Measurements of the Induced Polarization effect in alpine permafrost using Transient Electromagnetic and Complex Resistivity methods

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Abstract

We investigate the applicability of the Transient Electromagnetic (TEM) and Complex Resistivity (CR) methods to quantify the Induced Polarization (IP) effect in alpine permafrost

Keywords: Electrical resistivity induced polarization; transient electromagnetic; active layer; rock glacier; frozen rocks.

Introduction

Subsurface investigations in alpine regions with high spatial and temporal resolution are critical to quantify the impact of atmospheric events on the thermal status in permafrost, as well as their effect in the water balance. Geophysical imaging methods have emerged as suitable monitoring techniques as they provide quasi-continuous information about subsurface properties and temporal variations (Hauck & Kneisel, 2008). In particular, the electrical resistivity tomography (ERT) has become a popular method considering the distinctive response of water, ice and geologic media (e.g., Supper et al., 2014); as well as its sensitivity to temperature changes, permitting the quantification of permafrost degradation (Krautblatter et al., 2010).

Nevertheless, ERT measurements in winter can be challenging due to the poor contact between the electrodes and the ground, which significantly reduces the signal-to-noise ratio (S/N), or may even hinder the conduction of ERT surveys. Moreover, measurements in alpine fractured media may also bias the interpretation of the ERT results, considering the impossibility to differentiate the highly resistive response associated with air- and ice-filled fractures.

To overcome the limitations mentioned above, here we investigate the applicability of the Transient Electromagnetic (TEM) and Complex Resistivity (CR) methods to quantify the Induced Polarization (IP) effect in alpine permafrost. The IP is a measure of the electrical polarization (i.e., capacitive) properties of the subsurface, which can help in the interpretation of ERT for an improved lithological characterization. Moreover, the frequency-dependence of the IP effect has shown a clear dependence on the textural and thermal properties of rocks (Kemna & Weigand, 2014); thus it may permit an improved ice quantification in alpine investigations.

The application of TEM soundings alleviates the necessity of galvanic coupling, permitting the collection of data in coarse-blocky, snow- or ice-covered surfaces. Hence, we investigate the application of TEM measurements to permit a fast assessment on changes in the electrical resistivity of extensive areas, including locations not easily accessible for ERT and CR. We also investigate the applicability of TEM measurements to quantify changes in the active layer.

Material and methods

As a first step, we aimed at the collection of an extensive database of TEM and CR measurements to evaluate the applicability of both methods in alpine permafrost investigations. Selected sites comprise a broad range of morphological features: coarse blocky talus, rock glaciers, bedrock slopes and plateaus, as well as varying ground ice contents. Measurements are planned within Austria (A) and Switzerland (CH), at sites where ERT data is available for validation.

TEM measurements were collected using a single loop configuration, with 24 readings collected in the early times (4 – 238 μs) using a square loop of 25 m x 25 m and a current of 4 Amp. CR measurements were performed in the frequency-domain, in frequency range between 0.1 and 100 Hz, using 64 electrodes, with separation between electrodes varying between 1 m and 3 m for the different study areas to permit a fair comparison with existing ERT data.

Results and discussions

Collection of CR data at a broad frequency bandwidth, in both summer and winter, has been only possible at the Schilthorn rock slope (CH), where a thick debris soil layer and relative low ground ice content permit the injection of high current densities and enhanced S/N. However, CR measurements in other sites, such as the Hoher Sonnblick (A) - characterized by fractured rock and high ground ice content -, have resulted only in poor current injections (<50 mA), limiting data collection. The CR imaging results reveal anomalies with high variability in the IP effect as expected due to pore-space variations in textural parameters and ice content. Moreover, imaging results reveal a significant frequency-dependence in the IP effect. To illustrate this, Figure 1 shows representative IP spectra extracted from the inverted models for data collected at Schilthorn. Although promising, the increase in the IP effect at higher frequencies (>50 Hz) may indicate the contamination of the data with capacitive coupling associated to variations in the contact resistances between electrodes.

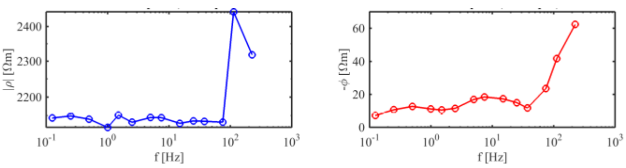

Figure 1. Frequency dependence of the CR in terms of its magnitude (left) and phase-shift (right) for shallow model parameters extracted from Schilthorn imaging results.

TEM measurements revealed in general relatively good data quality for measurements in the earlier times (~100 μs), which is related to the low S/N for "deeper" measurements in the resistive environments, as expected. Yet, the information contained in the early times permits to invert for models with variations in the electrical resistivity within the first 15-30 m.

Contrary to the previous observation, measurements collected in rock glaciers revealed higher quality for the later readings, permitting deeper investigations. Furthermore, most of the measurements revealed a signal reversal, such as the one presented in Figure 2 for measurements collected at Schafberg rock glacier (CH). Such negative values in the readings have been attributed to IP effects, for instance due to the polarization of ice (Marchant et al. 2014). In Figure 2 we present the measured voltage in TEM sounding as well as the inverted resistivity model. For validation, Figure 2 also shows the ERT results, where the anomaly with high resistivity values indicates the occurrence of ice-rich permafrost.

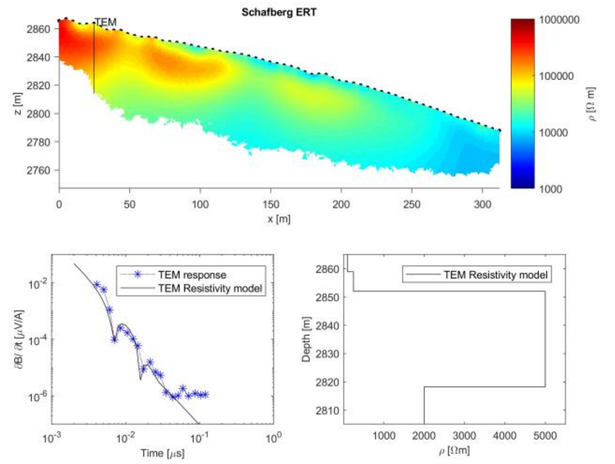

Figure 2. Resistivity model for ERT (top) and TEM (bottom) data collected in the Schafberg rock glacier.

Conclusions

The CR measurements reveal high spatial variability in the IP effect, which may permit an improved quantification of ice-content. Yet collection of high frequency CR data (>100 Hz) requires the correction for possible capacitive coupling effects in the data. Moreover, CR surveys require improved field methodologies to enhance the S/N. The TEM method is well suited for alpine permafrost investigations, yet further investigations are required to (1) improve the modeling in the early times, and (2) to understand the signal reversal observed and its interpretation with the IP due to ice.

Acknowledgments

The ATMOperm project funded by the Austrian Academy of Sciences (ÖAW).

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