Geophysical Research Abstracts
Vol. 20, EGU2018-17277, 2018
EGU General Assembly 2018

Constraining Refraction Seismic Tomography (RST) by means of Ground-Penetrating Radar (GPR) models for an improved spatial characterization of alpine permafrost

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In frame of the ATMOperm project funded by the Austrian Academy of Sciences, we conducted a series of Refraction Seismic Tomography (RST) and Ground Penetrating Radar (GPR) surveys at the summit of Hoher Sonnblick (3106 m.a.s.l., Austria) with the objective to determine the internal structures and distribution of mountain permafrost. RST permits to solve for variations in the velocity of seismic waves, typically related to lithological interfaces; yet the contrasting P-wave velocities (Vp) for frozen and unfrozen materials allow to map permafrost rocks and to quantify the active-layer thickness in an imaging framework. However, the interpretation of the seismic results may be challenging as an increase in the Vp may be caused not only by frozen rocks, but also by lithological changes. In particular at the Hoher Sonnblick, changes in the seismic velocity with depth are associated with the contact between highly fractured rocks in the near surface and less compacted materials at depth. Hence, further information is required to improve the interpretation of the seismic results. Due to the significant differences in the electrical properties between frozen and unfrozen materials, and the possibility to collect data with contactless instruments with high spatial resolution and in short periods of time, GPR is a well-established method in permafrost investigations. Hence, we present here the application of GPR to enhance imaging results obtained from RST surveys in alpine permafrost. Besides the processing of GPR data, analysis through numerical models was conducted for a proper interpretation of the radargrams. In a second step, structural information obtained from the processed radargrams was used to refine the initial model for the tomographic inversion of the RST data. The impact of the complementary information was quantified by statistical analysis of the inversion results obtained using an ensemble of different initial models and different inversion algorithms (Hole, Rayfract, PyGimli). For a further investigation regarding the benefit of complementary GPR data we created numerical models with different layer depths and varying electromagnetic properties of the layers. Based on these models we computed synthetic radargrams and synthetic seismic data (travel times). The synthetic RST imaging results allowed for a better understanding of the influence of GPR measurement configurations (e.g. continuous and point-wise measurements) and the limitations of this joint processing approach.