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Coupled thermal and geophysical modelling for monitoring of permafrost

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Geophysical methods, and especially the Electrical Resistivity Tomography (ERT) method, are being recognised as standard tools for the detection and monitoring of permafrost. Recent advances in automated data acquisition and processing have made their application worthwhile for continuous monitoring systems even in harsh and heterogeneous terrain. ERT yields 2- and 3-dimensional data of the subsurface and is sensitive to the unfrozen water and ice content, which is complementary to the 1-dimensional temperature measurements conducted in boreholes.

For future autonomous and widespread monitoring systems for permafrost, a purely geophysical approach is envisaged, because the low costs and minimal disturbance of the system to be monitored is one of the major advantages of geophysics as opposed to boreholes. However, the link between the indirectly measured geophysical property (e.g. electrical resistivity in case of ERT) of the subsurface and temperature is often non-trivial and cannot be determined without ground truth data from boreholes or extensive laboratory calibration.

In this contribution, we introduce a Bayesian filtering approach of coupled geophysical and thermal modelling to predict subsurface temperatures based on ERT monitoring data without the need for borehole or laboratory data. We use sequential Bayesian filtering or particle filtering, which has the advantage of continuously providing probability distributions of state (temperature) and parameters (e.g. the link between resistivity and temperature) whenever measurements become available. A particle filter approximates these distributions by a set of discrete, weighted particles. For each particle, initial state and parameter are drawn from prior distributions and thermal conduction is modelled independently. The modelled change in temperature is transferred to change in resistivity by a linear relation, and an ERT forward model is used to simulate the system response. Then, the particles are weighted according to the degree of agreement between measured and modelled ERT response. A re-sampling routine is used to ensure that, over time, the particles gravitate towards the posterior distributions in state and parameter estimate.

To test the approach, modelled and observed ground temperatures were compared at the high-altitude permafrost station on Schilthorn, Berner Oberland/Swiss Alps. First results using automated ERT monitoring data from the PERMOS (Permafrost Monitoring Switzerland) network show a good performance during a 6-month period in spring and summer 2009. Improvements can be achieved by using more sophisticated thermal models and by iterative procedures to determine the (vertically variable) material properties of the subsurface, such as porosity and thermal conductivity. The results were furthermore compared with results from the complex 1-dimensional coupled heat and mass transfer model COUP, which simulates the permafrost evolution without additional incorporation of geophysical subsurface data.