Geophysical Research Abstracts,
Vol. 10, EGU2008-A-11035, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-11035
EGU General Assembly 2008

Monitoring and quantifying subsurface ice and water content in permafrost regions based on geophysical data sets

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Based on recent observational evidence of climate change in permafrost regions, it is now recognised that a detailed knowledge of the material composition of the subsurface in permafrost regions is required for modelling of the future evolution of the ground thermal regime and an assessment of the hazard potential due to degrading permafrost. However, due to the remote location of permafrost areas and the corresponding difficulties in obtaining high-quality data sets of the subsurface, knowledge about the material composition in permafrost areas is scarce. In frozen ground subsurface material may consist of four different phases: rock/soil matrix, unfrozen pore water, ice and air-filled pore space. Applications of geophysical techniques for determining the subsurface composition are comparatively cheap and logistically feasible alternatives to the single point information from boreholes. Due to the complexity of the 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 soundings requires a relation between the measured variable (electrical resistivity, seismic velocity) and the rock-, water-, ice- and air content.

In this contribution we will present a model which determines the volumetric fractions of these four phases from tomographic electrical and seismic data sets. The so-called 4-phase model is based on two well-known geophysical mixing rules using observed

resistivity and velocity data as input data on a 2-dimensional grid. Material properties such as resistivity and P-wave velocity of the host rock material and the pore water have to be known beforehand. The remaining free model parameters can be determined by a Monte-Carlo approach, the results of which are used additionally as indicator for the reliability of the model results. Addressing the inherent uncertainty of geophysical inversions an ensemble inversion approach is introduced using multiple inversions of the same data set and clustering techniques to obtain the dominant, and therefore most reliable, subsurface features. 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.