



**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7392 (revised)**

**Air and Near Surface Ground Temperatures, Indices and
Summary Statistics from 1993 to 2012 for the Mackenzie
Valley Corridor, Northwest Territories**

C. Duchesne, D.W. Riseborough, and S.L. Smith

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Abstract

Since the early 1990s the Geological Survey of Canada has maintained a network of air and ground surface temperature monitoring sites along a transect in the Mackenzie corridor stretching from the outer Mackenzie Delta to northern Alberta. Data collected from these sites have been utilized to investigate the relationship between air and ground surface temperature for a range of terrain, vegetation and climatic conditions throughout the region. This report presents the data collected up to 2012.

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1. Introduction

The Mackenzie Valley landscape is characterized by widespread permafrost terrain ranging from continuous on the Beaufort coastal plain to sporadic discontinuous in the southern extent of the valley (Heginbottom et al., 1995). Components of the permafrost system, such as the active layer and the near-surface layer that freezes and thaws annually, respond to short-term fluctuations in climate. Since travel and construction activities often occur in the winter and are dependent on frozen ground conditions, the timing of these activities can vary with fluctuations in climate. Air temperature is an important factor in determining the ground thermal regime but the relationship between the air and ground temperature depends on site-specific conditions that determine the surface energy balance and control the ground surface temperature. Local conditions such as vegetation and snow cover influence the ground surface temperature and the onset of ground freezing and thawing and active layer development. Since the early 1990s the Geological Survey of Canada has maintained a network of air and ground surface temperature monitoring sites along a transect in the Mackenzie corridor stretching from the outer Mackenzie Delta to northern Alberta. Data collected from these sites have been utilized to investigate the relationship between air and ground surface temperature for a range of terrain, vegetation and climatic conditions throughout the region. This report presents all data collected from 1993 (at some sites) to the summer of 2012.

2. Background and general site description

The monitoring network includes 61 sites in the Mackenzie corridor extending from northern Alberta to the Mackenzie Delta and Tuktoyaktuk Peninsula, crossing regions of both discontinuous and continuous permafrost (Figure 1). Vegetation conditions range from boreal forest in the south to tundra in the north. The landscape of the region was largely shaped by continental glaciation and subsequent post-glacial drainage (Duk-Rodkin and Lemmen, 2000). The terrain comprises moraine, lacustrine, fluvial and deltaic deposits of the northern Interior Plains. Ice-rich sediments, in particular lacustrine silts and clays, are common (Aylsworth et al. 2000). Impeded drainage is a feature of many areas and this has resulted in the formation of wetlands, ponds and lakes and thick accumulations of peat. Extensive peatlands are found in the southern portion of the region, where organic cover may be several metres thick (Aylsworth and Kettles, 2000). In the north, the Mackenzie Delta region consists of a broad alluvial plain and surrounding tundra uplands (Burn and Kokelj, 2009).

In the central and southern portion of the corridor, permafrost is discontinuous, ranging in thickness from less than 15 m to greater than 60 m and the ground temperatures are generally above -2.5°C (Smith et al, 2010; Smith and Burgess, 2002). In the north, permafrost can be up to

several 100 m thick particularly in the tundra uplands. In the Mackenzie Delta region the abundance of lakes and variable vegetation conditions gives rise to large spatial variability in ground thermal conditions so that permafrost temperatures may range from values close to 0°C in the delta and as low as -6 or -7°C in the tundra uplands (Burn and Kokelj, 2009; Smith et al., 2010; Stevens et al. 2011; Wolfe et al., 2010).

Long winters characterize the climate of the Mackenzie corridor with freezing degree days ranging from 4516 to 3225 at Inuvik and Fort Simpson respectively, and thawing degree days from 1348 to 2087 for those two communities (Environment Canada, 2012). The mean January and July temperatures vary from -27.6°C to 14.2°C at Inuvik and from -25.4°C to 17.2°C at Fort Simpson based on 1971-2000 Environment Canada normals (Environment Canada, 2012). Total precipitation varies from 248 mm at Inuvik to 369 mm at Fort Simpson of which half falls as snow which may stay on the ground seven to eight months of the year (Environment Canada, 2012).

The transect generally follows the Mackenzie Valley (Figure 1) except to the south of Fort Simpson where sites are located along the Enbridge pipeline right-of-way. The most southerly site is about 25 km south of the NWT border (not shown on figures). Monitoring sites (Figure 1) are situated on mostly undisturbed terrain, selected on the basis of surficial material, soil, vegetation and forest type characteristic of the Mackenzie Valley region. The vegetation of the Mackenzie corridor varies from heath tundra north of treeline, progressing to open black spruce and shrub below treeline, to black spruce dominated in the central section, and to spruce and deciduous coverage in the south. Of the 61 sites, 7 are located north of the tree line (Figure 2). Several of the sites are associated with active layer monitoring (see Nixon and Taylor, 1998) while others are adjacent to the Enbridge pipeline right-of-way and are associated with the Pipeline Permafrost Terrain Research and Monitoring Program (see Pilon et al., 1989). Figure 2 through 4 show the location of monitoring sites in relation to ecoregions which represent broad recurring vegetation and landform patterns within a regional climatic framework (Ecosystem Classification Group, 2008). The extents of these maps are outlined in figure 1. Tables 1 to 3 present monitoring site descriptions (metadata) for each section.

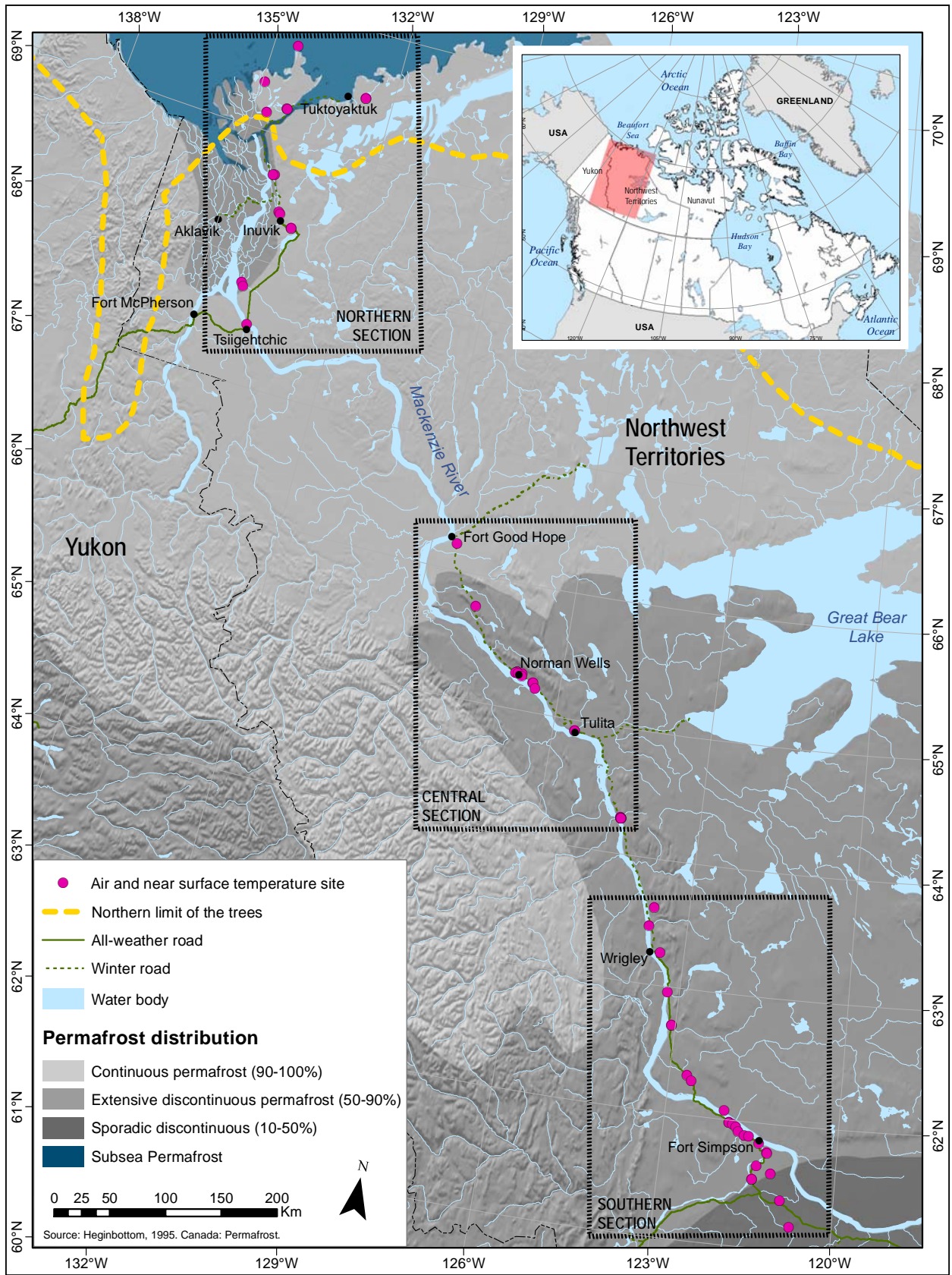


Figure 1. Location of air and near-surface temperature monitoring sites in relation to permafrost distribution (Heginbottom, 1995) in the Mackenzie Valley Corridor. Three sections for data presentation are outlined with dash lines.

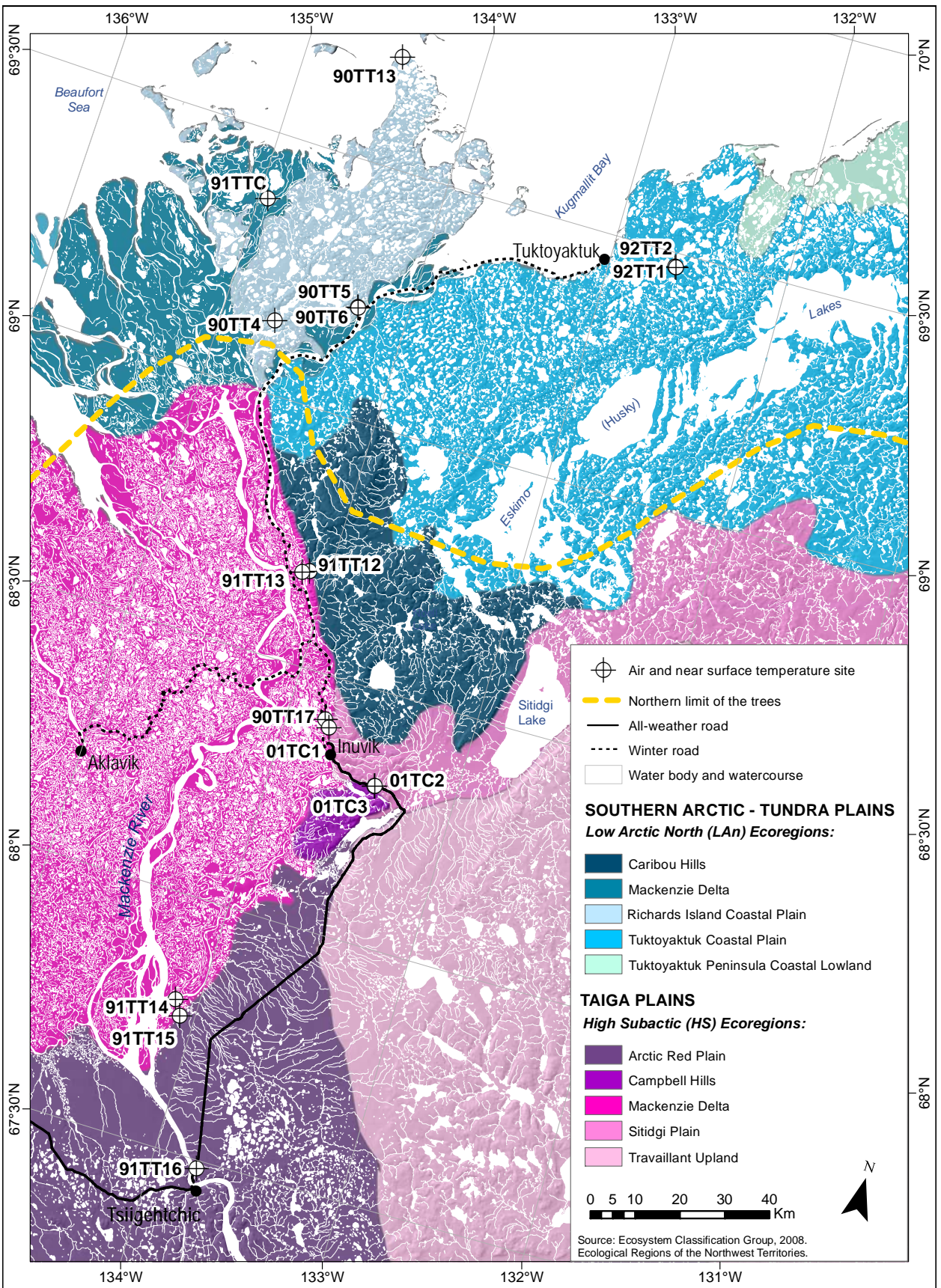


Figure 2. Monitoring sites in northern section.

Table 1. Site metadata for northern section.

GSC code	SITE NAME	LAT.	LONG.	AIR TEMP. First year Last year	Near Surf. TEMP. First year Last year	VEGETATION TYPE			LANDFORM	ECOREGION	PERMAFROST ZONE <small>(Heginbottom, 1996)</small>
						Groundcover	Shrub	Trees			
90TT13	North Head shore	69.7195	-134.4615	1994 2012	1994 2012	Sedge, lupin, labrador tea	Dwarf birch, willow	None	Thermokarst coastal plain 100 m from Beaufort coast	Tundra Plains: Low Arctic North	Continuous
92TT2	Involuted Hill flat	69.4742	-132.6345	1994 2012	1994 2012	Moss, herbaceous	Dwarf birch	None	Thermokarst basin	Tundra Plains: Low Arctic North	Continuous
92TT1	Involuted Hill top	69.4729	-132.6270	1994 2012	1994 2012	Moss	Dwarf birch	None	Top of low cuesta collapse form in thermokarst terrain	Tundra Plains: Low Arctic North	Continuous
91TTC	Taglu	69.3694	-134.9486	1994 2012	1994 2012	Vetch	Willow	None	Alluvial plain, surface of Mackenzie Delta	Tundra Plains: Low Arctic North	Continuous
90TT5	Lousy Point ridge	69.2186	-134.2848	1994 2012	1994 2012	Bearberry, labrador tea	Dwarf birch	None	Surface of glaciofluvial ridge above east channel, Mackenzie Delta	Tundra Plains: Low Arctic North	Continuous
90TT6	Lousy Point low terrace	69.2164	-134.2801	1994 2012	1994 2012	Bearberry, labrador tea, hearbaceous	Dwarf birch	None	Outwash terrace, river bank	Tundra Plains: Low Arctic North	Continuous
90TT4	YaYa Lake low	69.1431	-134.7041	1994 2012	1994 2012	Bearberry, labrador tea	Dwarf birch	None	Ice contact complex, depression	Tundra Plains: Low Arctic North	Continuous
91TT12	Reindeer Station plateau	68.6885	-134.1110	1994 2012	1994 2012	Moss	Dwarf birch	None	Till plain	Taiga Plains: High Subarctic	Continuous
91TT13	Williams Island	68.6829	-134.1452	1994 2012	1995 2012	Litter	Alder, willow	None	Surface of bar in Mackenzie Delta	Taiga Plains: High Subarctic	Extensive Discontinuous
90TT17	Navy Channel	68.4151	-133.7943	1997 2012	1997 2012	Litter, moss	Willow (low)	None	Surface of Holocene Mackenzie delta adjacent to eastern edge rising 10s of meters to till plain	Taiga Plains: High Subarctic	Continuous
01TC1	Navy Road	68.4009	-133.7620	None	2002 2012	Labrador tea, scattered lichen	Dwarf birch	Birch, alder	Alluvial fan surface	Taiga Plains: High Subarctic	Continuous
01TC2	Inuvik airport forest	68.3160	-133.4355	None	2002 2012	Cloudberry, cranberry, labrador tea	Willow, alder	Black spruce (open)	Side of low ridge in till plain	Taiga Plains: High Subarctic	Continuous
01TC3	Inuvik airport bog	68.3156	-133.4338	None	2002 2011	Moss, lichen	Dwarf birch, alder (scattered)	None	Bog developed in swale between low ridges of till plain	Taiga Plains: High Subarctic	Continuous
91TT14	Rengleng River mouth	67.7951	-134.1263	1994 2012	1994 2012	Moss, grass	Birch	White spruce (closed)	Alluvial plain	Taiga Plains: High Subarctic	Extensive Discontinuous
91TT15	Rengleng Lake	67.7662	-134.0788	1994 2007	1994 2008	Grass	Willow, birch	White spruce (open)	Inland lake shore	Taiga Plains: High Subarctic	Extensive Discontinuous
91TT16	Tsiigehtchic	67.4842	-133.7633	1994 2010	1994 2009	Litter	Alder (high)	None	Alluvial bar	Taiga Plains: High Subarctic	Continuous

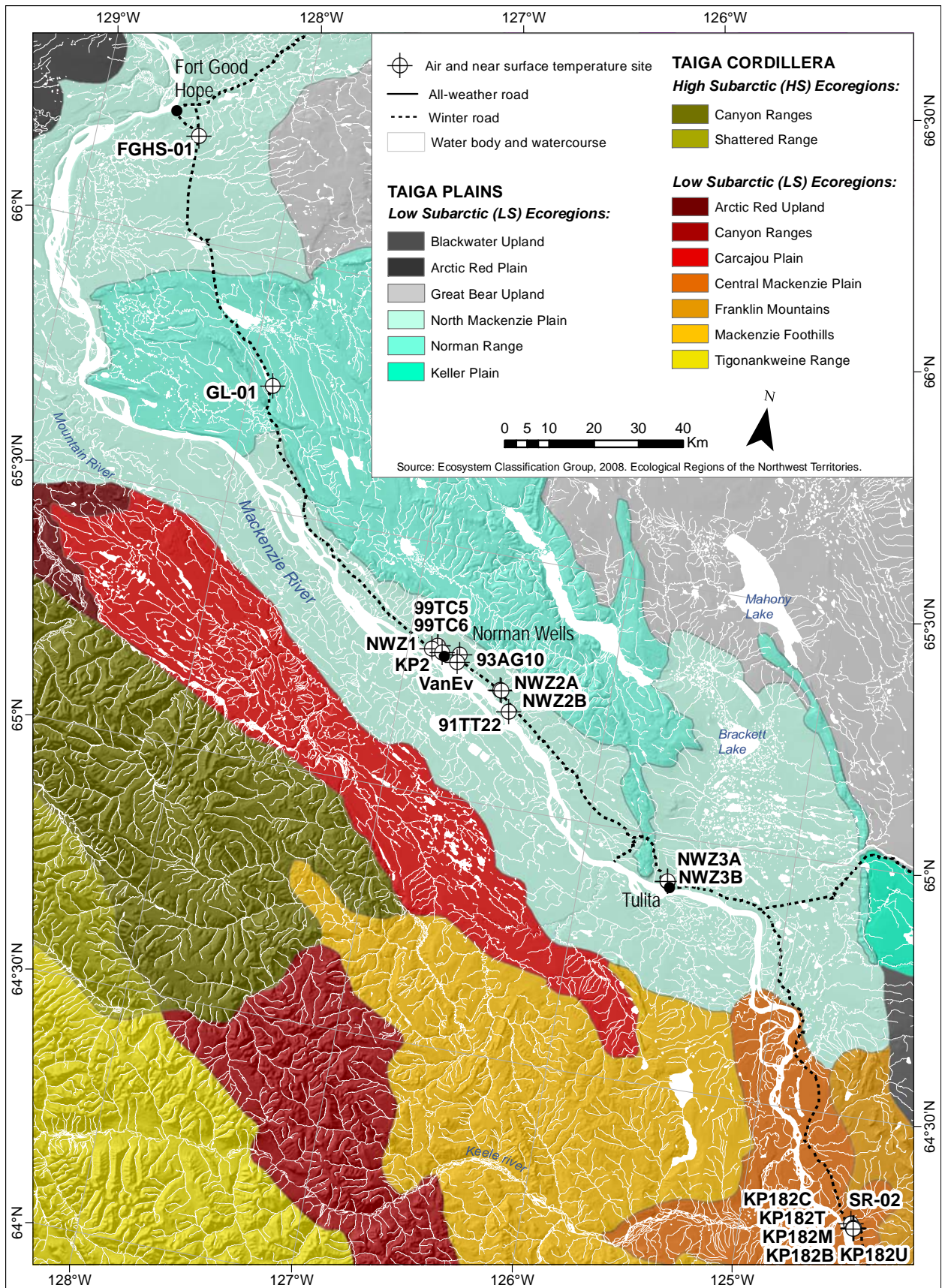


Figure 3. Monitoring sites in central section.

Table 2. Site metadata for central section.

GSC code	SITE NAME	LAT.	LONG.	AIR TEMP. First year Last year	Near Surf. TEMP. First year Last year	VEGETATION TYPE			LANDFORM	ECOREGION	PERMAFROST ZONE (Heginbottom, 1996)
						Groundcover	Shrub	Trees			
FGHS-01	Fort Good Hope South	66.2097	-128.4958	2007 2012	None	Graminoid	Undifferentiated shrubs (dense)	Black spruce (open)	Hummocky peatland	Taiga Plains: Low Subarctic	Continuous
GL-01	Gibson Lake	65.7473	-127.8881	2009 2012	None	Peat	Undifferentiated shrubs	None (recovering burn)	Hummocky moraine plain	Taiga Plains: Low Subarctic	Extensive Discontinuous
99TC6	NW cutline	65.2992	-126.8592	1999 2009	2003 2009	Moss, rosebush, Labrador tea	Undifferentiated spruce	Birch, spruce (closed)	Thermokarst surface of glaciolacustrine plain near small pond	Taiga Plains: Low Subarctic	Extensive Discontinuous
99TC5	NW fen	65.2990	-126.8607	None	2003 2009	Sedge, moss	None	Black spruce (closed)	Thermokarst surface of glaciolacustrine plain near small pond, hummocky	Taiga Plains: Low Subarctic	Extensive Discontinuous
NWZ1	84-1 Norman Wells Pump Station - Off R.O.W. Cable T4	65.2900	-126.8849	1999 2011	1999 2011	Moss, lichen	Ericaceous shrubs	Black spruce, tamarack (open)	Lacustrine deposit	Taiga Plains: Low Subarctic	Extensive Discontinuous
93AG10	Norman Wells upper air	65.2890	-126.7499	1994 2009	1994 2009/2009	Moss, lichen, herbaceous <i>*Herbaceous</i>	Alder, willow <i>* None</i>	Black spruce (open) <i>* None</i>	Till plain	Taiga Plains: Low Subarctic	Extensive Discontinuous
KP2	KP 2 - Off R.O.W.	65.2867	-126.8333	1994 2008	1995 2011	Moss, litter	Willow	Black spruce, birch	Lacustrine plain	Taiga Plains: Low Subarctic	Extensive Discontinuous
VanEv	BH14 - Van Everdinger Site	65.2727	-126.7540	1999 2011	1999 2011	Herbaceous	None	Scattered spruce, tamarack	Organic	Taiga Plains: Low Subarctic	Extensive Discontinuous
NWZ2A	84-2A Canyon Creek North A - Off R.O.W.	65.2335	-126.5263	1996 2005	1999 2008	Lichen, moss	Alder	Black spruce	Ground moraine / till	Taiga Plains: Low Subarctic	Extensive Discontinuous
NWZ2B	84-2B Canyon Creek North B - Off R.O.W. Cable T4	65.2324	-126.5202	1999 2010	1999 2011	Moss	Alder	White spruce	Colluvial deposits / gravel	Taiga Plains: Low Subarctic	Extensive Discontinuous
91TT22	Francis Creek	65.1930	-126.4691	1993 2008	1993 2008	Moss, Labrador tea	Alder, willow	Black spruce (mature)	Alluvial terrace cut into silty till	Taiga Plains: Low Subarctic	Extensive Discontinuous
NWZ3A	84-3A Great Bear River A - Off R.O.W.	64.9128	-125.5832	1995 2012	1995 2008	Lichen, moss	None	Black spruce	Alluvial terrace / silt Burned in June 1995	Taiga Plains: Low Subarctic	Extensive Discontinuous
NWZ3B	84-3B Great Bear River B - Off R.O.W. Cable T4	64.9128	-125.5832	None	1999 2005	Lichen, moss	Ericaceous shrubs	Black spruce	Eolian / Lacustrine Burned in June 1995	Taiga Plains: Low Subarctic	Extensive Discontinuous

GSC code	SITE NAME	LAT.	LONG.	AIR TEMP.	Near Surf. TEMP.	VEGETATION TYPE			LANDFORM	ECOREGION	PERMAFROST ZONE (Heginbottom, 1996)
				First year Last year	First year Last year	Groundcover	Shrub	Trees			
SR-02	Saline River	64.2897	-124.4853	2007 2009	None	Moss, Labrador tea	Willow, alder	Black spruce forest (burnt)	Glaciofluvial veneer over lacustrine	Taiga Cordillera: Low Subarctic	Extensive Discontinuous
KP182B	KP 182 Bottom of slope	64.2808	-124.4700	1995 2012	1995 2012	Burned and unburned peat	Birch, tamarack	Open spruce (some fire damage)	Colluvial deposits Burned in summer 1995	Taiga Cordillera: Low Subarctic	Extensive Discontinuous
KP182M	KP 182 Mid-slope	64.2805	-124.4700	1995 2012	1995 2012	Burned peat/organic	Birch, tamarack	Spruce (fire damaged)	Colluvial deposits Burned in summer 1995	Taiga Cordillera: Low Subarctic	Extensive Discontinuous
KP182U	KP 182 Unburnt	64.2805	-124.4670	1995 2012	1995 2012	Organic	None	Spruce (closed)	Colluvial deposits	Taiga Cordillera: Low Subarctic	Extensive Discontinuous
KP182C	KP 182 Crest of slope	64.2804	-124.4700	1995 2012	1995 2012	Bare clay / thin organic	Aspen, birch, willow	None (spruce destroyed by fire)	Colluvial deposits Burned in summer 1995	Taiga Cordillera: Low Subarctic	Extensive Discontinuous
KP182T	KP 182 Top of slope	64.2799	-124.4700	1996 2008	1997 2012	Bare / thin organic	Aspen	None (spruce destroyed by fire)	Colluvial deposits Burned in summer 1995	Taiga Cordillera: Low Subarctic	Extensive Discontinuous

* Metadata pertaining to the location of a second ground surface temperature sensor (in italic).

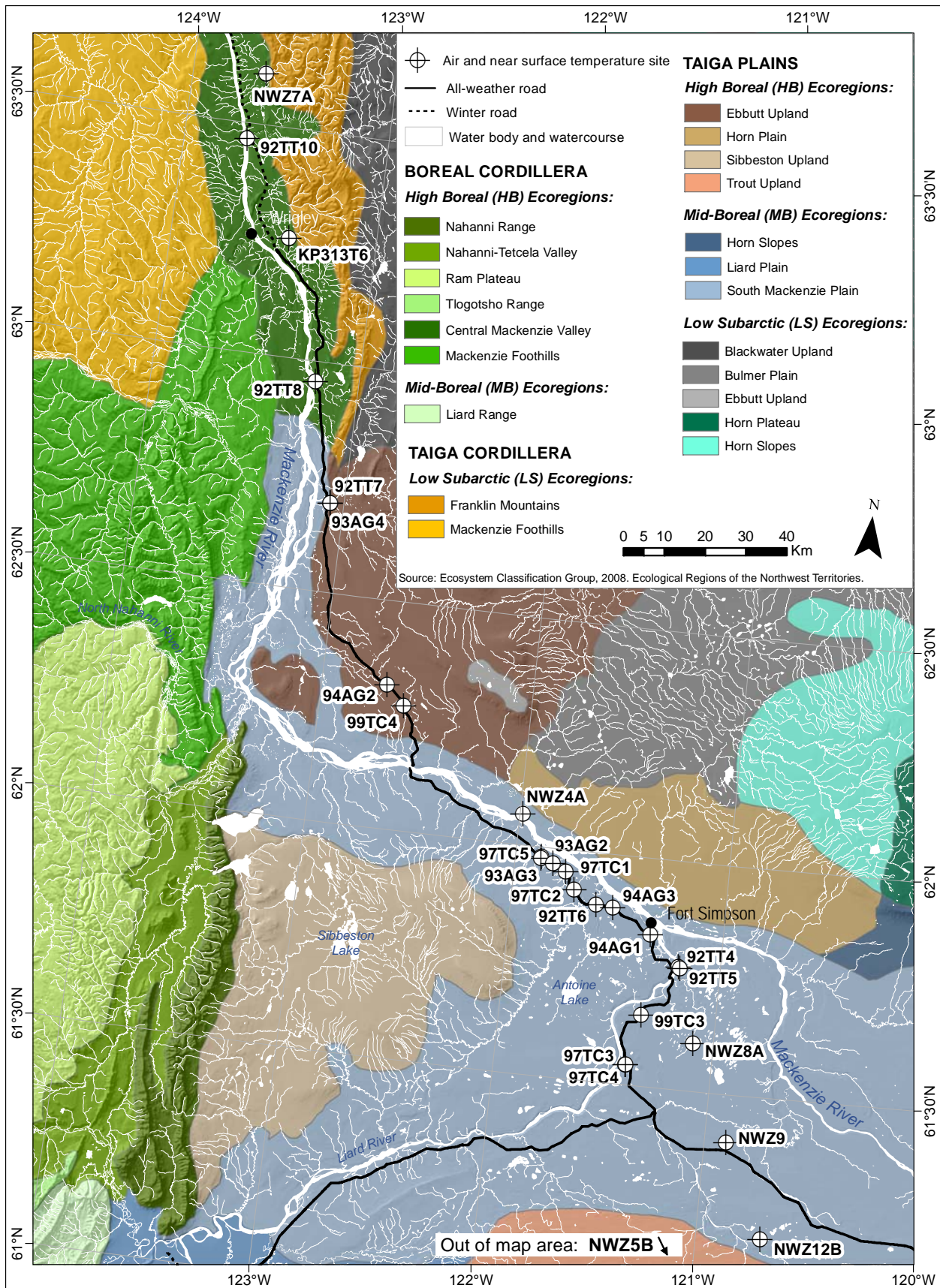


Figure 4. Monitoring sites in southern section.

Table 3. Site metadata for southern section.

GSC code	SITE NAME	LAT.	LONG.	AIR TEMP.	Near Surf. TEMP.	VEGETATION TYPE			LANDFORM	ECOREGION	PERMAFROST ZONE (Heginbottom, 1996)
						First year Last year	First year Last year	Groundcover			
NWZ7A	85-7A Table Mountain A	63.6132	-123.6451	1999 2011	2002 2011	Lichen, moss	Ericaceous shrubs	Black spruce, alder	Lacustrine clay	Boreal Cordillera: High Boreal	Extensive Discontinuous
92TT10	Ochre River cabin	63.4665	-123.6932	1993 2009	1993 2009	Moss	Alder	Black spruce (mature)	Low fluvial terrace cut into glaciolacustrine plain	Boreal Cordillera: High Boreal	Extensive Discontinuous
KP313T6	KP 313 Off R.O.W. Cable T6	63.2617	-123.4250	2001 2012	2001 2012	None	Ericaceous shrubs	Spruce (closed)	Peat (80 cm) over silt / clay, ice-rich terrain	Boreal Cordillera: High Boreal	Extensive Discontinuous
92TT8	River between two mountains	62.9578	-123.2091	1993 2011	1993 2011/2011	Litter and debris <i>* Feathermoss</i>	Alder, willow <i>* Rosebush</i>	Birch <i>* Open Black Spruce</i>	Alluvial terrace in silt (6m above river)	Boreal Cordillera: High Boreal	Extensive Discontinuous
92TT7	Willowlake River	62.6969	-123.0648	1993 2011	1993 2011	Feathermoss	Rosebush, juniper, alder	Black spruce (mature)	Top of inactive fluvial bar	Taiga Plains: Mid-Boreal	Extensive Discontinuous
93AG4	Willowlake River burn	62.6965	-123.0631	1993 2011	1993 2011/2004	Labrador tea <i>* Heath</i>	Willow <i>* None</i>	Birch <i>* Aspen</i>	Abandoned fluvial bar	Taiga Plains: Mid-Boreal	Extensive Discontinuous
94AG2	Wrigley pines	62.3156	-122.6909	1994 2011	1994 2011	None	None	Jack pine (dense)	Upland till plain	Taiga Plains: High Boreal	Extensive Discontinuous
99TC4	Wrigley peatland	62.2753	-122.6032	2000 2011	2001 2011	Moss, lichen	None	Spruce (small, scattered)	Irregular surface of raised peat plateau surrounded by lower bog surfaces and fen	Taiga Plains: High Boreal	Extensive Discontinuous
NWZ4A	84-4A Trail River A - Off R.O.W.	62.0703	-121.9883	1999 2006	1999 2006	Lichen, moss	Willow	Jack pine, aspen	Eolian sand and silt	Taiga Plains: Mid-Boreal	Extensive Discontinuous
93AG2	FS bog	61.9800	-121.8800	1993 2011	1993 2011/2011	Moss, heath <i>* Moss, Labrador tea</i>	Small willow <i>* None</i>	Small spruce (open) <i>* Black spruce (open)</i>	Raised bog with collapse depression developed on lacustrine plain	Taiga Plains: Mid-Boreal	Extensive Discontinuous
97TC5	Wrigley ferry transition	61.9769	-121.8816	1999 2009	2003 2011	Moss	None	Black spruce (open)	Surface of glacio-lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
93AG3	Cutline Spruce	61.9685	-121.8235	1993 2011	1993 2011/2004	Feathermoss <i>* Herbaceous</i>	None <i>* Birch, willow</i>	Mature white spruce <i>* None</i>	Lacustrine plain	Taiga Plains: Mid-Boreal	Extensive Discontinuous
97TC1	Aspen	61.9531	-121.7607	1999 2011	2003 2009	Leaf litter, gooseberry, bearberry	Rosebush, bearberry, alder	Aspen, white spruce	Surface of glacio-lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
97TC2	Mature Black spruce	61.9162	-121.7121	1999 2011	2003 2011	Feathermoss	White and black spruce	Black spruce (mature)	Surface of glacio-lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
92TT6	Martin River	61.8878	-121.6036	1993 2011	1993 2011	Moss	White spruce	White spruce	Glaciolacustrine plain	Taiga Plains: Mid-Boreal	Extensive Discontinuous

GSC code	SITE NAME	LAT.	LONG.	AIR TEMP.		VEGETATION TYPE			LANDFORM	ECOREGION	PERMAFROST ZONE (Heginbottom, 1996)
				First year Last year	Near Surf. TEMP. First year Last year	Groundcover	Shrub	Trees			
94AG3	FS aspen dune	61.8845	-121.5238	1993 2011	1993 2011/2004	Leaf litter, sedge, herbaceous <i>* None</i>	Alder, willow <i>* None</i>	Aspen (Mature) <i>* Spruce (mature)</i>	Top of dune formed on lacustrine plain	Taiga Plains: Mid-Boreal	Extensive Discontinuous
94AG1	FS deep cable	61.8350	-121.3390	1999 2011	1999 2011	Litter, moss	None	Black and white spruce	Surface of glacio- lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
92TT4	Manners Creek mouth	61.7701	-121.1932	None	1993 2008	Leaf litter, horsetail, herbaceous	Poplar, willow	Poplar, aspen	River bank at mouth of Manners Creek	Taiga Plains: Mid-Boreal	Extensive Discontinuous
92TT5	Manners Creek upper	61.7658	-121.1873	1993 2008	1993 2008	Leaf litter, dogwood	Bearberry, rosebush	Aspen	Alluvial terrace cut into glacial lacustrine plane	Taiga Plains: Mid-Boreal	Extensive Discontinuous
99TC3	Open Black spruce	61.6570	-121.3438	1999 2011	2003 2011	Feather moss	None	Black spruce	Surface of glacio- lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
NWZ8A	85-8A Manners Creek A - Off R.O.W. Cable T4	61.6047	-121.0935	2001 2008	1997 2008	Peat	None	White and black spruce (closed)	Organic	Taiga Plains: Mid-Boreal	Sporadic Discontinuous
97TC3	Liard shrub	61.5456	-121.3941	1999 2011	2003 2008	Sedge	Willow, birch	Scattered birch	Wetland on surface of glaciolacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
97TC4	Liard spruce	61.5451	-121.3935	None	2003 2011	Moss, herbaceous	None	Black spruce	Surface of glacio- lacustrine delta	Taiga Plains: Mid-Boreal	Extensive Discontinuous
NWZ9	85-9 Pump Station	61.3955	-120.8997	2000 2010	2000 2010	Moss, lichen	Ericaceous shrubs	Black spruce	Lacustrine complex	Taiga Plains: Mid-Boreal	Sporadic Discontinuous
NWZ12B	85-12B Jean Marie Creek B - Off R.O.W.	61.1918	-120.7060	1997 2010	1997 2010	Moss, lichen	Ericaceous shrubs	Black spruce	Organic	Taiga Plains: Mid-Boreal	Sporadic Discontinuous
NWZ5B	84-5B Petitot River north	59.7574	-119.5143	1999 2010	2000 2010	Moss	Ericaceous shrubs, black spruce	Black spruce (open)	Organic Burned in summer 2004	Taiga Plains: Low Subarctic	Sporadic Discontinuous

* Metadata pertaining to the location of a second ground surface temperature sensor (in italic).

3. Methodology

Most monitoring sites include instrumentation for measurement of air and near-surface ground temperatures (see Tables 1 to 3). Air temperature sensors, installed in radiation shields mounted 1.5 m above the ground surface, are connected to single-channel data loggers (Onset HOBO Stowaway or Vemco Minilog) to record temperatures at 3 to 6 hour intervals. Near-surface ground temperatures are measured at the same intervals with a sensor buried at a nominal depth of 3-7 cm that also utilizes a single channel data logger (Onset HOBO or Vemco). For the temperature range -25°C to 15°C, the resolution is 0.2°C and 0.3°C for the Vemco and HOBO loggers respectively. The accuracy of the temperature values is $\pm 0.3^\circ\text{C}$ for Vemco loggers and $\pm 0.4^\circ\text{C}$ for the HOBO loggers. Daily and annual mean air and ground surface temperatures were calculated using the high frequency data records.

Over the study period 1993-2012, a total of 53 air temperature sites operated for periods of one to 15 years. In any year the number of operating air temperature stations varied from one to 39, with the highest coverage from 2000 to 2010 (with 21-39 stations for years in this period).

Daily mean temperatures were used to calculate the air and ground surface freezing and thawing indices and n-factors. Dividing the year into freezing and thawing seasons, the freezing index (FDD) and thawing index (TDD) are defined as seasonally integrated temperatures, approximately equal to the sum of daily mean temperatures for the duration of the season. For example, the thawing index (following Klene et al., 2001) is:

$$TDD_S = \int_0^{\theta_s} T_F - T_S dt \approx \sum_0^{\theta_s} \overline{T_S} \quad (1)$$

where T_F = temperature of the freezing point (0°C); T_S = surface temperature in $^\circ\text{C}$, θ_s = duration of the thawing season, in days; and $\overline{T_S}$ = daily mean surface temperature in $^\circ\text{C}$. An equivalent equation applies to the freezing index, although by convention the freezing index is positive. Annual freezing indices were calculated based on the calendar year and (for high latitudes in the northern hemisphere) for a winter-centered year (i.e. from July to July).

N-factors relate seasonal air temperature to ground surface temperatures (Lunardini, 1978). The behaviour of the seasonal average air-ground surface temperature relationship can be summarized as the ratio of surface and air degree-days, or n-factor (Lunardini, 1981). For example, the surface thawing n-factor is defined:

$$n_T = \frac{TDD_S}{TDD_A} \quad (2)$$

where n_T = thawing n-factor; TDD_S = surface thawing index; and TDD_A = air thawing index.

With air and ground surface freezing and thawing index data, (Klene et al., 2001; Jorgenson and Kreig, 1988; Taylor, 1995, 2000) n-factors can be used to determine the surface thermal regime of different land-covers. As with the freezing index, the freezing n-factor was calculated for both the calendar year and for the winter-centered year.

The timing of the start and the end of the freezing and thawing periods for each year was calculated in the air and at the ground surface at each site. For the end-of-winter / spring season, dates of thaw initiation were noted when, within the period of March-1 to June-30, the mean daily temperature was positive with a negative value on the previous day; for the start-of-winter / autumn season, dates of freeze-up initiation were noted when, within the period of September-1 to December-31, the mean daily temperature was negative with a positive value on the previous day. During the spring season, the first change from negative to positive within the defined period is referred to as early thaw; the last change within the period is referred to as the latest thaw date; the mid thaw represents the median of these occurrences in the spring freeze/thaw cycle. Similarly, in autumn, the first change from positive to negative within the defined period is referred to as the first freeze; the last change within the period is referred to as the end of freeze up; the mid thaw represents the median of these occurrences in the autumn freeze/thaw cycle.

The zero-curtain refers to a time period where the ground temperature is nearly constant near the freezing point and is usually the results of the dissipation of latent heat of fusion during freezing or thawing (Van Everdingen, 1998), as well as osmotic potential variations induced by freeze-thaw events at the soil surface (Outcalt et al, 1990). In this report, the upper limit of the zero curtain was defined at 0.20°C and pertains to the precision of the loggers used to collect data; the lower limit of -0.5°C represents a combination of instrumental precision and the effect of variable water content at different sites. The zero-curtain was calculated by summing the total number of days with temperatures in this range.

4. Data overview

Air temperature is measured at 53 sites along the Mackenzie corridor (see Tables 1 to 3). The annual mean air temperature (AMAT) for all sites varied from -12.6 °C (2004) in the

Mackenzie Delta to +0.5 °C (2010) near the community of Fort Simpson. Figure 5 presents the AMAT at 39 sites for the year 2003, grouped by ecoregions (Ecoregion classification group, 2008). Year 2003 was chosen as it represents the most continuous record. Environment Canada climate station data based on daily means (with missing values interpolated) for Fort Simpson, Norman Wells and Inuvik are also plotted (Environment Canada, 2012). The data shows a latitudinal trend with values generally slightly cooler at monitoring sites than at climate station. This effect can be explained by microclimatic variation between sites located at airport on a grass surface as opposed natural environments with different vegetation covers.

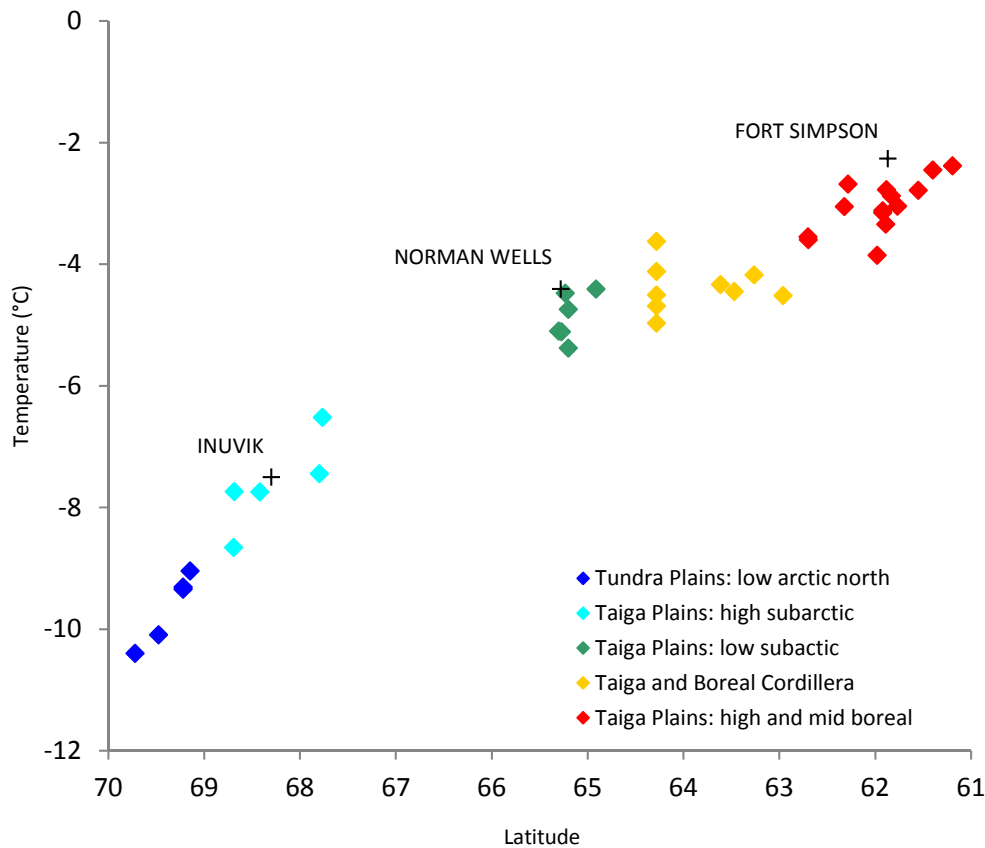


Figure 5. Monitoring sites annual mean air temperature for 2003 grouped by ecoregions. Environment Canada weather station data for three communities is also plotted (shown by crosses).

Near-surface temperature is measured at 58 sites along the Mackenzie Corridor (see Tables 1 to 3). The annual mean ground surface temperature (AMGST) ranges from -8.1 °C (2004) at a site on the shore of the Beaufort Sea to +4.2 °C (1996) adjacent to the pipeline right-of-way, approximately 40 km north of the community of Wrigley. Figure 6 presents the AMGST for 42 sites in 2003 where the different series represent the most prevalent ecoregions. In the case of AMGST, the distribution of temperature does not show a very clear latitudinal trend except for sites located in the Tundra Plains and Taiga Plains (high subarctic) regions where

ground temperatures are slightly lower with increasing latitude. The warm outlier point in the Tundra Plain series is a site where tall willow shrubs are dominant and where snow accumulation is probably more important. The scattering of the data points show the modulating effect of the vegetation through shading in the summer and snow capture in the winter.

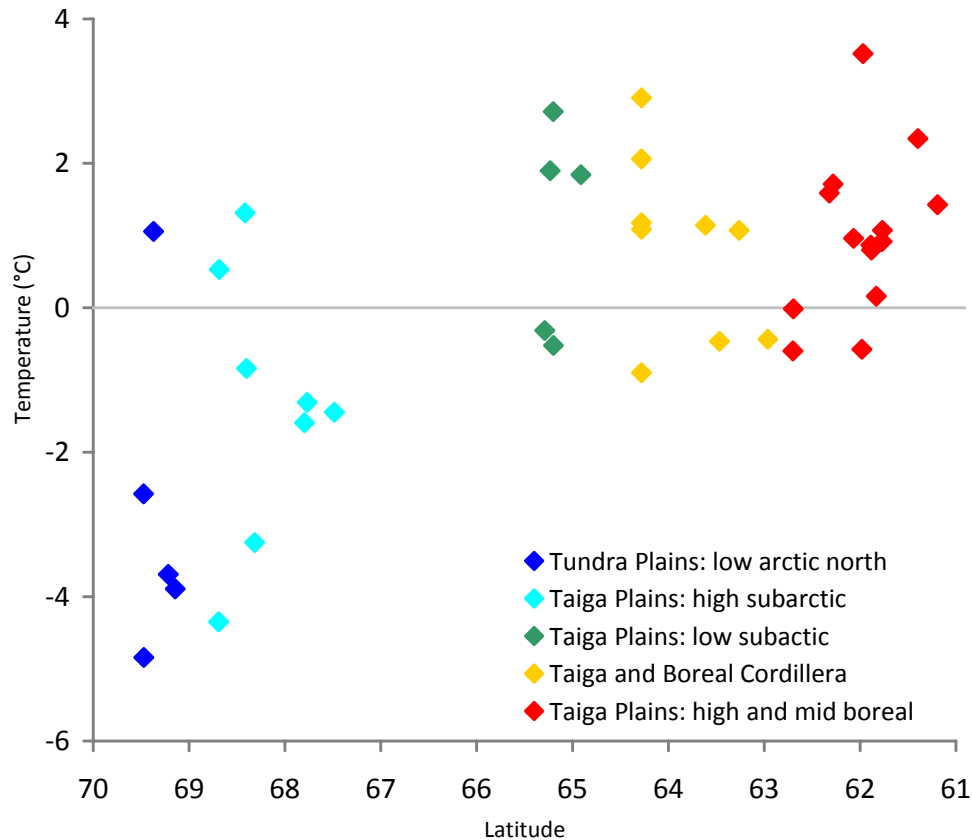


Figure 6. Monitoring sites annual mean ground surface temperature for 2003 grouped by ecoregions.

The range in air and near-surface ground temperature for different environments has also been determined. Figure 7 summarizes the average and the range of air temperature and near-surface ground temperature for the monitoring sites in the ecoregions of the Mackenzie corridor. In this figure, within the same ecoregion, the overall mean temperature (\blacklozenge) is for all years and all sites; the range (\diamond) represents the minimum and maximum annual mean temperature for all years and sites; and the whiskers (vertical bars) represent the range of overall average temperature for each individual site. The importance of interannual as opposed to inter-site variability within each ecoregion is highlighted in figure 7. Air temperature shows a latitudinal gradient with significant interannual variability (Figure 7a). In contrast, near-surface ground temperatures exhibit greater spatial variability (Figure 7b), which can be explained by the modulating effect of the snow cover, vegetation, and microtopographic effects on ground temperatures.

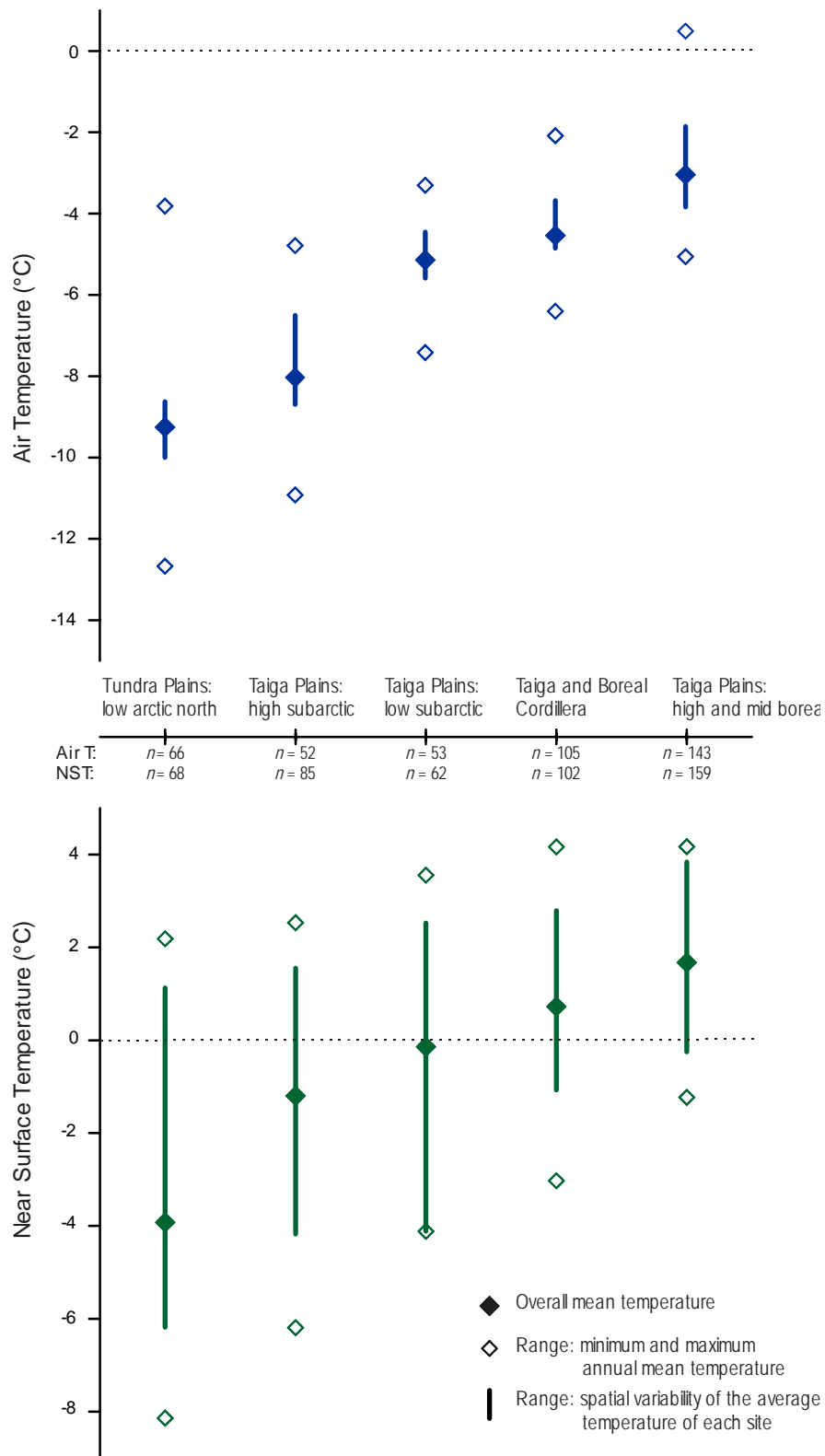


Figure 7. Mean and ranges of temperatures for air (a) and near-surface (b) sites by ecoregions.

5. Data presentation and database structure

As outline in figure 1, the data are presented for three sections: northern (Appendix A), central (Appendix B) and southern (Appendix C). The appendices present the AMAT and AMGST for each site in graphical format as well as a site location and photograph. Tables 1 to 3 present detailed site descriptions for each section. In the case of 5 sites, two temperature sensors measuring near-surface ground temperature were deployed. The metadata for the vegetation types for the second sensor is included in tables 1 to 3 in italic preceded by an asterisk and the AMGST is plotted in a light green on appendices A to C.

An accompanying database is organized in three directories following the same structure as the metadata and maps (northern, central and southern). Data is presented in comma delimited format with file name referring to the site “GSC code”. Two files per site are presented: the mean daily temperature data (GSCcode.csv) and the summary statistics data (GSCcode_m.csv). The following section provides a description of field for both the mean daily temperature and the summary statistic.

5.1 Mean daily temperature metadata

Filename : GSCcode.csv

<u>Heading</u>	<u>Description</u>
Date:	Date field (dd-mon-yy)
Air T (Celsius):	Daily mean air temperature (°C)
NST (Celsius):	Daily mean near-surface temperature (°C)

* N/A indicates that no values were available for that day.

5.2 Summary statistics metadata

Filename : GSCcode_m.csv

Air and ground temperature summaries present each year’s data side by side. The second row indicates the type of data (air or near-surface). The description below pertains to both air and ground temperature summaries except for zero-curtain calculations which are included for ground temperature only. When both air and near-surface temperatures are presented, n-factor

values are included under Air summaries. N/A indicates that no values were available for that parameter.

<u>Heading (rows)</u>	<u>Description</u>
Annual mean	Annual mean temperature (°C)
Months	Monthly mean temperature (°C) (presented for each month)
TDD	Thawing degree days (°C·days)
FDD – Year:	Freezing degree days for the calendar year (Jan-1 to Dec-31) (°C·days)
FDD – Winter:	Freezing degree days for the winter (Oct-1 to Apr-30 of the following year) (°C·days)
% of Year:	Percentage of the year where mean daily temperature was available
% of Thaw:	Percentage of the thaw season (May-1 to Sep-30) where mean daily temperature was available.
FDDY%	Percentage of the calendar year (Jan-1 to Dec-31) where freezing degree days were available
FDDW%	Percentage of the winter (Oct-1 to Apr-30 of the following year) where freezing degree days were available
nT	Thawing n-factor
nFa	Freezing n-factor for the calendar year (Jan-1 to Dec-31)
nFw	Freezing n-factor for the winter (Oct-1 to Apr-30 of the following year)
Early thaw	First day where daily mean temperature is positive (from a negative value the previous day)
Mid thaw	Median date of the spring freeze/thaw cycle
Latest thaw date	Last day where daily mean temperature is positive (from a negative value the previous day)
First freeze	First day where daily mean temperature is negative (from a positive value the previous day)
Mid freeze	Median date of the fall freeze/thaw cycle
End of Freeze up	Last day where daily mean temperature is negative (from a positive value the previous day)
Zero-Curtain Limits	Constant limits at which zero-curtain is calculated (see Methodology section)
Fall Zero-Curtain	Number of fall days when daily mean near-surface ground temperature falls between the zero-curtain limits
Spring Zero-Curtain	Number of spring days when daily mean temperature falls between the zero-curtain limits

6. Summary

The Geological Survey of Canada has maintained a network of 61 air and ground surface temperature monitoring sites from 1993 to present, intersecting a range of terrain, vegetation and climatic conditions along the Mackenzie Valley corridor. This open file presents a compilation until 2012. Annual mean air temperatures show a latitudinal trend in contrast with annual mean ground surface temperatures where the scattering of the data points illustrate the modulating effect of the vegetation on ground temperature. Range of air and ground surface temperature in different environments also highlights the importance of interannual and spatial variability, and informs on expected conditions which can be encountered in specific environment.

Acknowledgment

Data collection, management, processing and analysis have been supported by Natural Resources Canada and several other funding sources and agencies over the past two decades. These have included the Program for Energy Research and Development, Northern Energy Development Initiative, Action Plan 2000, Federal International Polar Year Program and the “NWT Cumulative Impact Monitoring Program” of Aboriginal Affairs and Northern Development Canada. Enbridge Pipelines (NW) Ltd. has also provided logistical support for monitoring along the pipeline corridor. Logistical support has been provided by Polar Continental Shelf Program. The support and assistance provided by communities in the region and the Aurora Research Institute is much appreciated. Numerous colleagues have assisted with data collection and management including F.M. Nixon, M. Ednie, J. Chartrand and M. Burgess. The review of this report by Dr Anne-Marie Leblanc at the Geological Survey of Canada was greatly appreciated.

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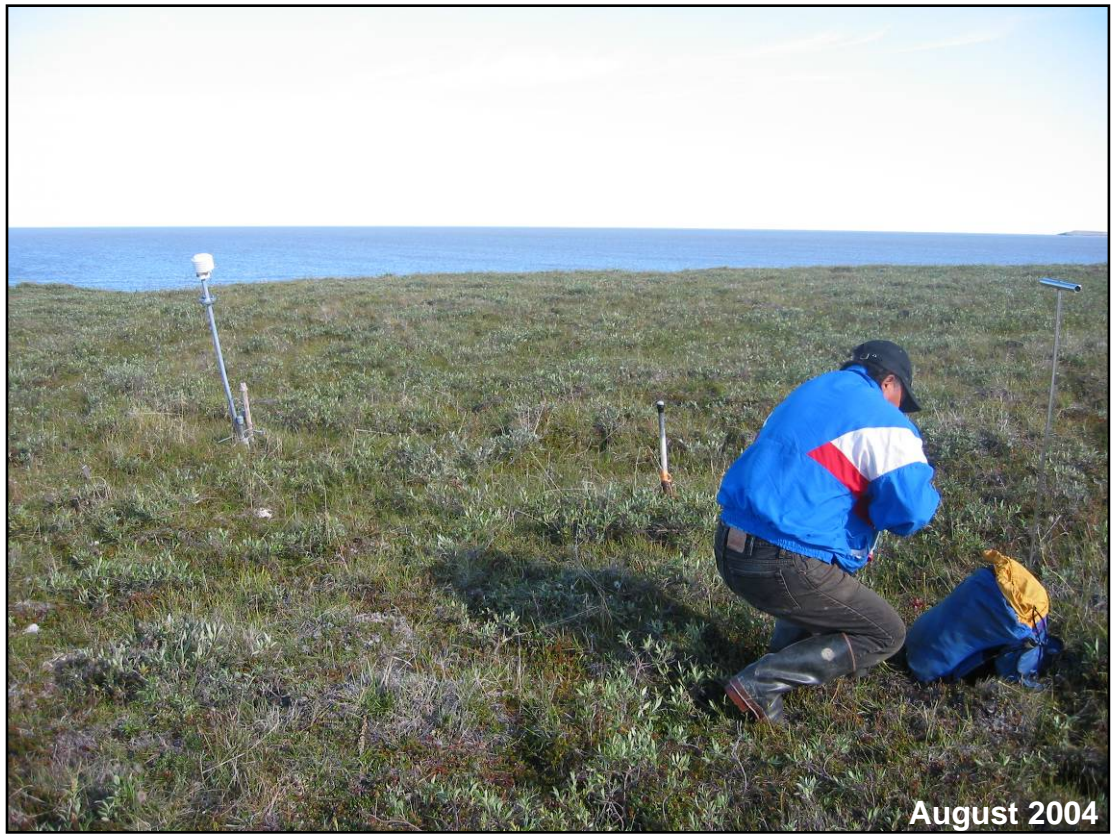
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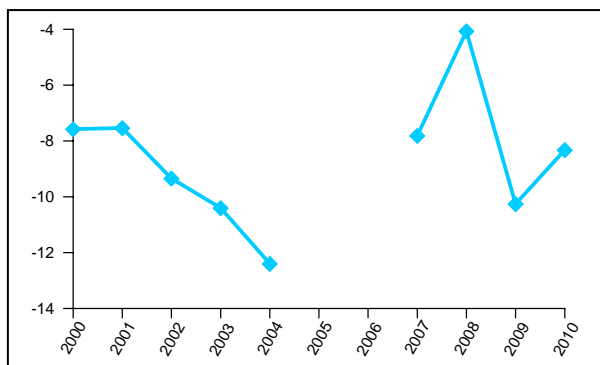
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Appendix 1. Northern Section

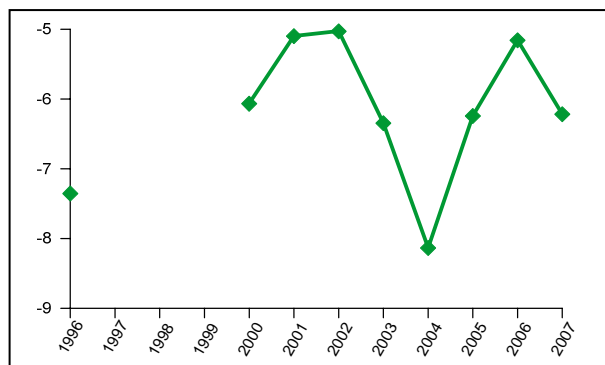
GSC Code: 90TT13
Name: North Head shore
Location: N 69.7194 W 134.4615



Annual mean air temperature (°C)



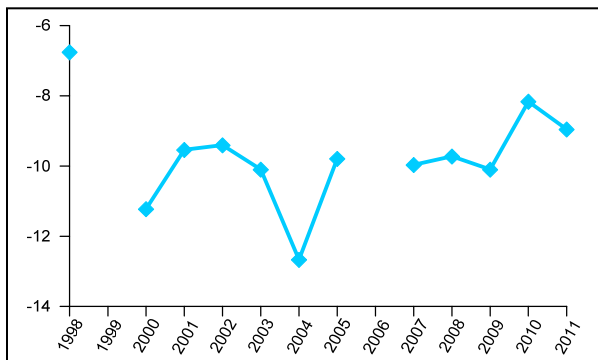
Annual mean ground surface temperature (°C)



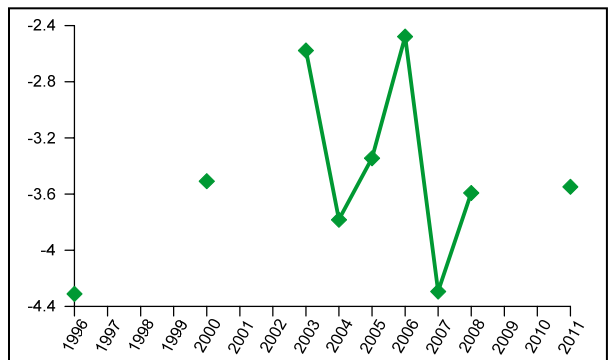
GSC Code: 92TT2
Name: Involved Hill flat
Location: N 69.4742 W 132.6345



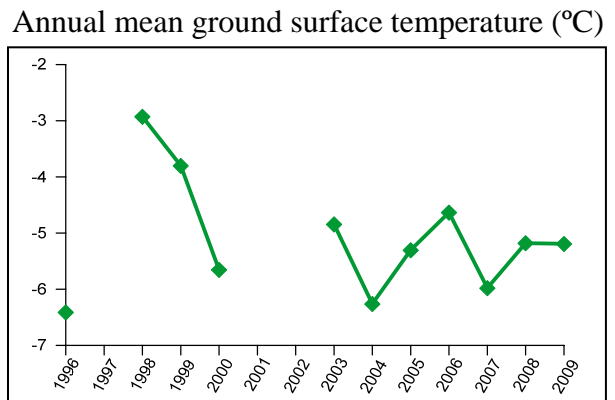
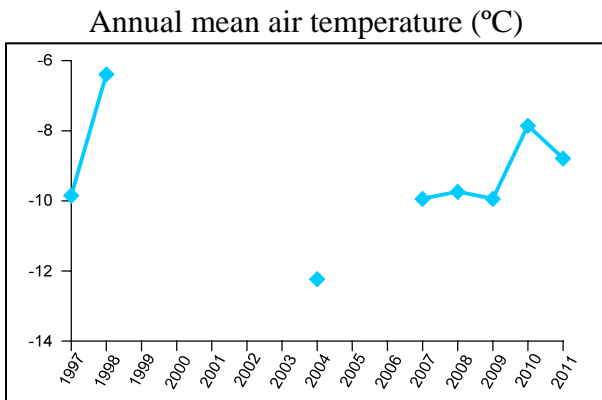
Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)



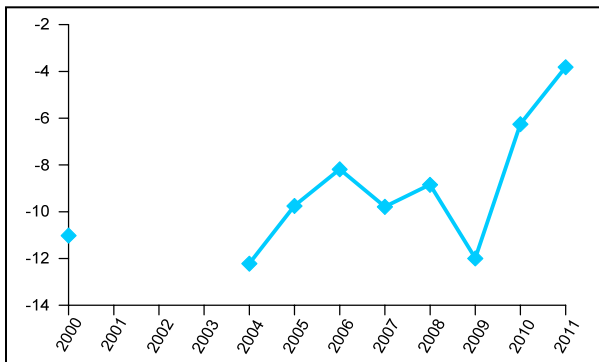
GSC Code: 92TT1
Name: Involved Hill top
Location: N 69.4729 W 132.6270



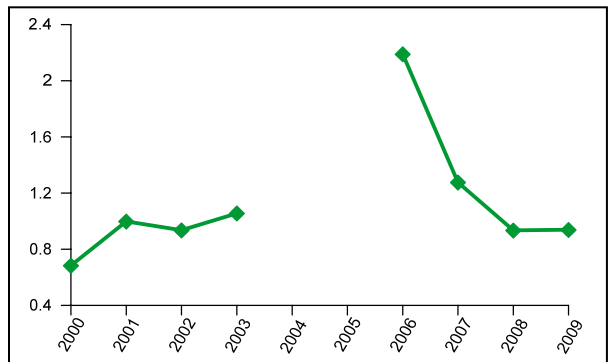
GSC Code: 91TTC
Name: Taglu
Location: N 69.3694 W 134.9486



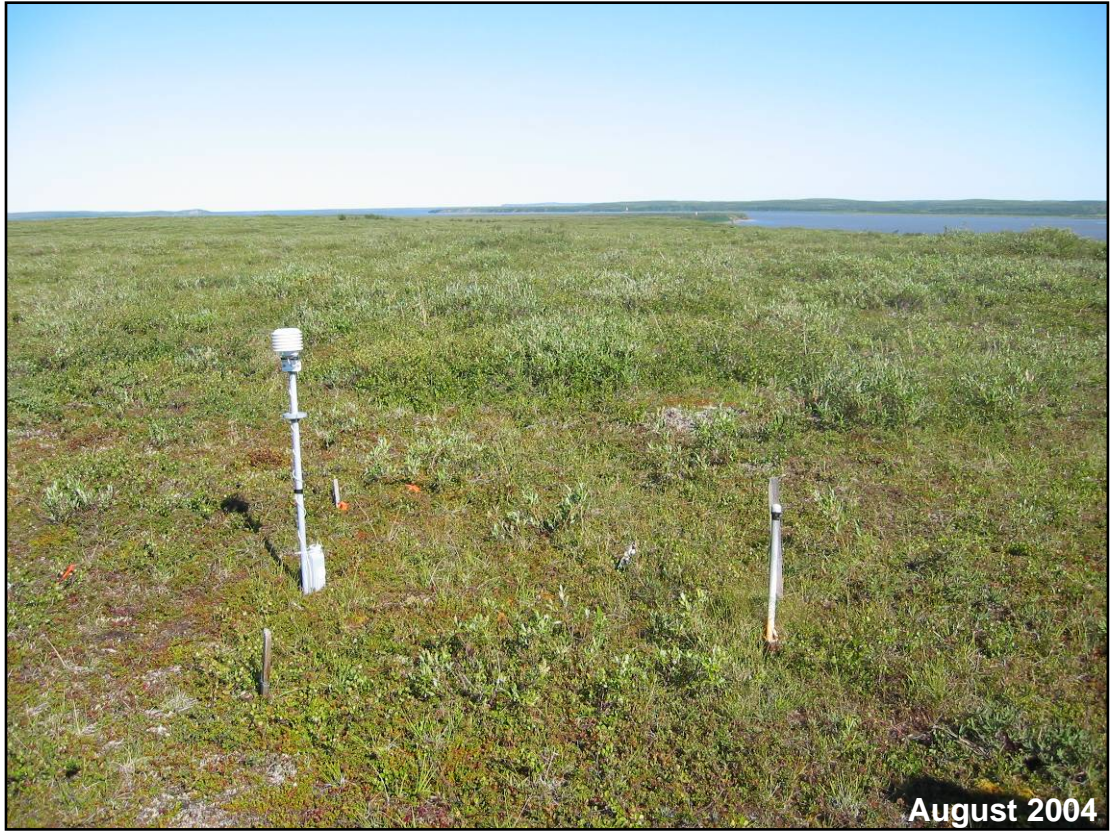
Annual mean air temperature (°C)



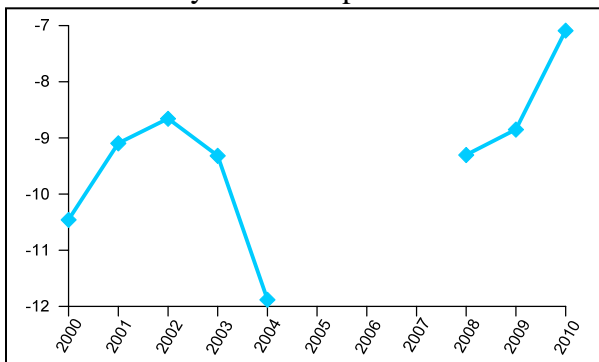
Annual mean ground surface temperature (°C)



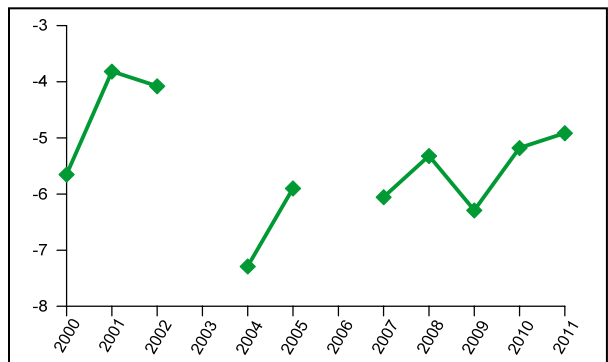
GSC Code: 90TT5
Name: Lousy Point ridge
Location: N 69.2186 W 134.2848



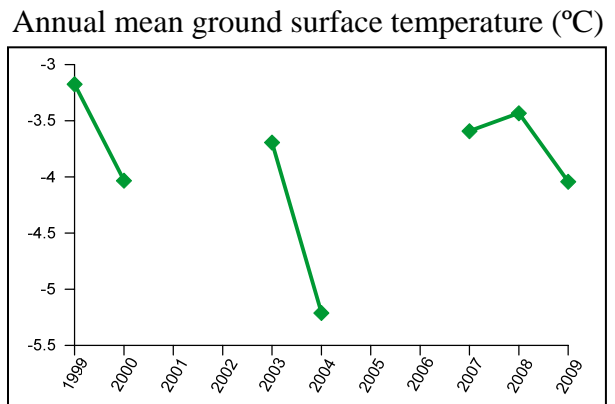
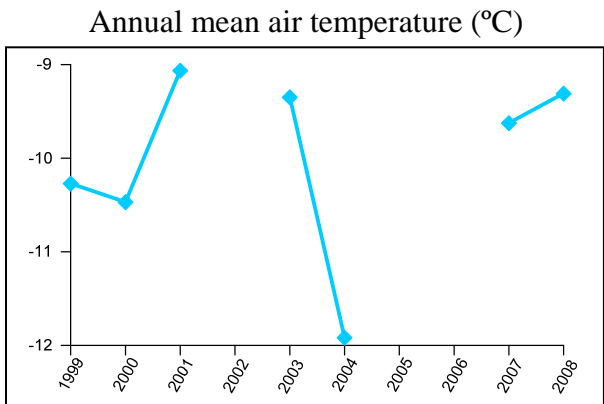
Mean monthly air temperature (°C)
July 1994 to April 1995



Annual mean ground surface temperature (°C)



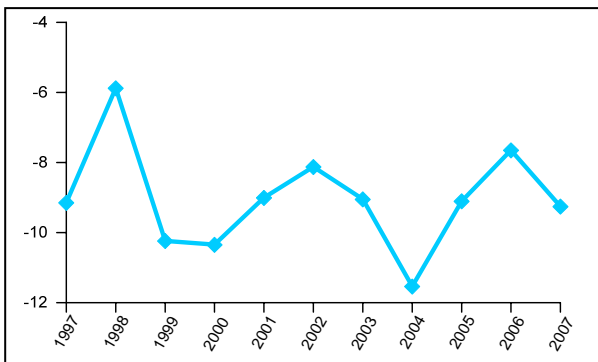
GSC Code: 90TT6
Name: Lousy Point low terrace
Location: N 69.2163 W 134.2801



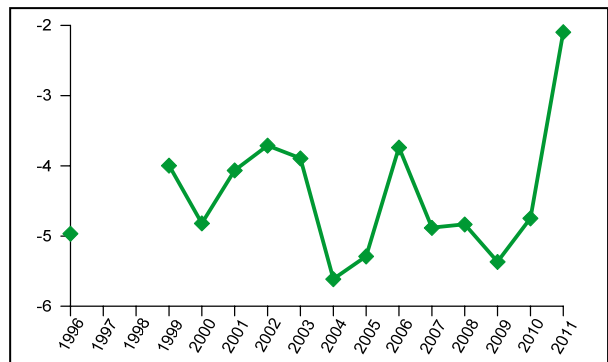
GSC Code: 90TT4
Name: YaYa Lake low
Location: N 69.1430 W 134.7041



Annual mean air temperature (°C)



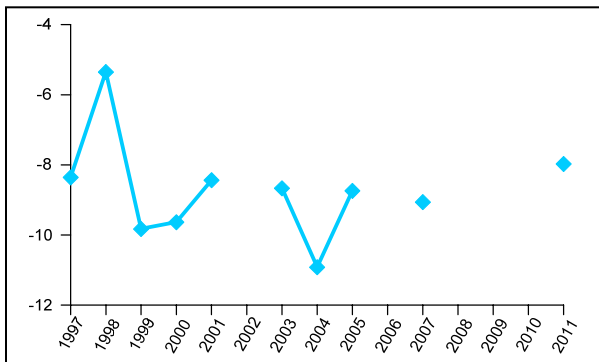
Annual mean ground surface temperature (°C)



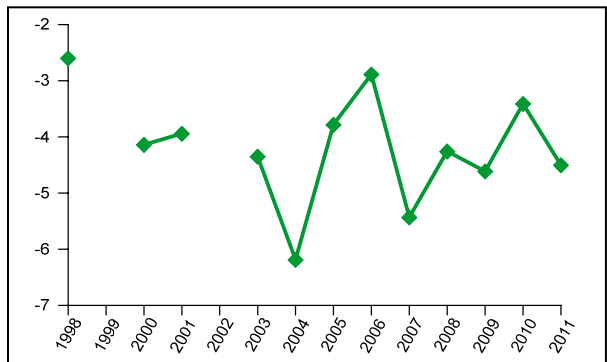
GSC Code: 91TT12
Name: Reindeer Station plateau
Location: N 68.6885 W 134.1109



Annual mean air temperature (°C)



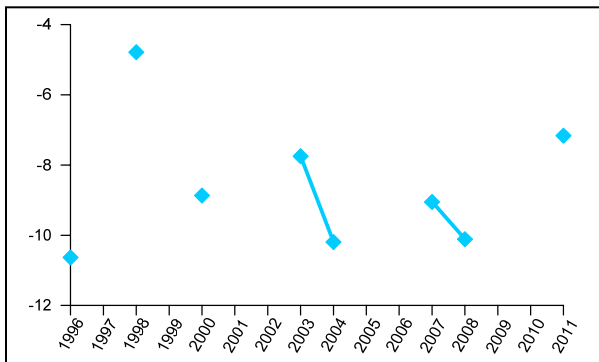
Annual mean ground surface temperature (°C)



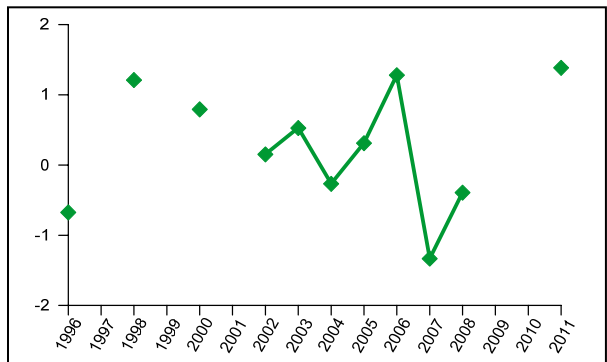
GSC Code: 91TT13
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Annual mean air temperature (°C)



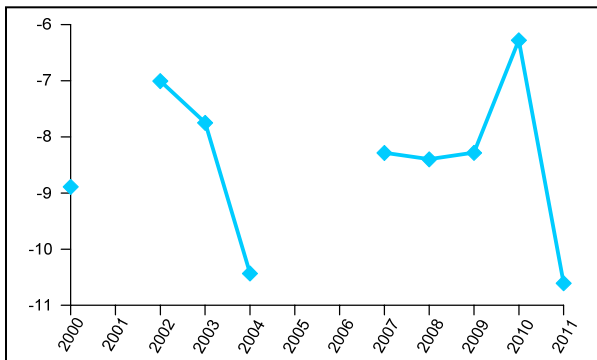
Annual mean ground surface temperature (°C)



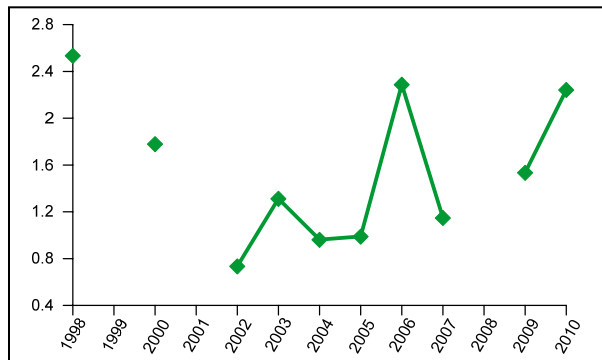
GSC Code: 90TT17
Name: Navy Channel
Location: N 68.4150 W 133.7942



Annual mean air temperature (°C)



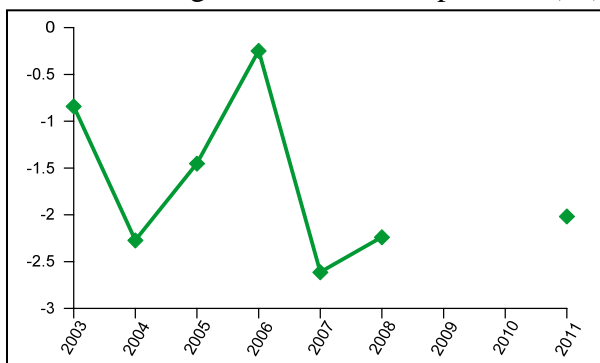
Annual mean ground surface temperature (°C)



GSC Code: 01TC1
Name: Navy Road
Location: N 68.4009 W -133.762



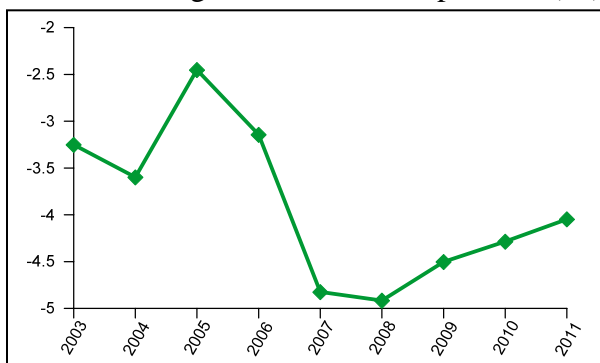
Annual mean ground surface temperature (°C)



GSC Code: 01TC2
Name: Inuvik airport forest
Location: N 68.3160 W 133.4355



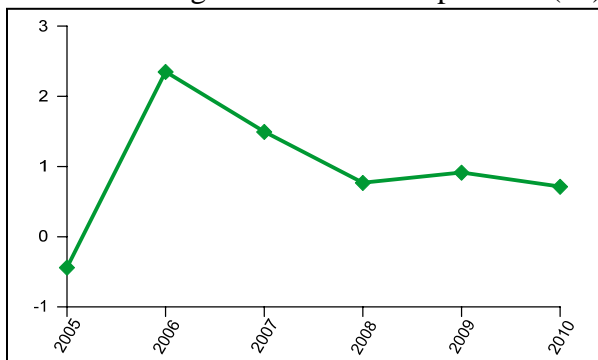
Annual mean ground surface temperature (°C)



GSC Code: 01TC3
Name: Inuvik airport bog
Location: N 68.3156 W 133.4338



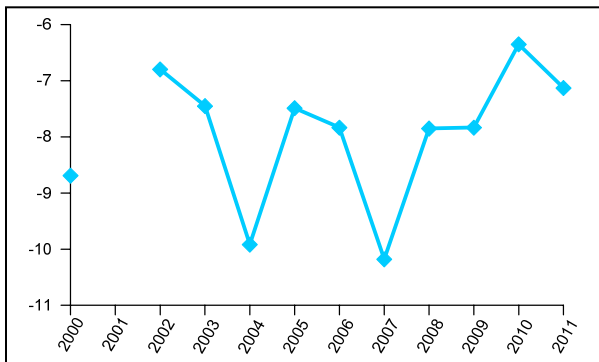
Annual mean ground surface temperature (°C)



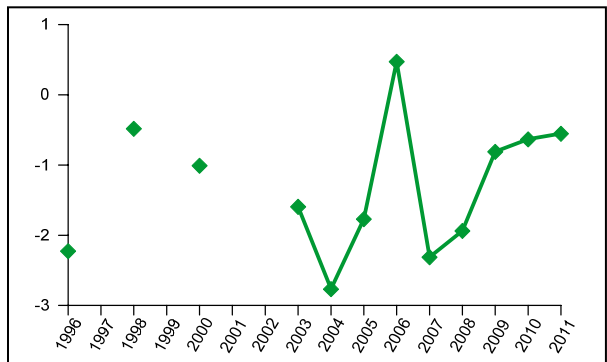
GSC Code: 91TT14
Name: Rengleng River mouth
Location: N 67.7951 W 134.1263



Annual mean air temperature (°C)



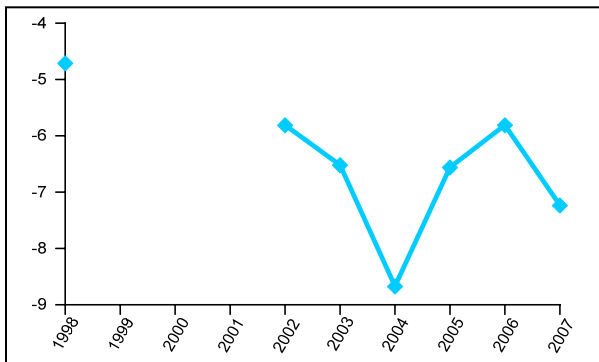
Annual mean ground surface temperature (°C)



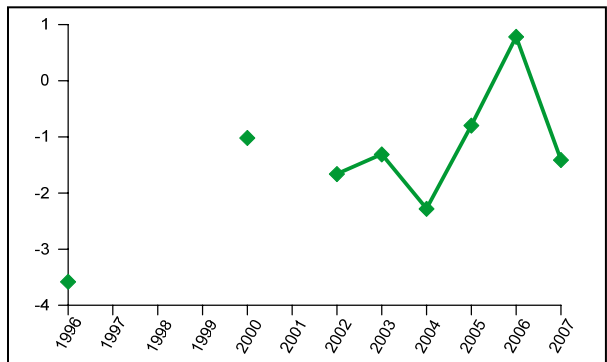
GSC Code: 91TT15
Name: Rengleng Lake
Location: N 67.7661 W 134.0788



Annual mean air temperature (°C)



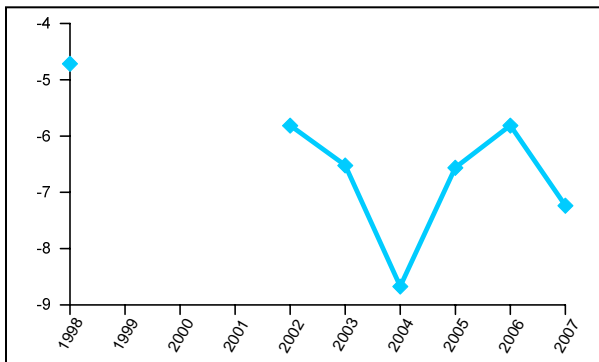
Annual mean ground surface temperature (°C)



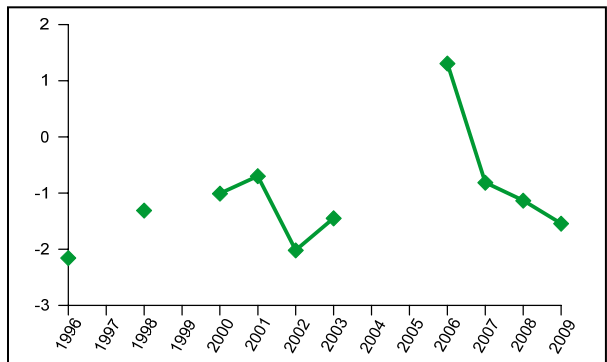
GSC Code: 91TT16
Name: Tsiigehtchic
Location: N 67.4842 W 133.7633



Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)

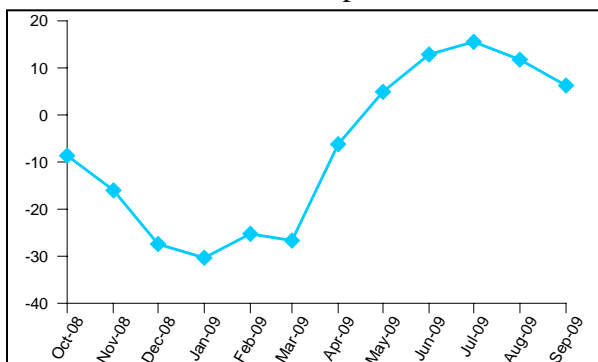


Appendix 2. Central Section

GSC Code: FGHS-01
Name: Fort Good Hope South
Location: N 66.2097 W 128.4958



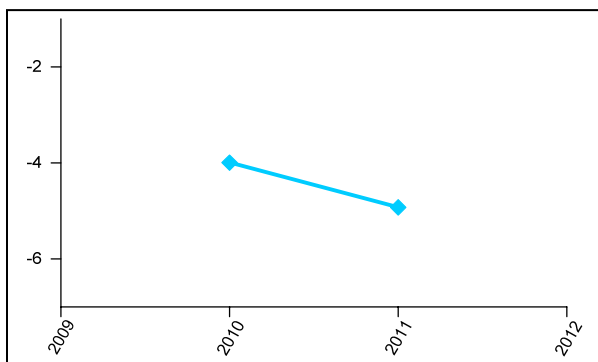
Monthly mean air temperature (°C)
October 2008 to September 2009



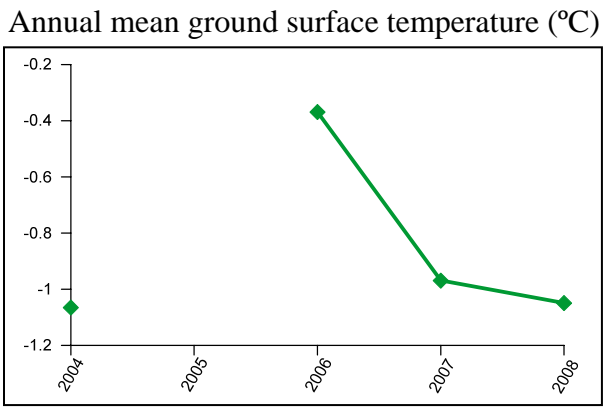
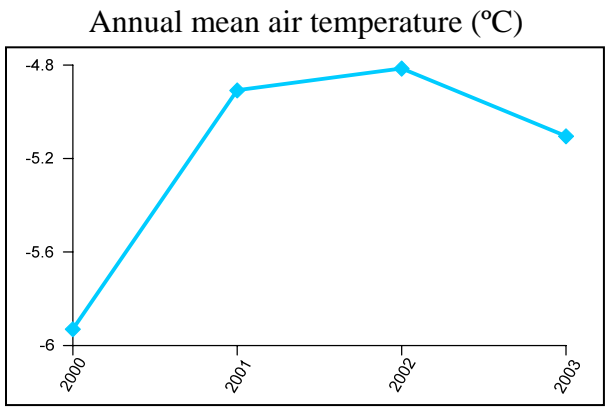
GSC Code: GL-01
Name: Gibson Lake
Location: N 65.7473 W 127.8881



Mean monthly air temperature (°C)



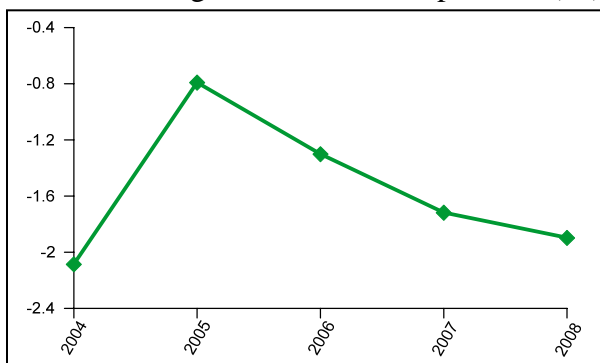
GSC Code: 99TC6
Name: NW cutline
Location: N 65.2992 W 126.8592



GSC Code: 99TC5
Name: NW fen
Location: N 65.2990 W 126.8607



Annual mean ground surface temperature (°C)



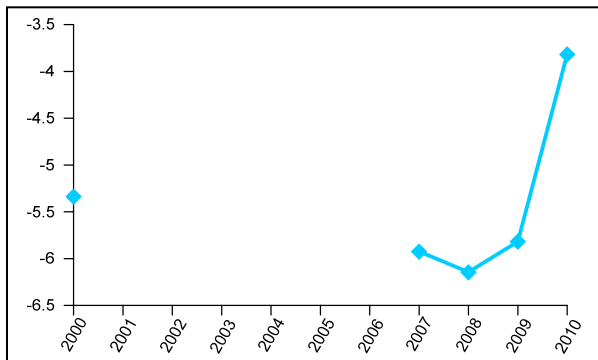
GSC Code: NWZ1

Name: 84-1 Norman Wells Pump Station - Off R.O.W. Cable T4

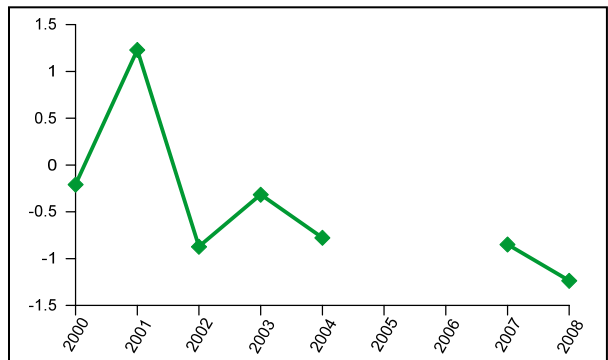
Location: N 65.2899 W 126.8849



Annual mean air temperature (°C)



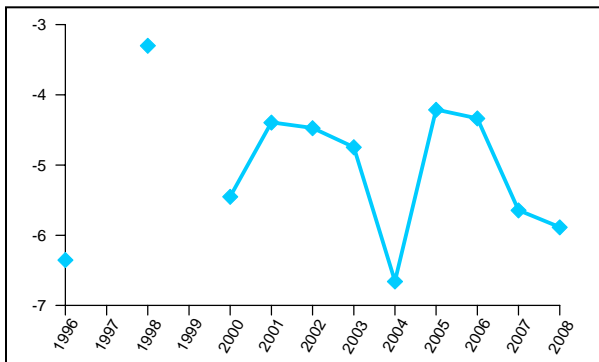
Annual mean ground surface temperature (°C)



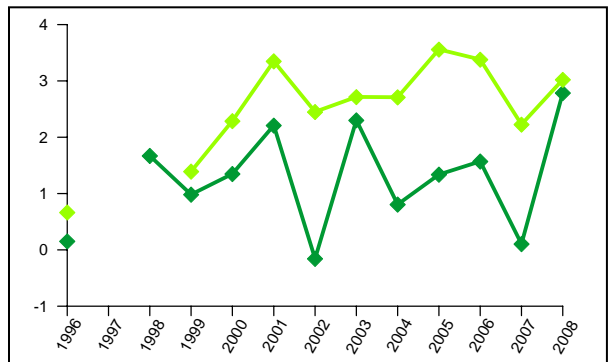
GSC Code: 93AG10
Name: Norman Wells upper air
Location: N 65.2889 W 126.7498



Annual mean air temperature (°C)



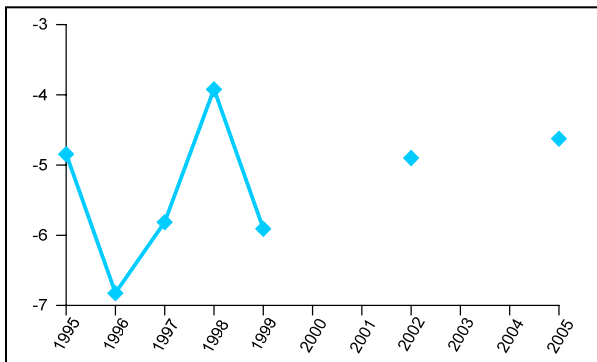
Annual mean ground surface temperature (°C)



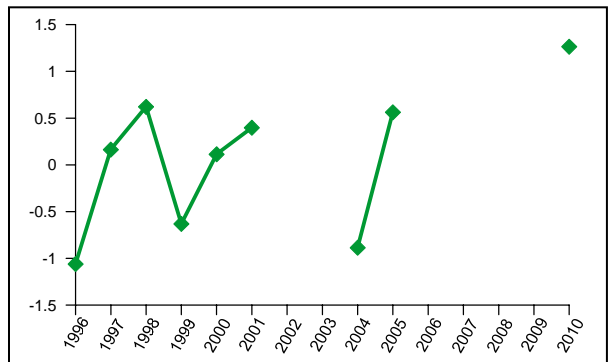
GSC Code: KP2
Name: KP 2 - Off R.O.W.
Location: N 65.2866 W 126.8333



Annual mean air temperature (°C)



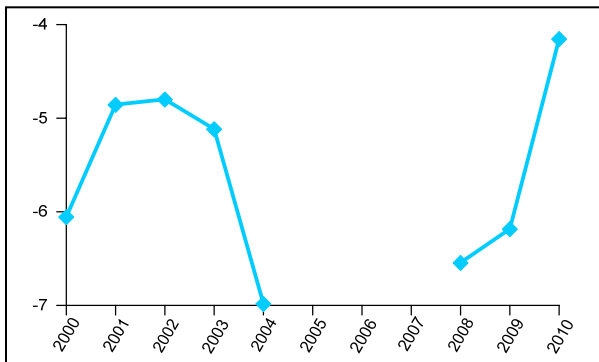
Annual mean ground surface temperature (°C)



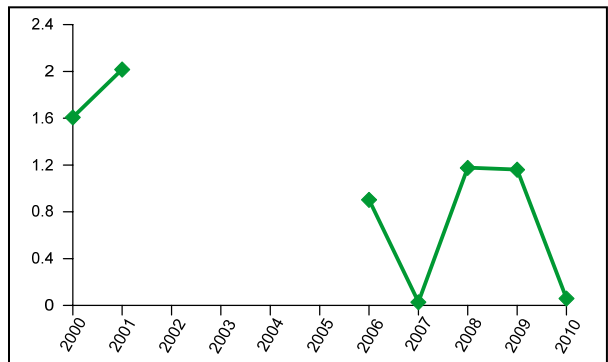
GSC Code: VanEv
Name: BH14 - Van Everdingen Site
Location: N 65.2727 W 126.7540



Annual mean air temperature (°C)



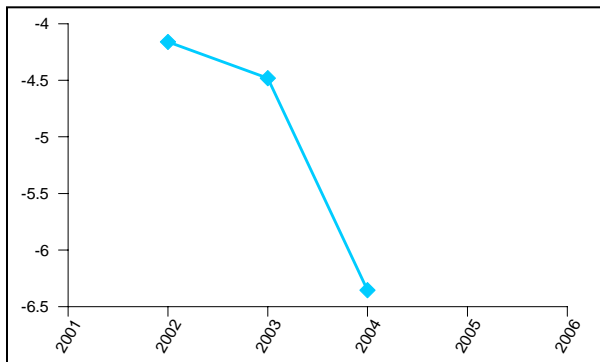
Annual mean ground surface temperature (°C)



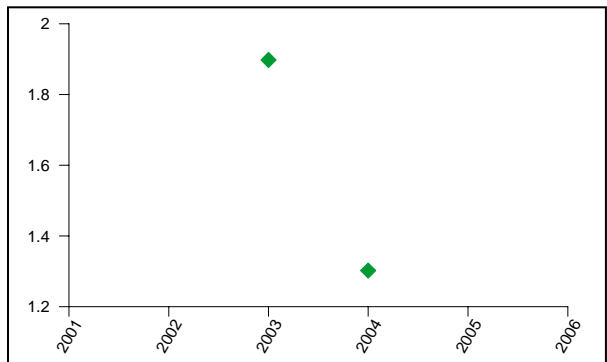
GSC Code: NWZ2A
Name: 84-2A Canyon Creek North A - Off R.O.W.
Location: N 65.2335 W 126.5262



Annual mean air temperature (°C)



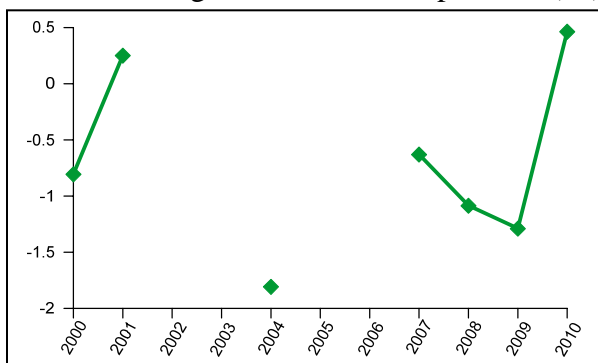
Annual mean ground surface temperature (°C)



GSC Code: NWZ2B
Name: 84-2B Canyon Creek North B - Off R.O.W.
Location: N 65.2335 W 126.5262



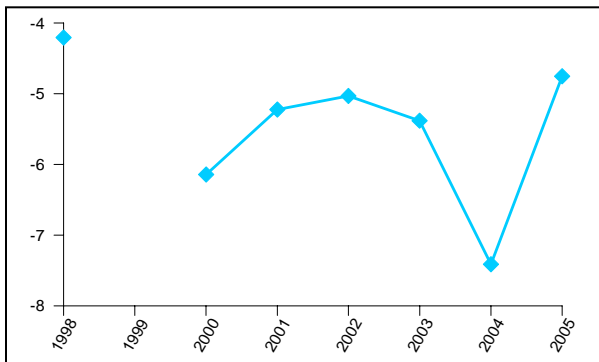
Annual mean ground surface temperature (°C)



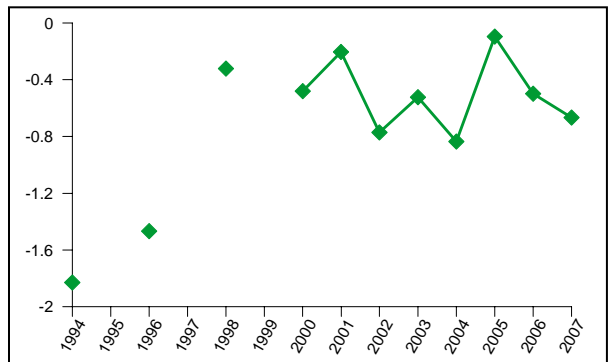
GSC Code: 91TT22
Name: Francis Creek
Location: N 65.1929 W 126.4691



Annual mean air temperature (°C)



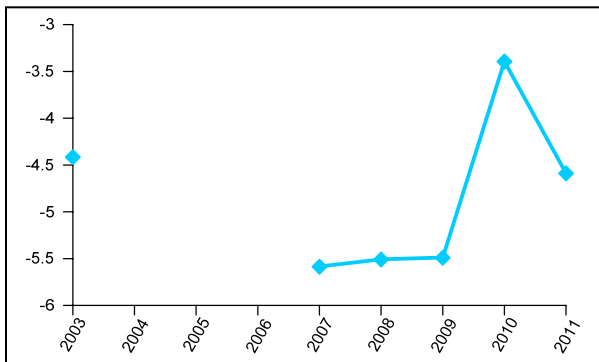
Annual mean ground surface temperature (°C)



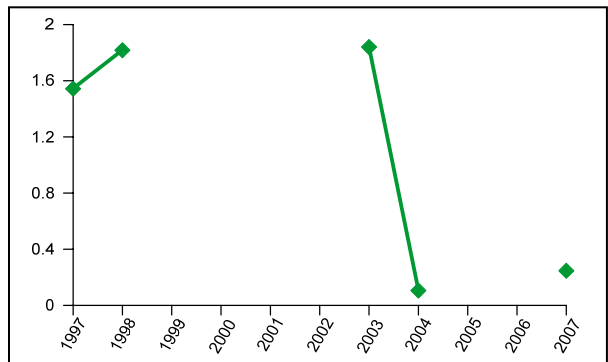
GSC Code: NWZ3A
Name: 84-3A Great Bear River A - Off R.O.W.
Location: N 64.9128 W 125.5831



Annual mean air temperature (°C)



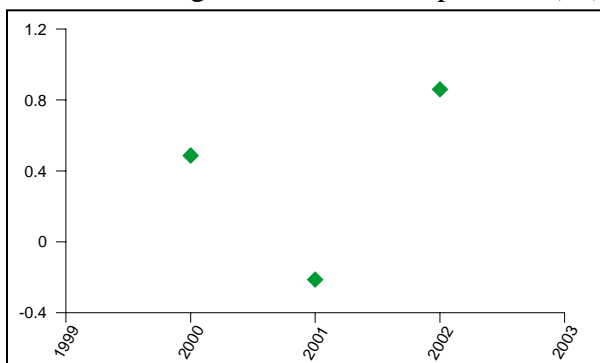
Annual mean ground surface temperature (°C)



GSC Code: NWZ3B
Name: 84-3B Great Bear River B - Off R.O.W. Cable T4
Location: N 64.9128 W 125.5831



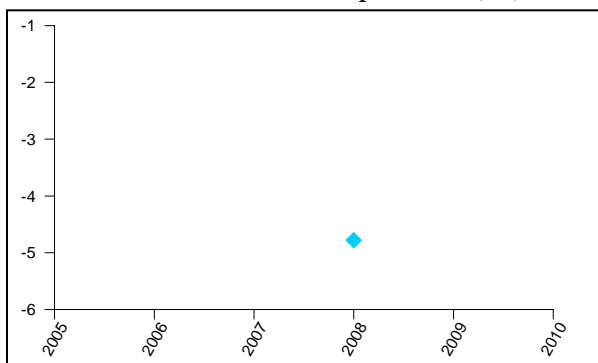
Annual mean ground surface temperature (°C)



GSC Code: SR-02
Name: Saline River
Location: N 64.2897 W 124.4853



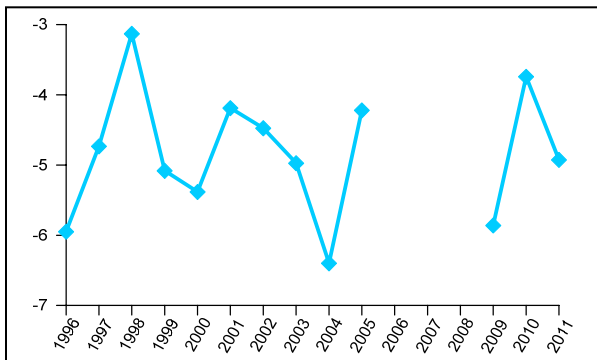
Annual mean air temperature (°C)



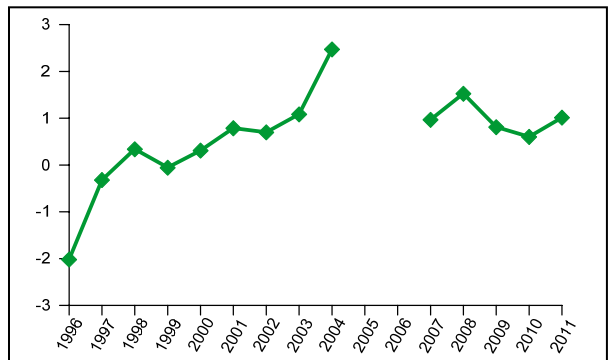
GSC Code: KP182B
Name: KP 182 Bottom of slope
Location: N 64.28078 W 124.4700



Annual mean air temperature (°C)



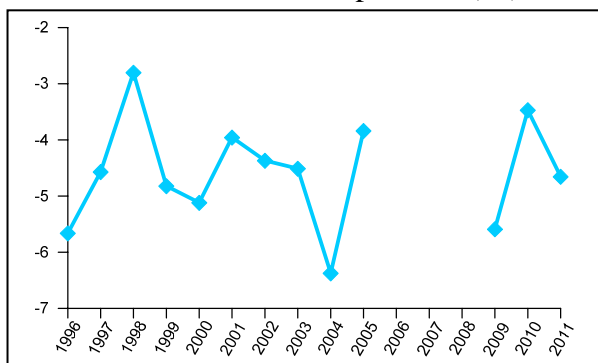
Annual mean ground surface temperature (°C)



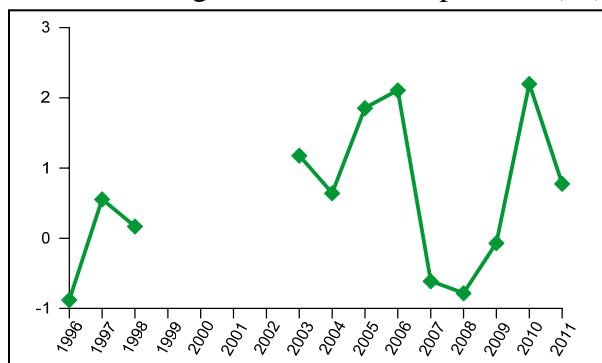
GSC Code: KP182M
Name: KP 182 Mid-slope
Location: N 64.2805 W 124.4700



Annual mean air temperature (°C)



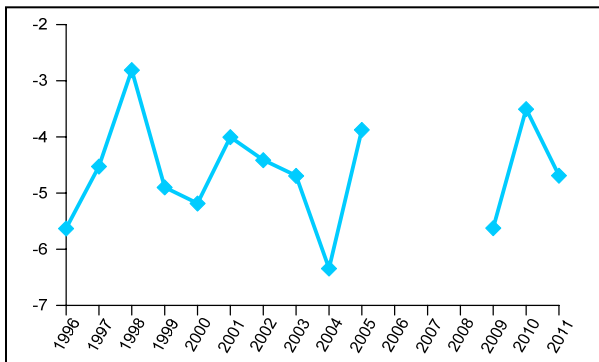
Annual mean ground surface temperature (°C)



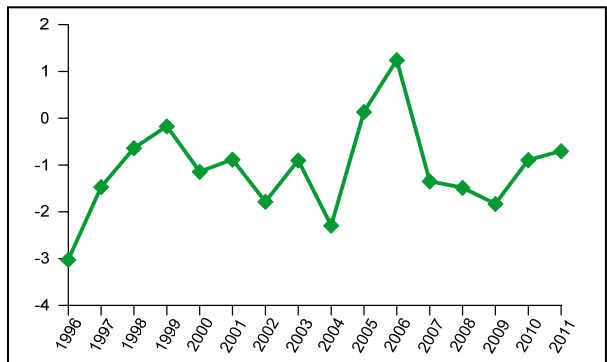
GSC Code: KP182U
Name: KP 182 Unburnt
Location: N 64.2805 W 124.4670



Annual mean air temperature (°C)



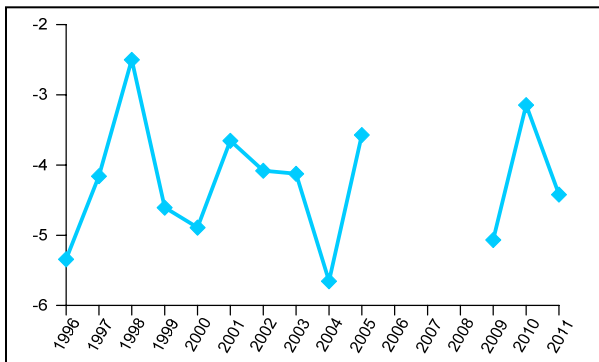
Annual mean ground surface temperature (°C)



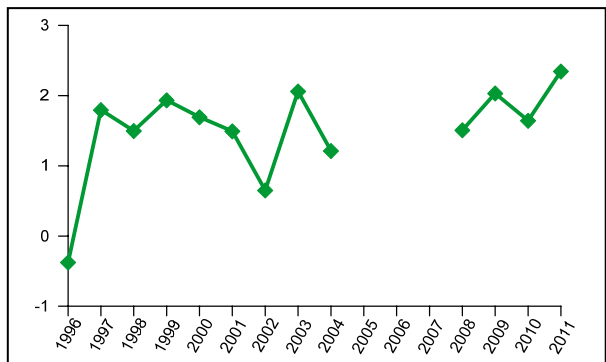
GSC Code: KP182C
Name: KP 182 Crest of slope
Location: N 64.2803 W 124.4700



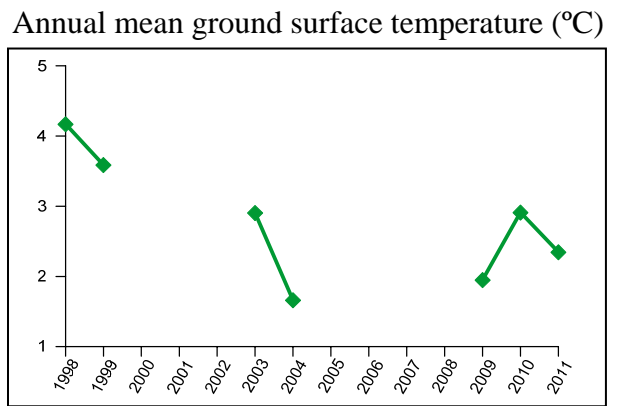
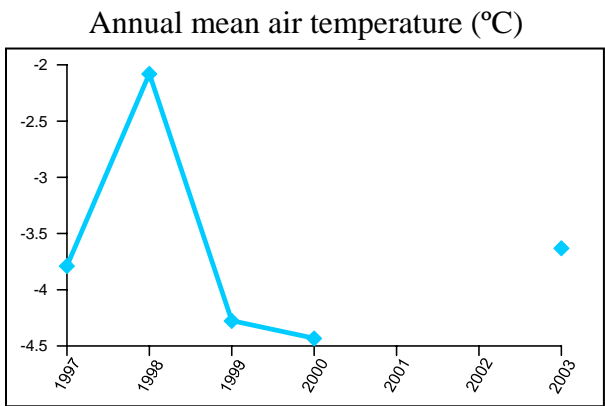
Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)

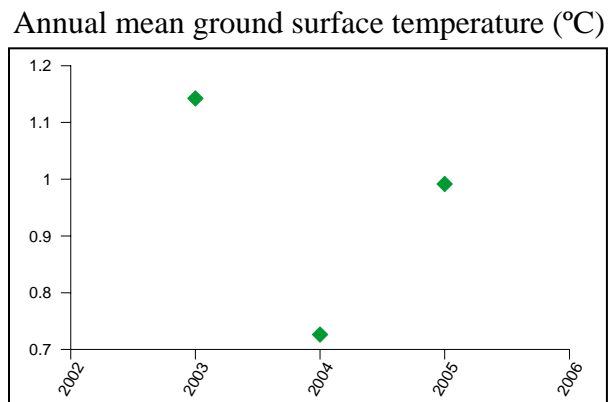
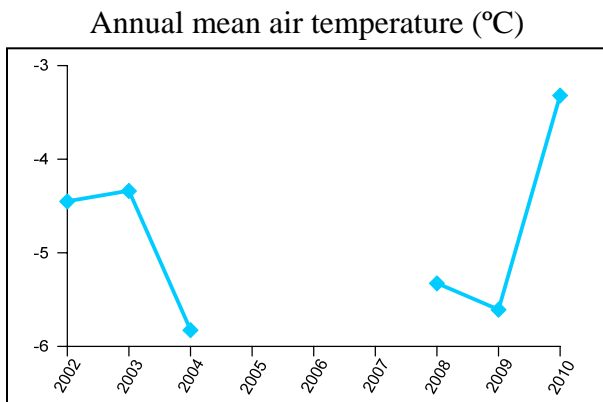
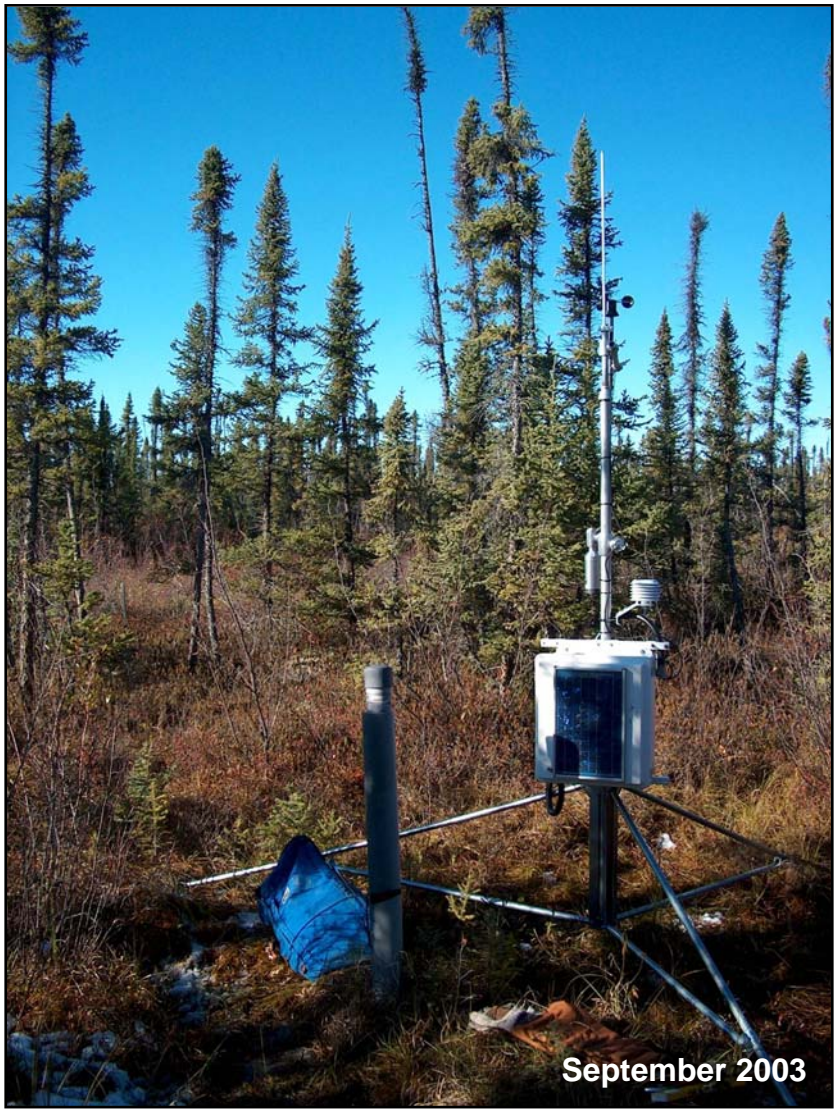


GSC Code: KP182T
Name: KP 182 Top of slope
Location: N 64.2799 W 124.4700



Appendix 3. Southern Section

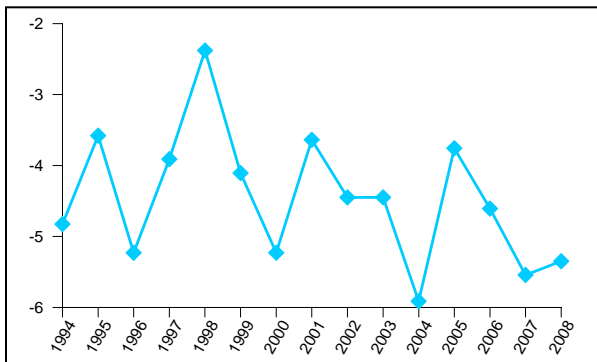
GSC Code: NWZ7A
Name: 85-7A Table Mountain A
Location: N 63.6132 W 123.6451



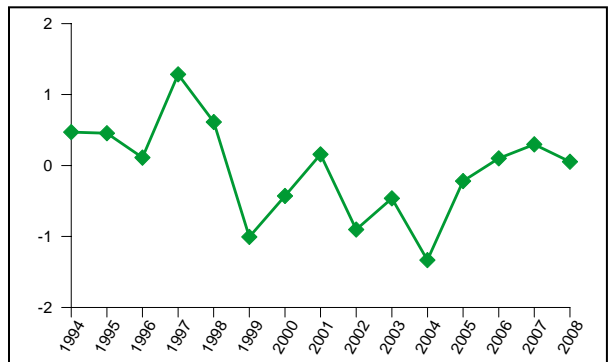
GSC Code: 92TT10
Name: Ochre River cabin
Location: N 63.4664 W 123.6932



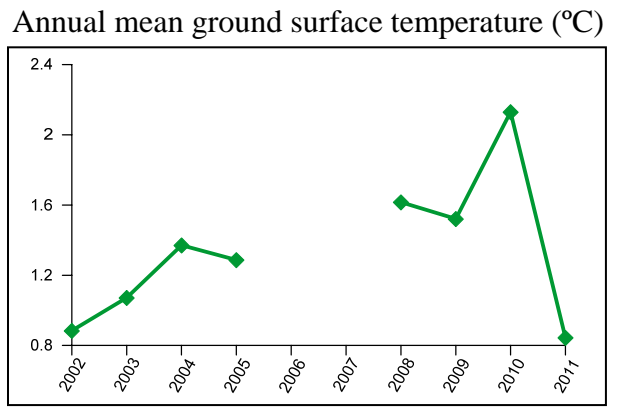
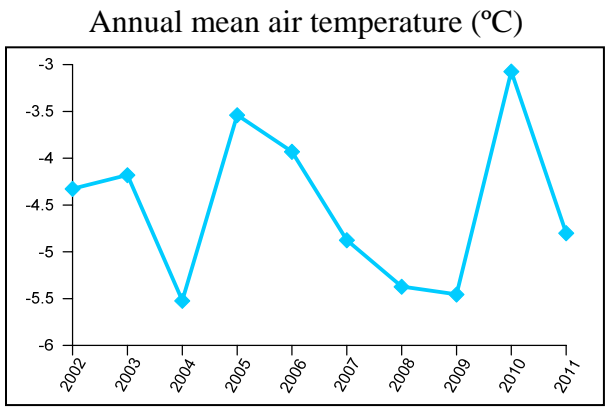
Annual mean air temperature (°C)



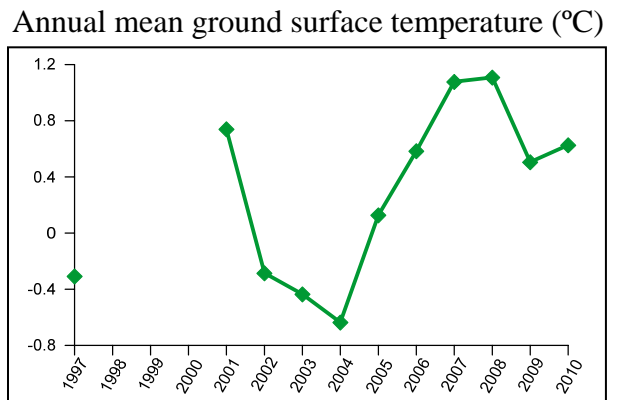
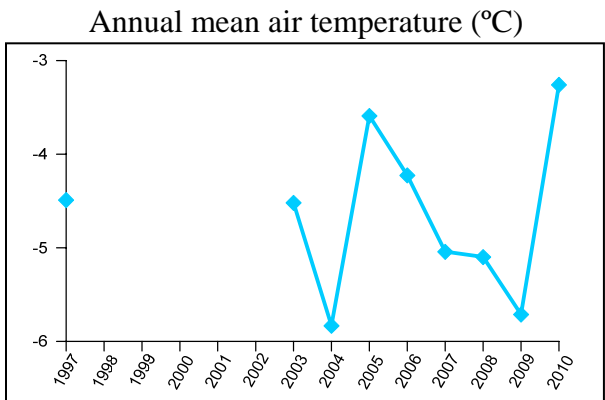
Annual mean ground surface temperature (°C)



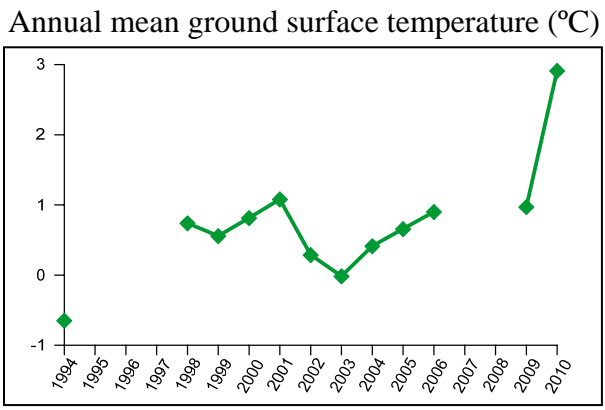
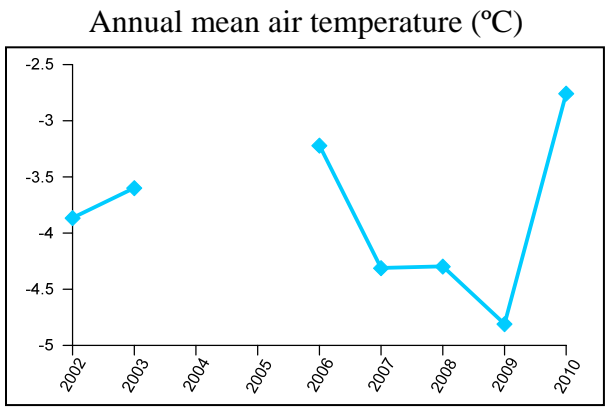
GSC Code: KP313T6
Name: KP 313 Off R.O.W. Cable T6
Location: N 63.2616 W 123.4250



GSC Code: 92TT8
Name: River between two mountains
Location: N 62.9578 W 123.2090



GSC Code: 92TT7
Name: Willowlake River
Location: N 62.6968 W 123.0648



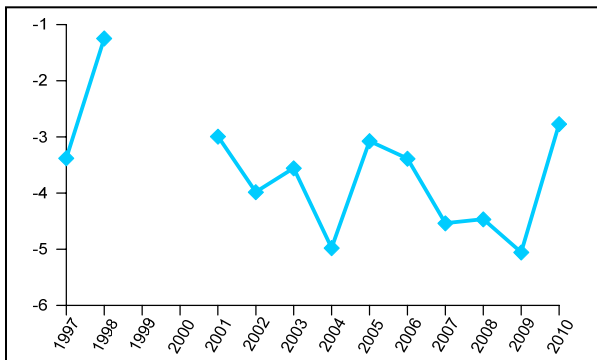
GSC Code:

Name: Willowlake River burn

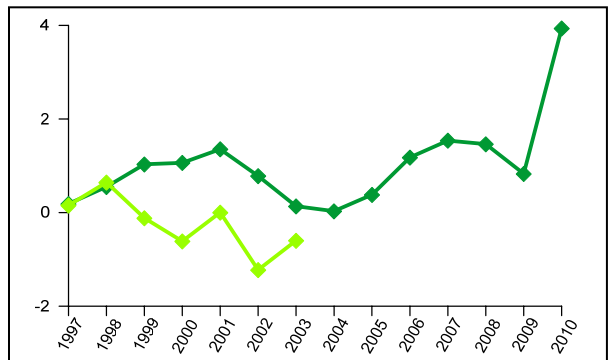
Location: N 62.6965 W 123.0630



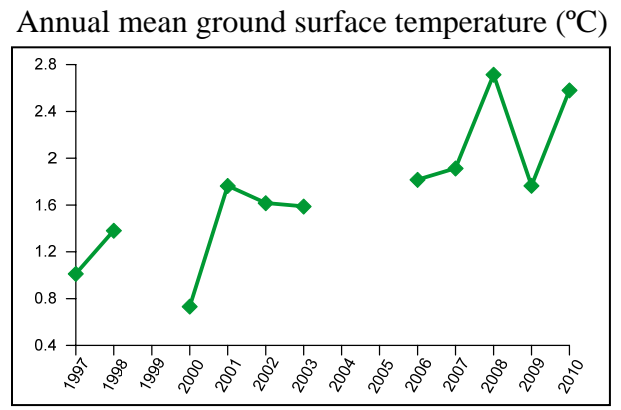
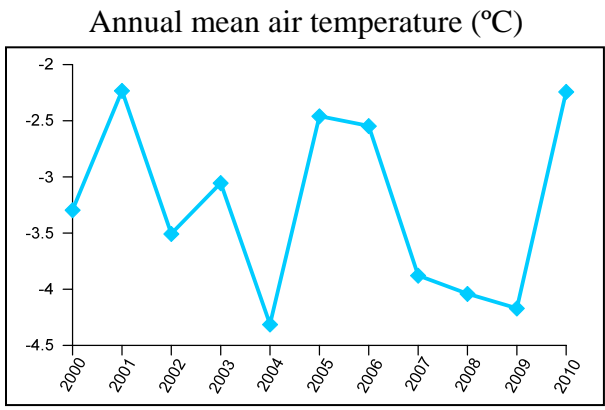
Annual mean air temperature (°C)



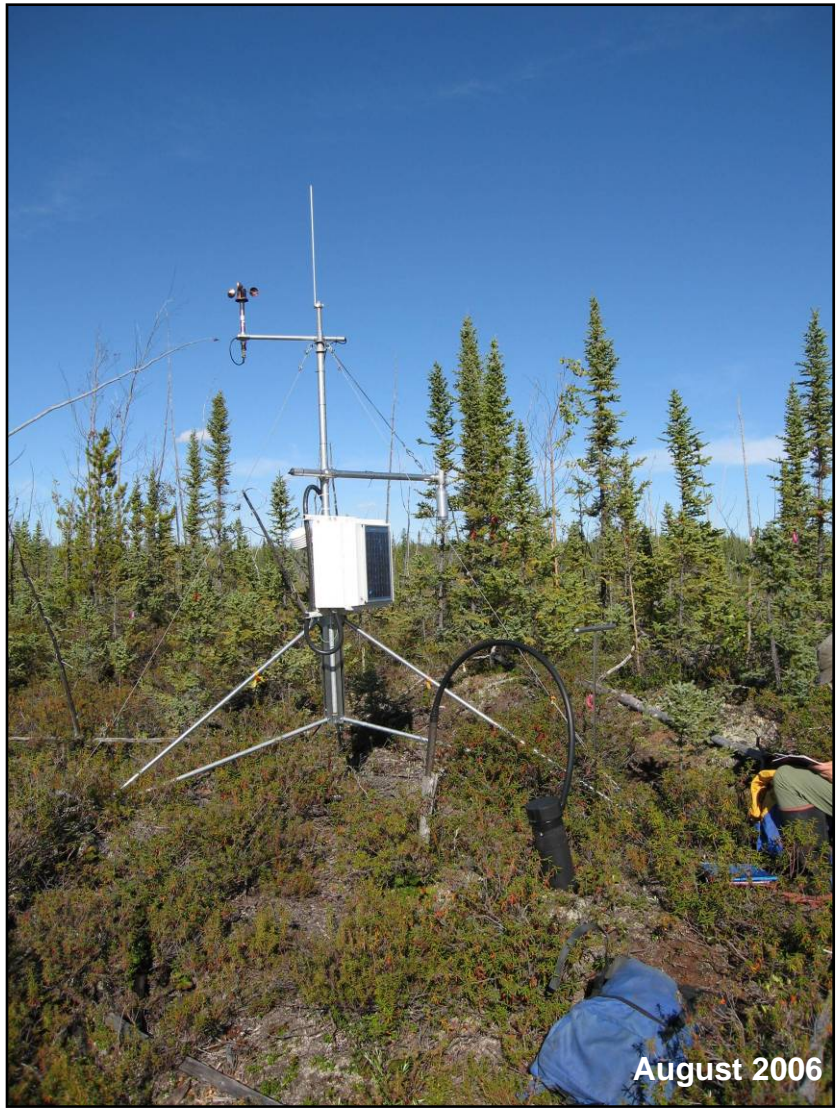
Annual mean ground surface temperature (°C)



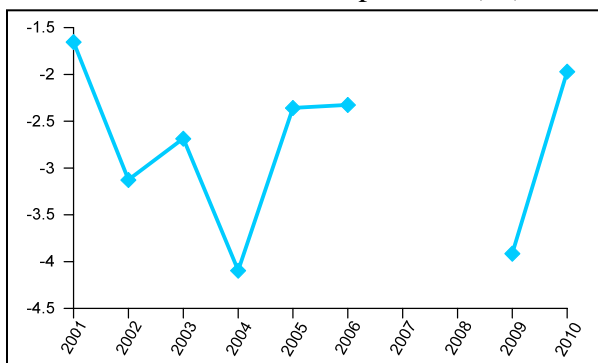
GSC Code: 94AG2
Name: Wrigley pines
Location: N 62.3155 W 122.6908



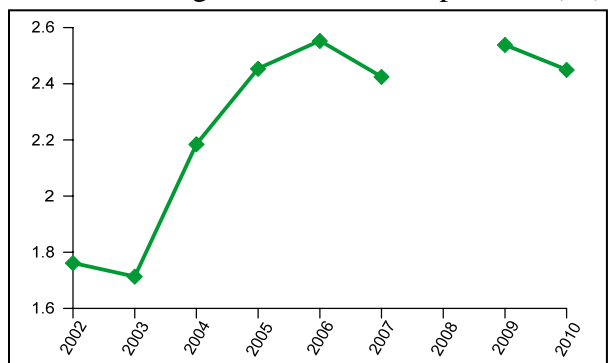
GSC Code: 99TC4
Name: Wrigley peatland
Location: N 62.2752 W 122.6032



Annual mean air temperature (°C)



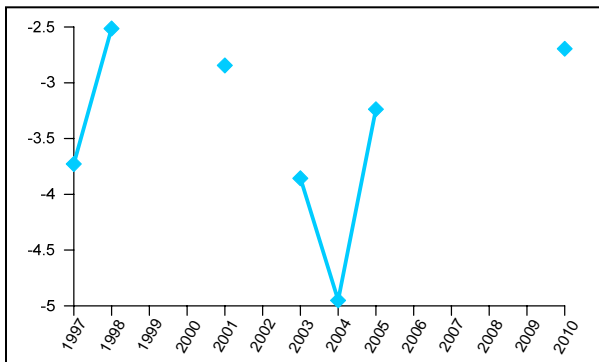
Annual mean ground surface temperature (°C)



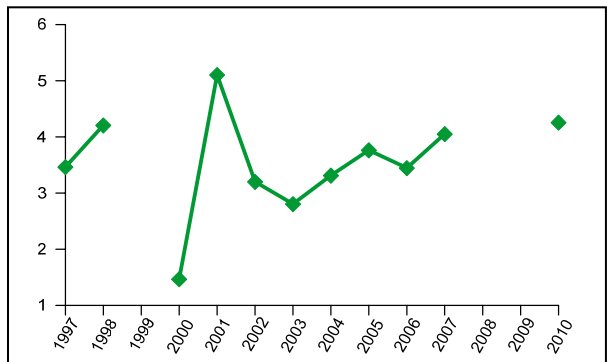
GSC Code: NWZ4A
Name: 84-4A Trail River A - Off R.O.W.
Location: N 62.0703 W -121.9883



Annual mean air temperature (°C)



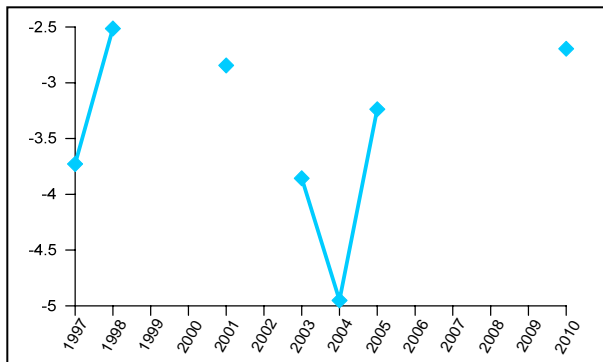
Annual mean ground surface temperature (°C)



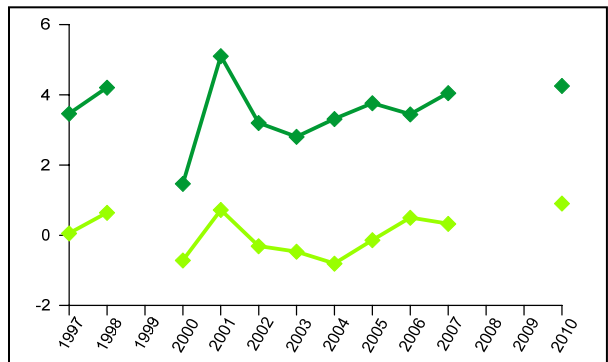
GSC Code: 93AG2
Name: FS Bog
Location: N 61.9800 W 121.8800



Annual mean air temperature (°C)



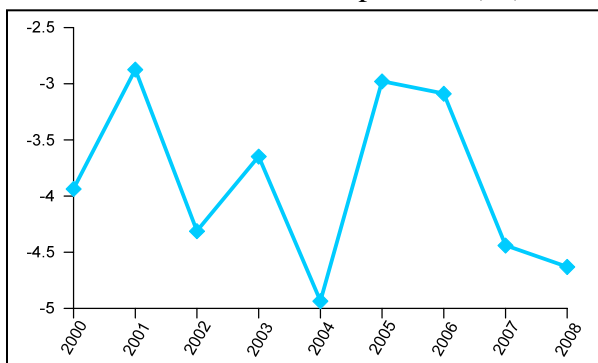
Annual mean ground surface temperature (°C)



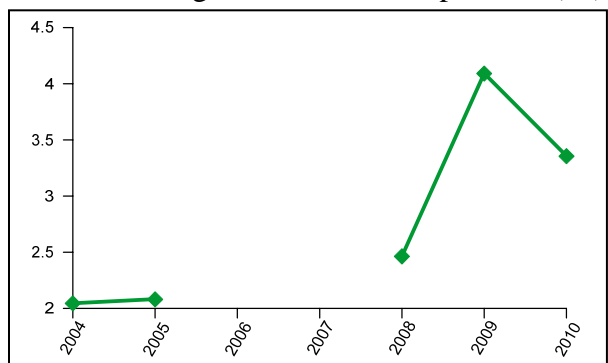
GSC Code: 97TC5
Name: Wrigley ferry transition
Location: N 61.9769 W -121.88159



Annual mean air temperature (°C)



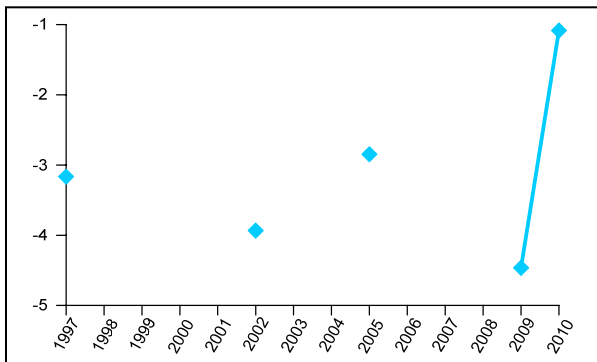
Annual mean ground surface temperature (°C)



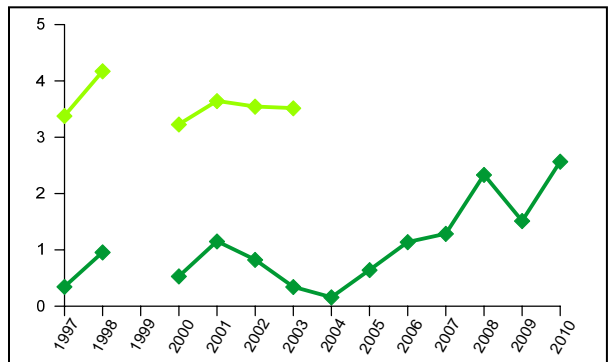
GSC Code: 93AG3
Name: Cutline Spruce
Location: N 61.9685 W 121.8235



Annual mean air temperature (°C)



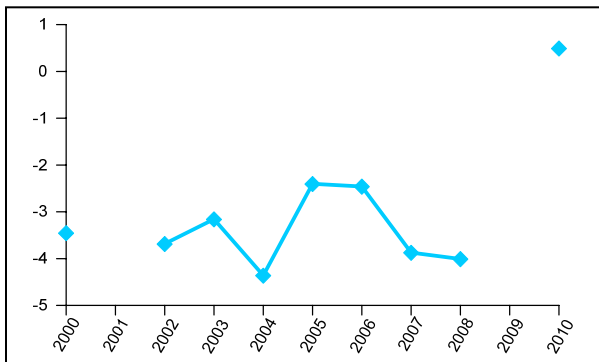
Annual mean ground surface temperature (°C)



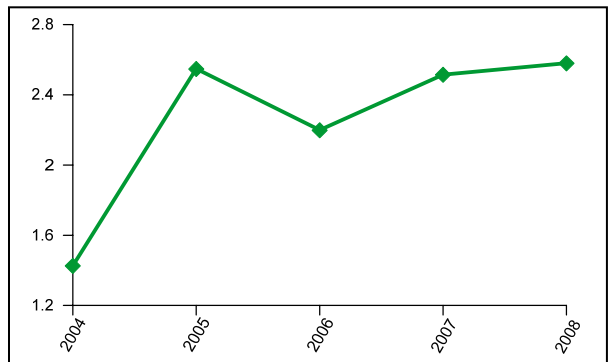
GSC Code: 97TC1
Name: Aspen
Location: N 61.9531 W 121.7607



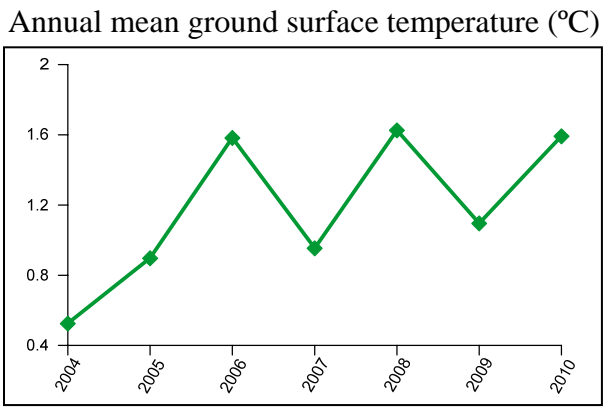
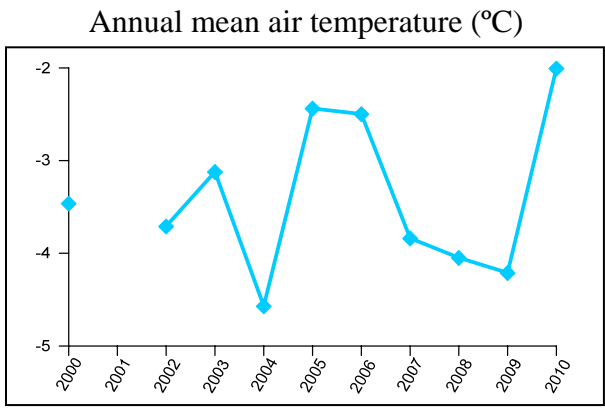
Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)



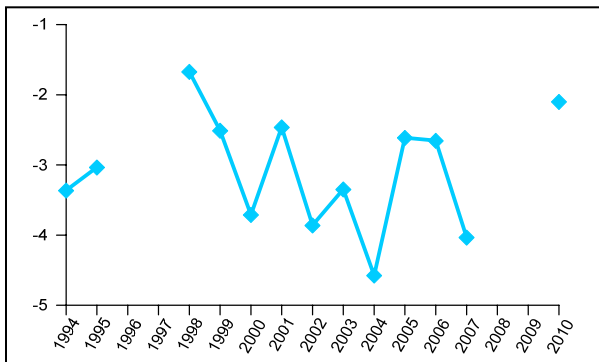
GSC Code: 97TC2
Name: Mature black spruce
Location: N 61.9162 W 121.7121



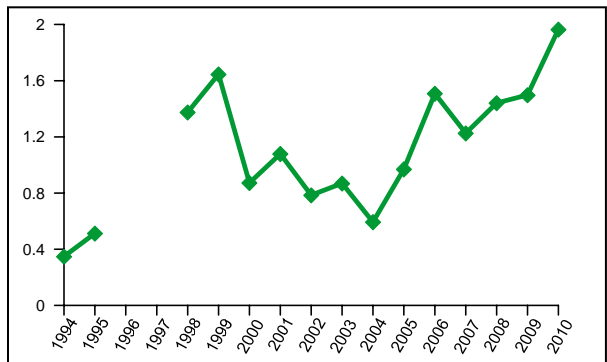
GSC Code: 92TT6
Name: Martin River
Location: N 61.8877 W 121.6035



Annual mean air temperature (°C)



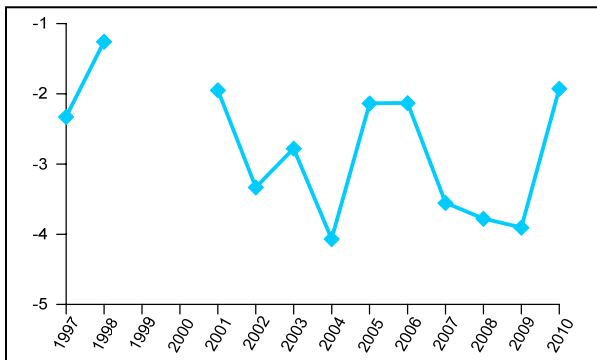
Annual mean ground surface temperature (°C)



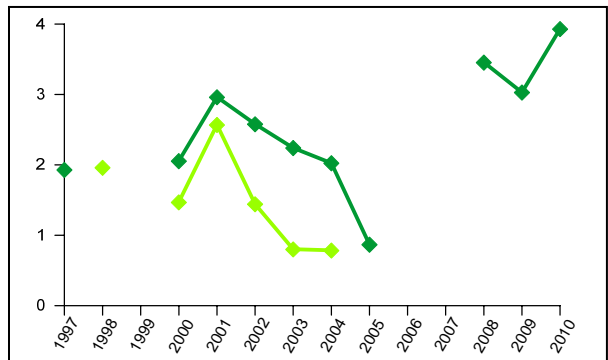
GSC Code: 94AG3
Name: FS aspen dune
Location: N 61.8845 W 121.5237



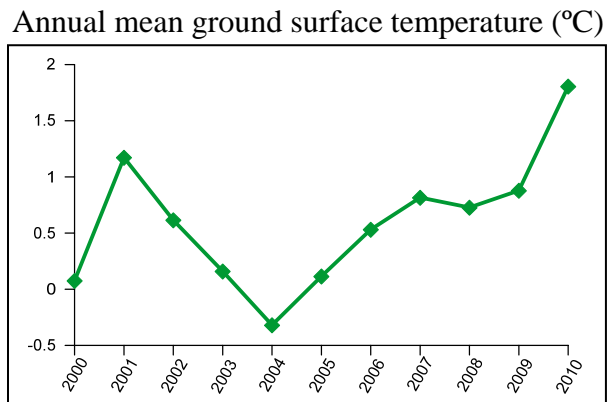
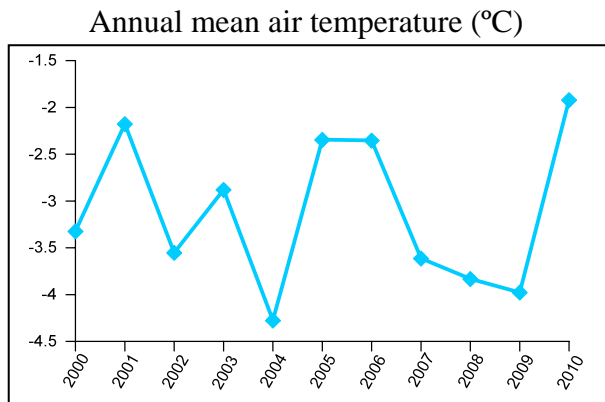
Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)



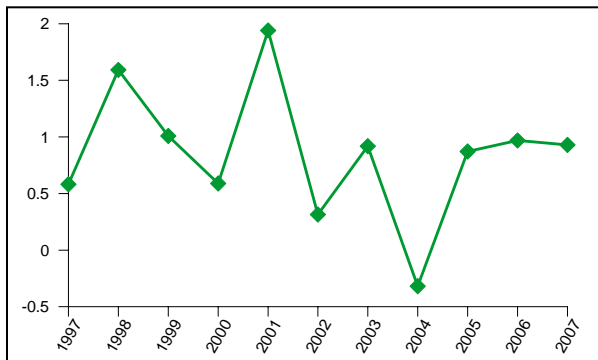
GSC Code: 94AG1
Name: FS deep cable
Location: N 61.8349 W 121.3390



GSC Code: 92TT4
Name: Manners Creek mouth
Location: N 61.7701 W -121.19319



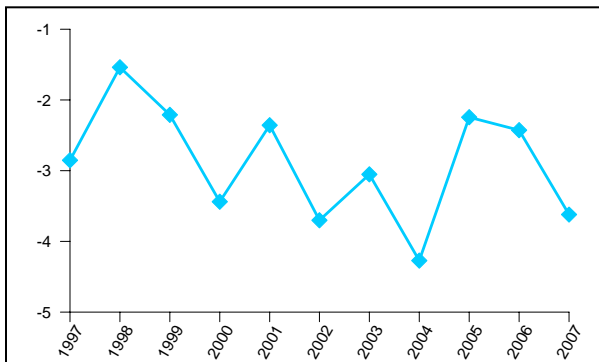
Annual mean ground surface temperature (°C)



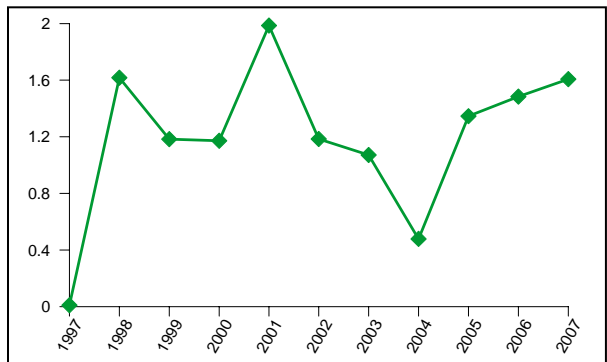
GSC Code: 92TT5
Name: Manners Creek upper
Location: N 61.7657 W 121.1873



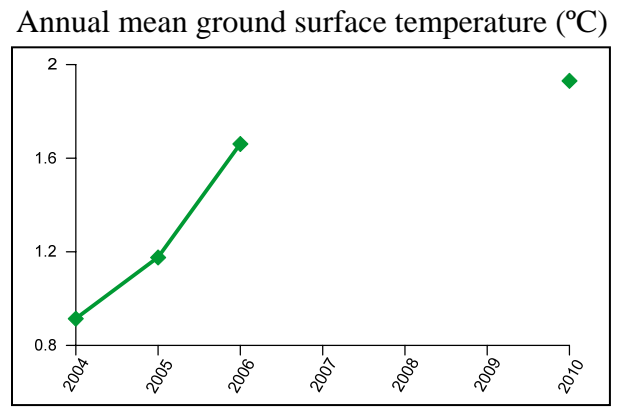
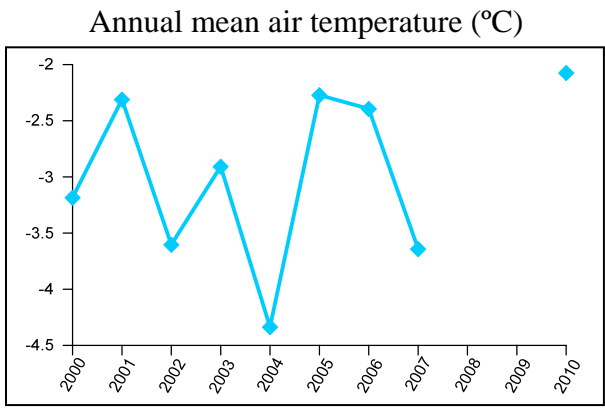
Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)



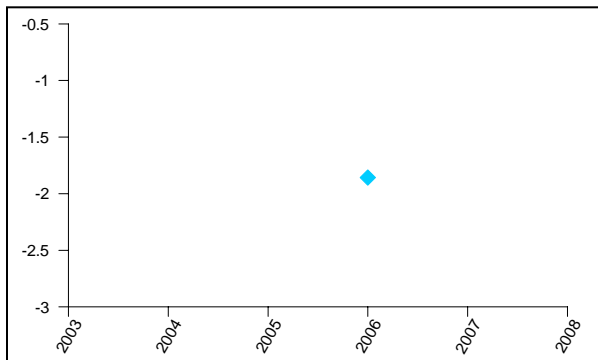
GSC Code: 99TC3
Name: Open Black Spruce
Location: N 61.6570 W 121.3438



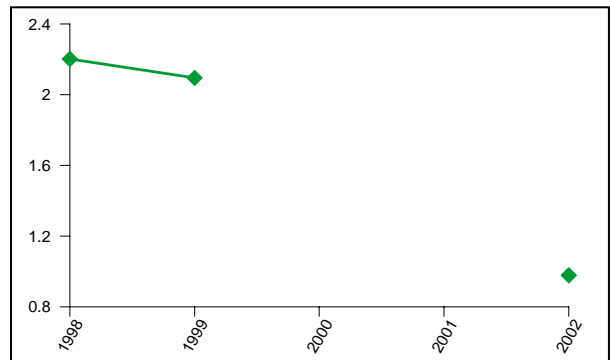
GSC Code: NWZ8A
Name: 85-8A Manners Creek A - Off R.O.W. Cable T4
Location: N 61.6047 W 121.0934



Annual mean air temperature (°C)



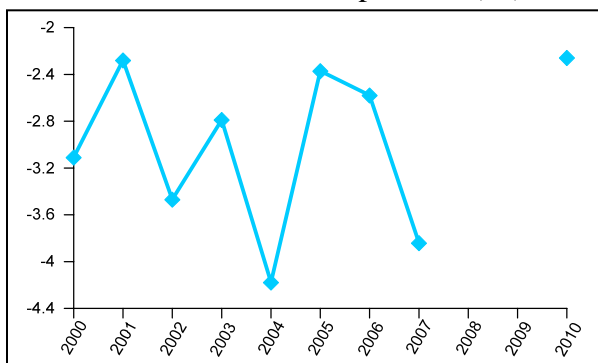
Annual mean ground surface temperature (°C)



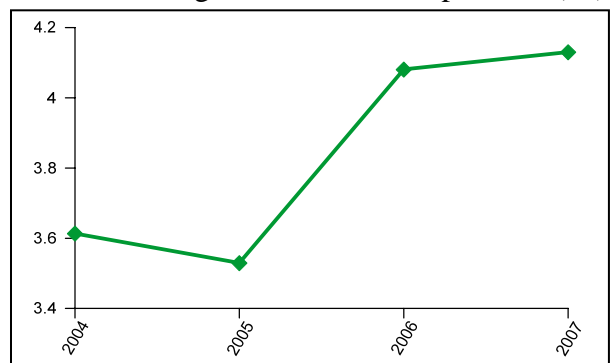
GSC Code: 97TC3
Name: Liard shrub
Location: N 61.5456 W 121.3941



Annual mean air temperature (°C)



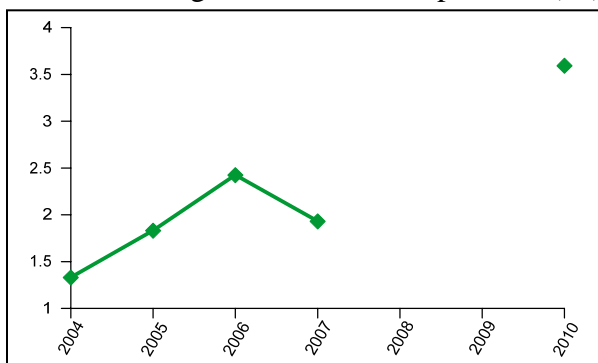
Annual mean ground surface temperature (°C)



GSC Code: 97TC4
Name: Liard spruce
Location: N 61.5451 W 121.3935



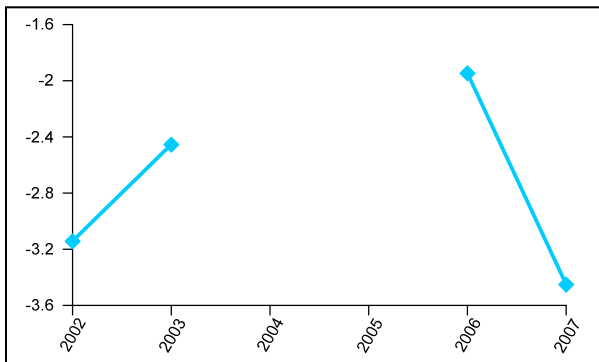
Annual mean ground surface temperature (°C)



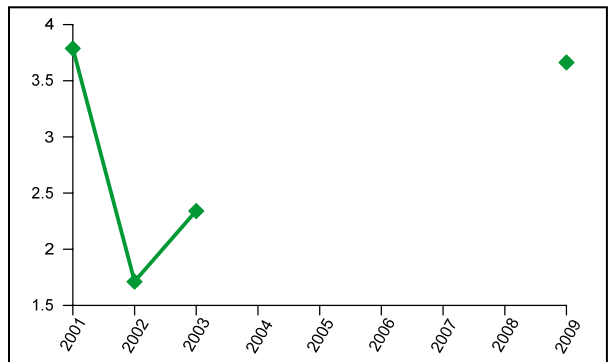
GSC Code: NWZ9
Name: 85-9 Pump Station
Location: N 61.3955 W 120.8996



Annual mean air temperature (°C)



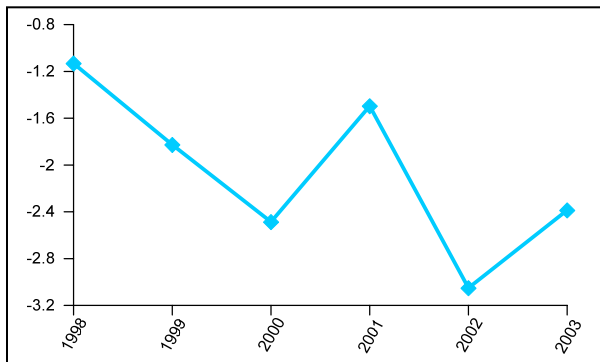
Annual mean ground surface temperature (°C)



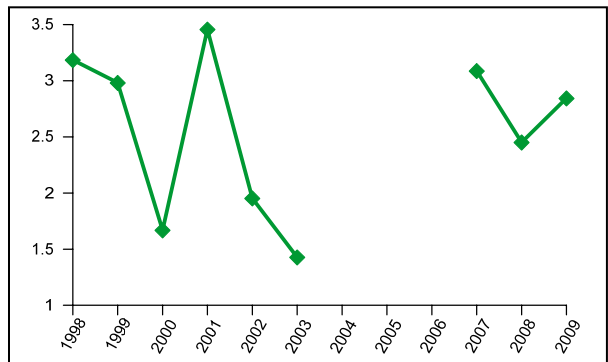
GSC Code: NWZ12B
Name: 85-12B Jean Marie Creek B - Off R.O.W.
Location: N 61.1918 W 120.7060



Annual mean air temperature (°C)



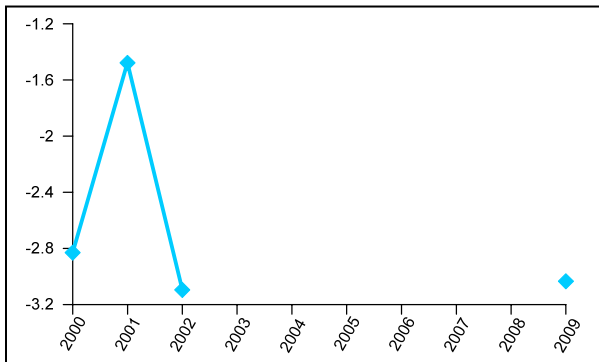
Annual mean ground surface temperature (°C)



GSC Code: NWZ5B
Name: 84-5B Petitot River north
Location: N 59.7574 W 119.5143



Annual mean air temperature (°C)



Annual mean ground surface temperature (°C)

