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Modelling alpine permafrost distribution in the Hohe Tauern region, Austria

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Abstract

An assessment of natural hazards or the creation of risk maps in high alpine catchments very often requires the consideration of potential permafrost occurrence. The present study for the first time shows a high resolution and index based permafrost distribution for the region Hohe Tauern (approx. 4400 km²), which is based on the empirical model PERMAKART 3.0. The approach integrates three different relief classes (rock walls, steep slopes, foot slope position) in a topoclimatic key. The modelling results were validated with more than 600 BTS (bottom temperature of snow cover) measurements. At present an area of 550 km² is affected by permafrost to a lesser or greater extent. The occurrence of permafrost varies according to aspect and relief conditions in some locations more than 1000 m in altitude.In the national park "Hohe Tauern" (1856 km²) 25% of the area is underlain by permafrost. The produced permafrost map assists planers and decision-makers and contributes to better understanding of our mountain ecosystem.

Keywords

permafrost occurrence, PERMAKART 3.0, field geophysics, Bottom Temperature of Snow cover, GIS, Hohe Tauern

Introduction

Detailed knowledge about the current permafrost occurrence is of crucial importance with respect to climate change. In mountain areas, however, permafrost distribution is spatially very heterogeneous and available models have several limitations and uncertainties. Moreover, permafrost is a thermal phenomenon, defined by temperatures of lithosphere material at or below 0°C during two or more consecutive years, and sensitively reacts to increasing temperatures but is not easy to detect (Harris et al. 2003; Noetzli et al. 2007; Noetzl i& Gruber 2009; Haeberli et al. 2010). Thawing permafrost is one consequence of warming trends in the European Alps which causes a continuous change in permafrost distribution and influences a number of earth surface processes such as rock falls or debris flows (Krainer 2007; Sattler et al. 2011; Deline et al. 2012)(Fig. 1). New and accurate maps of permafrost for use by multiple audiences and outreach products regarding permafrost should be developed.

Early attempts regarding permafrost distribution in the Austrian Alps were based on an extensive rock glacier inventory of the Eastern Austrian Alps (Lieb 1996, 1998). For the entire Austrian Alps afirst digital permafrost distribution map with an adapted topoclimatickey was created by Ebohon & Schrott (2008). Austria has currently a surface area of approximately 1600 km² which is underlain by permafrost (Ebohon & Schrott 2008). Although this constitutes to only 2% of its entire territory, in its western part, like Tyrol, it can be as much as 10% and in the Hohe Tauern mountain region we expect extensive permafrost above 2500 m a.s.l. exceeding the surface area of present glaciers (see Tab.1)

The main objectives of this study are

(i) to develop a new index-based accurate permafrost distribution map for amountain area in the Austrian Alps (Hohe Tauern),
(ii) to calibrate and validate the empirical approach with numerous field evidences (bottom temperature of snow cover, field geophysics, geomorphological mapping), and
(iii) to assist the national park administration "Hohe Tauern" with a valuable outreach product for science and education purposes.

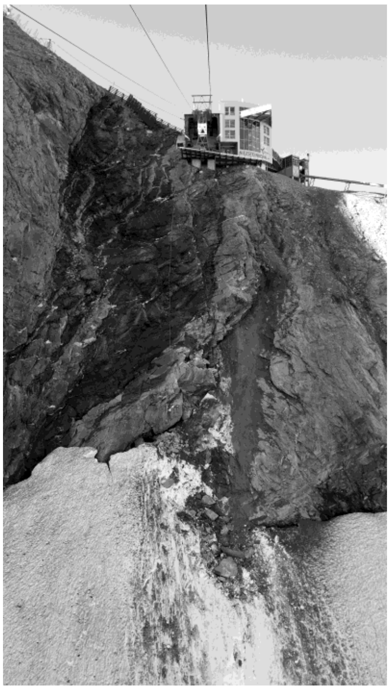

Figure 1: Permafrost related rock fall at the Kitzsteinhorn at approx. 2950 m (August 18, 2012 at 3pm). At the slip surface ice became visible after the failure. The Kitzsteinhorn region is one of our six test sites. Photo taken by M. Keuschnig.

Study area

The study area Hohe Tauern in Austria is situated in Salzburg, EasternTyrol and Carinthia, which counts to the eastern European Alps. The area under investigation comprises the "Hohe Tauern"national park (1856 km²) and its surroundings with a total surface area of approximately 4.400 km² (s. Tab. 1).The mountain ranges of Venedigergruppe, Granatspitzgruppe, Glocknergruppe, Schobergruppe, Goldberggruppe und Ankogelgruppeall belong to this area and comprise partly glacierized catchments.Numerous active rock glaciers in the Hohe Tauern region indicate the presence of discontinuous permafrost (BARSCH 1996; KRAINER & MOSTLER 2002).Within our study area we have selected six test sites for extensive local permafrost investigations, ground truth observations and validation purposes. Namely, from west to east: the Obersulzbachtal (glacierized), the Amertal, the Kitzsteinhorn (glacierized), the Glatzbach catchment (Glorer Huette), the Gradental, and the Kreuzkogel (see SCHROTT et al. 2012, OTTO et al. 2012).

Methods and data

In the field we applied measurements of the bottom temperature of snow cover (BTS), ground surface temperature recordings using UTL logger, and field geophysics (DC-resistivity, ground penetrating radar).This information was used to calibrate thetopoclimatic key and the lower limits of permafrost, respectively (see Fig.2).

Bottom-temperature of snow cover (BTS) and ground surface temperature (GST)

The bottom temperature of snow cover was introduced by HAEBERLI (1973) and is defined as the temperature measured at the snow/ground interface at the end of the winter (typicallybetweenFeb./Marchand April). In total we carried out 626 BTS measurements within our six test sites. In addition we installed at different locations 25 Universal temperature loggers (UTL) to record ground surface temperature (GST).

Field geophysics

Electrical resistivity (ERT) and ground penetrating radar (GPR) are meanwhile standard tools for permafrost detection (SCHROTT & SASS 2008).In this study we used our results of geophysics to calibrate the topoclimatic key and to cross check with BTS and modelling results (for details see OTTO et al. 2012).

Empirical-statistical GIS modelling

Permafrost occurrence is influenced by climatic (air temperature, solar radiation), topographic (aspect, slope), and site specific surface conditions (snow cover and duration, debris and boulder size). Air temperature and potential solar radiation can be considered indirectly by means of a topoclimatic key which distinguishes between slope and foot of slope locations (HAEBERLI 1975).The used topoclimatic key contains 24 different "relief classes" subdivided in eight different aspects each with three slope angles classified as rock slopes/walls, steep slopes (>11°) and slope foot-positions (Fig. 2). The altitudinal limits were adjusted to the Eastern Austrian Alps and differ from the original topoclimatic key which was developed for Switzerland in the model PERMAKART1.0 (KELLER 1992; KELLER et al. 1998). PERMAKART uses the statistical relationship between topographic parameters and empirically identified permafrost occurrences. For the model validation we used our BTS and GST measurements. Model calibration was realised in an iterative process using field data from geophysics which indicate permafrost absence or presence. These data were subsequently used for a further adjustment of the altitudinal limits with a general upwards shift of 50 m compared to the previous topoclimatic key applied by

EBOHON & SCHROTT (2008). An innovative amelioration of PERMAKART 3.0 is the index-based classification of permafrost probability from 1 to 100. A further important improvement of PERMAKART 3.0 is based on the new findings regarding rock permafrost temperatures (GRUBER et al. 2004). Therefore we added in the new model rock slopes as a separate unit which considers somewhat higher altitudinal limits compared to steep slopes(for modelling details see SCHROTT et al. 2012).To improve spatial accuracy we used a DEM with a grid resolution of 10 m.

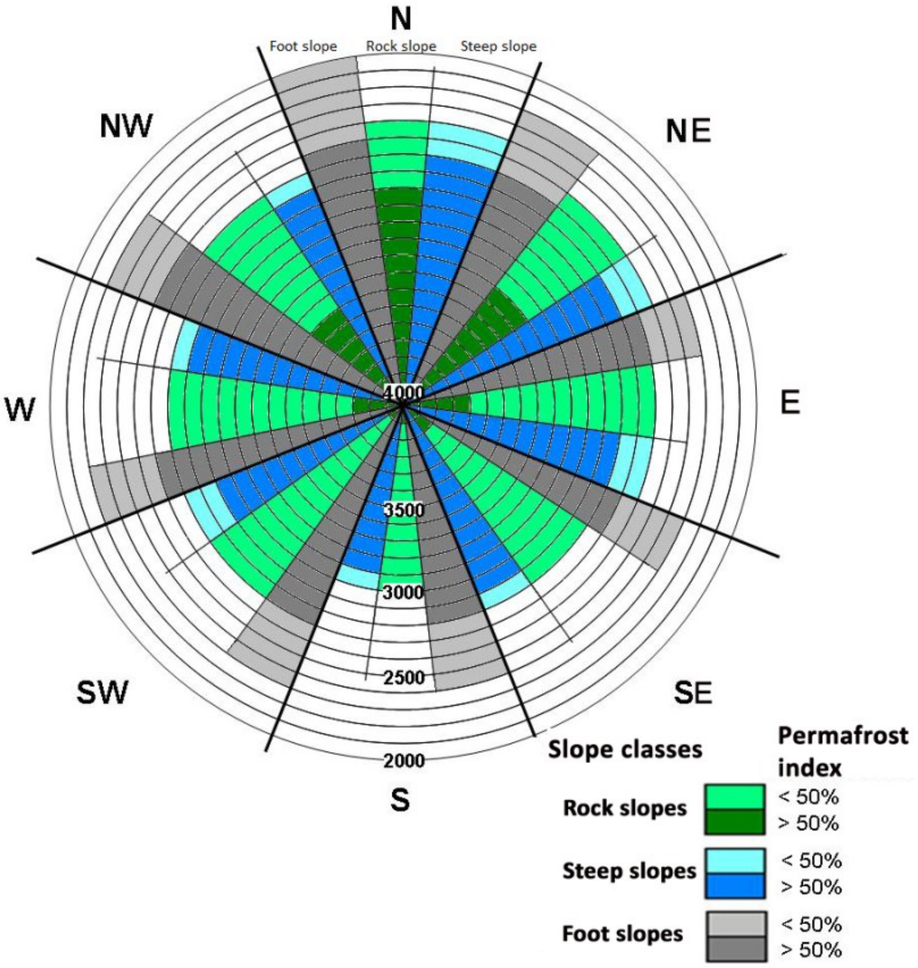

Figure 2: The adapted and modified topoclimatic key for the Hohe Tauern region used in the model PERMAKART 3.0. Three different classes of slopes (rock slopes, steep slopes, slope-foot position; read from left to right in each class) in eight aspects were analysed using a 10 m DEM.

Results

For the entire study area of the Hohe Tauern region (4378 km²) we estimatedan area of 550 km² which is currently underlain by permafrost to a lesser or greater extent. This corresponds to approximately 13% of the total area. For the national park "Hohe Tauern" with a surface area of 1856 km² the permafrost area becomes even more predominant with almost 25% (Tab. 1). In comparison to permafrost, glaciers cover only 160 km² showing currently a strong retreat which leads to a decrease in both surface area and ice volume. At present we observe especially between 3000 and 3500 m a.s.l. the most extensive glaciation (see Fig. 3).

Table 1: Surface areas underlain by permafrost and glaciers for the national Park "Hohe Tauern" and the states of Salzburg, East Tyrol and Carinthia.

Total area (4379 km²)	Permafrost distribution (km²)	Portion of surface area underlain by permafrost (%)	Glacier surface area (km²)(2003)
Study area	553,2	12.6	163.2
State Salzburg	182,8	2.6	60.8
State Tyrol[1]	218,4	10.8	66.2
State Carinthia	152	1.6	36.2
National park[2] "Hohe Tauern" (1856 km²)	455,4	24.8	159.8

[1]only East Tyrol; [2]includes states of Salzburg, East Tyrol and Carinthia

According to this approach permafrost can occur on north facing steep slopes (between 11 and 45 degrees) above an altitude of 2400 m, whereas onsouth facing slopes higher permafrost indices can be only expected above 3000 m. In slope foot-positions permafrost probability is modelled down to 2000 m on north facing slopes compared to 2400 m at south facing slopes.

Field geophysics

For details regarding local permafrost detection using geophysics we refer to OTTO et al. (2012) and KEUSCHNIG et al. (2011).

Validation of modelling results

BTS values provide the most comprehensive data set with a total of 626 measurements and allow a sophisticated validation in all six test sites. Permafrost occurrence is matched by overall 69%, classified into 46% in category (a) and 23% in (b), respectively. Very good matching is achieved in southeast, south and southwest-facing slopes (for details see SCHROTT et al. 2012).

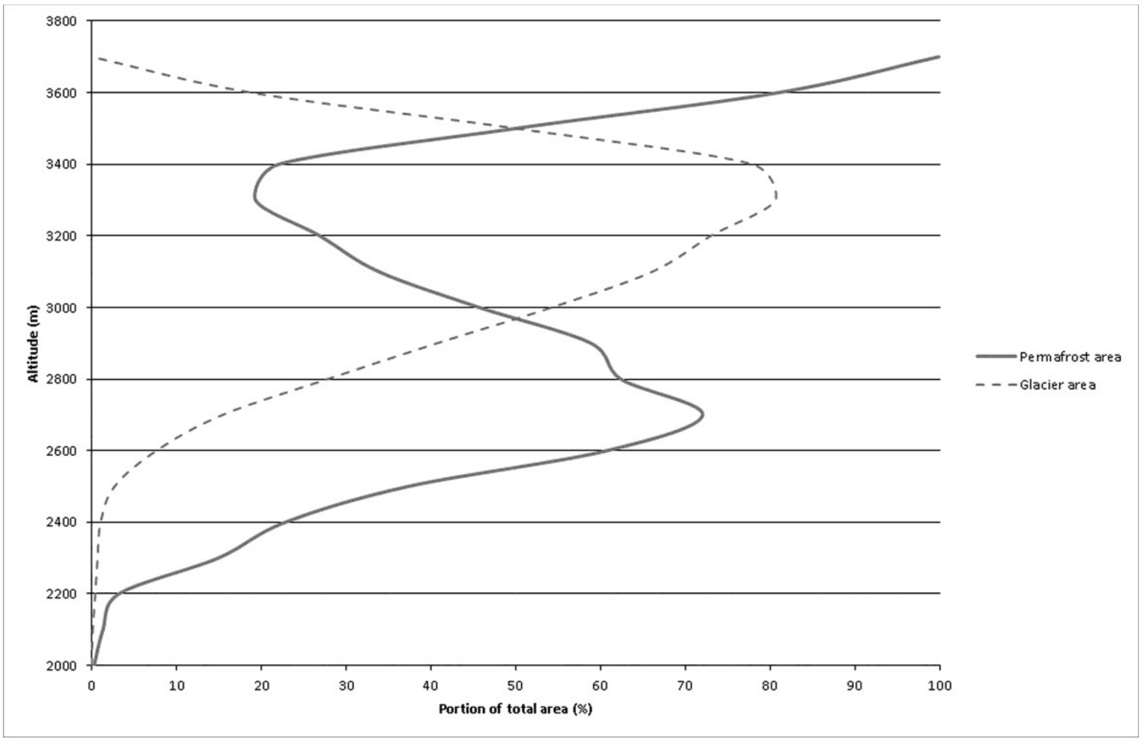

Figure3: Hypsometrical curves of glacier and permafrost extension derived from our data set used in the PERMAKART 3.0 model.

Discussion

Potential scenarios

In the European Alps climate change with warming trends can be observed since the second half of the 19th century and the mean annual air temperature increased in Austria since 1850 about 2°C (Böhm 2009). Mountain permafrost reacts sensitively to warming but somewhat delayed and almost invisible. Borehole temperature measurements in mountain permafrost in the Alps controlled by the Swiss Permafrost Monitoring Network (PERMOS) and more recently by the MOREXPERT project provide valuable information about permafrost evolution (NÖTZLI & VON DER MÜHLL 2010; KEUSCHNIG et al. 2011).In a first attempt we calculated potential altitudinal shifts of lower limits of permafrost assuming rising mean annual temperatures of 1 and 2K, respectively. Based on the average lapse rate of -0.51°K/100m we estimate theoretical shifts of lower limits of permafrost of 195 and 390m, respectively. This hypothetical assumption is, however, a strong simplification due to non-existing linear relationships between air and ground temperature. Nevertheless the proposed simple scenario can be considered as a raw indicator how permafrost distribution may change if degradation will occur extensively.

Thawing and degradation of mountain permafrost within rock walls is considered to be an important process influencing the slope stability of steep slopes and rock faces in alpine mountain ranges (KRAUTBLATTER & FUNK 2010).The interpretation of differing observations concerning permafrost thawing and degradation and potential natural hazards (e.g. rock falls, debris flows) remains a major challenge (SATTLER et al. 2011; HAEBERLI et al. 2010).

Conclusion and perspectives

For the first time a detailed permafrost distribution map is available for the region of the Hohe Tauern including the entire national park. Present permafrost occurrence is still a widespread phenomenon comprising 550 km² or approximately 13 % of the entire area. The visualized permafrost distribution primarily serves as an indication map at a regional scaleand provides the basis for a deeper understanding of permafrost related hazards. The map assists planers in permafrost related constructions, but does not substitute local investigations if detailed knowledge concerning permafrost occurrence is required.Effective adaptation measures of engineering structures in mountain permafrost terrain and estimates about permafrost evolution depend on detailed knowledge concerning permafrost distribution.

As a rule of thumb, permafrost can be expected above 2500 m a.s.l. in northerly exposed slopes and above 3000 ma.s.l. in southerly exposed slopes. A major challenge remains the estimation of the future development of permafrost in the Alps. Strong topographic variations (e.g. snow cover and duration, subsurface structure, rock vs. debris area) and different permafrost temperatures cause a different sensitivity to climate change even at a local scale (GRUBER & HAEBERLI 2007). Extensive borehole measurements in the Alps indicate the strong influence of snow cover on subsurface temperatures which enhance the heterogeneous pattern of permafrost in mountain areas (NOETZLI & VON DER MÜHLL 2010). A potential future application of the new PERMAKART 3.0 model is the integration of the cooling influence of a relatively thin (max. 40 cm) snow cover in early winter.

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