Thermal regime within coarse debris of talus slopes in the alpine periglacial belt and its effect on permafrost

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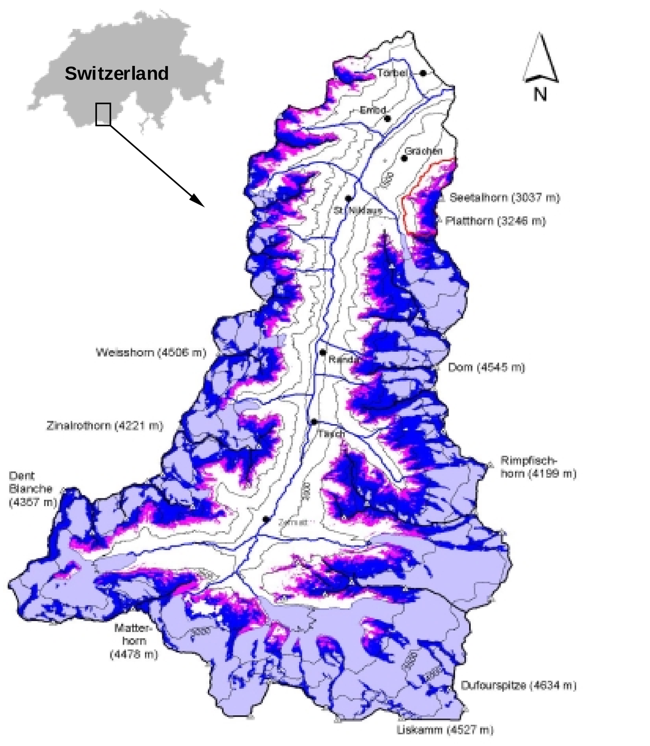

Figure 1: Overview map of the Matter valley. The red line indicates the research area Grächen-Seetalhorn displayed in Figure 2; Light blue = glaciers, dark blue = permafrost likely, pink = permafrost possible; Permafrost distribution according to mod2 (GRUBER 2000)

Investigations of polar permafrost occurrences indicate that different surface cover types have an important influence on the ground thermal regime. In the discontinuous permafrost zone, they are regarded as the decisive factor determining the local permafrost distribution pattern. Similarly, a coarse debris cover typical for alpine periglacial environments can be treated as an independent layer with certain vertical extent and variable amounts of "lithospherical" (solid material) and "atmospherical" (air-filled spaces) components. It forms a transition zone between the near ground atmosphere and the lithosphere with microclimatological conditions different from those of well defined surfaces of finer grained substrates. The objective of the current study is to investigate the microclimate within coarse debris cover layers in high mountain environments. To quantify their influence on the heat exchange between the local atmosphere and the near surface ground, special attention is dedicated to thermal conditions. Furthermore, their influence on the distribution pattern of discontinuous mountain permafrost is of specific interest.

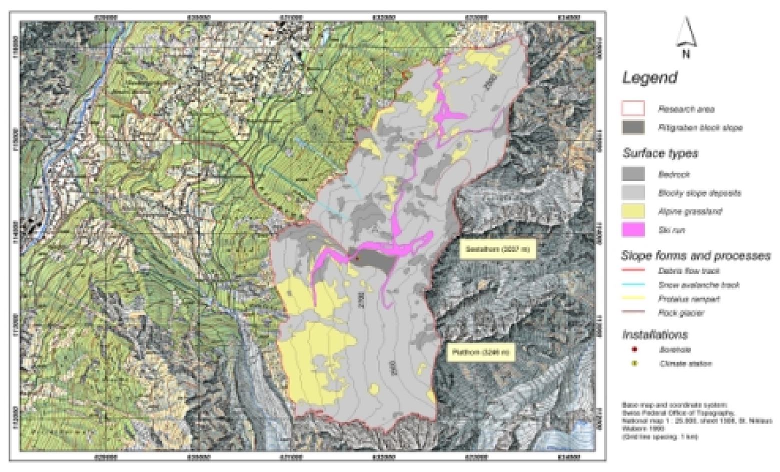

Figure 2: Map of the research area Grächen-Seetalhorn

1 Introduction

Talus slopes covered with coarse debris are widespread geomorphological phenomena in the periglacial belt of high mountains. Another phenomenon controlled predominantly by climatic factors is permafrost. Microclimatic energy exchange processes at the earth's surface play a dominant role in permafrost evolution. The distinct topography in high mountains in connection with alternating surface characteristics leads to remarkable differences in the subsurface temperature regime and to correspondingly small-scale permafrost distribution patterns, especially in the zone of discontinuous mountain permafrost.

2 Research Area

The research area Grächen-Seetalhorn is located in the Mattertal, Valais, Swiss Alps (cf. Figure 1). The Ritigraben catchment consists of a block slope, which covers an area of about 1.4 km² at an altitude between 2600 and 2900 m a.s.l. Block sizes at the surface range from 0.5 up to several cubic meters. The block cover shows a micro relief of alternating ridges and little troughs parallel to the slope with an altitudinal difference of up to 4 m (cf. Figure 3).

Figure 3: View into the Ritigaben block slope with the meteorological station

Figure 4 shows the sequence of layers and the corresponding measurement equipment, which was installed in the lower part of the Ritigraben block slope at an altitude of 2615 m a.s.l.

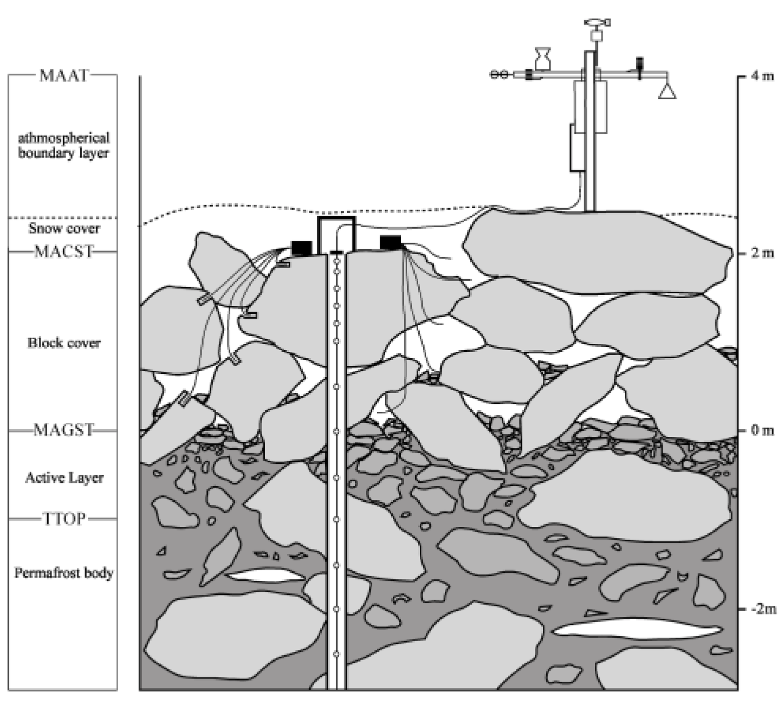

Figure 4: Layer names and schematic illustration of instrumentation in the Ritigraben block slope

3 Measuring Setup

Local climatic conditions are recorded by a meteorological station. It is equipped with sensors taking hourly records of net radiation, air temperature, relative humidity, surface temperature, snow depth, precipitation, and wind speed and direction. The ground thermal regime is measured in a 30 m deep borehole instrumented with a thermistor chain consisting of 30 NTC thermistors (type Yellow Springs Instruments YSI 44006, relative accuracy estimated at ± 0.02°C according to Isaksen et al. 2001) in depths ranging from 0.1 to 30 meters.

To measure rock- and air temperatures within the block cover, two types of temperature sensors were constructed. In both cases the sensor element consists of a high precision platinum thin film thermometer Pt 1000 1/3DINB (LxWxH = 10x2x0.25 mm). The sensors were connected to a 5-channel-minilogger (Type Wickenhaeuser TL_LOG5) by a half bridge circuit. After a four point calibration the relative accuracy of temperature measurements can be indicated with at least 0.02°C.

Rock and soil temperature sensor elements were sealed in closed high-grade steel tubes with a wall thickness of 0.2 mm. Air temperature sensor elements were fixed in open steel tubes in a position, so that the tip of the Pt 1000 sticks out of the tube and is in direct contact with the air (cf. Figure 5).

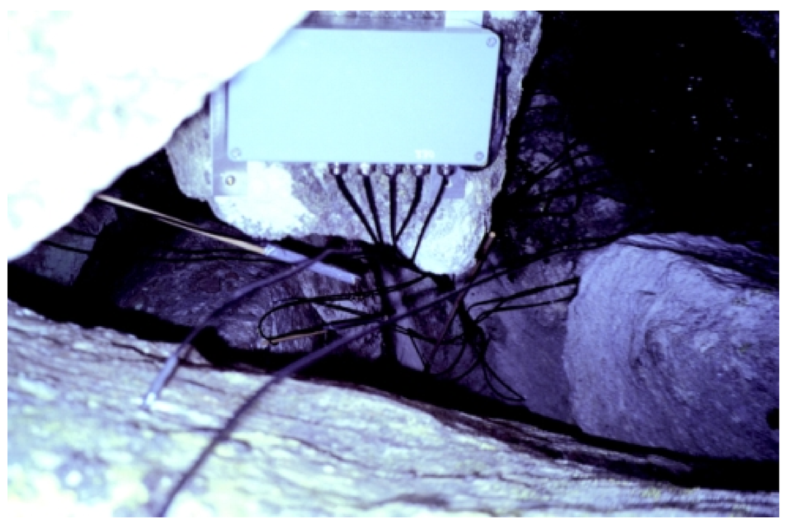

Figure 5: Example of block layer air and rock temperature sensors

Block layer rock and air temperatures are measured in a profile of four subsequent measurement points. The profile follows the drainageway of the local microrelief. Each measurement point consists of two loggers with five rock and air temperature sensors installed in different depths. Additional four measurement points form two cross-sections to the main profile to include also other microtopographical positions in the blockslope.

4 Current Results

Hourly meteorological and daily borehole temperature data are available since April 2002. Block layer temperature loggers were installed on August 15th 2002.

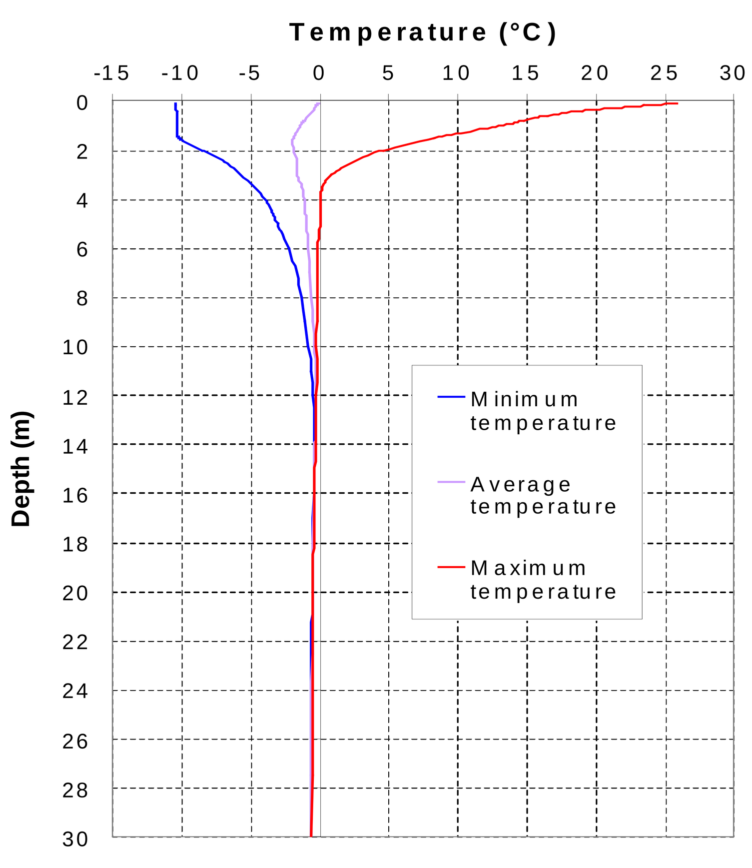

Figure 6: Ground temperature envelope, Ritigraben block slope, 2615 m a.s.l. (April 2002 - March 2003)

The first year of borehole temperature data presented in figure 6 display a marked asymmetry. The heat input during summer penetrates down to only 3.5 m in spite of extreme temperature gradients of up to 10°C/m. A sharp bend in the maximum curve occurs at that depth. The maximum temperature remains very close to 0°C during the whole summer between 3.5 and 5 m depth. Penetration of surface cooling during winter reaches down to 14 m depth, corresponding to the depth of the zero annual amplitude. These differences in ground thermal properties between "summer" and "winter" conditions can only be explained by phase change processes at a permafrost table located between 3.5 and 5 meters depth during summer 2002. The resulting thermal offset in ground temperatures according to GOODRICH (1978) is indicated by a mean temperature of –1.3°C in 3.5 m depth, which is 1.2°C colder than the mean temperature at 0.1 m depth. The permafrost body can be characterized as "warm" with mean temperatures of –0.36°C at the ZAA and –0.61°C in 30 m depth.

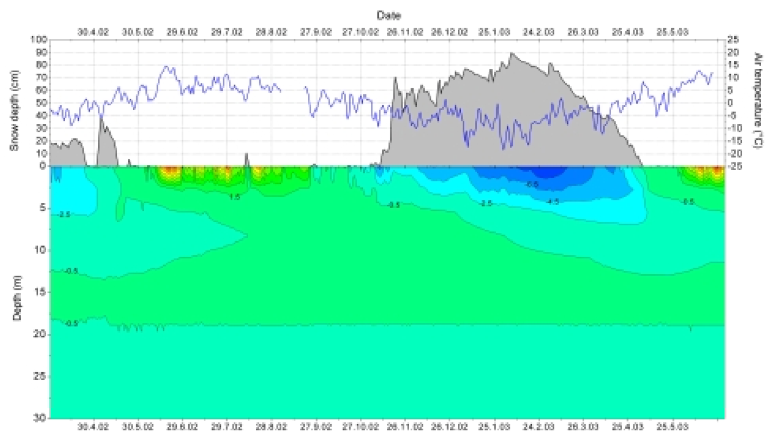

Figure 7: Daily means of snow depth, air temperature and borehole temperatures at the Ritigraben station (April 2002 – June 2003)

Figure 7 clearly outlines the marked differences of the summer and winter thermal regime. The effect of summer warming hardly reaches any lower than the vertical extent of the block cover, whereas winter cooling reaches a depth of more than 10 meters. The subsurface temperature graph shows the permeability of the block cover and the underlying ground for advective effects. This is indicated by the marked meltwater infiltration down to 7 m depth in mid May 2002 and the rapid cooling down of the whole subsurface in connection with a summer snowfall event on August 10th 2002.

As the research area belongs to the driest regions in the Alps, the winter snow cover rarely suffices to completely cover the block slope. Big surface blocks penetrating the snow cover and especially large voids not closed by the snow cover lead to a very effective cooling down of the block cover. Figure 8 shows, that advection of cold atmospheric air can be measured within the block cover until the end of January 2003. This is indicated by minimum temperatures below -15°C and hourly temperature change rates of up to 2°C.

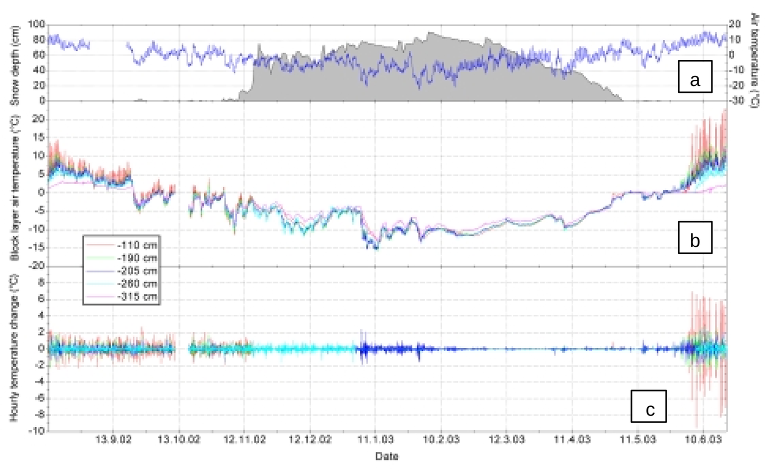

Figure 8: Hourly values of air temperature and snow depth (a), block layer air temperatures (b) and hourly temperature change rates of block layer air temperatures (c) at Ritigraben block slope (15th August 2002 – 21st June 2003)

Furthermore, the curve of the sensor at 315 cm depth indicates the existence of an air layer in the deepest voids of the block cover, which shows only very inert and gradual reactions to summerly warming. In the contrast to this, the response on the advection of cold air in autumn and winter is very immediate.

Figures 9 and 10 show a comparison of ground temperature courses in a soil profile a few meters outside (Fig. 9) and a rock temperature profile in the drainageway of the Ritigraben block slope (Fig. 10).

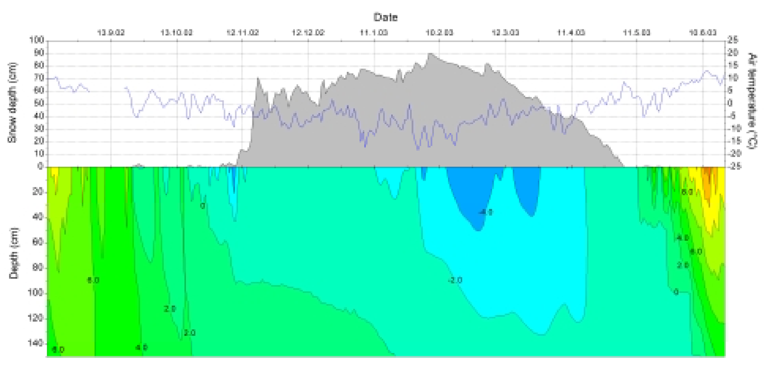

Figure 9: Daily means of snow depth and air temperature at Ritigraben station and ground temperatures at a comparison soil profile nearby (15th August 2002 - 21st June 2003)

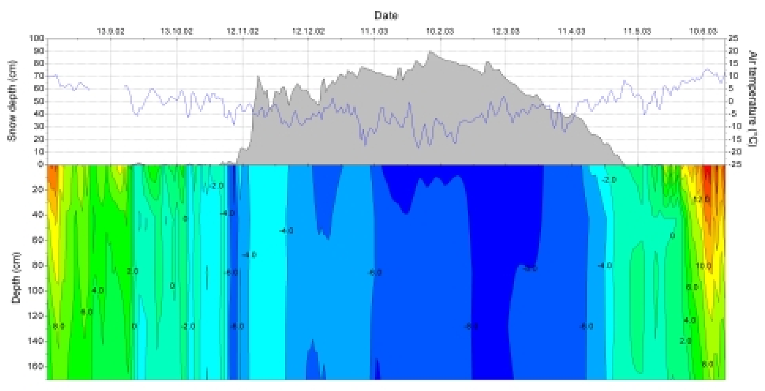

Figure 10: Daily means of snow depth, air temperature and block layer rock temperatures, Ritigraben block slope (15th August 2002 - 21st June 2003)

While the temperature regime at the soil profile is controlled by conductive processes, the vertical orientation of the temperature-time distribution pattern of rock temperatures in the block slope is an unambiguous indicator of predominantly advective energy transfer caused by infiltration of water and air. This statement particularly applies for cooling events, which unexceptionally and immediately affect the complete vertical extension of the measurement profile.

5 Conclusions and Outlook

The subsurface thermal regime at Ritigraben block slope is strongly affected by advective processes. At the borehole location the cooling effect by infiltration of cold atmospheric air during autumn and winter is balanced by the effect of a continuous snow and permafrost meltwater flow in spring and summer. BTS-measurements conducted in March 2000 and 2003 indicate, that the effective subsurface cooling coincides with the distribution of block cover layers in the area. Manual readouts of a 17 m deep borehole in the area (Seetalhorn summit station, 2870 m a.s.l.) in 1999 and 2000 gave remarkable lower ground temperatures. Therefore, the "warm" conditions at the borehole location may not be representative for the area.

Temperature measurements in five additional boreholes through the Ritigraben block slope are planned in summer 2003 to verify this hypothesis.

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