# The Influence of Substrate and Surface Characteristics on the Ground Thermal Regime and Mountain Permafrost Distribution Results from the Matter Valley, Valais, Swiss Alps

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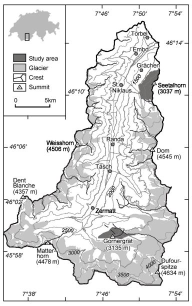


***Figure 1*** Overview map of the Matter valley with location of the study areas Grächen-Seetalhorn and Zermatt-Gornergrat

Shallow ground temperature measurements in the discontinuous permafrost belt of the Matter Valley demonstrate, how the ground thermal regime is influenced by a combination of various site characteristics on a local scale. Especially surface characteristics play a major role in this context besides the highly differentiating relief factors aspect and slope. The high variability of these influencing factors causes an equivalent small-scale permafrost distribution pattern with sharp changes between permanently frozen and unfrozen areas. Measurement data allowed a clear separation of the thermal behaviour of coarse block layers and fine-grained substrates. Varying textures of subsurface material in fine sediment govern the ground thermal regime due to their influence on soil moisture content. A blocky surface texture leads to a shift of heat transfer processes from conduction to convection. Unlike convective processes in finer grained substrates, it is the convection of air, which plays a major role in the thermal regime of this substrate type.

BTS measurements in the two test areas matched the continuous recordings well and allowed an areal extrapolation of this point information. In both areas, permafrost can be expected only beneath surfaces consisting of coarse debris. Even at an altitude of around 3000 m a.s.l. permafrost seems to be absent in soil substrate. A high resolution model of permafrost distribution for the investigated test areas incorporates the insights gained during the measurement campaign.

## 1 Objectives

The aim of this study is to confine the range of ground temperature conditions caused by the variability of substrate types on a local scale. Altogether 125 sensors recorded shallow ground temperature regimes in two test areas with discontinuous permafrost (Figure 1). Fine grained substrates as well as accumulations of coarse blocks have been instrumented in both areas in various depths up to 3 m. Selected data of two years of measurements are presented and conclusions are drawn on the relationship between local variations of topography and substrate types and the resulting permafrost distribution pattern.

## 2 Results

Figure 2 displays a comparison of the thermal regimes in coarse debris and fine grained substrate caused by identical meteorological conditions.

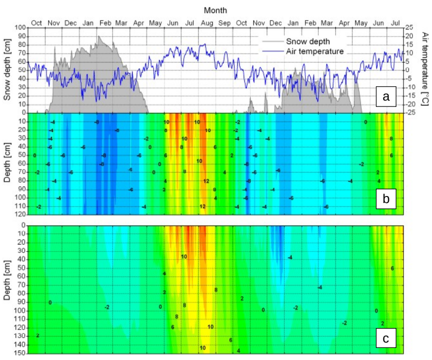


***Figure 2*** Comparison of the thermal regimes in coarse debris (b) and near-by fine substrate (c) caused by identical weather conditions (a); Grächen-Seetalhorn area, October 2002 - July 2004, daily mean values

Obviously, the thermal regimes are quite similar during the summer months June to August, while pronounced differences exist in autumn and winter.

These differences are a direct consequence of the extreme texture of coarse blocks. Grain sizes of several decimetre and more lead to a complementary void system of similar dimensions. This substrate type is characterised by an excellent permeability at least during snow-free periods.

The high permeability is responsible for an enhanced vertical energy transfer by means of free convection, as soon as temperature and therefore density stratification in the fluid phase become unstable. According to the data presented in Figure 2 this is the case during phases of pronounced atmospheric cooling typical for autumn and early winter.

A strong warming of the block layer surface during summer conversely causes a stable stratification in the fluid phase, which prohibits free convection in the pore air. These conditions result in a temperature distribution similar to the conductive regime typical for fine-grained materials.

Hourly Rayleigh numbers have been calculated for those (snow-free) periods, in which the pre-conditions for unstable stratification in the pore air were given (i.e. upper boundary colder than lower boundary). The Rayleigh number in the form

$$Ra = \frac{\rho^2 cg\beta KH\Delta T}{\mu k_m}$$

$\rho$ = fluid density
$c$ = fluid heat capacity
$g$ = acceleration due to gravity
$\beta$ = fluid expansion coefficient
$K$ = permeability of the porous material
$H$ = layer thickness
$\Delta T$ = temperature difference between upper and lower boundary
$\mu$ = fluid dynamic viscosity
$k_m$ = thermal conductivity of the block material

has been used (e.g. Johansen 1975, Kane et al. 2001).

As block sizes decline with depth, two Rayleigh numbers for the upper and lower part of each profile were calculated. Equivalent diameters were set to 0.3 m and 0.1 m, respectively and porosity was estimated at 40%. This results in permeability values of 8.89 x $10^{-5}$ $m^2$ for the upper and 9.88 x $10^{-6}$ $m^2$ for the lower domains of the block layer. Threshold values for the onset of free convection in the fluid phase of porous media are indicated with 27 (Johansen 1975) and 20 (Serkitjis & Hagentoft 1998) respectively in previous works. These threshold values are exceeded by far especially in autumn and early winter according to Figure 3 .

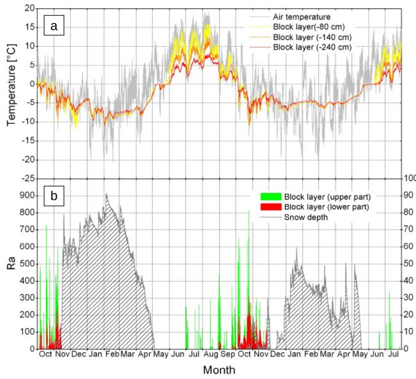


***Figure 3*** Air and void temperatures (a) as well as Rayleigh numbers and snow depth (b) at Ritigraben block slope (Grächen-Seetalhorn area) October 2002 - July 2004, hourly values

Rayleigh numbers at further locations in the Grächen-Seetalhorn area showed a similar distribution pattern as displayed in Figure 3. Mean values of 189 for the upper part and 66 for the lower part of the block cover are clearly above the threshold value of 20. Mean critical temperature gradients in the region of Ra 20-27 were calculated as 0.1°C $m^{-1}$ near the surface and 0.5°C $m^{-1}$ at the base of the block layer.

Texture differences of the surface material, especially the contrast between fine-grained (soil) substrate and coarse blocks, cause the most striking contrasts in the thermal regime of the near surface ground in both test areas as shown in Figure 4.

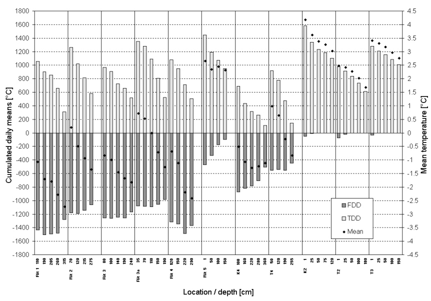


***Figure 4*** Cumulated daily means of Freezing and Thawing Degree Days and mean temperatures for selected locations; coarse blocks: Rit 1-4, K 4, T 4; fine-grained material: Rit 5, K 2, T 2+3
October 2002 - September 2003

Mean temperatures between -0.84°C and -2.69°C at the base of the profiles clearly separate the block covered locations from fine-grained substrates, where the corresponding means range between +1.68°C and +3.02°C. Therefore, negative means of ground temperatures can be expected at the block locations Rit 1-4, K4 and T4 exclusively.

The amounts of surface offset caused by the special microclimate of coarse debris layers are summarised in Table 1.

***Table 1*** Mean temperatures at seleceted locations and derived amounts of temperature reduction in coarse debris (October 2002 – September 2003)

| Test area | Block locations | | Fine-grained locations | | Temperature reduction [°C] |
|---|---|---|---|---|---|
| | Location (depth) | Mean temperature [°C] | Location (depth) | Mean temperature [°C] | |
| Grächen-Seetalhorn | Rit 1 (160 cm)<br>Rit 2 (140 cm)<br>Rit 3 (140 cm)<br>Rit 3a (150 cm)<br>Rit 4 (160 cm) | -1.56<br>-0.53<br>-1.43<br>-0.71<br>-1.51 | Rit 5 (150 cm) | 2.32 | 3.88<br>2.85<br>3.75<br>3.03<br>3.83<br>**Ø 3.47** |
| Zermatt-Gornergrat | K 4 (100 cm)<br>T 4 (190 cm) | -0.51<br>-0.23 | K 2 (120 cm)<br>T 2 (180 cm) | 3.02<br>1.68 | 3.53<br>1.91 |

## 3 Conclusions

According to the results an order of factors influencing the ground thermal regime in the discontinuous permafrost belt of the Matter valley is proposed. The presence or absence of a surface layer consisting of coarse blocks constitutes the most prominent factor. The combined effects of surface texture and snow cover characteristics are responsible for differences between the ground thermal regimes of the two test areas, causing higher (negative) surface offsets and accordingly lower ground temperatures in the Grächen-Seetalhorn area despite a higher MAAT. The observed influences of texture and moisture content of finer sediment as well as slope orientation are of secondary importance. Nevertheless, they are responsible for variations in ground temperatures at a local scale.

The new permafrost distribution model mod3 (Hof 2004) incorporates the results presented above (Figure 5).

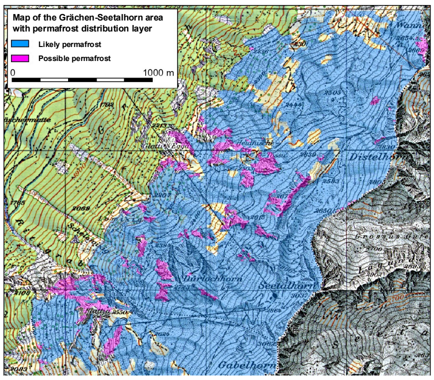


***Figure 5*** Permafrost distribution in the central and northern part of the area Grächen-Seetalhorn according to mod3 (Hof 2004)

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