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Application of hydrogeophysical methods to monitor and quantify the subsurface ice and water content in frozen regions

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Near surface geophysical methods can be used to obtain a detailed knowledge of the material composition and freeze and thaw processes in the subsurface of frozen or partly frozen regions. A determination of the characteristics of the subsurface is required to model the future evolution of the ground thermal regime and to assess the hazard potential due to degrading permafrost. In addition, repeated geophysical surveys can be used to monitor freeze and thaw processes without the necessity of drilling boreholes, which can be difficult to obtain in the remote locations of most permafrost areas.

In frozen ground subsurface material may consist of four different phases: rock/soil matrix, unfrozen pore water, ice and air-filled pore space. To characterise the frozen subsurface, a combination of complementary geophysical methods (e.g. electrical resistivity tomography (ERT) and refraction seismic tomography) is often favoured to avoid ambiguities in the interpretation of the results. The indirect nature of geophysical surveys requires a petrophysical relationships between the measured variable (electrical resistivity, seismic velocity) and the rock-, water-, ice- and air content. In this contribution a new model (the so-called 4-phase model) will be introduced, which determines the volumetric fractions of the four phases from combined tomographic electrical and seismic data sets. The model will be applied on geophysical monitoring data to quantify changes in ice and unfrozen water content and to analyse freeze and thaw processes in permafrost regions. The inherent uncertainty of geophysical

inversions is addressed by applying an ensemble inversion approach using multiple inversions of the same data set and clustering techniques to obtain the dominant, and therefore most reliable, subsurface features. The ensemble includes variations in the inversion parameters for both electric and seismic inversions as well as variations in the free paraneters of the 4-phase model. Validation of the model results was obtained using borehole data from different permafrost sites. First results confirm the good model performance for various field cases in permafrost research.