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Quantitative Pseudo-3D electrical resistivity tomography in steep instable permafrost rocks

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Temperature is a key control of rock- and ice mechanical properties of instable permafrost rocks. As boreholes cannot be installed in instable rocks and thermal modelling is difficult to perform in highly dissected bedrock, temperature-referenced geophysics could (in future) become a key method for the assessment and monitoring of hazardous permafrost rocks. Here we show the first approach to measure quantitative pseudo-3D electrical resistivity tomography (ERT) in permafrost rocks.

In 2006, a 3D ERT array was installed across a NE-SW exposed crestline at 3150 m a.s.l. in the Steintaelli, Valley of Zermatt, Switzerland. The 3D array consists of five parallel 41-electrode arrays with midpoints on the crestline. To cope with the heterogeneity of dissected rock, an in-line electrode spacing of 2 m was applied and the offset between the five arrays was 4 m. Electrode positions were aligned with a laser tachymeter and the x, y and z information was used to create a decimetre-resolution digital elevation model. Topographic information was accommodated in the finite-element grids underlying the ERT modelling with adjusted boundary conditions. The 3D array was measured repeatedly in 2006, 2007 and 2008. Three temperature loggers recorded rock temperatures in 10 cm depth in the field. The temperature-resistivity behaviour of two rock samples was measured in the laboratory.

To obtain quantitatively reliable ERT values, we used an appropriate ERT data error model, derived from the analysis of normal-reciprocal measurement discrepancies, in the smoothness-constrained inversion code CRTomo. The error analysis yielded a relative resistance error of 8-9 % for high resistances in all transects. Repeated laboratory measurements of water-saturated paragneiss samples from the study site indicate an equilibrium freezing point at –0.1 ˚C (spontaneous freezing point –1.1 ˚C) with resistivity values ranging from 11-14 kΩm. Resistivity at –2 ˚C approaches values between 24-32 kΩm.

ERT images show consistent results for all transects. Decametre large frozen rock bodies ($>10^{4.2}$ Ωm = 16 kΩm) dominate NE-exposed slopes. Permafrost at depth ranges between $10^{4.2}$ and $10^{4.5}$Ωm (= 32 kΩm), which refers to laboratory values between –0.1 ˚C and –2 ˚C, and is surrounded by a large zone in the range of $10^{4.0}$-$10^{4.2}$Ωm indicating freezing or melting around –0.1 ˚C. The presence of ice-filled crevices on the crestline and the NE face appears to have a crucial influence on spatial and temporal permafrost development. Next to 3-4 m deep melting from the surface, elongated recesses of unfrozen rock indicate melting by cleft water up to 10 m depth. ERT images in August 2006, after the cool winter 2005/2006, indicate the presence of massive ice-intercalations in two transects, while those of 2007 and 2008 indicate gradual widespread permafrost degradation.