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Coupled thermo-geophysical inversion for high-latitude permafrost monitoring – assessment of the method and practical considerations

Sonia Tomaskovicova (1), Eskild Paamand (2), Thomas Ingeman-Nielsen (1), and Peter Bauer-Gottwein (2)

(1) Technical University of Denmark, The Arctic Technology Centre, Department of Civil Engineering, Kgs. Lyngby, Denmark (soto@byg.dtu.dk), (2) Technical University of Denmark, Department of Environmental Engineering, Kgs. Lyngby, Denmark

The sedimentary settings of West Greenlandic towns with their fine-grained, often ice-rich marine deposits are of great concern in building and construction projects in Greenland, as they lose volume, strength and bearing capacity upon thaw. Since extensive permafrost thawing over large areas of inhabited Greenlandic coast has been predicted as a result of climate change, it is of great both technical and economical interest to assess the extent and thermal properties of such formations. Availability of methods able to determine the thermal parameters of permafrost and forecast its reaction to climate evolution is therefore crucial for sustainable infrastructure planning and development in the Arctic.

We are developing a model of heat transport for permafrost able to assess the thermal properties of the ground based on calibration by surface geoelectrical measurements and ground surface temperature measurements. The advantages of modeling approach and use of exclusively surface measurements (in comparison with direct measurements on core samples) are smaller environmental impact, cheaper logistics, assessment of permafrost conditions over larger areas and possibility of forecasting of the fate of permafrost by application of climate forcing.

In our approach, the heat model simulates temperature distribution in the ground based on ground surface temperature, specified proportions of the ground constituents and their estimated thermal parameters. The calculated temperatures in the specified model layers are governing the phase distribution between unfrozen water and ice. The changing proportion of unfrozen water content as function of temperature is the main parameter driving the evolution of electrical properties of the ground. We use a forward modeling scheme to calculate the apparent resistivity distribution of such a ground as if collected from a surface geoelectrical array. The calculated resistivity profile is compared to actual field measurements and a difference between the synthetic and the measured apparent resistivities is minimized in a least-squares inversion procedure by adjusting the thermal parameters of the heat model. A site-specific calibration is required since the relation between unfrozen water content and temperature is strongly dependent on the grain size of the soil.

We present details of an automated permanent field measurement setup that has been established to collect the calibration data in Ilulissat, West Greenland. Considering the station location in high latitude environment, this setup is unique of its kind since the installation of automated geophysical stations in the Arctic conditions is a challenging task. The main issues are related to availability of adapted equipment, high demand on robustness of the equipment and method due to the harsh environment, remoteness of the field sites and related powering issues of such systems.

By showing the results from the new-established geoelectrical station over the freezing period in autumn 2012, we prove the 2D time lapse resistivity tomography to be an effective method for permafrost monitoring in high latitudes. We demonstrate the effectivity of time lapse geoelectrical signal for petrophysical relationship calibration, which is enhanced comparing to sparse measurements.