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Quantifying subsurface ice and unfrozen water content using a geophysical model approach

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Cryospheric subsurface material may consist of four different phases: solid (rock, soil matrix), liquid (unfrozen water), gaseous (air-filled pore space and cavities) and frozen liquid (ice). Except for the analysis of borehole data the composition of the subsurface material can only be inferred through indirect geophysical investigations. Due to the possible complexity of the subsurface a combination of complementary geophysical methods (e.g. electrical resistivity tomography, seismic tomography and ground-penetrating radar) is often favoured to avoid ambiguities in the interpretation of the results.

The indirect nature of geophysical soundings requires a relation between the measured variable (e.g. electrical resistivity, seismic velocity, dielectric constant) and the respective parts of the material composition (rock, water, air, ice). In this work we would like to present a new model approach which determines the volumetric fractions of these four phases along a 2-dimensional profile from tomographic electrical and seismic data sets.

The 4-phase model is based on two well-known geophysical mixing rules for electrical resistivity and seismic P-wave velocity. In addition to prescribing the material dependent free parameters in the electrical mixing rule, the resistivity and P-wave velocity of the rock material (if present) and the pore water have to be known. Besides, one of the volume fractions has to be explicitly prescribed (usually the porosity). The model was tested using several electric and seismic data sets from various frozen and non-frozen field sites in mountainous terrain.

First results confirm the applicability of the model for various field cases in permafrost research. Especially the detection and confirmation of the presence of ground ice was substantially improved. Analysis of the spatial variability of the subsurface, e.g. the

detection of isolated air cavities or the differentiation between regions with small and large ice and/or unfrozen water contents, is facilitated, as the two geophysical data sets (resistivity, velocity) are combined to give 2-dimensional profiles of ice-, water- and air content. Extensive validation using a series of shallow boreholes is needed to further analyse the applicability of the model for different cryospheric environments.