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One decade of permafrost monitoring at the Zugspitze (Germany/Austria)

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Mechanical and thermal properties of frozen rock slopes determine its stability and due to permafrost degradation, impose an increasing risk on people and infrastructure in high mountain regions. Electrical resistivity tomography (ERT) became the dominating major tool for temporal and spatial permafrost monitoring. Electric resistivity of frozen rock is highly temperature sensitive and can differentiate between frozen and unfrozen conditions (Krautblatter *et al.*, 2010). Here we present results from one decade of ERT-based permafrost monitoring at the Zugspitze, assessing monthly spatial variations of permafrost distribution and quantitative information on rock temperature. We hypothesize a link between seasonal and long-term climate variance, permafrost temperature development and its spatial variability. Long term geophysical monitoring allows the validation of calculated rock temperatures from ERT-measurements.

ERT-measurement are conducted along two transects in the main and side gallery of the Kammstollen adjacent to the Zugspitze north face. Derived rock/permafrost temperatures are based on laboratory calibration of electric resistivities to rock temperatures for Wetterstein limestone by Krautblatter *et al.* (2010). Two high-resistivity bodies along the investigation area reach resistivity values $\geq 10^{4.5}$ Ωm ($\cong -0.5$ ˚C), indicating frozen rock, displaying a core section with resistivities $\geq 10^{4.7}$ Ωm ($\cong -2$ ˚C) (Krautblatter *et al.*, 2010). Seasonal variability is seen by laterally aggrading and degrading marginal sections (Krautblatter *et al.*, 2010), showing an areal alternation between $\sim$1,500 to $>$3,000 m^2 in the core. External climate forcings affect rock temperatures with a signal propagation time of $\sim$2 - 5 months. Short-term influences by cleft/pore water percolating through highly fractured zones via conductive heat transport cause the breakthrough of water passage into the core section from summer forward accounting for local warming of adjacent rock masses. Our preliminary results are:

1. Rock/permafrost temperatures calculated from measured resistivities are in good accordance with locally measured and interpolated rock temperatures from the LfU borehole at the Zugspitze summit. Thus indicating a validation of permafrost/rock temperatures via geoelectric measurements.

2. Calculated temperatures from ERT-data show a phase shift of $\sim$2 (past $T_{air,max}$) to $\sim$5 month (past $T_{air,0^\circ C}$) compared to measured air temperatures. This time span equates the time needed by the climate signal to propagate through the rock wall via conductive energy transport resulting in recession and readvance of the zero-curtain in rock.

3. The areal extend of the frozen rock mass shows a seasonal alternation between 35 to 60 % of the entire investigation area in conformity with the variability of measured resistivities.

Here we aim to assess the relationship between apparent resistivities, the ground thermal regime and meteorological forcings over an entire decade in steep rock wall permafrost. Based on time lapse ERT and meteorological data we present an approach to build a coupled thermo-geophysical model for conductive heat transfer in permafrost/frozen rock undergoing seasonal freeze-thaw cycles and long-term climatic change.

Krautblatter, M., Verleysdonk, S., Flores-Orozco, A. & Kemna, A. (2010): Temperature-calibrated imaging of seasonal changes in permafrost rock walls by quantitative electrical resistivity tomography (Zugspitze, German/Austrian Alps). *J. Geophys. Res.* 115: F02003.