EGU21-13815, updated on 27 Jul 2021
https://doi.org/10.5194/egusphere-egu21-13815
EGU General Assembly 2021

Decennial multi-approach monitoring of thermo-hydro-mechanical processes, Kammstollen outdoor laboratory, Zugspitze (Germany)

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The warming of alpine bedrock permafrost in the last three decades and consequent reduction of frozen areas has been well documented. Its consequences like slope stability reduction put humans and infrastructures at high risk. 2020 in particular was the warmest year on record at 3000m a.s.l. embedded in the warmest decade.

Recently, the development of electrical resistivity tomography (ERT) as standard technique for quantitative permafrost investigation allows extended monitoring of this hazard even allowing including quantitative 4D monitoring strategies (Scandroglio et al., in review). Nevertheless thermo-hydro-mechanical dynamics of steep bedrock slopes cannot be totally explained by a single measurement technique and therefore multi-approach setups are necessary in the field to record external forcing and improve the deciphering of internal responses.

The Zugspitze Kammstollen is a 850m long tunnel located between 2660 and 2780m a.s.l., a few decameters under the mountain ridge. First ERT monitoring was conducted in 2007 (Krautblatter et al., 2010) and has been followed by more than one decade of intensive field work. This has led to the collection of a unique multi-approach data set of still unpublished data. Continuous logging of environmental parameters such as rock/air temperatures and water infiltration through joints as well as a dedicated thermal model (Schröder and Krautblatter, in review) provide important additional knowledge on bedrock internal dynamics. Summer ERT and seismic refraction tomography surveys with manual and automated joints' displacement measurements on the ridge offer information on external controls, complemented by three weather stations and a 44m long borehole within 1km from the tunnel.

Year-round access to the area enables uninterrupted monitoring and maintenance of instruments for reliable data collection. "Precisely controlled natural conditions", restricted access for researchers only and logistical support by Environmental Research Station Schneefernerhaus, make this tunnel particularly attractive for developing benchmark experiments. Some examples are the design of induced polarization monitoring, the analysis of tunnel spring water for isotopes investigation, and the multi-annual mass monitoring by means of relative gravimetry.

Here, we present the recently modernized layout of the outdoor laboratory with the latest monitoring results, opening a discussion on further possible approaches of this extensive multi-approach data set, aiming at understanding not only permafrost thermal evolution but also the connected thermo-hydro-mechanical processes.

Krautblatter, M. et al. (2010) 'Temperature-calibrated imaging of seasonal changes in permafrost rock walls by quantitative electrical resistivity tomography (Zugspitze, German/Austrian Alps)', Journal of Geophysical Research: Earth Surface, 115(2), pp. 1–15. doi: 10.1029/2008JF001209.

Scandroglio, R. et al. (in review) '4D-Quantification of alpine permafrost degradation in steep rock walls using a laboratory-calibrated ERT approach (in review)', Near Surface Geophysics.

Schröder, T. and Krautblatter, M. (in review) 'A high-resolution multi-phase thermo-geophysical model to verify long-term electrical resistivity tomography monitoring in alpine permafrost rock walls (Zugspitze, German/Austrian Alps) (submitted)', Earth Surface Processes and Landforms.