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A high-resolution multi-phase thermo-geophysical permafrost rock model to verify long-term ERT monitoring at the Zugspitze (German/Austrian Alps)

Tanja Schroeder and Michael Krautblatter
Chair of Landslide Research, Technical University of Munich, Munich, Germany

In the context of climate change, permafrost degradation is a key variable in understanding rock slope failures in high mountain areas. Permafrost degradation imposes a variety of environmental, economic and humanitarian impacts on infrastructure and people in high mountain areas. Therefore, new high-quality monitoring and modelling strategies are needed.

We developed a new, numerical, thermo-geophysical rock permafrost model (TGRPM) to assess spatial-temporal variations of the ground thermal regime in steep permafrost rock walls on the basis of 13-years of Electrical Resistivity Tomography (ERT) monitoring of permafrost at the Zugspitze. TGRPM is a simple to understand and workable numerical 2D MATLAB-model, which is adaptable to different topographic and sub-surface conditions, and further relies on a minimum of input-data to assess the surface energy balance and the ground thermal regime. It simulates the thermal response for permafrost rock walls, including their complex topography, to climate forcing over multiple years. It aims to assess seasonal and long-term permafrost development in steep alpine rock walls, as well as serving as a straightforward calculation routine, which is solely based on physical processes and does not require any fitting of certain parameters.

At first, the model was tested against direct temperature measurements from the LfU-borehole at the Zugspitze summit to prove its accuracy. Then, it is run against a 13-year ERT data-set from the Zugspitze Kammstollen to validate the ERT measurements.

Here, we show the first thermo-geophysical model referencing thermal evolution in a permafrost rock wall with temperature-calibrated ERT. The TGRPM successfully computes the thermal evolution within the Zugspitze mountain ridge from a 2D coupled energy balance and heat conduction scheme in complex topography. It furthermore validates the temperature-resistivity relationship by Krautblatter et al. (2010) for natural rock walls reaching a correlation of 85 to 95 % between measured, ERT-derived and modelled temperatures.

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.