Improved estimation of ice and water contents in alpine permafrost through constrained petrophysical joint inversion: The Hoher Sonnblick case study

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Abstract

Quantitative estimation of subsurface water and ice content values is critical for the understanding and modeling of permafrost evolution in alpine regions. Geophysical methods permit the assessment of subsurface conditions in a noninvasive and quasicontinuous manner; in particular, the combination of seismic refraction tomography (SRT) and electrical resistivity tomography (ERT) through a petrophysical model can quantitatively estimate ground water and ice content values. For the Hoher Sonnblick study area (3106 m.a.s.l., Austrian Alps), we have investigated the improved estimation of water and ice content values based on SRT, ERT, and ground-penetrating radar data collected in June and October 2019. We solve for the water and ice content values following different approaches, namely, (1) the independent inversion and subsequent transformation of the imaging results to the target parameters through a petrophysical model and (2) the petrophysical joint inversion (PJI) of the data sets. Supported by a synthetic study, we determine that the incorporation of structural and porosity constraints in the PJI allows for an improved quantitative characterization of subsurface conditions. For our measurements at Hoher Sonnblick, the constrained PJI resolves a shallow debris layer characterized by high air content and porosity, on top of a layer with lower porosity corresponding to fractured gneiss, and the bedrock layer with the lowest porosity. For both time steps, we find high water content at the lower end of the investigated area. Substantial variations in the subsurface ice content resolved between June and October 2019 indicate a correlation between the high water content and the meltwater discharge within the debris layer. Our results demonstrate that the constrained PJI permits an improved characterization of subsurface hydrologic parameters in alpine permafrost environments.