KEYNOTE LECTURE: Use of geoelectrical monitoring methods for characterizing thermal state,ice content and water flow in permafrost environments

Andreas Kemna[1], Maximilian Weigand[1], Adrian Flores Orozco[2], Florian Wagner[1], Christin Hilbich[3], Christian Hauck[3]

(1) University of Bonn, Bonn, Germany;
(2) Technical University of Vienna, Austria;
(3) University of Fribourg, Fribourg, Switzerland

keywords: permafrost, ERT, IP, SP

Recent years have shown an increasing use of geoelectrical monitoring methods to better understand subsurface structures and processes in permafrost environments. With the methodological, technological and computational advancements over the last two decades, permafrost applications of electrical methods have evolved from simple qualitative mapping or sounding to quantitative imaging and monitoring, and interest in electrical properties has been extended from resistivity to induced polarization (IP) and self-potential (SP).

Electrical resistivity tomography (ERT) is the most widely used approach today to characterize and monitor the subsurface thermal state (frozen vs. unfrozen), with successful applications both in sub-arctic and high-mountain permafrost. Given the multiple petrophysical controls on resistivity, however, thermal state characterization based on resistivity alone strongly relies on adequately calibrated resistivity-temperature relationships. Moreover, resistivity can provide information on the thermal state, but it is not directly sensitive to water flow, which due to advective heat transport is one of the key controls on the complex physical process dynamics in thawing permafrost systems.

These limitations of ERT have recently directed our interest towards the use of the spectral IP (SIP) method for permafrost characterization. In a series of laboratory experiments, we investigated the SIP response of rocks over controlled freeze-thaw cycles. The results reveal the characteristic polarization response of ice in the higher SIP frequency range, which – although methodologically and technically challenging – suggests potential of the SIP method for improved imaging and quantification of ice content in permafrost field studies. Results of first field measurements on a limestone rock wall at the Zugspitze mountain (Germany) are promising in this regard, as the high-frequency IP responses of frozen and unfrozen areas were found to be distinctly different.

With a view to monitoring the dynamics of water flow in the active layer of permafrost, we tested the applicability of the SP method at the Schilthorn mountain (Switzerland). Here, as typical of high-mountain slopes, variability in topography, precipitation and snow cover gives rise to complex spatio-temporal flow patterns in the active layer, which are not accessible by conventional monitoring methods. The SP monitoring data, collected on a permanently installed array of electrodes with high temporal resolution over entire seasonal thawing and freezing periods, reveal strong variations from the onset of thawing in spring until autumn, when the signals gradually return to relatively low variations coinciding with the re-freezing of the ground. While the results suggest that SP monitoring is capable of capturing water flow dynamics in permafrost settings, technical challenges do still exist, comprising for instance the effective removal of outliers and electrode effects in the data.

{Conclusions on next page}

We conclude that geoelectrical methods can play an important role in the monitoring and thus understanding of permafrost dynamics. ERT and SIP are capable of providing thermal state information, including estimates of ice/water content if calibrated petrophysical models are employed, with high spatial resolution. If complemented by SP, also water flow can be monitored with high temporal resolution. In conjunction, the state and flow information provided by these methods is of highest relevance for an adequate parameterization and calibration of hydro-thermal process models and thus the improved prediction of the future evolution of terrestrial permafrost systems under the influence of global warming.