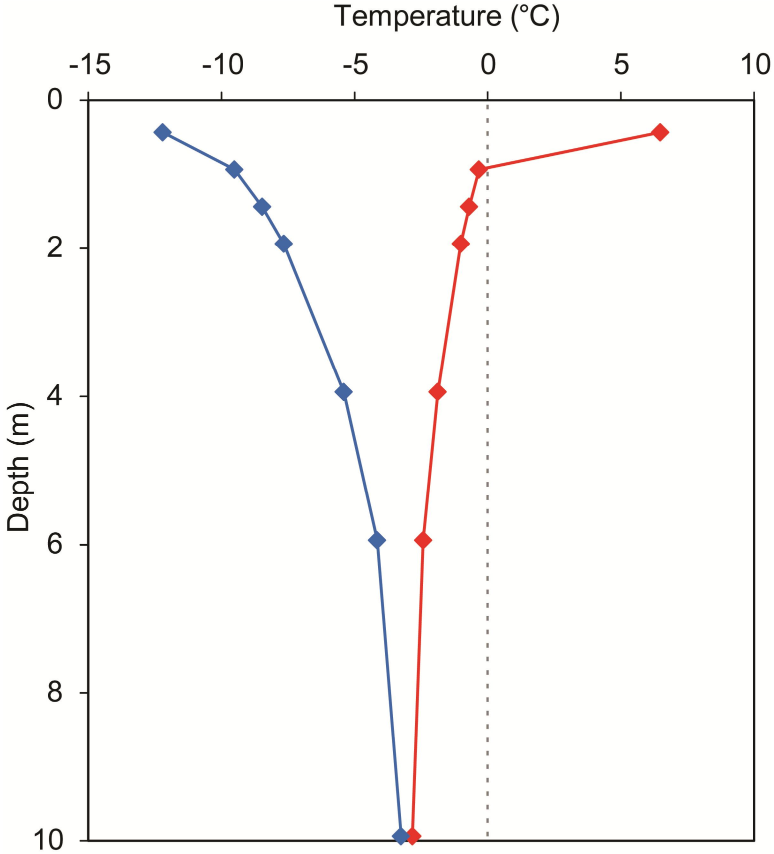


Depth (m)	Temperature (°C) Max	Min
1.0	-0.24	-5.12
2.0	-0.47	-2.57
4.0	-0.68	-1.01
6.0	-0.64	-0.72
9.0	-0.72	-0.75



AH2013-T8

Latitude: 62.554 N   Longitude: 140.974 W
Elevation: 610 m a.s.l.
Max Thaw Depth: 0.876 m



Depth (m)	Temperature (°C)	
	Max	Min
0.44	6.48	-12.21
0.94	-0.33	-9.51
1.44	-0.69	-8.47
1.94	-1.01	-7.66
3.94	-1.87	-5.40
5.94	-2.42	-4.15
9.94	-2.83	-3.26