Hydro-Geophysical characterization of the arctic environment, Ny-Ålesund (Svalbard)

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Hydro-Geophysical characterization of the arctic environment, Ny-Ålesund (Svalbard)

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Introduction

The Arctic research station in Ny-Ålesund (Svalbard, Norway) is an international base for several research fields. It shines for hydrogeological studies, being situated in a little basin in which the entire water cycle from glaciers to sea can be studied in an area of a few kilometers squared. Hydrogeological studies are easily linked to other research fields, such as geophysics, geochemistry, geomorphology, and biology, making multidisciplinary research possible and valuable.

Few geophysical campaigns have been carried out in Svalbard (Ross et al. 2007; Kasprzak et al. 2017). The Ny-Ålesund area lacks geophysical subsoil characterization as well, even if some exploratory drillings were made in the first half of the 20th century for coal mining purposes. The area is geophysically interesting and challenging, because of the presence of permafrost, springs, and old coal mines; spatial heterogeneity in geophysical properties is also expected because of geologic faults and geomorphologic features linked to the past ice movement. To explore the subsoil in arctic tundra environments, past research has successfully employed two geophysical techniques, Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) (Leger et al., 2017; Hauck and Kneisel, 2008, Sjöberg et al. 2015), which allowed the researchers to detect frozen/unfrozen areas and to distinguish the active layer from permafrost.

The ICEtoFLUX project and the geophysical campaigns

The research project ICEtoFLUX ("HydrologIcal changes in ArctiC Environments and water-driven biogeochemical FLUXes") was financed by Arctic Research Program "PRA" 2022-2024 and deals with the hydrological characterization of the arctic environment. The project goal is to quantify the hydrological dynamics and the interactions between the glacier and the river basin with a multidisciplinary approach that includes hydrological, geochemical, microbiological and geophysical measures. The long-term aim is to understand the temporal evolution of the permafrost and the effects of climate change on the sub-permafrost aquifer.

The geophysical surveys took place in the summer of 2022 and focused on ERT and GPR acquisitions. The investigated areas were the Bayelva basin (on the left in Fig. 1) and the mine area (on the right). In the eastern part of the investigated area within the Bayelva basin, geophysical acquisitions overlapped the alignment of four piezometers (2 m deep) realized by the ICEtoFLUX project for the physical-chemical and hydrological monitoring of the active layer. The ERT profiles were acquired with 10 m of spacing between the electrodes in order to characterize the deep features, such as the permafrost thickness and the sub-permafrost aquifer. Moreover, 1 m of electrode spacing was adopted in specific areas to inspect, with higher resolution, the active layer and the supra-permafrost aquifer. Around 8.3 km of electric lines were carried out. These ERT profiles are shown in Fig. 1 (yellow lines).

GPR measurements with 40 MHz and 400 MHz antennas were carried out in the area of the Climate Change Tower, close to the four piezometers aforementioned, for a total of around 2 km of GPR lines. Coincident ERT and GPR profiles with different acquisition settings were designed along the line of piezometers in order to correlate the geophysical results with the geochemical data and water table information coming from the piezometer monitoring (see Fig. 1).

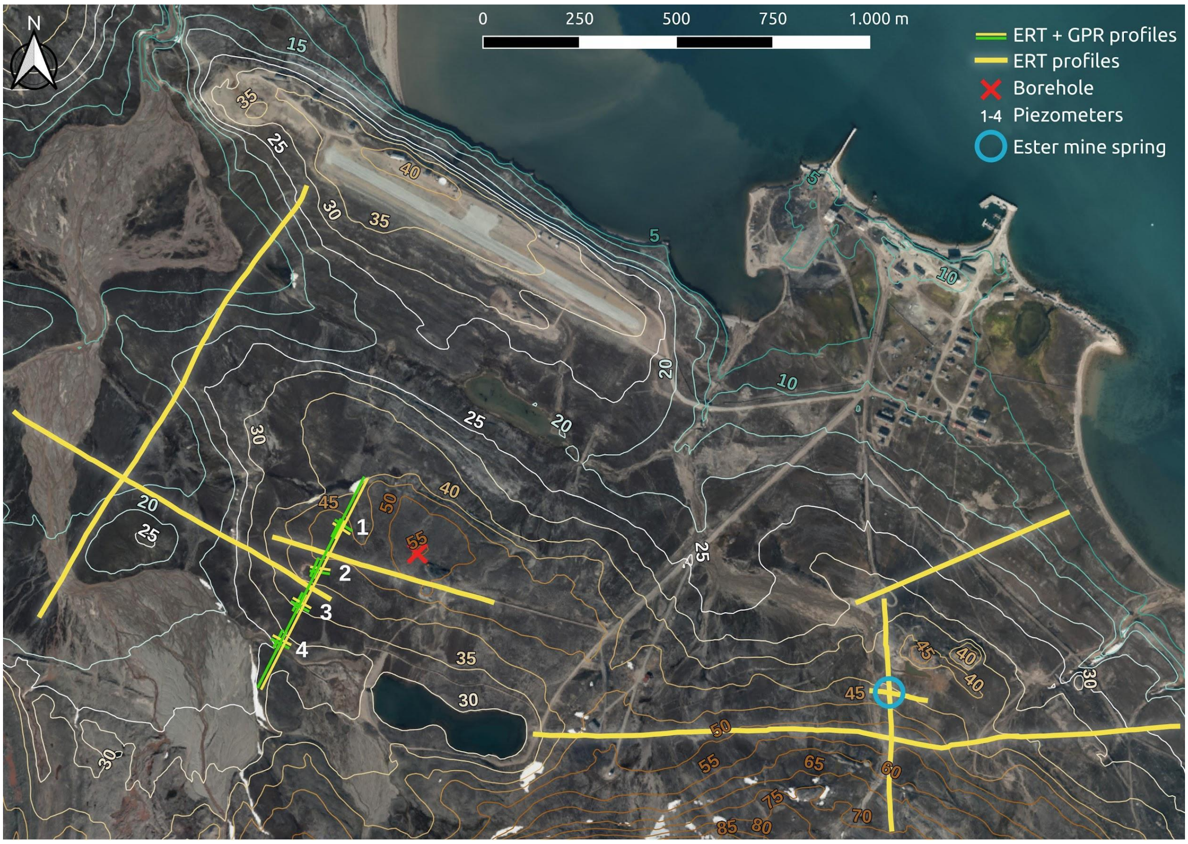

Fig. 1 – Map of the geophysical campaign carried out in Ny-Ålesund (Svalbard) in the summer of 2022. The ERT profiles are plotted in yellow and the GPR profiles in green. The investigated area on the west is the Bayelva river basin, while that on the east is the former mine. The piezometers are indicated with white numbers. The red cross is a recent borehole (48.5 m deep). The blue circle indicates the position of a spring (Haldorsen and Heim, 1999).

Results

The ERT and GPR profiles along the piezometer #1 here presented were acquired with 1 m of electrode spacing and 400 MHz of frequency.

The electric data inversion was carried out using the software Res2dinvx64 Version 4.0 (Geotomo Software, Loke and Barker, 1996). The inversion results including topography gave a misfit of 3.9%; the resistivity model is plotted in Fig. 2a. The dashed line in figure 2a shows the interface between the active layer, which is electrically less resistive (around 400 Ohm m), and the underlying layers that can be associated to the permafrost (ρ > 1.0 kOhm m). A more detailed reconstruction of the transition between the active layer and the permafrost is retrieved by the GPR results, of the B-scan acquired along the same profile (Fig. 2b). In the radargram, the continuity of the main reflector, located at a depth of approximately 2 meters below the ground surface, clearly marks the top of the permafrost (black dashed line in Fig. 2b), allowing to delineate its morphology.

The reliability of the response of ERT and GPR methods and their complete integrability is testified by the good agreement of the results. Overlapping the ERT and the GPR profiles in Fig. 2, the top of the permafrost (black dashed line in figure 2a exactly falls in the transition zone between the less resistive layer (active layer) and the more resistive one (permafrost).

The resistivity distribution and radargrams of the other ERT and GPR lines, which investigated deeper subsoil structures, showed a more complex framework with strong local heterogeneities, which can be explained by hydrological evidence suggested by the piezometers monitoring in terms of very different water quantity and physical-chemical features (electrical conductivity and temperature) in space and time.

These results will be further interpreted along with hydrological and geochemical data, with additional geological/geomorphological information provided by the project partners.

Conclusion

This novel characterization of the subsurface properties of a vast area in Ny-Ålesund provides many geophysical models useful to better understand the hydrogeology and hydrological processes of the area. Thanks to the 1m spaced ERT measurements and 400 MHz GPR, the active layer and its local discontinuities are correlated to the time series of piezometers. With the other (10m spaced) ERT surveys, deeper frozen permafrost areas are distinguished from unfrozen permafrost zones, allowing to map supra- and sub-permafrost aquifers. The preliminary interpretation of the ERT section obtained by commercial software will be updated by using the open-source software ResIPy for a more quantitative interpretation of the petrophysics of the active layer and permafrost. Correlations with climate will be developed in the piezometers area, and future time-lapse geophysical measurements will map yearly or seasonal changes in the permafrost in Ny-Ålesund.

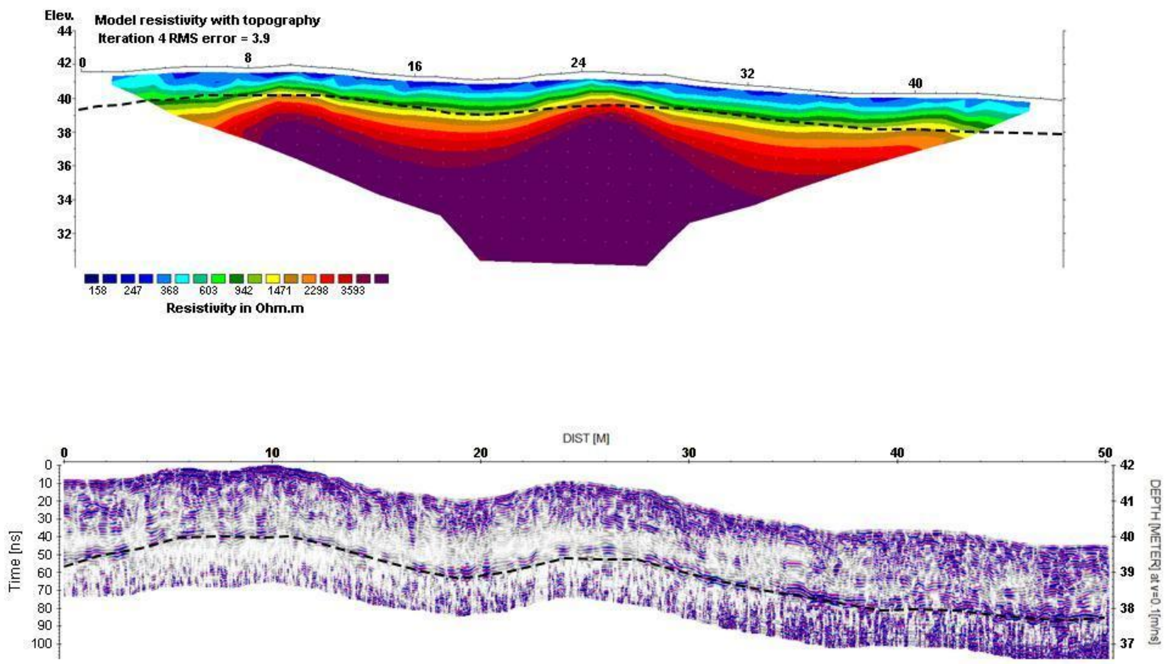

Fig. 2 a) the resistivity model of the ERT crossing the piezometer #1 (the northernmost in Fig. 1, 1 m electrode spacing); b) the GPR result for the piezometer line (400 MHz antenna). The meaning of the black dashed lines is explained in the main text.

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