Five-Year Ground Surface Temperature Measurements in Finnmark, Northern Norway

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Abstract

In 2002 a new permafrost monitoring program was initiated in Finnmark, northern Norway. A series of miniature temperature dataloggers were installed for continuous monitoring of ground surface and air temperatures. Results suggest that permafrost is widespread in Finnmark. However, the great areas of birch and pine forest in Finnmark appear to correspond to areas without permafrost, due to the forest acting as a snow fence and causing snow to accumulate. Above the timberline, snow depth seems to be the most critical factor for the formation of permafrost.

Keywords: mean ground surface temperatures; Northern Norway; permafrost distribution.

Introduction

Permafrost is widespread in the higher mountains of Norway. Extensive studies in southern Norway show that the lower regional altitudinal limit of mountain permafrost is strongly correlated to the mean annual air temperature (MAAT) and decreases eastwards with increasing continentally (e.g., Etzelmüller et al. 2003). However, there are, to date, few quantitative studies of the distribution of permafrost in northern Norway.

In 2002, a new permafrost monitoring program was initiated in Finnmark, which is the northernmost county of mainland Norway (Fig. 1). A series of miniature temperature dataloggers (MTDs) were installed for monitoring ground surface and air temperatures. Continuous ground surface monitoring was performed at five main sites in a transect starting at Varangerhalvøya in the extreme northeast of Norway, continuing southwest to the interior of Finnmarksvidda, and then northeastwards to the Gaissane.

The main aim of this study is to determine mean ground surface temperatures (MGST) at representative sites in Finnmark in order to provide an initial indication of the presence or absence of permafrost. The results are related to climate data, mainly air temperature and snow cover. In addition, a land-cover classification of the whole county is made that gives a first qualitative picture of the relationship between climate, vegetation and permafrost distribution in Finnmark. A review of the literature of permafrost occurrence in northern Scandinavia is presented, together with new results from 5 years of temperature monitoring.

Literature Review

Permafrost in northern Scandinavia

Until the 1980s, permafrost research in Northern Scandinavia was mainly concentrated on palsas, and a number of studies (cf. references in Åhman 1977) were undertaken following the pioneer work of Fries and Bergström (1910).

However, in the beginning of the 20th Century, field observations and theoretical considerations by Reusch (1901) suggested that permafrost was present in the mountains of Scandinavia. In the following decades few reports on permafrost occurrence in northern Scandinavia were published. A review of Scandinavian permafrost investigations up to 1950s is provided by Ekman (1957). During the drilling of a well at 1220 m a.s.l. in northern Sweden, permafrost was encountered at 70 m depth in bedrock (Ekman 1957). Frozen ground was also encountered during construction work in northern Finland and Sweden (e.g., Ekman 1957, Åhman 1977), but it is often difficult to decide whether these findings are perennially or only seasonally frozen ground (King & Seppälä 1988).

Since the beginning of the 1960s, research on permafrost outside the palsa mires has increased, with most reports on geomorphological indicators (Jeckel 1988).

In the 1980s, studies using geophysical methods encountered extensive permafrost at 50–100 m depth in bedrock in mountain areas of northern Sweden (e.g., King 1982) and Finland (King & Seppälä 1987). On a mountain in northern Sweden, Jeckel (1988) reported a mean ground temperature (MGT) at 2.3 m depth to be -0.8°C at 880 m a.s.l. In a 100 m deep borehole at Tarfalaryggen (1550 m a.s.l.) in northern Sweden, it has subsequently been shown that MGT is approximately -3 ºC and permafrost thickness is estimated to exceed 300 m (Isaksen et al. 2001). In northern Finland, Bottom Temperature of Snow (BTS) measurements suggested a lower limit of permafrost at 600-650 m a.s.l. on north-facing slopes (Jeckel 1988). In Finnmark, quantitative studies on permafrost distribution are limited and are

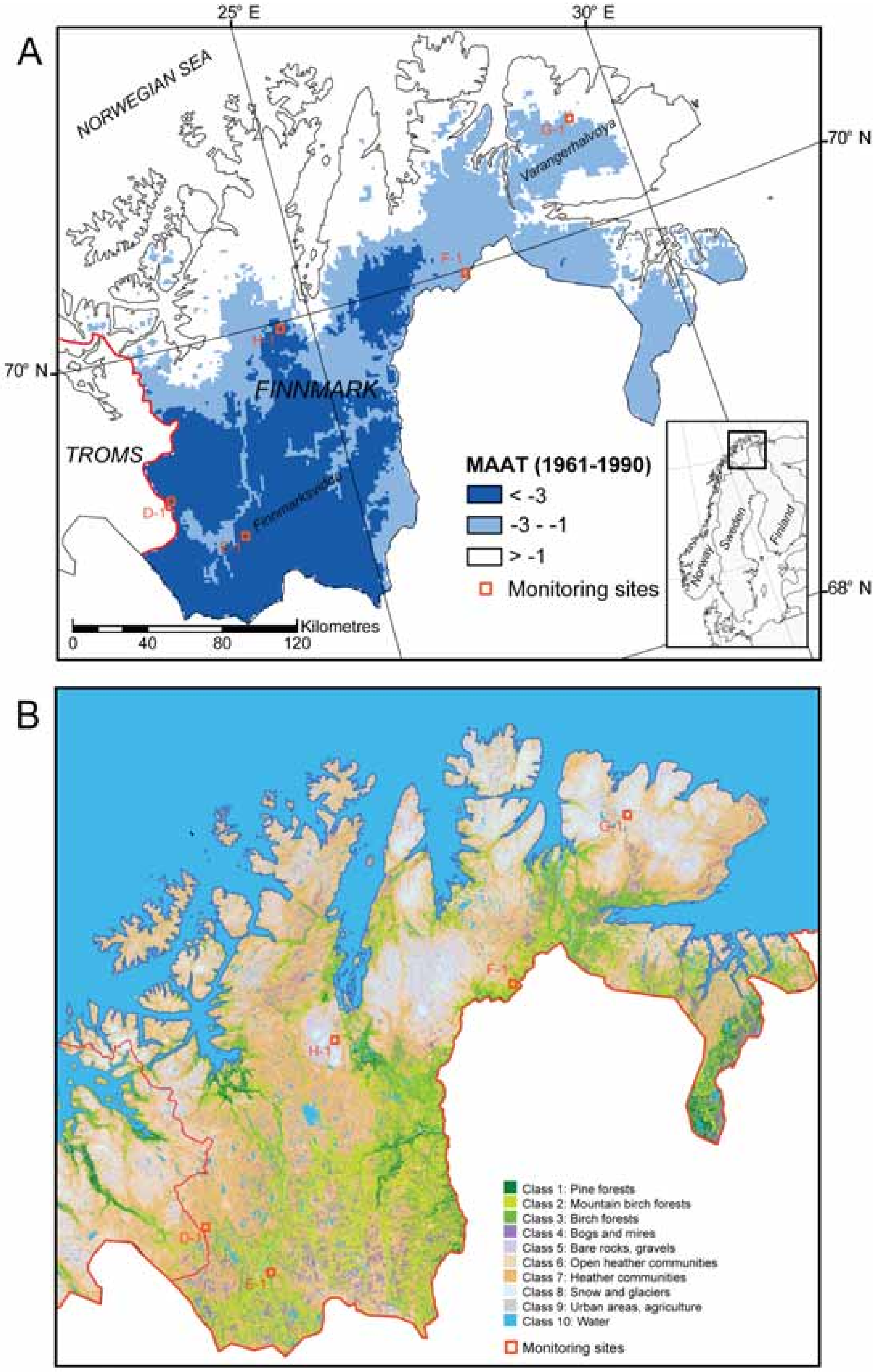

Figure 1. A) Location map showing the monitoring locations and three classes of the mean annual air temperature (MAAT, 1961-1990) in Finnmark (based on Tveito et al. 2000). (D-1) Biedjovággi; (E-1) Ávži; (F-1) Eliasvárri; (G-1) Basečearru; (H-1) Gaissane. The dark blue shows areas where MAAT is below -3°C, light blue shows areas where MAAT is between −3°C and −1°C and white is MAAT above -1°C. B) Classified land-cover map of Finnmark county based on Landsat TM/ETM+ satellite images (see text for details).

mostly restricted to palsa mires (e.g., Sollid & Sørbel 1998, Hofgaard 2007). In some settlements, however, permafrost degradation has caused problems during construction work (e.g., Lien 1991).

Study Sites

Three of the sites (D, G, and H), were chosen to optimize comparability and to ensure that the thermal properties were not excessively complex (Fig. 1). These were located at exposed locations, in the main ridge-crest or plateau areas, where snow accumulation is low. The last two sites are located in open (F) and dense (E) mountain birch forest.

The inner part of Finnmark (Finnmarksvidda, site E) is a plain having strong continentally and has the lowest MAAT when reduced to sea level in Norway. Typically, in this area, MAAT is -2.5°C to -4°C, with mean summer temperatures of 8°C to 10°C and mean winter temperatures of -15°C to -20°C. In winter, mean maximum snow depth is 25–75 cm. Towards the N (Site H) and NW (Site D), continentality decreases, with more mountains and more complex climate settings. Towards the NE, at Varangerhalvøya (Site G), mountain plateaus dominate, and the area is in the Arctic climate zone.

Methods

Land-cover classification

In this study, a land-cover map of Finnmark county (Fig. 1B) is developed (in 200 x 200 m resolution), reflecting degrees of density in the vegetation cover. The land-cover map is a subsection of the vegetation map produced for the entire country of Norway. In this map, a total number of 45 Landsat TM/ETM+ images were processed during six operational stages: (1) spectral classification, (2) spectral similarity analysis, (3) generation of classified image mosaics, (4) ancillary data analysis, (5) contextual correction, and (6) standardization of the final map products (Johansen & Karlsen 2005). Analysis performed on the spectral-only data is often denoted as the pre-classification stage of the process, whereas the post-classification process involves analysis and subsequent contextual corrections of the pre-classified image using ancillary data. In the final standardization part of the process, the defined classification units are related and described according to classification schemes well-established in the Norwegian botanical literature (Fremstad 1997). From the overall vegetation map of Norway, different thematic maps can be extracted.

Continuous temperature measurements

Nine (out of 20 in total) UTL-1 (Geotest, Switzerland) MTDs were used to determine the mean ground surface temperatures (MGST). They were buried at the surface (c. 0.05 m depth) and installed in Autumn 2002 and 2003. In addition, one logger was used to monitor the air temperature at G-1. At the other sites, air temperatures were obtained by interpolation from nearby weather stations (Table 1). The thermistors in the MTDs are of the type TMC-1T, with accuracy better than the 0.27°C given by the manufacturer (Hoelzle et al. 1999). The MTDs were programmed to record the ground surface temperature every 6 hours (2 hours in Gaissane). In addition, the MTDs gave important information concerning damping of short-term air temperature fluctuations through the snow (reflecting the development and thickness of snow cover), the time when melting occurred at the bottom of the snowpack, and when snow disappeared.

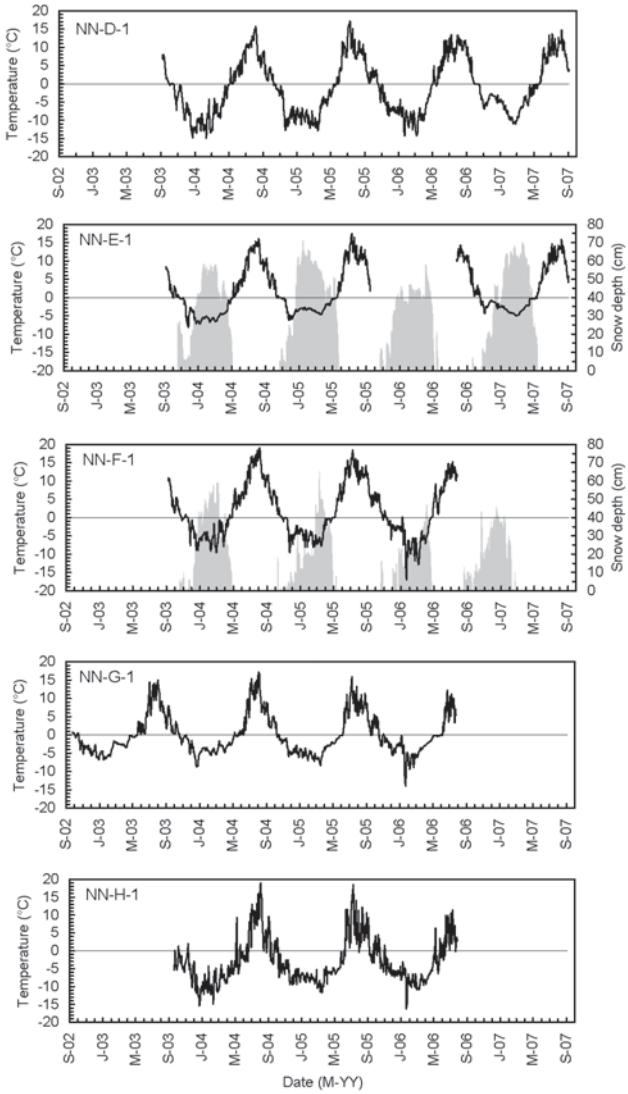

Figure 2. Daily ground surface temperatures obtained at the 5 main locations in Finnmark during 2002–2007. For E-1 and F-1, observed snow depth (grey bars) from nearby official stations are shown.

Climate data from official weather stations were used to normalize the data sets in respect to the normal standard period 1961–1990, in order to establish the long-term MGST. The method is described by Ødegård et al. (2008). From the MTDs, monthly mean of ground surface temperatures were calculated and analyzed with the best nearby correlated air temperature from an official meteorological station having long-time series (e.g., 30-year period or more). A high correlation suggests low influence of snow and latent heat effects, which give a strong coupling between the air

Table 1. Key temperatures observed at monitoring sites. MGST = Mean ground surface temperature for observation period, maximum and minimum of 12-months running mean of MGST during observation period. MAT = Mean air temperature observed (Obs) and interpolated from nearest station (Int). MAT-anomaly: Air temperature deviation for observation period from nearest station. Air temperature at G-1 is for the period Sep03–Jun06. For interpolation of air temperature at G: 2,3,4, a gradient 0.53°C/100 m was used from G-1 (Laaksonen 1976). For the other interpolated values, the same gradient was used from nearest official weather station. H-1 and H-2 were from Farbrot et al. (2008). Type = Land type class (cf. Fig. 1B).

Site	Type	Alt. m a.s.l.	Period observed	MGST Obs.	MGST max Obs.	MGST min Obs.	MAT Obs.	MAT Int.	MAT-anomaly	MAGST Normal	MAAT Normal
D-1	6	739	Oct 03-Aug 07	-1.1	-0.1	-1.7	-	-3.4	1.5	-2.2	-4.9
E-1	3	355	Oct 03-Aug 07	1.6	2.0	1.0	-1.2	-	1.5	1.2	-2.6
F-1	2	130	Oct 03-Jun 06	2.2	2.5	1.9	-	0.6	1.9	0.8	-1.3
G-1	5	502	Oct 02-Jun 06	0.3	0.7	-0.2	-1.2	-	1.4	-1.0	-2.9
G-2	5	480	Oct 02-Jun 06	1.0	1.2	0.5	-1.1	-	1.4	-0.4	-2.8
G-3	5,6	415	Oct 02-Jun 06	1.3	2.1	0.5	-0.8	-	1.4	-0.3	-2.4
G-4	6	355	Oct 02-Jun 06	1.7	2.2	1.2	-0.5	-	1.4	0.1	-2.1
H-1	5	1034	Oct 03-Jun 06	-2.4	-2.1	-2.8	-	-2.9	1.6	-3.6	-4.5
H-2	5	618	Oct 03-Jun 06	-0.9	-0.6	-1.2	-	-0.9	1.6	-2.2	-2.5

and ground surface temperatures. Monthly air temperature anomalies (in respect to the 1961–1990 average) can then be used to correct the monthly observed ground surface temperature during the observation period (see Table 1).

Results

Vegetation types in Finnmark

The land cover map of Finnmark portrays the density of the vegetation cover at different levels. The coniferous pine forests are mainly located to the southern, continental parts of the county, constituting the largest areas along the main rivers in the area. In addition, the Pasvik area, south of Varangerhalvøya, is characterized by well-developed pine forests. The mountain birch forest, occupying large areas on Finnmarksvidda, is characterized by an open forest layer with heather and lichen species dominating the ground layer. The more dense and fertile birch forests are located mainly in the coastal regions. The differentiation in the mountain belt generally reflects the low-, the mid-, and the high-alpine belt of the region. Heather communities, with a closed vegetation cover, characterize the low-alpine belt. In the mid-alpine belt, the vegetation cover is more scattered due to harsher climate conditions. The high-alpine belt has bare rocks, boulder fields, and gravel ridges. Few vascular species are adapted to the climate conditions found here. This belt is characterized by mosses and lichen species.

Mean ground surface temperature (MGST)

Mean ground temperatures from 3–5 years of continuous monitoring (Fig. 2 and Table 1) show that:

a) the highest MGST were found in the forested areas (G-1 and E-1);
b) the lowest MGST were observed at the two highest sites (H-1) Gaissane and (D-1) Biedjovággi were bare rock and boulder fields dominate;
c) 12-month running means of MGST show large variation within the observation period at all sites. The difference between the highest and lowest 12-month MGST are between 0.6°C and 1.6°C; and
d) the mean air temperature (MAT) is generally 1–2.5°C lower than MGST. The largest difference is found at the two forested sites (2.8°C), while at the most exposed locations (H) the difference is only 0–0.4°C.

Correlation between ground surface temperature and air temperatures at G-1 is shown in Fig. 3. The results indicate a strong correlation. In general, the site is exposed to strong winds, leading to only a thin snow cover in late winter, probably not more than 0.3–0.5 m.

Data from official weather stations close to the monitoring sites show that the MAT during the observation period was 1.4–1.9°C above the 1961–1990 normal. By normalizing the observed MGT-values (Ødegård et al. 2008), data suggest that mean annual ground surface temperature (MAGST) is below 0°C at six sites. Only the two sites located in forest (E and F) and the lowermost site at Varangerhalvøya (G-4) have positive MAGST.

Discussion

In Norway, the Nordic mountain birch limit is close to the 8°C tetratherm (mean air temperature for June–September) (Wielgolaski 2005). However, the tetratherm limits decrease in relatively continental areas with high day temperatures during summer. This means that continental sites generally have a higher forest limit than more maritime sites even though the MAAT is equal (Meier et al. 2005, Wielgolaski 2005). Forest (mainly birch) is present in the interior of Finnmark where MAAT is far below 0°C (Fig. 1). The timberline is located at about 500 m a.s.l. on Finnmarksvidda (Meier et al. 2005).

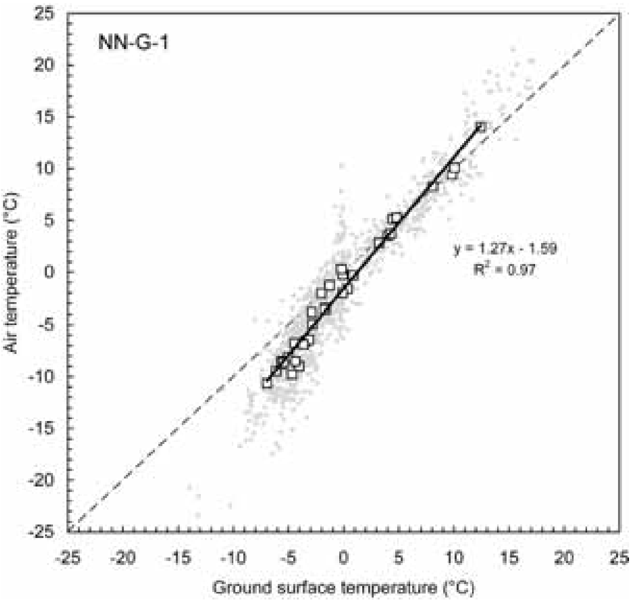

Figure 3. Mean daily (grey small dots) and monthly (open squares) ground surface temperature versus mean daily and monthly air temperature (2 m) during the period of record at G-1 Basečearru (Varangerhalvøya). Linear least squares regression coefficients and coefficient of determination (R^2) for the monthly values are shown.

Two sites, E-1 and F-1, are significantly warmer than the other study sites. The reason is the influence of the forest, which collects snow and therefore has a quite different energy-balance compared to wind-swept locations. Although cooler in summer due to radiation interception and higher evaporation (e.g., Rouse 1984), the near-surface ground temperatures in the forest are considerably warmer in winter than the other locations (Table 1). Hence, the forest in Finnmark largely prevents permafrost formation, making the forest line altitude very important in defining the permafrost limits. Although Scandinavian treelines are expected to advance in response to climate warming, there are indications of recessive treelines in northern Norway in contrast to southern Norway (Dalen & Hofgaard 2005). Above timberline, snow depth appears to be the most critical factor for the formation of permafrost (cf. King & Seppälä 1988). Results from Farbrot et al. (2008) and this study (Table 1) suggest that MGST above timberline in Finnmark can differ by 1–2°C due to variations in snow thickness. This is somewhat lower than values reported from southern Norway (e.g., Hauck et al. 2004, Ødegård et al. 2008).

King (1984) suggests that mountain permafrost in Scandinavia may be divided into continuous, discontinuous and sporadic. Their lower limits correspond to MAAT of -6°C and -1.5°C and sporadic permafrost may occur even in areas with positive MAATs. The transition between these belts is gradual. The temperature values for the lower limits are valid for the central Scandinavian mountain areas with moderately continental climate. The climate of Finnmark shows strong continentality, with generally thin snow cover. The results obtained from the MTDs and Farbrot et al. (2008) suggest that the proposed limits suggested by King (1984) can be adjusted in this region by lowering the limit of discontinuous permafrost to a MAAT of -1°C (Fig. 1). In areas colder than -3°C, permafrost seems to be widespread above timberline.

Conclusions

Miniature temperature dataloggers recording ground surface temperatures have been shown to provide data suitable for mapping the spatial variation in mean annual ground surface temperatures in Finnmark, and thus the possible presence or absence of permafrost at the sites. Results suggest that:

- Permafrost is widespread in Finnmark. The lower limit of discontinuous permafrost outside the palsa mires corresponds to mean annual air temperatures (MAAT) of approximately -1°C,
- Permafrost is probably present in the interior part of Varangerhalvøya. This is probably the northernmost permafrost area in north-western Europe (outside Russia) and can be regarded as polar permafrost
- Birch and pine forest in Finnmark appears to correspond with areas without permafrost. Trees cause snow to accumulate and insulate against strong ground cooling. Below the timberline and beside the palsa mires, formation of permafrost is possible at local exposed sites where snow does not accumulate, or cleared areas (in villages, on roads etc),
- Snow depth seems to be the most critical factor for the formation of permafrost above the timberline. However, variations in mean annual ground surface temperatures due to variations in snow depth seem to be lower in Finnmark (cf. Table 1) than in southern Norway, probably due to generally lower precipitation. Permafrost is apparently widespread in Finnmark in areas above timberline having MAAT lower than -3°C,
- Air temperatures for the previous 3–5 years have been 1.5–2.0°C warmer than the 1961–1990 average. In Finnmark permafrost is "warm" as it is only a few degrees below 0°C, which makes it very vulnerable to warming (cf. Isaksen et al. 2007), and
- The present monitoring program in Finnmark is being continued and will be included within the Norwegian funded IPY-project *Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard*, (Christiansen et al. 2007). The relation between MGST and snow and vegetation should be further investigated, and similar measurements should be made at other sites to see if these findings can be generalized to larger areas.

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