EGU21-13419, updated on 26 May 2022
https://doi.org/10.5194/egusphere-egu21-13419
EGU General Assembly 2021

4D-Quantification of alpine permafrost degradation in a bedrock ridge using multiple inversion schemes and deformation measurements

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Warming of permafrost in steep rock walls decreases their mechanical stability and could triggers rockfalls and rockslides. However, the direct link between climate change and permafrost degradation is seldom quantified with precise monitoring techniques and long-term time series. Where boreholes are not possible, laboratory-calibrated Electrical Resistivity Tomography (ERT) is presumably the most accurate quantitative permafrost monitoring technique providing a sensitive record for frozen vs. unfrozen bedrock. Recently, 4D inversions allow also quantification of frozen bedrock extension and of its changes with time (Scandroglio et al., in review).

In this study we (i) evaluate the influence of the inversion parameters on the volumes and (ii) connect the volumetric changes with measured mechanical consequences.

The ERT time-serie was recorded between 2006 and 2019 in steep bedrock at the permafrost affected Steintälli Ridge (3100 m asl). Accurately positioned 205 drilled-in steel electrodes in 5 parallel lines across the rock ridge have been repeatedly measured with similar hardware and are compared to laboratory temperature-resistivity (T–ρ) calibration of water-saturated samples from the field. Inversions were conducted using the open-source software BERT for the first time with the aim of estimating permafrost volumetric changes over a decade.

(i) Here we present a sensitivity analysis of the outcomes by testing various plausible inversion set-ups. Results are computed with different input data filters, data error model, regularization parameter (λ), model roughness reweighting and time-lapse constraints. The model with the largest permafrost degradation was obtained without any time-lapse constraints, whereas constraining each model with the prior measurement results in the smallest degradation. Important changes are also connected to the data error estimation, while other setting seems to have less influence on the frozen volume. All inversions confirmed a drastic permafrost degradation in the last 13 years with an average reduction of 3.900±600 m^3 (60±10% of the starting volume), well in agreement with the measured air temperatures increase.

(ii) Average bedrock thawing rate of ~300 m^3/a is expected to significantly influence the stability of the ridge. Resistivity changes are especially evident on the south-west exposed side and in the

core of the ridge and are here connected to deformations measured with tape extensometer, in order to precisely estimate the mechanical consequences of bedrock warming.

In summary, the strong degradation of permafrost in the last decade it's here confirmed since inversion settings only have minor influence on volume quantification. Internal thermal dynamics need correlation with measured external deformation for a correct interpretation of stability consequences. These results are a fundamental benchmark for evaluating mountain permafrost degradation in relation to climate change and demonstrate the key role of temperature-calibrated 4D ERT.

Reference:

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