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Alpine permafrost field applications of a petrophysical joint inversion of refraction seismic and electrical resistivity data to image the subsurface ice content

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Electrical Resistivity Tomography (ERT) is one of the most commonly used geophysical methods for permafrost monitoring. Ice can be well distinguished from liquid water due to its different electrical properties. However, this method has also limitations as it requires to solve an inverse problem which is usually underdetermined and has no unique solution. To reduce the uncertainties and improve the interpretability of the inversion model, geophysical methods are usually combined with ground truth measurements and/or other geophysical methods. High mountain regions are often characterised by unsaturated and frozen ground conditions. The pore space in the subsurface can therefore be filled with air, ice and/or liquid water. But ice and air are both materials characterized by very high electrical resistivity and are consequently hard to distinguish using ERT alone. Ice can, however, be well distinguished from air from their P-wave velocity properties (3500 m/s vs 330 m/s). This is why Refraction Seismic Tomography (RST) is a suitable supplementary geophysical method to be combined with ERT to assess ice or liquid water content and their respective spatio-temporal variabilities.

To fully exploit two geophysical datasets for improvement of the reliability of the results and reduce the occurrence of inversion artefacts, several possibilities to combine the independent data sets exist. Wagner et al. (2019) successfully developed a petrophysical joint inversion scheme to determine the liquid water, ice, air and rock contents using the general framework for joint inversions provided in pyGIMLI (Rücker et al., 2017). Synthetic data sets have been used to validate the general applicability of the approach. In this contribution, we apply this joint inversion scheme to several field data sets, which span a large range of conditions from ice-rich permafrost (rock glacier) to ice-poor permafrost sites. In a first step, we use the petrophysical equations (Archie's law and time-averaging equation) employed by Hauck et al. (2011) in the so-called 4-phase model (4PM). The joint inversion results demonstrate the possibility to estimate a plausible porosity, in addition to air, water and ice contents. In a second step, we extend the joint inversion approach to other petrophysical equations, better representing the diversity of field site substrates. The sensitivities of the different parameters are analysed and the calculated water and ice contents are discussed in relation with the active layer thickness and temperature data set, when available.

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