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Implementing a long-term monitoring site focusing on permafrost and rockfall interaction at the Kitzsteinhorn (3.203 m), Hohe Tauern Range, Austria – A status report from the MOREXPERT project.

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Abstract

The research project MOREXPERT („Developing a Monitoring Expert System for Hazardous Rock Walls“) has initiated a new long-term monitoring site focusing on bedrock permafrost and rockfall interaction. The project’s primary objective is the development of an expert system for the stability assessment in high-alpine rock faces. For this reason a state-of-the-art monitoring system has been established at the Kitzsteinhorn (3.203 m). The monitoring comprises various methods that allow the acquisition of combined information on subsurface, surface and atmospheric conditions: Five deep boreholes deliver temperature data from depths of up to 30 m. More than 40 spatially distributed temperature loggers provide information on near-surface thermal dynamics. Two permanently installed ERT profiles (Electrical Resistivity Tomography) are used to derive quasi-continuous information on ground temperatures. In order to detect changes occurring at the surface terrestrial laserscanning is carried out. Atmospheric conditions are monitored at six different weather stations.

Keywords

climate change adaptation, mountain permafrost, natural hazards, rockfall

Introduction

Within this contribution we explain the motivation and scientific basis of the research project MOREXPERT. Moreover, we discuss the applied methods, the monitoring design and the relevance of our study site in an international research context. Permafrost potentially reacts very slowly to external change. Thus, long-term data series are essential for a thorough understanding of permafrost evolution. Establishment of the Kitzsteinhorn monitoring site has started in October 2010. Given the relatively short period of time, long-term data series are not available for the Kitzsteinhorn site yet. Therefore no extensive discussion of measurement results (e.g. borehole temperatures) is found within the present contribution.

Motivation and Objectives

Over the last decades and centuries many mountain regions have experienced significantly increased frequentation for settlement, employment and transportation purposes. The European Alps were particularly affected by this development. In addition, recreational use has taken on greater importance, which is illustrated by millions of tourists, who visit the Alps and its protected areas every year. This development makes instability of rock faces in high mountain areas an increasingly important risk factor man and infrastructure, especially within the context of recent warming trends in the Alpine region (GRUBER et al. 2004). Numerous rockfall events in the Alps suggest an increasing occurrence of gravitational mass movements due to rising temperatures in recent years. During the hot summers of 2003 and 2005 a large number of rockfall events were triggered from steep bedrock areas affected by permafrost. In several cases massive ice was visible in the exposed detachment zones (GRUBER & HAEBERLI 2007). However, long-term field data/observations on the complex relationship between rock temperatures and the occurrence of rockfall events are rare. This lack of data serves as one of the primary incentives for establishing a new long-term monitoring site at the Kitzsteinhorn.

On a theoretical level MOREXPERT therefore aims at an improved understanding of permafrost-related processes operating in high-alpine rock faces. On a technical level the project targets the development of a robust monitoring system that resists the harsh environmental conditions of high mountain environments. In order to support risk management strategies MOREXPERT will furthermore develop an expert system for slope stability assessment in steep bedrock. The expert system is considered to be a transferable good-practice guide that can be applied to potentially hazardous rock faces in other areas. It will contain operating procedures and working routines as well as recommendations for required data resolutions and efficient data analysis.

State of Mountain Permafrost Research

Permafrost is defined as ground that remains at or below 0°C for at least two consecutive years (Brown et al. 1998, IPA). Mountain permafrost research is a young scientific discipline whose systematic beginnings date back to the 1970s (Barsch 1973; Haeberli 1975). Academic research of mountain permafrost has experienced a marked upswing in recent decades for several reasons. Permafrost (degradation) has major implications for the occurrence of debris flows, rockfall events or even large-scale rock avalanches. Furthermore, mountain permafrost has been recognized as a major technical challenge for the successful realization of construction projects in high-mountain environments (Bommer et al. 2010). Recently, particularly the occurrence of potentially permafrost-related rockfall events has garnered the attention of researchers. Numerous laboratory experiments have confirmed that permafrost warming or thawing in steep bedrock causes a significant alteration of rock mechanical properties and ice mechanical properties (Mellor 1973;Davies et al. 2000; Krautblatter et al. 2012). In order to foster long-term research on mountain permafrost evolution the projects Permafrost and Climate in Europe (PACE), the Swiss Permafrost Network (PERMOS) and the Longterm Permafrost Monitoring Network (PermaNET) have initiated permafrost monitoring sites in the European Alps. Particularly high mountain peaks in the western Alps (e.g. Schilthorn, Matterhorn) have been instrumented for continuous monitoring of permafrost. In Austria, extensive permafrost monitoring with deep boreholes and geophysicshas been limited to the research site located at Hoher Sonnblick (3.106 m).

Study Site

The study site is located at the Kitzsteinhorn (3.203 m), Hohe Tauern Range (Fig. 1). The monitored area encompasses the entire summit pyramid of the Kitzsteinhorn, covering an elevation difference of more than 300 m and an area of approximately 3.5 ha. Due to its topographical features (no neighbouring summits, pyramidal shape) the Kitzsteinhorn is particularly well-suited for the investigation of the influence of aspect and elevation on ground thermal conditions.

Regarding it geology the Kitzsteinhorn primarily consists of calcareous-micaschists. Stress release and intense physical weathering resulted in the formation of an abundance of joint sets with large apertures. The pronounced retreat of the Schmiedingerkees glacier in recent decades led to the exposure of oversteepened rock faces, which are frequently affected by minor rock fall events (Hartmeyer et al. 2012).

The study site extends across the Kitzsteinhorn skiing area and the Hohe Tauern national park. The tourism infrastructure existing within the study area (cable car, ski lifts) provides easy access and convenient transportation, an essential prerequisite for the establishment of an extensive long-term monitoring program. The west ridge of the Kitzsteinhorn is crossed by a tunnel ("Hanna-Stollen"), which allows the acquisition of thermal information from depths of up to 80 m.

Figure 1: The study area of the MOREXPERT project is located at the Kitzsteinhorn, Hohe Tauern Range, Austria (© Markus Keuschnig/Günther Prasicek).

Applied Monitoring Methods

Subsurface Monitoring

Temperature Measurement in Boreholes

In order to investigate subsurface temperatures five boreholes with depths between 20 and 30 m were drilled (Fig. 2). The boreholes were created by rotary drilling using air flush to avoid contamination of frozen ground with water. The drillings were conducted perpendicular to the terrain surface. All boreholes are instrumented with an innovative temperature measurement system that has been developed within the MOREXPERT project. It consists of a special polyethylene casing with non-corrosive brass segments at the designated depths of the temperature sensors. The specific design of the thermistor chain which is inserted into the casing allows the temperature sensors to establish direct contact with the brass segments. The utilized temperature sensors are Pt100 thermistors with an accuracy of +/-0.03°C. Due to the high thermal conductivity of the brass segments this newly developed solution enables significantly improved thermal coupling between the sensors and the surrounding rock and is therefore able to deliver highly representative temperature data. The new system has been designed and manufactured by the Austrian company GEODATA.

Figure 2: Air flush rotary drilling at the Kitzsteinhorn west face (© Ingo Hartmeyer)

In Addition to 12 UTL (Universal Temperature Loggers) in loose material, more than 30 shallow boreholes have been drilled to investigate near-surface temperatures up to a maximum depth of 80 cm (Fig. 3). For temperature measurement within these shallow boreholes a new methodological strategy for near-surface rock temperature measurement has been developed (KEUSCHNIG et al. 2012). Every drilling site consists of two shallow boreholes with depths of 10 cm and 80 cm. In order to enable a small drilling diameter (18 mm) and therefore minimize the extent of the drilling works, iButtons® are used for temperature measurement. The iButton® is a miniature temperature logger that integrates a battery, a computer chip, a real-time clock and a temperature sensor in stainless steel can. The present study represents the first time that iButtons® are applied for temperature measurement in bedrock. The integrated digital thermometer measures temperature with a resolution of 0.0625°C, accuracy is ±0.5°C.

Figure 3: Drilling of a shallow borehole for near-surface rock temperature measurement at the Kitzsteinhorn south face (© Ingo Hartmeyer).

Electrical Resistivity Tomography

During ERT measurements an electric current is injected into the ground using two electrodes. The resulting voltage difference is recorded at two potential electrodes. Repeated measurements with changing electrode configuration provide a dataset of the apparent subsurface resistance. The underlying resistivity distribution can then be calculated through inverse modelling (HAUCK & KNEISEL 2008).ERT is well-suited to distinguish between frozen and unfrozen subsurface regions as a marked increase of electrical resistivity occurs at the freezing point of water-containing materials such as moist rock or soils (SASS 2004).

For monitoring purposes, ERT measurements are repeated at specific time intervals using the same survey geometry. Thus, temporal and spatial permafrost variability can be resolved (HILBICH et al. 2008). Rock faces are well-suited for the quantitative interpretation of ERT data as bedrock usually has a relatively homogenous constitution and an accurately defined pore volume. However, joints and fractures represent distortions that potentially alter the subsurface electrical field considerably (KRAUTBLATTER et al. 2010).

Surface Monitoring

Terrestrial Laserscanning

Terrestrial Laserscanning (TLS) creates highly accurate, three-dimensional images of the scanned area. By sweeping a laser beam over a defined scene, a laser scanner is able to record millions of data points. TLS allows an accurate quantification of changes in geometry and volume in steep terrain over distances of several hundreds of meters (KENNER et al. 2011).

All scans are performed using a Riegl© LMSZ620 (Fig. 4), georeferencing is carried out with differential GPS data. Object distance varies from 50 to 500 m. Data processing is performed using the software Riscan Pro. Final registration of TLS data is carried out by means of multi-station-adjustment.

Figure 4: Terrestrial Laserscanning below the Magnetköpfl (© Ingo Hartmeyer)

Crackmeter

Marked changes in joint aperture frequently point to imminent rockfall events. Joint apertures will be continuously monitored in two localities (Magnetköpfl and cable car summit station) using crackmeters. A crackmeter consists of two anchors installed on opposite sides of the joint and a wire that is fixed between the anchors. Changes in distance between the anchors is measured and recorded by a data logger. Instrumentation with crackmeters currently is in the planning stage.

Atmospheric Monitoring

Knowledge of meteorological variables is crucial for the understanding of future permafrost development. Six weather stations are located within the study area or in its direct vicinity (< 2 km away), permitting continuous observation of external forcing of ground thermal conditions. At the weather stations, which are located at altitudes between 2.400 m and 2.940 m, air temperature, radiation, humidity, wind speed, wind direction, snow height and precipitation are recorded.

Monitoring Implementation

In the preceding chapter the applied methods were introduced. Spatially distributed measurements of near-surface rock temperatures (shallow boreholes, depth: up to 80 cm) and temperature measurements in large depths (deep boreholes, depth: up to 30 m) allow a very precise characterization of the ground thermal regime. Moreover, the introduced combination of methods allows the additional acquisition of surface and atmospheric information. Thus, changes occurring at the surface (e.g. rockfall events) can be directly related to potential subsurface changes (e.g. deepening of active layer), which potentially represents an important step towards the coupling of warming and destabilization trends in steep bedrock.

Even in a relatively small study area like the Kitzsteinhorn summit region it is necessary to define specific monitoring hot spots which are provided with a particularly high instrumentation density. A rough rockfall impact assessment served as basis for the definition of monitoring hot spots. The assessment delivered three comparatively homogenous monitoring scales: the cable car summit station, the Magnetköpfl and the Kitzsteinhorn summit pyramid (Fig. 5).

An occurrence of a rockfall event at the highly frequented cable car summit station would have serious consequences for visitors, employees and the infrastructure itself. Thus, the highest possible monitoring density has been chosen for the immediate surroundings of the station. Here, temperature measurements in deep and shallow boreholes are carried out in combination with ERT surveys. In order to additionally monitor surface changes TLS and crackmeter measurements are conducted.

The second monitoring scale is represented by the Magnetköpfl (2.950 m), a minor neighbouring peak of the Kitzsteinhorn. It is significantly less frequented than the summit station and therefore warrants a reduced monitoring density. Nonetheless, due to the existence of infrastructure and the regular presence of tourists in its direct influence, extensive monitoring has to be carried out in its vicinity. At the Magnetköpfl a high number of shallow boreholes have been drilled and an automated ERT-array (operated by the 'Geological Survey of Austria') has been installed to survey ground thermal conditions. Crackmeter measurements will be carried out to observe joint aperture development.

The Kitzsteinhorn summit pyramid features no infrastructure and is rarely frequented. Probability of harm to man and/or infrastructure as a result of a rockfall event is very low. Monitoring density at this scale level is reduced to spatially distributed measurements of near-surface rock temperatures and TLS campaigns that do not cover the entire summit pyramid due to its size.

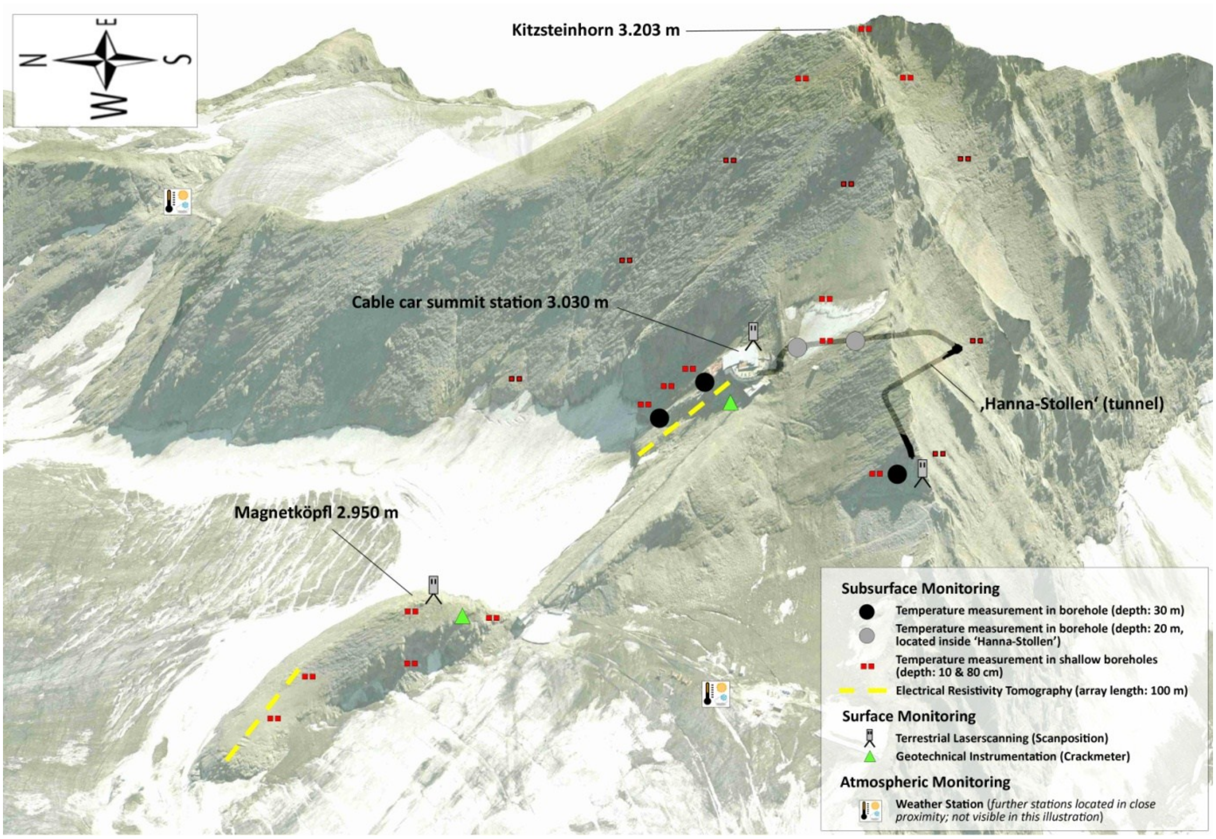

Figure 5: Monitoring installations at the Kitzsteinhorn (© Ingo Hartmeyer)

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