Near-surface ground temperatures and permafrost distribution at Gornergrat, Matter Valley, Swiss Alps

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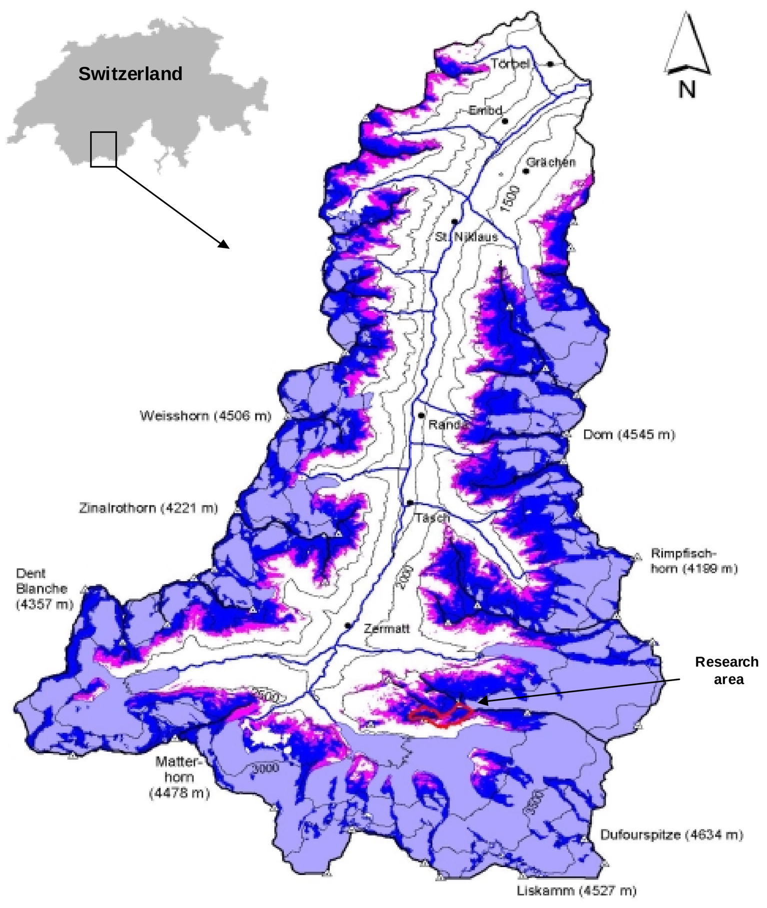

Figure 1: Overview map of the Matter Valley with research area and permafrost distribution (mod2, GRUBER 2000); light blue = glaciers, dark blue = permafrost probable, pink = permafrost likely.

Due to substantial research during the past twenty years the permafrost distribution of the Matter Valley is generally well known. However, the adapted permafrost distribution models for the Matter Valley (e.g. GRUBER 2000) do not consider the properties of local underground material, which can vary significantly within short distances, especially in high mountain environments. Besides other factors like air temperature, solar radiation and snow cover, changes in substrate and soil moisture conditions strongly influence the ground thermal characteristics and consequently the distribution of mountain permafrost.

The zone of discontinuous permafrost is characterised by rather warm ground temperatures insignificantly below zero, which makes it highly susceptible to increasing air temperatures. The rising of the lower permafrost limits by active-layer thickening and permafrost degradation by basal melting are possible responses to long-term climate changes (WILLIAMS & SMITH 1989). The aim of our investigations therefore was, to study quantitatively shallow ground thermal regimes within the discontinuous permafrost zone of the Gornergrat area. Ground temperature measurements are performed at eight vertical profiles differing in substrate and moisture conditions. The ground temperature records can be correlated with the soil properties and other microclimatic factors of each location. The possible effects of different soil characteristics on the discontinuous permafrost distribution are discussed. In view of the global climate change, the local variations of permafrost conditions at its sensitive lower limit is of scientific as well as applied importance.

1 Research Area

The Gornergrat area is located at the upper end of the Matter Valley in the southern Swiss Alps (*Figure 1*). It ranges between 2700 and 3200 meters a.s.l., surrounded by some of the highest peaks of the Alps. The continental climate conditions cause a high glacier equilibrium line associated with a periglacial belt of large vertical extent. According to KING (1996), discontinuous permafrost can be expected in an altitudinal range between 2800 and 3500 meters a.s.l. indicated by numerous active rock glaciers.

The east-west running crest between Gornergrat (3135 meters a.s.l.) and Hohtälligrat (3286 meters a.s.l.) divides the study area in a northern part called 'Kelle' and a southern part named 'Tuft'.

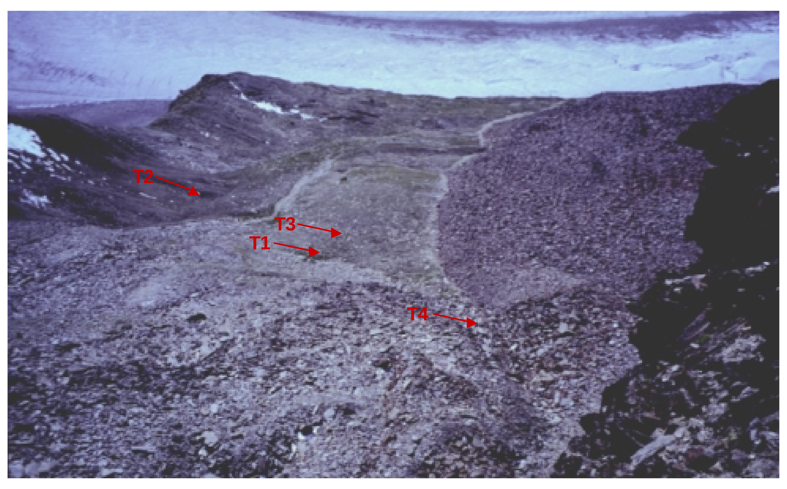

Figure 2: View from Hohtälligrat (3286 m a.s.l.) down to the „Tuft" with rock glacier (right) and solifluction lobes (left) in August 2002. The red arrows indicate the locations of the instrumented profiles T1–T4.

Both areas are located within the zone of discontinuous permafrost, showing a rich periglacial morphology like solifluction lobes, patterned ground and rock glaciers. The permafrost models (e.g. GRUBER 2000) applied to the Matter Valley indicate probable permafrost occurrence for both areas. However, since these models are too general to consider the site specific variations in soil properties which greatly affect the thermal regime, the local permafrost pattern of the research area is yet not known.

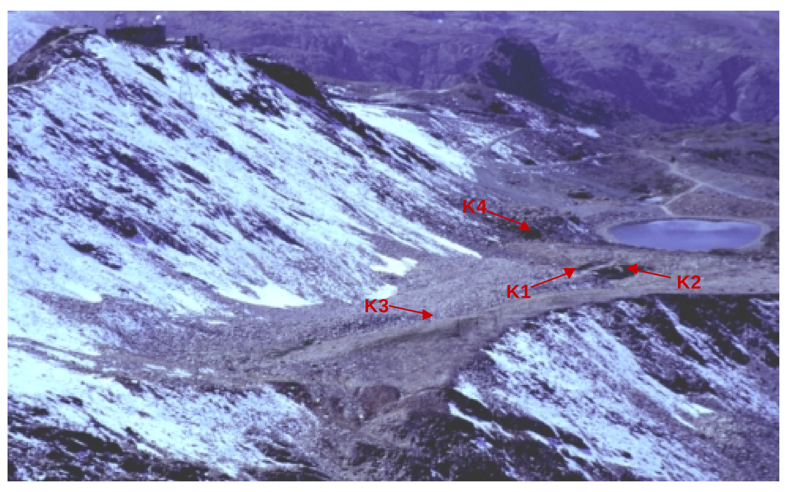

Figure 3: View from Hohtälli to the „Kelle" in August 2002. The red arrows indicate the locations of the instrumented profiles K1–K4.

2 Selected Study Sites

Shallow ground temperature measurements are performed at eight vertical profiles differing in orientation, substrate (*Table 1*) and moisture conditions (*Table 2*). In terms of local soil characteristics each of the four instrumented profiles in the Tuft corresponds roughly to a similar profile in the Kelle. Due to their location within local wet plains the profiles T (Tuft)1 and K (Kelle)1 show a rather high soil moisture content. In contrast, the sandy K2 is a very dry location, whereas T2, T3 and K3 have moderate water contents. Except for K2, all other sites show a sparsely vegetation cover of moss, lichen and grass and are located at around 3000 meters a.s.l. (*Table 1*).

In order to compare the thermal regimes of soils and coarse debris, two additional locations (K4 and T4) within the surface layer of active rock glaciers were chosen. *Figures 2* and *3* give a general survey of the study areas "Tuft" and "Kelle" with the instrumented profiles.

At the same time similar measurements are carried out in the Ritigraben catchment in the northern part of the Matter Valley by HERZ et al. (2003) with the main objective of investigating the microclimate within coarse debris cover layers.

Table 1: Information on the instrumented profiles at Gornergrat.

Profile	Altitude (m)	Depth of sensors (cm)	Location	Soil material (until 100 cm)	Humus (%) within upper horizon
T1	3005	1, 25, 50, 100, 160	moist plain	0-15 loam 15-100 sandy loam	9.7
T2	3000	1, 25, 50, 100, 180	solifluction lobe	0–100 loam	15.0
T3	3000	1, 25, 50, 100, 150	elevation	0–100 sandy loam	4.5
T4	3010	50, 120, 190, 255	active rock glacier		
K1	2950	1, 25, 50, 100, 150	moist plain	0–15 loam 15–100 silty loam	9.5
K2	2950	1, 25, 50, 75, 120	dry plain	0– 40 sand 40–100 loamy sand	2.3
K3	3005	1, 25, 50, 100, 140	mound	0–100 sandy loam	6.3
K4	2950	100, 160, 220, 280, 360	active rock glacier		

Meteorological data are available for the 'Kelle' and the permafrost monitoring site at Stockhorn plateau (3410 meters a.s.l.) close to the research area.

3 Ground Temperature Measurements

In August 2002 eight data loggers with five sensors each were installed, measuring shallow ground temperatures at different depths. According to the results of the sensor calibration, an relative accuracy of 0.02 °C can be expected. Technical details about the loggers and the calibration method are given in HERZ et al. (2003).

The instrumented vertical profiles in mineral soil (T1 - T3 and K1 - K3) have a maximum depth of 180 cm, whereas T4 and K4 at the rock glaciers reach down to 360 cm (*Table 1*). Initially the measurement interval was set at 15 minutes, and was changed to hourly registrations by the end of October 2002. So far, data from August 23rd 2002 until June 20th 2003 are available. The measurements will be continued at least until September 2003 to receive data of one annual cycle.

In addition to the permanent temperature records, BTS measurements were carried out in March 2003. Due to the poor accessibility of the Tuft area during wintertime, BTS measurements could only be carried out in the Kelle.

4 Results

The remarkable differences in thermal characteristics between the moist and dry profiles are striking.

Table 2: Moisture content of all profiles measured directly after snowmelt at June 20th 2003.

	Soil moisture content (% acc. to weight)					
Depth (cm)	**T1**	**T2**	**T3**	**K1**	**K2**	**K3**
1	48.9	60.2	18.0	42.8	0.7	20.9
25	36.0	25.5	18.3	42.6	12.2	9.7
50	29.3	22.1	16.0	40.0	34.6	3.0
75	26.2	13.4	13.0	24.9	6.7	2.5
100	25.6	13.5	13.3	18.8		5.6

During the snow free period the dry location K2 shows considerably larger temperature ranges and a smaller time lag with increasing depth than the moist profiles K1 and T1, independent from their orientation (*Figure 4*).

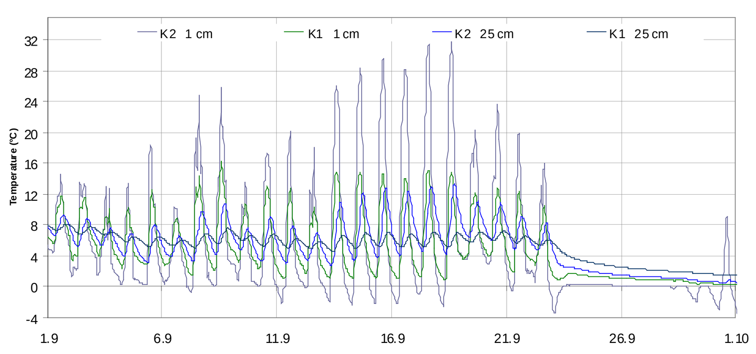

Figure 4: Hourly temperature records of the moist profile K1 and the dry K2 profile (01.09. – 01.10.).

These striking temperature variations seem to have two reasons: first, K2 is the only location without any vegetation cover. Even though the vegetation cover of all other sites is sparse, it seems to insulate the underlying ground and to damp the temperature variations at the surface as well as within the upper ground. Secondly, the high sand content of K2 (*Table 1*) prevent the storage of soil moisture. Consequently, the damping effect of water due to its high heat capacity and low thermal conductivity, which seems to be the crucial influencing variable of the thermal regime in the moist profiles, does not exist at profile K2.

The influence of moisture on the thermal regime becomes also evident by comparing the calculated average hourly temperature changes of the soil profiles (*Figure 5*). The two moist locations K1 and T1 show the lowest changes whereas the dry K2 profile displays by far the highest temperature variations at all measured levels.

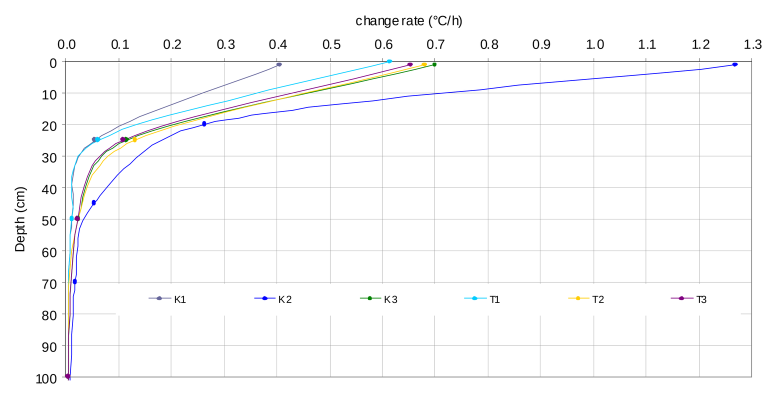

Figure 5: Average hourly temperature changes by depth of each soil profile during the snow free period (23.08.–27.10.2002).

During the snow free periods, differences in orientation i.e. solar radiation seem to affect mainly the surface temperatures. With increasing depth the soil properties - especially the moisture conditions - seem to have the major impact on the thermal regime. Apart from the surface ground temperatures, which are considerably higher at the southern location, the two moist profiles show similar temperatures and temperature ranges at all other measured levels independent of their orientation.

Data show that the thermal regimes of coarse blocky layers apparently follow other physical principles than these of mineral soils. Even though some of the soil profiles show significant temperature variations at the surface, the temperature amplitude and the hourly temperature changes at all other measured levels are significantly greater within the rock glaciers (*Figures 6* and *7*).

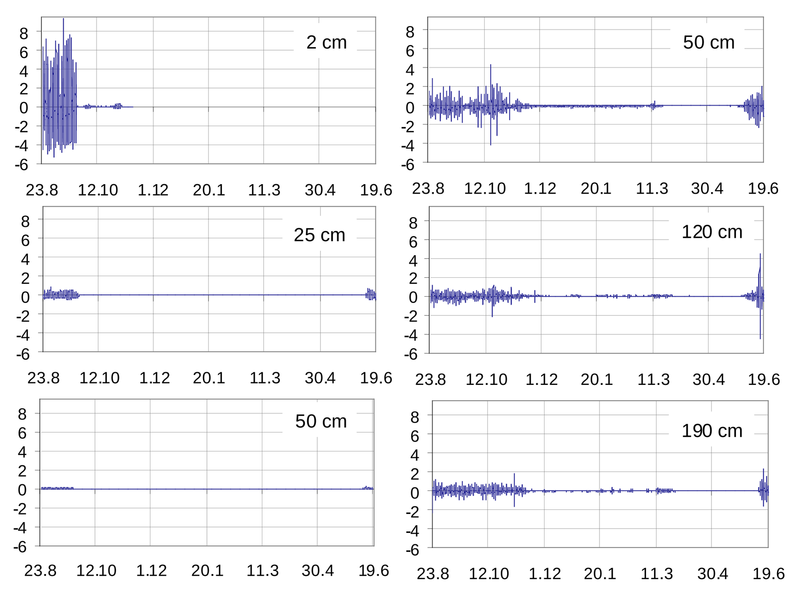

Figure 6: Hourly temperature changes at the soil profile T3 (left) and rock glacier profile T4 (right) at different depths (23.08.2002 – 20.06.2003).

The time lag between surface and soil temperature changes increasing with depth is missing at the rock glacier profiles (*Figure 7*). Conforming with the soil locations, the coarse blocky layer also shows a decreasing amplitude with increasing depth, but without any time delay. Even in a depth of 280 cm the temperature within the rock glacier still shows a daily course without time lag, whereas daily fluctuations in mineral soils occur considerably more damped and temporally delayed and reach down to a depth of only around 50 cm (*Figures 6* and *7*). Moreover, the block layer reacts stronger to a surface cooling than to a surface warming, whereas it is vice versa at the soil profiles.

In contrast to the mainly conductive thermal processes within the mineral soils, non-conductive heat transfer, mainly air circulation between the voids, seem to be the crucial process explaining the thermal differences between the block and the mineral soil locations. This phenomenon would also explain the direct response of the temperature changes within the block layer to a change in air temperature at the surface. However, during wintertime a thick continuous snow cover prevents the exchange between the atmosphere and the block layer completely and no remarkable temperature changes can be realised during the winter period (*Figures 6 and 7*).

As expected, permafrost seems to be present at both rock glacier sites, were winter temperatures down to –6 °C could be measured.

Even though the already mentioned permafrost models indicate "permafrost probable" for all the investigated locations, the data of the winter season 2002/2003 clearly show that no permafrost can be expected at all soil profiles. The coldest location shows not less than –1.5 °C at the snow / ground interface, the southern oriented T3 even remains above 0 °C. The BTS measurements carried out in the Kelle confirm these warm temperatures.

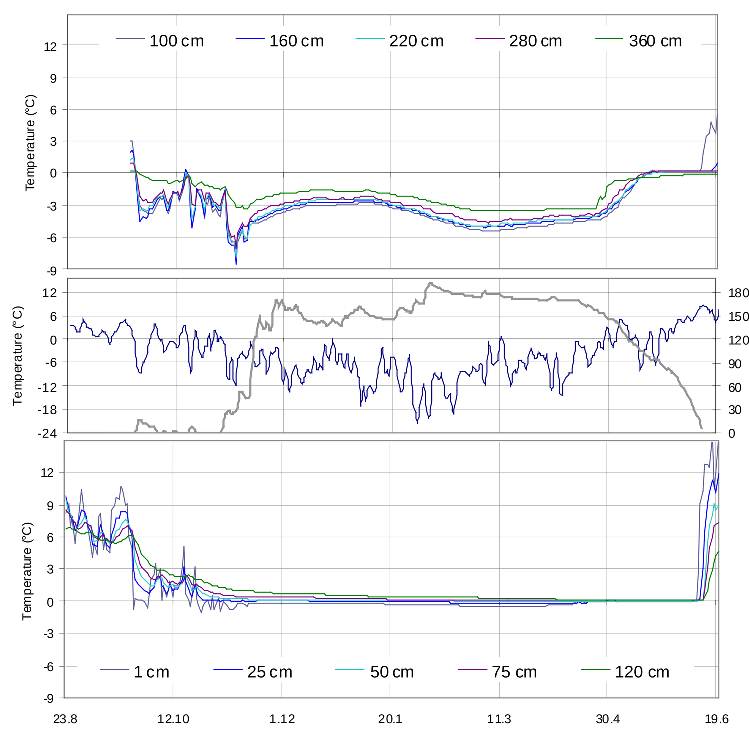

Figure 7: Average daily temperatures at five probe levels at K4 (top) and K2 (bottom) (23.08.–20.06.2003). In between average daily air temperatures in blue and snow depths in grey measured close to K2 for the same period.

5 Conclusions

The recorded data show considerable differences between the thermal regimes of soil substrates and coarse blocky layers. Even though the instrumented soil profiles are located in direct vicinity to the rock glaciers, only the coarse blocky layers seem to be underlain by permafrost. Thus, the data confirm the results of HARRIS & PEDERSEN (1998), that permafrost occurrences below the regional lower limit can be explained with the different thermal properties of blocky materials compared to mineral soils.

By comparing the thermal regimes of the profiles in soil substrate, the importance of the moisture content is striking: the temperature amplitude is damped considerably and the time lag with depth is exceeding that of drier locations.

The existing sophisticated permafrost models deliver good results on an overview scale. However, when it comes to the local pattern of discontinuous permafrost, field work and data collection are still essential. In order to achieve consolidated findings it is necessary to know about the particular site characteristics which considerably influence the local distribution of discontinuous permafrost.

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