# Investigating Heat and Moisture Fluxes in High-Alpine Rock Walls Around the Jungfraujoch with a Wireless Sensor Field

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## Introduction

Warming and thawing permafrost in steep alpine bedrock can affect slope stability and complicate the operation of man-made infrastructure.

Corresponding heat flux and phase change processes in porous fractured rock are currently poorly understood, especially their boundary conditions. In order to develop theoretical models for hazard assessment and the support of infrastructure maintenance, we need continuous and reliable measurements of physical parameters in natural and diverse areas. At present, limited measurement data exist for selected locations, but large measurement series do not exist which is in part due to the lack of inexpensive and suitable measurement systems.



Figure 1) Rock fall at the Matterhorn (below the Carell hut) in summer 2003. The ice on the detachment surface is clearly visible.
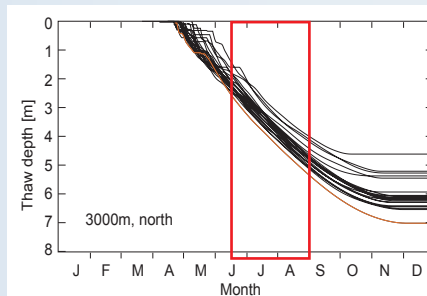Photo: L. Trucco



Figure 2) Modelled maximum annual active layer depth at one location between 1982 and 2003. Each line represents the progression of thaw and is then kept at the maximum value for the rest of the year. 1982-2002 are shown in black, 2003 in orange. Excess thaw during 2003 is clearly visible. However, pervious depths are exceede in October for the first time based on this purely conductive model while most rock fall occured in the period shown with the red square. This is a strong hint at the importance of advective heat transfer in frozen or thawing rock.

In the hot and dry summer 2003, strong rock fall activity was observed between mid-June and August and attributed zo permafrost thaw (Fig. 1). Thermal modelling confirmed deeper thaw than during previous decades (and possibly centuries, Fig. 2), however, the respective thaw depths were only reached in October or later, based on purely conductive heat transfer. This hints at advective heat transport in the fracture space that quickly introduces heat to great depths where the latent and sensitive heat flux could be an explanation of higher energy exchange between atmosphere and permafrost rock. Observations of strong water percolation into the tunnels of the Sphinx and the Aiguille du Midi for the first time during 2003 give further support to this hypothesis.

## Wireless Network for Environmental Sensors

The project PERMASENS aims at developing and demonstrating a flexible, distributed and self-organizing wireless network adapted to geophysical sensors. The first generation of such a sensor field will be installed in autumn 2006. It will monitor in near real-time the temperature as well as rock moisture content and gradients in the near surface layer. The PERMASENSE data chain consists of several wireless nodes to which multiple sensors are attached, a GPRS gateway node for data uplink as well as a database server with Internet connection and a web-based front-end for data retrieval and network monitoring (Fig. 3).
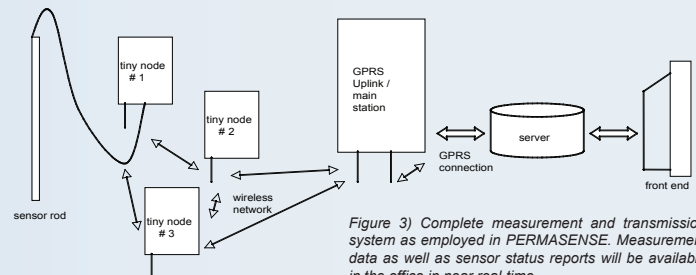


Figure 3) Complete measurement and transmission system as employed in PERMASENSE. Measurement data as well as sensor status reports will be available in the office in near real-time.

## Physical Parameters and Construction of the Sensors



Figure 4) 14mm sensor rod with conductive foam electrodes. A thermistor on the reverse side measured temperatures.

The sensors are mounted in a fiberglass rod and measure temperature and electrical conductivity between electrodes with high accuracy at four depths inside the 95cm deep drill hole. The direct current conductivity of the rock depends on its pore water content and the phase state of this water. The resistance of dry rock is magnitudes higher then the one of saturated but frozen rock and if this water thaws the resistance decreases again about two magnitudes.

Measurement electronics are kept inside the rod to minimize the effect of temperature fluctuations. As drilling effort should be minimized, the diameter of the drilling hole is only 14mm so that the wiring and mounting of the electronics become a challenge.

## Installation at Sphinx, Jungfraujoch

In August 2006, first reconnaissance and test setup was done on Jungfraujoch. The whole system with 15 nodes and sensors rods will be installed mid September 2006 on the Jungfrau east ridge and Sphinx. The system will then be operated for several years.
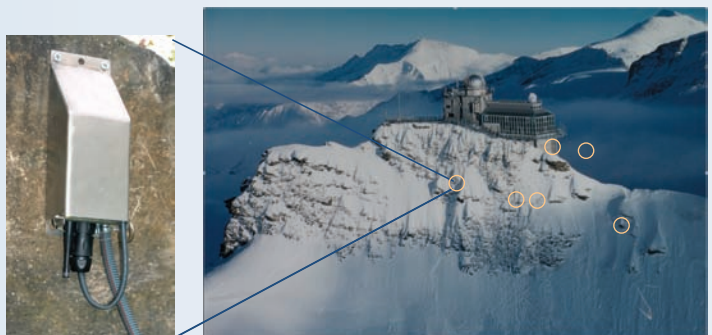


Figure 4) PERMASENSE node within weatherproof enclosure and protectiv housing mounted aroud Sphinx on 3550 a.s.l. Battery supply is sufficient for at least one year autonomous logging and communication. Snow covered nodes store there data and transmit as soon as they have contact to other nodes, again.

Figure 5) Installation of sensorrod with setting tool and protection of the cables leading to the node. The sensor rod is inserted without glue into the cleaned hole and just sealed at the surface. The rod will be removable with the setting tool.



## Expected Results and Perspectives

The data generated with this first generation is expected to provide valuable insight into the advective component of the near-surface heat transfer as well as freeze-thaw processes. We plan to build a second generation of sensors for summer 2007 that can also measure crack dilatation, moisture/ice content and possibly acoustic events. This will permit to further deepen our understanding of permafrost and rock weathering in steep slopes.

Beyond helping the modelling of permafrost processes, this network technology is also applicable to natural hazard surveillance. With better wireless sensor solutions, larger areas can be permanently monitored and linked to warning system while maintenance cost is minimized because sensor status and battery volage can be monitored from the office in near real-time. In high-mountain areas where field work is expensive end dependent on weather conditions this is a valuable asset.