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Ensemble inversions of geophysical data in alpine permafrost

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In many disciplines of engineering and geosciences, the accurate determination of the state variables in the near subsurface on different spatial and temporal scales by geophysical methods plays a major role in the quantitative assessment of physical processes. Especially subsurface monitoring problems in the context of climate change, such as thawing permafrost soils or rock formations, require reliable, cost-effective and accurate data acquisition and processing techniques. In order to quantify and monitor the different phase contents in frozen ground different tomographic geophysical measuring methods can be applied in combination. However, due to geometric constraints and underdetermined parts of the inverse problem, frequently the tomographic methods cannot reliably identify structures or processes and quantify the state variables involved with an adequate resolution and accuracy on the given scale.

This is because the inversion process and the choice of inversion parameters, i.e. the regularisation parameters, determine how well the inverted model will reproduce the real distribution of the physical property. Choice of regularisation parameters is not absolute and cannot be reliably based upon observation, but must be fitted or depend on experience. To assess the inherent uncertainty range in non-unique geophysical inversions, Rings & Hauck (2009) proposed a so-called ensemble approach for Electrical Resistivity Tomography (ERT) data, where ensembles of 50 different inversion models are created for one set of measurements by randomly varying the parameters for a regularisation based inversion routine. The ensemble members are sorted into clusters of similar models and the mean model for each cluster is computed to analyse the range of possible inversion results (similar to the well-known equivalence models for Vertical Electrical Soundings). By distinguishing persisting features in the mean models from singular artefacts in individual tomograms the interpretation of inversion results can be significantly improved.

In this contribution we extended the ensemble approach to Refraction Seismic Tomography (RST) data and applied both approaches to ERT and RST data from several case studies on alpine permafrost. In addition, simulations with synthetic data were conducted to show the usefulness of the approach. The results helped to distinguish between inversion artefacts and reliable subsurface features and improved the reliability analysis of quantitative interpretations, e.g. the depth of the active layer or the ability to detect the permafrost base. First results from applications to ERT monitoring data in permafrost show that seasonal electrical resistivity changes are larger than the uncertainty ranges from the regularisation parameters, whereas interannual changes (e.g. changes between late-summer measurements of different years) can be well within the inherent uncertainty range.