MAGST in Mountain Permafrost, Dovrefjell, Southern Norway, 2001–2006

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Abstract

A monitoring program to measure ground and air temperatures was started in autumn 2001 in Dovrefjell (62°15′N, 9°20′E), a mountainous area in southern Norway. Ground temperatures are measured in a transect from deep seasonal frost at 1039 m a.s.l. to discontinuous mountain permafrost at 1505 m a.s.l. in 11 boreholes 9 m deep. This is the first transect of this type set up in Scandinavia. Preliminary results are presented including measurements at 0.2 m and 8.5 m depth. The collected ground surface temperatures (GST) show pronounced fluctuations and large interannual variability. A simple normalization procedure is suggested to relate the observed GST to the reference period 1961-1990. The results suggest that even with an averaging period of 5 years the MAGST could deviate more that 1°C from the 30-year average. The period 2001–2006 is generally found to be warmer than the reference period, suggesting thawing permafrost at sites with discontinuous or thin snow cover.

Keywords: MAGST; monitoring; mountain permafrost; Norway.

Introduction

Permafrost is known to be widespread in the world mountain ranges, but scientific investigations only started during the past few decades (Haeberli 1973, Haeberli & Patzelt 1982, Ødegård et al. 1992, Haeberli et al. 1993). The focus of these investigations has been on degrading permafrost and reduction in the stability of mountain slopes (e.g. Harris et al. 2001). Slow thaw of deeper subsurface materials may provoke larger-scale instability on steeper slopes in areas previously considered stable (Dramis et al. 1995). Other studies are related to buildings and other installations directly affected by ground thawing (Haeberli 1992, Haeberli et al. 1993). Permafrost is sensitive to changes in surface energy exchange; it is therefore important to investigate the marginal permafrost areas. Equally important is an understanding of the dominant processes for permafrost development and degradation in mountain areas.

The use of miniature temperature data loggers (MTDs, Fig. 1) for mountain permafrost studies has greatly increased during the last decade. Large amounts of ground surface temperature data now exist from many mountain areas. Continuous temperature recordings make it possible to determine, for example, the mean monthly and annual ground surface temperature (MMGST and MAGST) at selected sites.

This paper presents preliminary results from a monitoring program to measure ground and air temperatures in Dovrefjell (62°15′N, 9°20′E), a mountainous area in southern Norway (Fig. 2). Ground temperatures are measured in a transect from deep seasonal frost at 1039 m a.s.l. to discontinuous mountain permafrost at 1505 m a.s.l. in 11 boreholes 9 m deep in the period 2001–2006. This is the first transect of this type set up in Scandinavia. The analysis includes measurements at 0.2 m and 8.5 m depth. The collected ground surface temperatures (GST) show pronounced fluctuations and large interannual variability. A simple normalization procedure is suggested to relate the observed GST to the reference period 1961–1990.

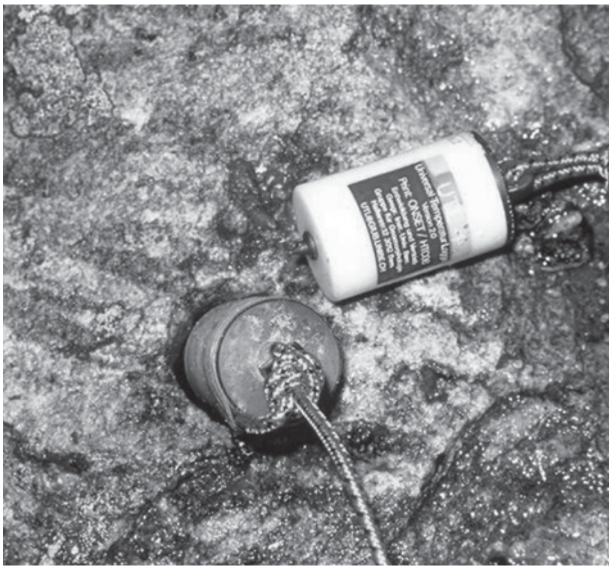

Figure 1. Miniature temperature datalogger (MTD) used in this study. This tool is especially designed for rough field conditions. The thermistor in the MTDs is a TMC-1T with a temperature range of −30°C to +40°C and with accuracy given by the manufacturer to be ±0.13°C. The loggers are available from GEOTEST in Switzerland.

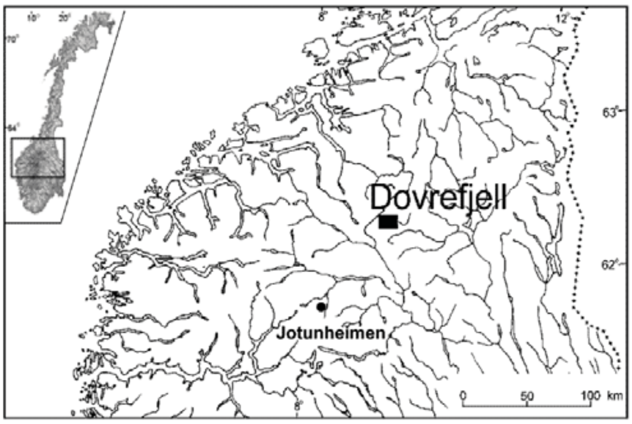

Figure 2. The research area in central southern Norway.

Table 1. Mean ground temperatures 2001–2006, column 2 shows normalized temperatures described in the next section.

BH-nr	Mean 2001-2006 0.2m depth	Normalised 0.2m depth	Mean 2001-2006 8.5m depth
DB1	-1.1	-1.9	-0.2
DB2	-1.0	-2.1	-0.3
DB3	0.7		0.2
DB5	-0.8	-1.7	0.6
DB6	-0.7	-1.7	-0.3
DB7	0.5		1.4
DB8	0.8		2.0
DB10	1.5	0.9	2.6
DB11	1.4	0.8	2.1

Research Area and Previous Studies

The setting and overall scope of the monitoring program in Dovrefjell were presented by Sollid et al. (2003). Key information from the boreholes like position, altitude, surface material, and snow depth are described in this paper.

Ground temperatures are correlated with elevation. The lower limit of the mountain permafrost in Dovrefjell is about 1500 m a.s.l., mapped using the BTS (Bottom Temperature of Snow) method (Ødegård et al. 1996, Isaksen et al. 2002). This limit is representative for areas with a stable snow cover of 1–2 m. Sporadic permafrost is present at elevations down to 1000 m a.s.l. in some palsa bogs (Sollid & Sørbel 1998)

Regression based on 18 climate stations in the vicinity (Aune 1993) indicates that the 0°C isotherm is located at 910 m a.s.l. The mean temperature lapse rate is 0.44°C/100 m (Tveito et al. 2000). The average yearly precipitation is 600 mm (Østrem et al. 1988). Unstable and stormy weather are common in winter, and the dominant wind direction is from the southwest.

Field Data

This study is based on analysis of a subset of the observations including monthly averages from 9 boreholes at 0.2 m depth and 8.5 m depth (Table 1, Figs. 3, 4). DB1, 2, and 6 are located at exposed sites, at main ridge-crest or plateau

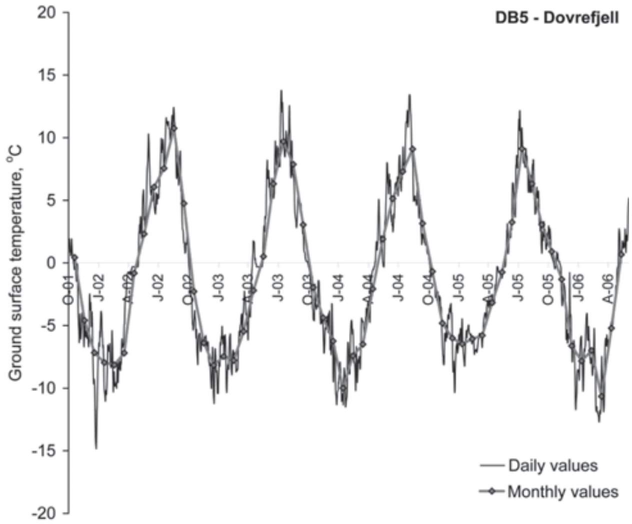

Figure 3. Daily and monthly time series of ground surface temperature at monitoring site DB5 in Dovrefjell, 2001–2006. The temperature series shows large interannual variability.

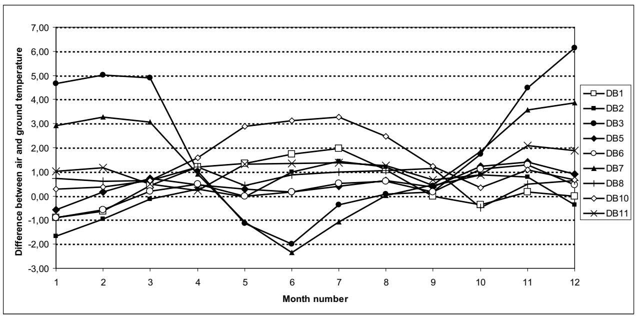

Figure 4. Difference between air temperatures and observed MAGST at the monitoring sites (0.2 m depth–averages 2001–2006).

locations, where winter snow accumulation is minimal. Sites DB5, DB10, and DB11 have discontinuous snow cover in the vicinity of the boreholes. DB 3, 7 and 8 have a maximum snow cover between 0.3 m and 1.0 m as measured in late winter. DB1, DB2, and DB6 are in permafrost; the other boreholes have deep seasonal frost.

Normalization Procedure

In the normalization procedure the monthly scale was selected. The monthly scale improves the correlation between air and ground temperatures (Fig. 5), and captures the overall seasonal variations (Fig. 4). The World Meteorological Organization (WMO) established a standard for a “normal” period to ensure that calculations of climate averages (the “normals”) are calculated on a consistent period. A 30-year period is considered long enough to calculate a representative average, and to reduce the impact that one-off, extreme events have on the average. Thus, in this study the official standard normal period 1961–1990 is used.

The normalization procedure starts with the calculation of the MMGST from MTDs by averaging the observations. The second and more complicated step is to obtain mean

Table 2. Difference between observed and normalized air temperatures at Fokstugu (1961–1990).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JUN-AUG	OCT-APR	YEAR
2002	3.2	2.1	1.4	3.9	2.2	1.2	1.1	4.7	1.9	-3.8	-3.4	-3.1	2.3	0.0	1.0
2003	2.1	2.2	3.1	2.2	-1.0	1.1	3.3	0.6	0.8	-2.5	2.0	1.8	1.7	1.6	1.3
2004	-1.6	2.5	1.7	3.5	0.5	-1.1	-0.2	2.0	1.1	-0.5	0.5	3.0	0.2	1.3	1.0
2005	4.3	0.8	0.0	2.2	-2.0	-2.4	2.4	-0.2	1.5	2.0	3.4	0.8	-0.1	1.9	1.1
2006	2.4	1.1	-4.0	-0.3	-0.6										
Average	2.1	1.7	0.4	2.3	-0.2	-0.3	1.7	1.8	1.3	-1.2	0.6	0.6	1.0	1.2	1.1

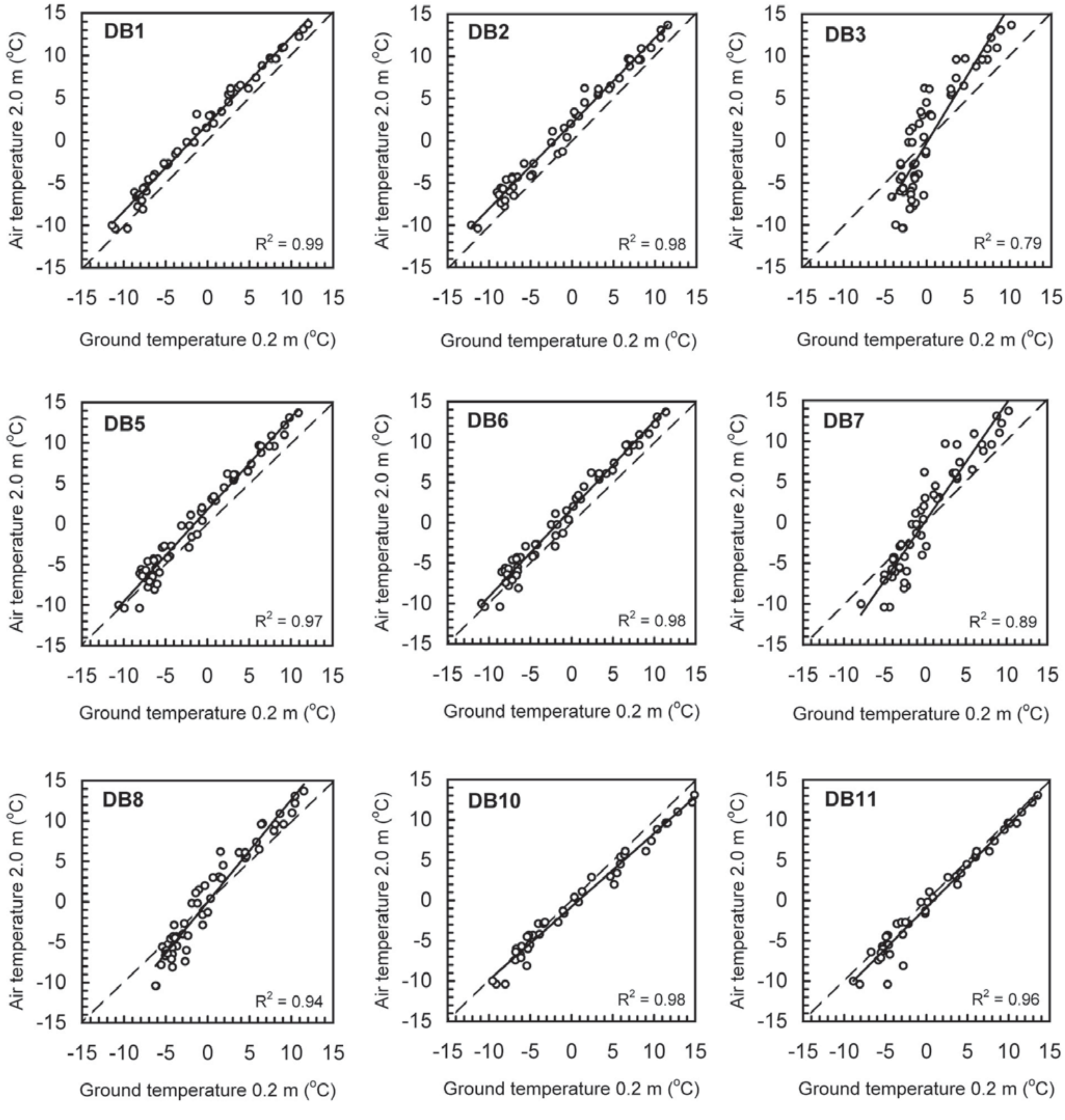

Figure 5. Recorded monthly ground surface temperature for monitoring sites in Dovrefjell vs. monthly air temperature for the weather station at Fokstugu. The snow thickness at several of the monitoring sites is low and for DB1, DB2, and DB6 most of the time snow is completely absent, due to redistribution by wind. Monitoring sites DB3, DB7, and DB8 are highly influenced by snow.

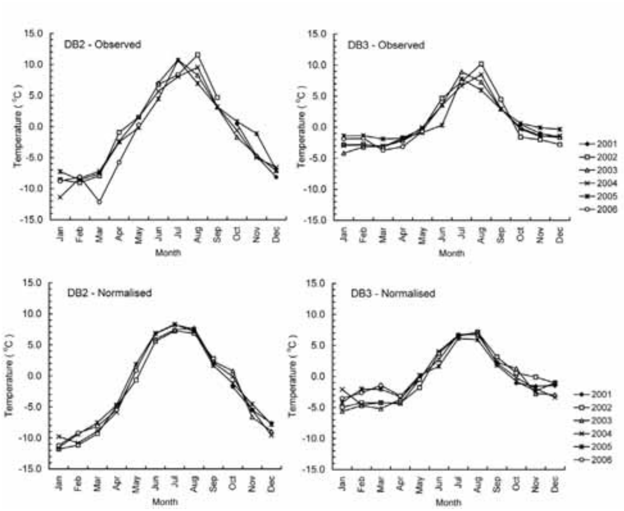

Figure 6. The upper graphs show observed ground surface temperature at selected monitoring sites DB-2 (left) and DB-3 (right). The lower graphs show normalized values for the ground surface temperatures at the same two sites.

monthly air temperature maps and monthly anomaly maps of the air temperature with reference to a standard normal period, in this study 1961–1990.

In Norway 1 km gridded temperature maps and anomaly maps are available from the Norwegian Meteorological Institute (Tveito et al. 2000). The spatial analyses were based on 1247 stations in Fennoscandia using residual kriging. The trend components were defined by a stepwise linear regression.

One alternative method is to obtain air temperature data from a nearby meteorological station having a long time series (e.g. 30-year period or more). A monthly mean temperature anomaly field in a radius of, for example, 30–50 km tends to be quite homogenous, typically within in the range of ±0.3°C.

A high correlation between air and ground temperatures suggests low influence of snow and latent heat effects, which suggests a strong coupling between the air temperatures and the ground surface temperatures. At these sites the monthly air temperature anomalies are simply applied to the MMGST to obtain a normalized estimate.

Results

The normalization procedure outlined above was applied to 6 boreholes (DB1, DB2, DB5, DB6, DB10, and DB11) to obtain the first estimate of MAGST based only on a few years of measurements. The normalization procedure reduces the monthly and interannual variability in the dataset (Fig. 6), especially during summer. At exposed sites with a thin snow cover, the variability in the normalization results during autumn and winter is mainly due to problems with the extrapolation of data obtained from the meteorological stations. For some time periods during autumn and winter, the air temperature in valleys is often lower than in the surrounding mountains because of temperature inversions. This is the case at the Fokstugu meteorological station approximately 15 km from the research area.

For the monitoring period autumn 2001 to spring 2006 the MAGST at exposed sites are on the range 0.6ºC to 1.1°C higher than the 1961–1990 average (Table 1, column 1 and 2).

For determination of MAGST for sites having a thick snow cover the suggested method is not applicable during winter due to the insulating effect of the snow (DB3, DB7, and DB8).

Except DB3 the average ground temperatures observed at 8.5 m depth are higher than MAGST at 0.2 m depth. The averages during the monitoring period range from 0.4°C to 1.2°C higher than MAGST. At DB3 the average at 8.5 m depth is 0.5°C colder than MAGST. This is a good illustration of the complexity of the ground thermal regime in mountain permafrost/deep seasonal frost. The distance between DB2 and DB3 is only 55 m.

Discussion and Conclusions

Observations in 9 shallow boreholes, in warm permafrost (3 boreholes) and deep seasonal frost (6 boreholes), in the period from autumn 2001 to spring 2006 show the limitations of surface measurements in the validation of mountain permafrost models. The results suggest that even with an averaging period of 5 years the MAGST could deviate more that 1°C from the 30-year average (1961–1990). This study shows that a simple normalization procedure based on air temperature anomaly maps could be applied at some sites with a good coupling between air and ground temperatures. A more general normalization procedure would require more sophisticated methods.

The period 2001–2006 is generally found to be warmer than the reference period, suggesting thawing permafrost at sites with discontinuous or thin snow cover.

The ground temperature averages at 8.5 m depth are generally found to be higher than the averages at 0.2 m depth. This is surprising because the conductivity ratio between unfrozen and frozen surface material (Kt/Kf) will cause an offset between the MAGST and the ground temperature at the top of the permafrost. The thermal offset is caused by different thermal properties in the thawed and frozen states (Romanovsky & Osterkamp 1995). These conductivity controlled models show good performance in arctic low-land applications when compared with borehole data (Smith & Riseborough 2002, Wright et al. 2003).

In mountain terrain the surface is often covered with blocks, introducing a top surface layer where non-conductive heat transfer mechanisms are important. Another complication is the redistribution of snow due to wind drift, resulting in a highly variable snow cover, even on scales of just a few meters. This is definitely the case at the observed boreholes and needs to be considered in order to obtain modeling results that can be compared with borehole data. There is also a possibility for lateral heat transfer in a complex soil-water system, but conclusive statements cannot be made based on this study.

The plan is to continue the monitoring for several decades, for the study of permafrost temperatures under future climate development and probable accelerated warming in the mountains of southern Norway.

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