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Quantification of ground ice through petrophysical joint inversion of seismic and electrical data applied to alpine permafrost

Coline Mollaret[1], Florian M. Wagner[2], Christin Hilbich[1], and Christian Hauck[1]
[1]Department of Geosciences, University of Fribourg, Fribourg, Switzerland (coline.mollaret@unifr.ch)
[2]Institute for Applied Geophysics and Geothermal Energy, RWTH Aachen University, Aachen, Germany

Quantification of ground ice is particularly crucial for understanding permafrost systems. The volumetric ice content is however rarely estimated in permafrost studies, as it is particularly difficult to retrieve. Geophysical methods have become more and more popular for permafrost investigations due to their capacity to distinguish between frozen and unfrozen regions and their complementarity to standard ground temperature data. Geophysical methods offer both a second (or third) spatial dimension and the possibility to gain insights on processes happening near the melting point (ground ice gain or loss at the melting point). Geophysical methods, however, may suffer from potential inversion imperfections and ambiguities (no unique solution). To reduce uncertainties and improve the interpretability, geophysical methods are standardly combined with ground truth data or other independent geophysical methods. We developed an approach of joint inversion to fully exploit the sensitivity of seismic and electrical methods to the phase change of water. We choose apparent resistivities and seismic travel times as input data of a petrophysical joint inversion to directly estimate the volumetric fractions of the pores (liquid water, ice and air) and the rock matrix. This approach was successfully validated with synthetic datasets (Wagner et al., 2019). This joint inversion scheme warrants physically-plausible solutions and provides a porosity estimation in addition to the ground ice estimation of interest. Different petrophysical models are applied to several alpine sites (ice-poor to ice-rich) and their advantages and limitations are discussed. The good correlation of the results with the available ground truth data (thaw depth and ice content data) demonstrates the high potential of the joint inversion approach for the typical landforms of alpine permafrost (Mollaret et al., 2020). The ice content is found to be 5 to 15 % at bedrock sites, 20 to 40 % at talus slopes, and up to 95 % at rock glaciers (in good agreement to the ground truth data from boreholes). Moreover, lateral variations of bedrock depth are correctly identified according to outcrops and borehole data (as the porosity is also an output of the petrophysical joint inversion). A time-lapse version of this petrophysical joint inversion may further reduce the uncertainties and will be beneficial for monitoring and modelling studies upon climate-induced degradation.

References:

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