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A multisite data set of near-surface soil temperature, active-layer thickness, and soil and vegetation conditions measured in northwestern Canada, 2016-2017

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ABSTRACT

Quantifying and understanding spatial variation in permafrost conditions at the landscape-scale is important for land use planning and assessing the impacts of permafrost thaw. This report documents detailed field data observed at 110 sites in two areas in northwestern Canada from 2016 to 2017. One area is a northern boreal landscape near Inuvik and the other is a tundra landscape near Tuktoyaktuk. The observations include near-surface soil temperatures (Tnss) at 107 sites, and active-layer thickness, soil and vegetation conditions at 110 sites. The data set includes the original Tnss records, the calculated daily, monthly, and annual averages of Tnss, soil and vegetation conditions at these sites, and photographs taken in the field. This data set will be useful for understanding the spatial heterogeneity of permafrost and validating modelling and mapping products.

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1. INTRODUCTION

Air temperature has direct impacts on ground temperature and permafrost conditions through energy exchanges between the land and atmosphere (e.g., Brown, 1960). With the expected effects of climate warming on permafrost thaw, most permafrost ground temperature observations focused on monitoring long-term changes at selected sites, which typically are sparsely distributed (e.g., Biskaborn et al., 2019). Soil, vegetation, and hydrological conditions have strong impacts on the water and energy exchanges at the ground surface and within the soil, and therefore affect ground thermal condition and permafrost distribution (e.g., Williams et al., 2020; Zhang et al., 2021). Field probing of thaw depths (e.g., Brown et al., 2000) and some multisite observations of ground temperatures (e.g., Smith, 1975; Garibaldi et al., 2021) have shown significant spatial variation over short distances. This high degree of spatial heterogeneity at the landscape-scale is important for land use planning and understanding the impacts of permafrost thaw on infrastructure, hydrology, ecosystem processes, and feedbacks to the climate system. Therefore, it is important to quantify and understand the spatial variations of permafrost conditions at the landscape-scale. In this project, we made multisite field observations of near-surface soil temperature (Tnss), active-layer thickness, and soil and vegetation conditions from 2016 to 2017 in two areas near Inuvik and Tuktoyaktuk that represent northern boreal and sub-arctic tundra ecosystems in northwestern Canada. This report documents the detailed data collected in the field. The analysis of the data, including background information and general conditions of the study areas, can be found in Zhang et al. (2021).

2 STUDY AREAS AND FIELD OBSERVATION METHODS

We made observations at multiple sites in two areas in the east of the Mackenzie Delta region in northwestern Canada. One is in the northern boreal forest region near Inuvik and the other is in the sub-arctic tundra region near Tuktoyaktuk (Figure 1a, 1b). We refer to these as "boreal" and "tundra" areas, respectively. Based on the vegetation and land surface conditions, we selected eight ecotypes typical in each area. In the boreal area, the eight ecotypes include coniferous forest, deciduous forest, tall-shrubs, shrubs with sparse trees, bogs, high-centred polygons; bare soils, and a solifluction affected area. The eight ecotypes typical in the tundra area include tall-shrub tundra (height > 1.0 m), medium-shrub tundra (height from 0.5 to 1.0 m), low-shrub tundra (height < 0.5 m), tussock tundra, high-centred polygons, low-centred polygons, marsh on the margins of lakes, and bare soil. Figure 2 shows typical conditions in these ecotypes. Field photographs of all the sites can be found in the sub-directory **Field_site_photos**.

In each study area, we selected between 1 to 15 sites for each ecotype using Google Earth imagery and field reconnaissance. All sites were within an acceptable walking distance (< 2 km) along the Inuvik-Tuktoyaktuk Highway (ITH). We aimed to select sites covering different topography, vegetation and ground conditions in each study area. We measured and instrumented 50 sites in the boreal area and 45 sites in the tundra area. We also selected six and nine sites near the toe of the embankment of the ITH in the boreal and tundra areas, respectively. In total, 110 sites were investigated and equipped with temperature sensors in the summer of 2016 (Figure 1). One hundred and seven of the temperature loggers were successfully retrieved in 2017.

Table 1. The ecotypes and their codes used in the data set for the two study areas

The boreal area		The tundra area	
Ecotype name	Ecotype code	Ecotype name	Ecotype code
Tall-shrubs	ST1	Tall-shrub tundra	ST2
Coniferous forest	FC	Medium-shrub tundra	SM
Deciduous forest	FD	Low-shrub tundra	SL
Shrubs with sparse trees	STrees	Tussock tundra	Tu
Bogs	Bog	Marsh on lake margins	Marsh
High-centred polygons	PolyH1	High-centred polygons	PolyH2
A solifluction affected area	Soli	Low-centred polygons	PolyL
Bare soils	BS1	Bare soils	BS2

Near-surface soil temperature was measured using Thermochron iButtons® as they are reasonably accurate and reliable (Angilletta and Krochmal, 2003). Tests of 170 iButtons (Model DS1921-F51) in the laboratory and field showed that their accuracy is about 0.3 °C, always better than 0.5 °C, and consistent over time (Angilletta and Krochmal, 2003). iButtons are small and rugged and therefore can be installed quickly at multiple sites without disturbance to the terrain. Several permafrost studies have used iButtons to measure near-surface ground temperatures (e.g., Gubler et al., 2011). We installed 110 iButtons (model DS1921G-F5#) from August 16 to 24, 2016, and retrieved 107 of them from August 15 to 22, 2017 with one and two iButtons being lost in the boreal and the tundra areas, respectively, likely due to disturbances from wildlife. These iButtons can record 2048 temperature values from −40 to 85 °C with a resolution of 0.5 °C and an accuracy of about 1 °C. We used a time-step of 255 minutes (the maximum time-step of the data logger) so that the iButtons recorded temperatures for almost one year (362.7 days). To protect them from water damage, we wrapped each iButton in a small Nasco Whirl-Pak® plastic bag (7.6 x 12.7 cm) and secured it with duct tape. We did that twice to prevent water damage to the iButtons (Figure 3). At each site we installed one wrapped iButton in the soil at 13 cm (5 in) below the ground surface (when mosses or lichen were present we measured depth from their surface). The site was marked by a small steel-wire flag to facilitate retrieval of the loggers.

At each site, we recorded location (latitude, longitude, and elevation), topography (slope and aspect), general land cover characteristics, and soil conditions in the field. We also recorded attributes of vegetation conditions including ecotype, plant height, diameter at breast height (DBH) for trees, and visual estimates of percentage covers of major vegetation types. The DBH we recorded was from the largest DBH of the tree around the observation site. Similarly, the height of the tallest vegetation was recorded around each observation site. Standing vegetation < 2 m in height was measured using a measuring tape, and trees and shrubs > 2m high were estimated. Surface organic layer thickness (including mosses and lichen), the texture of mineral soil, and drainage conditions were measured by digging small pits using a flat-bladed shovel, usually to the bottom of thawed soil. If the organic layer thickness exceeded the thaw depth, we recorded the organic layer as greater than the maximum thaw depth measured in the field. Thaw depths were measured using a 100 cm stainless steel probe in 2016 and 2017 when we installed and retrieved the iButtons. At some sites with deep thaw, we probed from the soil pits and reached about 120 cm depth. If we could not reach frozen ground, we recorded the thaw depth as greater than the depth we reached. We referred to the measured thaw depth as active-layer thickness in this data set. Several photographs at each site were also taken to document vegetation and soil conditions.

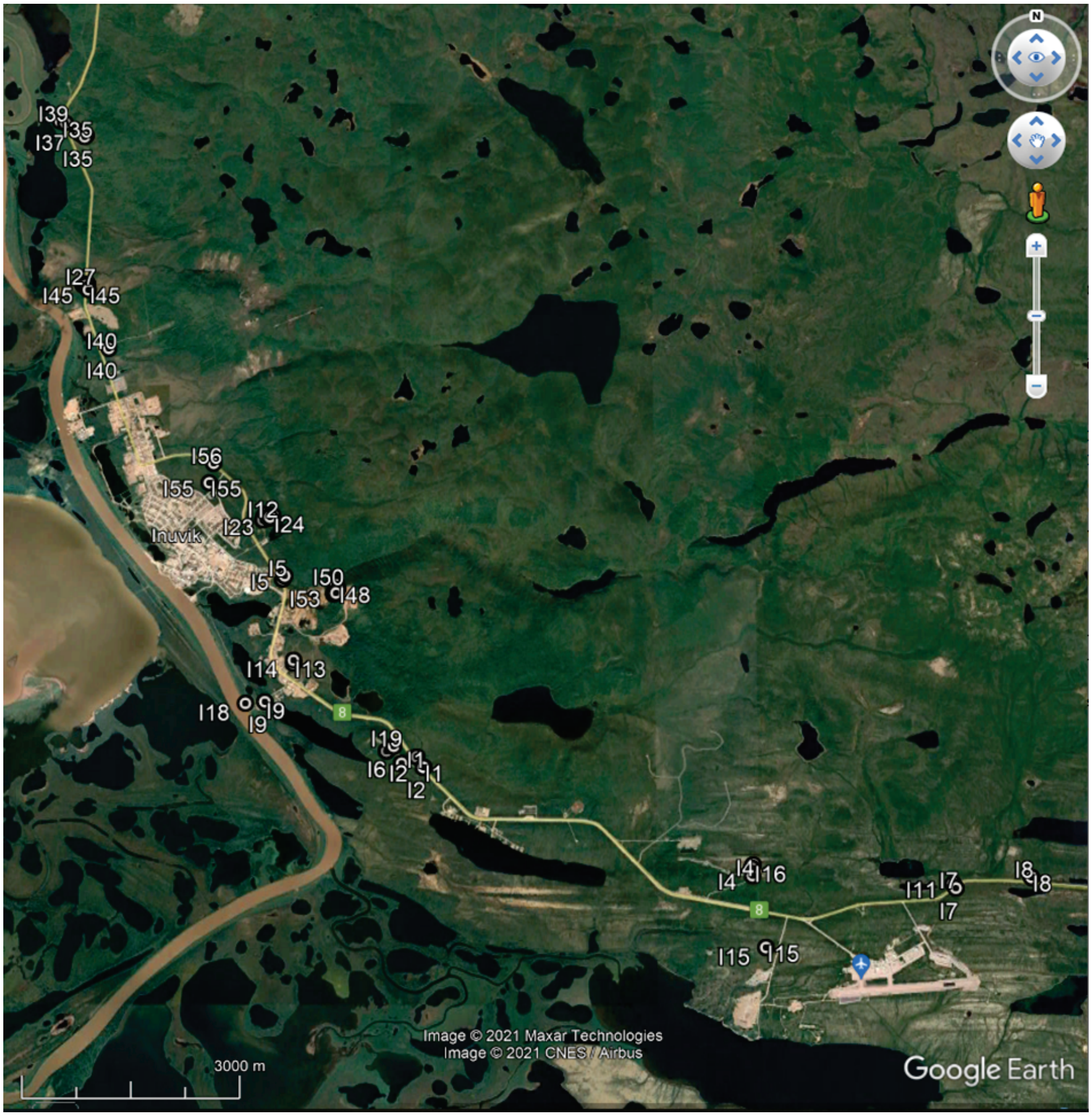

Figure 1a. The observation sites in the boreal area in Inuvik area.

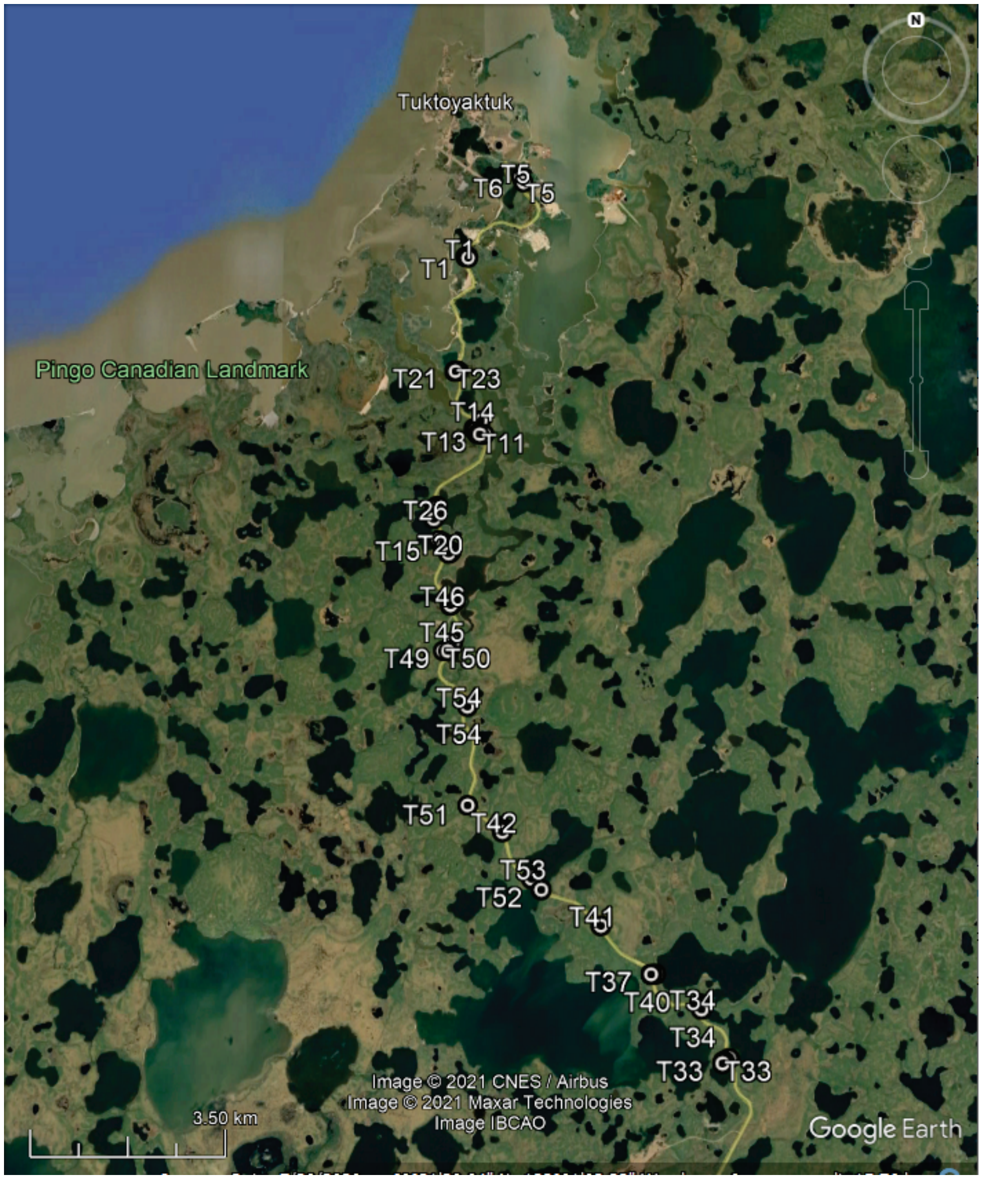

Figure 1b. The observation sites in the tundra area in Tuktoyaktuk area.

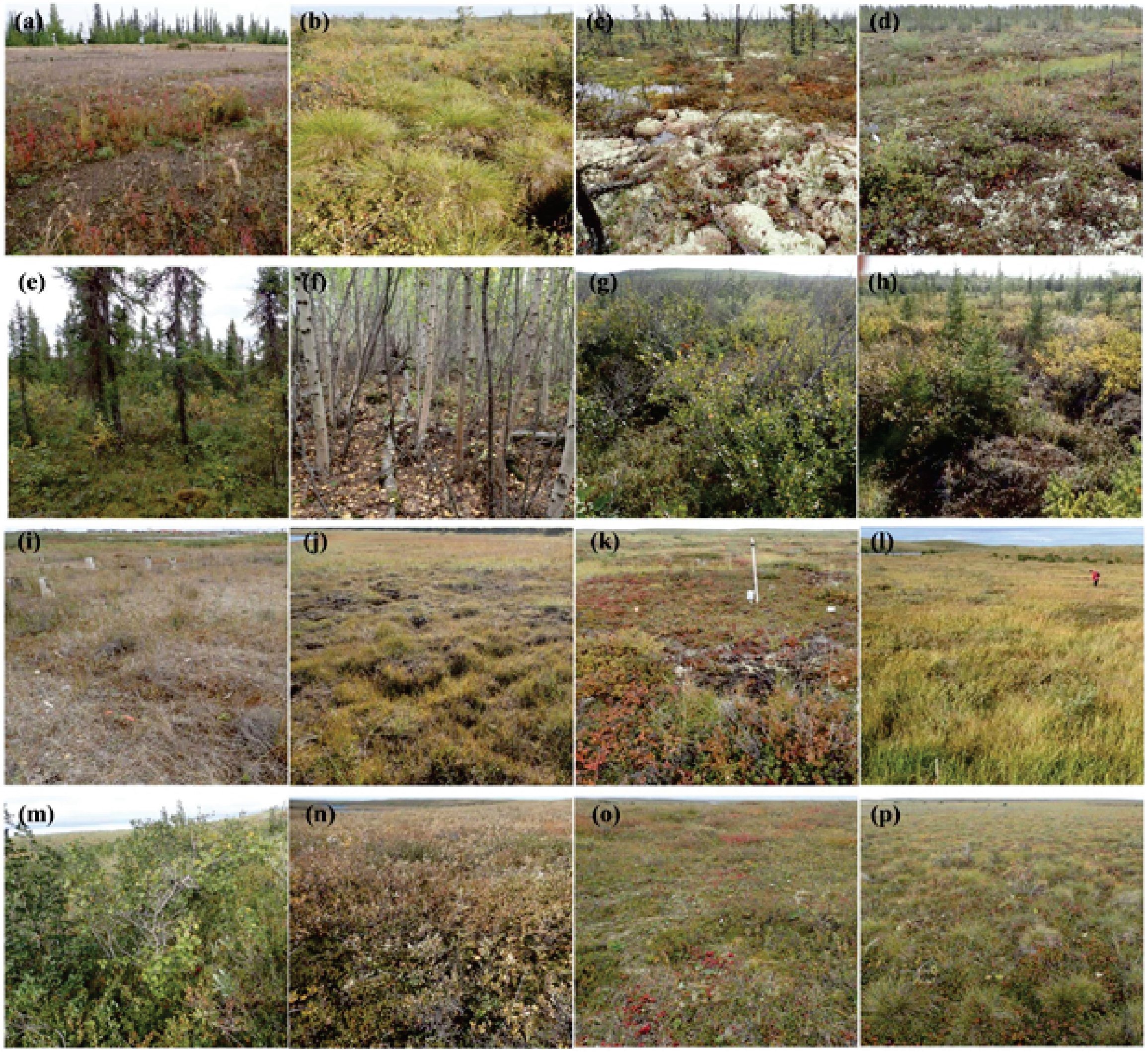

Figure 2. Field photographs of the typical ecotypes in the boreal area (a-h) and the tundra area (i-p) (Zhang et al., 2021). a) bare soil, b) a solifluction affected area, c) bog, d) high-centred polygons, e) coniferous forest, f) deciduous forest, g) tall-shrubs, h) shrubs with sparse trees, i) bare soil, j) marsh on lake margins, k) high-centred polygons, l) low-centred polygons, m) tall-shrub tundra, n) medium-shrub tundra, o) low-shrub tundra, and p) tussock tundra. Their NRCan Photo Database Numbers (NPDN) are a) 2021-316, b) 2021-381, c) 2021-315, d) 2021-325, e) 2021-396, f) 2021-392, g) 2021-358, h) 2021-370, i) 2021-406, j) 2021-478, k) 2021-428, l) 2021-425, m) 2021-415, n) 2021-485, o) 2021-449, and p) 2021-423.

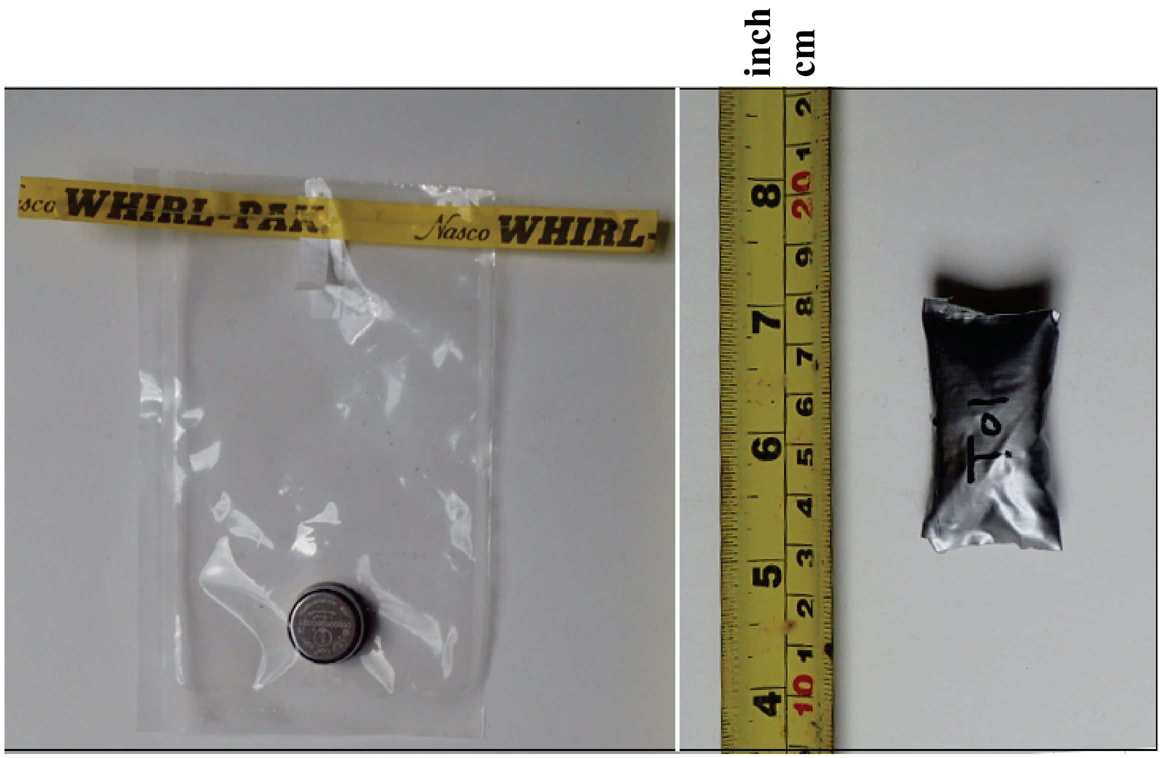

Figure 3. An ibutton in a Nasco Whir-Pak ® plastic bag (left), and the wrapped iButton for field installation (right). Each iButton was twice wrapped in a Nasco Whir-Pak ® plastic bag and secured by duct tape to prevent water damage. The NPDN of this photography is 2021-492.

3 THE DATA SET

3.1 The observations and variables in the data set

The following is the items of the field observations and derived variables included in the data set.

- Site location (latitude, longitude, and elevation).
- Topographic and general site conditions (site description, including slope, aspect, ecotype, land cover conditions, and drainage). The ecotypes and their codes are listed in Table 1. The drainage class was assigned based on the field condition of the site (Table 2).
- Vegetation conditions (major plant types, heights, and coverages, including mosses and lichen, and DBH for trees).
- Soil conditions (organic layer thickness and degree of decomposition, the texture of the mineral soils).
- Thaw depths probed at the site in 2016 and 2017 during fieldwork.
- Original Tnss data recorded every 255 minutes.
- Daily, monthly, seasonal and annual averages of Tnss calculated from the original Tnss data. Daily average Tnss was calculated based on the original records by averaging five or six records from each day. The temperatures recorded before deployment and after retrieval were excluded in the calculation. The monthly average Tnss was calculated based on the original records rather than the calculated daily data. The average Tnss in August was calculated using the records in August 2016 and August 2017. The annual average Tnss was calculated based

on the monthly averages as the data in August were no complete and varied from 27 to 30 days. We also calculated the following variables based on the daily average Tnss: freezing-degree-days (FDD) during the observation period, thawing-degree-days (TDD2017) from January 1, 2017 to the end of the observation period, the number of freezing days during the observation period (days when daily mean Tnss < 0 °C), zero-curtain during freezing period (the number of days when daily mean Tnss was between -0.1 to 0.1°C from September 20 to November 15, 2016), zero-curtain during the thawing period (the number of days when daily mean Tnss was between -0.1 to 0.1°C from April 20 to June 20, 2017).

- Site photographs.

Table 2. Drainage classes and the corresponding field conditions.

Drainage class	General field condition
1	Very poorly drained. Water level is near the surface (0-20cm).
2	Poorly drained. Water accumulated in active layer but the water level was below 20 cm depth.
3	Imperfectly drained. The soil is wet and near saturation but usually no water accumulation in the pit.
4	Moderately well drained. The soil is moist.
5	Well drained. The soil is moist to dry, usually in gentle slopes.
6	Rapidly drained. The soil is moist to dry in steeper slopes, and the site has >5 cm organic matter on the surface.
7	Very rapidly drained. The soil is dry, usually coarse and in slopes without much organic matter on the surface.

3.2 The files and the structure of the data set

The data set includes a metadata (this file), a kmz file (Google Earth placemark file) for the site locations, three xlsx (Microsoft Excel) files for site conditions, thaw depths, daily and monthly Tnss, one sub-directory containing 107 csv (comma-separated values) files for the original iButton records, and one sub-directory containing six PDF (Portable Document Format) files for field photographs.

- **Site_data.xlsx**: A Microsoft Excel file which includes all the field records except Tnss and site photographs.

- **Site_locations.kmz**: A kmz file can be used to show the locations of the observation sites on Google Earth.

- **Daily_Tnss.xlsx**: A Microsoft Excel file for the calculated daily average Tnss. The file also includes some daily meteorological data from climate stations. For the boreal area, the daily minimum, maximum and mean air temperature, precipitation and snow depth on the ground were from the Inuvik climate station (68°16'N, 133°31'W. Climate ID: 2202578, WMO ID: 71364) from Environment and Climate Change Canada. For the tundra area, the daily minimum, maximum and mean air temperature were from a meteorological station (69°21'47.4"N, 133°2'8.7"W) about 9 km from Tuktoyaktuk established by Environment and Natural Resources in Government of the Northwest Territories.

- **Monthly_Tnss.xlsx**: A Microsoft Excel file which includes the calculated monthly, seasonal and annual average Tnss, freezing-degree-days (FDD), thawing-degree-days in 2017

(TDD2017), frozen days, and zero-curtain during the freezing and thawing periods. The file also includes average organic layer thickness (OLT), average active-layer thickness observed in 2016 (ALT2016) and in 2017 (ALT2017).

- **iButton_records**: a directory which includes two sub-directories for the original Tnss recorded by the iButtons in the two study areas. The **Boreal_Area** sub-directory includes 55 csv text files for the Tnss recorded at the 55 sites, and the **Tundra_Area** sub-directory include 52 csv text files for the Tnss recorded at the 52 sites. The file names of the text files indicate the site identifications and the codes of the iButtons. The first letters "**I**" and "**T**" are for the sites in the boreal area near Inuvik and in the tundra area near Tuktoyaktuk, respectively. The "_" in the middle of the code represents "0000" in the original ibutton code. For example, the file **T1_DF_36B2A421.csv** is the original Tnss data recorded at site T1 ("**T**" for the tundra area near Tuktoyaktuk) by the iButton DF000036B2A421. The csv file can be viewed using Microsoft Wordpad or other text file editors (the notepad does not show line-breaks). It can also be opened using Microsoft Excel, but sometimes the date field does not show correctly. In each csv file, the first 13 lines are the information on the iButton settings. The temperature data begin from line 16 after a heading-line. In each line, the data are arranged as date (day/month/year), time (hour, minute and second), AM or PM, unit of the temperature (C for Celsius), and the temperature. The time was in Canadian Eastern Daylight Saving time.
- **Field_site_photos**: A directory contains six PDF files of the field photographs. The range of the sites included in a file is indicated in the file name. For example, the file **Field_Photos_I1-15.pdf** includes the field photographs for the sites from I1 to I15 ("I" is for sites in the boreal area near Inuvik). Each site usually includes one photograph of vegetation conditions and one photograph of the soil conditions. All the photographs were taken by the lead author of this report. The NPDN of each photo was indicated in the caption.

4 SUMMARY

It is important to quantify and understand spatial variation in permafrost conditions at the landscape-scale. This report documents detailed field measurements from 110 sites in a northern boreal area and a sub-arctic tundra area in northwestern Canada. The observations include Tnss at 107 sites from 2016 to 2017, active-layer thicknesses in these two years, and soil and vegetation conditions at 110 sites. The data set includes the original Tnss records, the calculated daily, monthly and annual averages of Tnss, vegetation and soil conditions, and photographs of the sites. This data set contributes to understanding the spatial heterogeneity of permafrost and will be useful for validating permafrost modelling and mapping products.

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