Response to Reviewer2's comments

The paper titled "A new repository of electrical resistivity tomography and ground penetrating radar data from summer 2022 near Ny-Ålesund, Svalbard" contributes interesting geophysical dataset to the scientific community, particularly from the Ny-Ålesund area, which has been lacking due to logistical challenges in remote polar regions. The dataset, comprising ERT and GPR surveys, provides an opportunity to deepen our understanding of subsurface dynamics in the Arctic. The dataset is easily accessible via the provided Zenodo identifier, and it is well-organized and user-friendly. However, while I acknowledge the dataset's potential relevance, further discussion regarding its implications, potential applications, and avenues for future research could enhance the value of this contribution and facilitate interdisciplinary collaborations. The current presentation resembles more of a technical report rather than a scientific discussion of dataset.

Dear anonymous Reviewer2,

We would like to thank you for the time you spent reviewing our manuscript and for the encouraging comments. We have added a new section "**7 Discussion**" to delve into the implications of the presented database and the avenues for future research. The other requests for improvement are presented below, with point-by-point replies.

Regards,

The authors.

1. ***Abstract****: Incorporating a brief mention of specific findings or insights gained from the dataset, even if preliminary, would provide readers with an overview of the study's potential implications.*

Thank you for the comment. We have revised the abstract: "… These examples can support the identification of the active layer, the occurrence of spatial variation of soil conditions at depth, and the presence of groundwater flow through the permafrost. The resistivity models revealed deep resistive structures, probably related to the heterogeneous permafrost, which are often interrupted by electrically conductive regions, that may relate to aquifers and/or faults. To a large extent, the data set can provide new insight into the hydrological dynamics and polar and climate changes studies on the Ny-Ålesund area. The data set is of major relevance because there is little geophysical data published about the Ny-Ålesund area. …"

2. ***Introduction:*** *The introduction could benefit from expanding on other geophysical methods commonly used in Arctic environments, such as seismic and EMI, while discussing why certain methods were chosen by authors, and also addressing potential limitations or uncertainties associated with their applications in such regions. Additionally, previous geophysical studies in the region (if any) should be discussed to highlight the novel contributions of this new data repository. Furthermore, elaborating on how this dataset can contribute to addressing existing gaps in knowledge about groundwater flow dynamics, active layer and permafrost (the aim of paper as suggested by authors) in Arctic regions would contextualize its significance within the broader scientific community.*

Thank you for your comment. We have revised the Introduction section as suggested. We have rearranged the order of the paragraphs and added more information about the chosen geophysical methods, the geophysical characterization of the study area and the importance of our study. This is the revised text:

"… the past movement of the glaciers (Orvin, 1934; Dallmann, 2015).

Ny-Ålesund is also an ideal place for hydrogeological studies, because 3 km away from the settlement there is the Bayelva River catchment, where the entire water cycle from the glaciers to the sea can be studied within an area of a few squared kilometers (see Fig.1). Applied geophysics can be of great help to unravel the complexity of the water cycle and to improve knowledge about groundwater flow by means of non-destructive measurements from the surface (Hauck and Kneisel, 2008). In formerly glacierized watersheds, hydrologic processes are evolving, with new storage mechanisms and distribution of water resources, such as more persistent rivers and developed groundwater systems. Over the past years, investigations on the Arctic freshwater increased but wide knowledge about processes that govern water flow dynamics in High Arctic basins is still quite limited (Svendsen et al., 2002).

Geophysical techniques, such as Electrical Resistivity Tomography (ERT)~~, and~~ Ground Penetrating Radar (GPR), passive and active seismic methods (Kula et al. 2018), and electromagnetic induction (EMI) methods (Kasprzak. 2020; Hill, 2020), have been used to survey Arctic areas all around the world, for example to detect heterogeneity in the permafrost, to monitor glacial and periglacial processes or to understand the role of ice in the hydrology (Hauck and Kneisel, 2008; Rossi et al., 2022). EMI methods have been adopted in the Svalbard Archipelago to characterize geology (Beka et al., 2016; Beka et al., 2015; Beka et al., 2017a), possible geothermal applications (Beka et al., 2016) and CO_2 storage (Beka et al., 2017a). This paper focuses on the ERT and the GPR methods for the reasons explained below.

The ERT method has been successfully adopted in the Arctic environment because of its effectiveness in imaging the variation in the electrical resistivity values of aquifers, permafrost, and active layer, both in the first meters of subsoil and at depth, depending on the chosen electrode spacing. They can be easily distinguished by their difference in the resistivity values: high for the permafrost and low for the water-saturated soil.

…

~~The permafrost has been mainly investigated by~~ Several goals have been achieved by investigating the permafrost by means of GPR and ERT~~,~~ (or their combination) to ~~test monitoring systems for~~ monitor its temporal variations (Westermann et al., 2010), its physical properties (Schwamborn et al., 2005), the properties of the patterned ground typical of permafrost areas (Park et al., 2023), its water content coupled with Time Domain Reflectometry (Lee et al., 2018), its impacts to quarry activities (Koster and Kruse, 2016), and landslide phenomena (Kuschel et al., 2019). ~~In glacier research, the local polythermal glaciers of the Kongsfjorden peninsula were studied, mainly with the GPR technique, to investigate the cold-temperate transition surfaces (Schannwell et al., 2014), ice thickness (Saintenoy et al., 2011), snow-firn properties (Kohler et al., 2003), buried ice (Soldovieri et al., 2009), glacier dynamics and hydrology (Tolle et al., 2011).~~

~~Ny-Ålesund is an ideal place for also hydrogeological studies, because 3 km away from the settlement there is the Bayelva River catchment, where the entire water cycle from the glaciers to the sea can be studied within an area of a few squared kilometers (see Fig.1). Applied geophysics can be of great help to unravel the complexity of the water cycle and to improve knowledge about groundwater flow by means of non-destructive measurements from the surface. In formerly glacierized watersheds, hydrologic processes are evolving, with new storage mechanisms and distribution of water resources, such as more persistent rivers and developed groundwater systems. Over the past years, investigations on the Arctic freshwater increased but wide knowledge about processes that govern water flow dynamics in High Arctic basins is still quite limited (Svendsen et al., 2002).~~

The surroundings of Ny-Ålesund have been previously investigated by means of ERT surveys for glacier and landslide monitoring and GPR surveys for glaciological studies. The Research in Svalbard Portal provides the list of the past and present projects carried out around Ny-Ålesund and adopting geophysical techniques. A non-exhaustive list is composed of the projects PRISM, SEISMOGLAC and CalvingSEIS, GRAVITE, among the others. Other non-geophysical studies involving the surroundings of Ny-Ålesund included borehole investigations, geotechnical surveys, numerical modeling and other complementary measurements of the soil or groundwater. The Bayelva catchment has been largely investigated from a glaciological standpoint (Boike et al., 2018), but there are sporadic studies on its freshwater (Doveri et al., 2019; Repp, 1988; Haldorsen and Heim, 1999; Killingtveit et al., 2003).

However, even though numerous studies about Ny-Ålesund adopted ERT or GPR techniques, most of them did not focus on the characterization of the permafrost, that was mainly investigated by boreholes. In addition, no research has been found that provided spatially extensive information about the permafrost distribution all over the Ny-Ålesund area, at both scales of the active layer and deep aquifers.

The ICEtoFLUX (I2F) project …".

The new added references are:

- Kula, D., Olszewska, D., Dobiński, W., and Glazer, M.: Horizontal-to-vertical spectral ratio variability in the presence of permafrost, Geophysical Journal International, 214, 219–231, https://doi.org/10.1093/gji/ggy118, 2018
- Kasprzak, M.: Seawater Intrusion on the Arctic Coast (Svalbard): The Concept of Onshore-Permafrost Wedge, Geosciences, 10, 349, https://doi.org/10.3390/geosciences10090349, 2020.
- Hill, G. J.: On the Use of Electromagnetics for Earth Imaging of the Polar Regions, Surv Geophys, 41, 5–45, https://doi.org/10.1007/s10712-019-09570-8, 2020.
- Beka, T. I.: Geoelectrical structures beneath Spitsbergen-Svalbard derived from magnetotelluric imaging., Ph.D. thesis, the Arctic University of Norway, Faculty of Science and Technology, Department of Physics and Technology, 2016.
- Beka, T. I., Smirnov, M., Bergh, S. G., and Birkelund, Y.: The first magnetotelluric image of the lithospheric-scale geological architecture in central Svalbard, Arctic Norway, Polar Research, 34, 26766, https://doi.org/10.3402/polar.v34.26766, 2015.
- Beka, T. I., Smirnov, M., Birkelund, Y., Senger, K., and Bergh, S. G.: Analysis and 3D inversion of magnetotelluric crooked profile data from central Svalbard for geothermal application, Tectonophysics, 686, 98–115, https://doi.org/10.1016/j.tecto.2016.07.024, 2016.
- Beka, T. I., Senger, K., Autio, U. A., Smirnov, M., and Birkelund, Y.: Integrated electromagnetic data investigation of a Mesozoic CO2 storage target reservoir-cap-rock succession, Svalbard, Journal of Applied Geophysics, 136, 417–430, https://doi.org/10.1016/j.jappgeo.2016.11.021, 2017a.
- Beka, T. I., Bergh, S. G., Smirnov, M., and Birkelund, Y.: Magnetotelluric signatures of the complex tertiary fold–thrust belt and extensional fault architecture beneath Brøggerhalvøya, Svalbard, Polar Research, 36, 1409586, https://doi.org/10.1080/17518369.2017.1409586, 2017b.

3. ***Study Area:*** *The authors have included numerous references to previous geophysical studies in this region within this section. In my view, this content would be better placed in the introduction to complete the literature*

review and further justify the necessity of this new geophysical data repository. Currently, the section presents a lengthy list of references without establishing a clear connection to how these studies are related to the better understanding of "study area". On the other hand, the section lacks detailed and specific information regarding the characterization of the study area, which is essential in my opinion to justify the applied geophysical methodology and array configuration. For instance, while the aim of the investigation appears to be the characterization of groundwater flow in relation to the active layer and potentially through or below the permafrost, there is a notable absence of information concerning the permafrost, active layer dynamics, and groundwater in this section. Information regarding the expected spatiotemporal variability of the active layer, the nature of the permafrost (e.g., continuous or discontinuous) and its extension, and climate data are absent! Information about climate data play a significant role in the dynamic interactions between groundwater, the active layer, and permafrost. Furthermore, the potential availability of borehole data in this region could provide valuable insights into permafrost conditions and potential degradation. Access to such information would enable readers to better understand the rationale behind the choice of geophysical methods and array design, particularly concerning the trade-off between resolution and depth of investigation and also interpretation of data and modelling results.

Thank you for your constructive comment. We have revised section "**2 Study area**". We moved the paragraph regarding previous geophysical studies from Section 2 to Section 1 (the introduction). We also added more information about previous studies regarding boreholes, springs, permafrost and climate in Ny-Ålesund. We described the piezometers drilled as part of the I2F project. Figure 1 has been updated with more labels about the main glaciers and lakes of the investigated area. This is the added text:

"… on the upper horizon.

The mining exploration period (the first half of 20th century) left a heritage of information about the subsurface of Ny-Ålesund. Several pits and boreholes were drilled into the frozen soil, to reach the coal seams. The pits were from 5 to 20 m deep, while the boreholes were up to 100 m deep. Relative information, stratigraphy and geological sections, mainly reported shales, sandstones, and coal, are accurately described in the appendix tables in Orvin (1934). These boreholes pointed out widespread permafrost conditions but were not intended to carefully assess the permafrost extension and spatial variability which are hence not possible to be inferred.

Recent studies on the permafrost temporal variability have been performed by pits and borehole temperature monitoring. A comprehensive review of the permafrost monitoring activities near Ny-Ålesund can be found in the SESS report 2018 (Orr et al., 2019). An extensive 20-year borehole data set near the Bayelva river has been published by Boike et al. (2018) and highlights the recent climate variability in Ny-Ålesund.

Near the old mine area, southeast of Ny-Ålesund, between the fjord and the mountain of the Vestre Lovénbreen glacier, recent changes in a complex sub-permafrost hydrological network have been studied (Haldorsen et al., 1996). During the mining period the Tvillingvatnet Lake, in the west side of the mining area, was reported to receive influx water from a sub-permafrost aquifer. During winter, the lake was not frozen, and the miners discovered nearby a confined aquifer. The sub-permafrost aquifer was fed by glacier waters, probably the nearby Austre Brøggerbreen, which extended closer to the lake than today. Nowadays, the Tvillingvatnet Lake freezes during winter thus suggesting that the sub-permafrost influx has apparently stopped or greatly reduced. The chemical analyses on the water of the lake showed that it now probably comes from a supra-permafrost aquifer coming from the hillside of the Vestre Lovénbreen mountain (Haldorsen et al., 2002). A similar fate has happened to the Ester Spring. This spring is reported since the mining period (around 1930) and was characterized by a continuous water flux of multiple liters per second during winter and constant chemical properties during the year. The spring water was supposed to come from the Vestre Lovénbreen glacier, which infiltrates into a moulin and are heated underground due to the geothermal heat, making it possible to warm the permafrost and exit from the Ester Spring (Booij et al., 1998; Van der Ploeg, 2002). However, the flux has decreased across the last decades and then stopped in 2007.

According to the literature studying this site, the changes observed in the Ester Spring are linked to the global warming effects on the Vestre Lovénbreen glacier (Haldorsen et al., 2011, 2010; Haldorsen and Heim, 1999). Due to the warming temperatures and thinning of the glacier, it has lost part of its insulation effect against the cold winter (Pälli et al., 2003). Therefore, the geothermal heat flux is no more able to keep the glacier base at the pressure-temperature melting point, and the water and heat transfer from the moulin to the Ester Spring could have stopped for this reason (Putkonen, 1998). Supporting this hypothesis, an amount of water larger the past is observed to melt and drain to the tongue of the glacier through superficial streams, while in the past the melting at the tongue was minimal.

All the abovementioned publications, while being particularly delved into the specific aspects of the permafrost processes, rely on a few deep boreholes or focuses on specific areas in the surroundings of Ny-Ålesund. Therefore, at this stage it is still not possible to depict a comprehensive overview of the spatial variability of permafrost in the study area, especially at significant depth.

In this context, the proposed shallow and deep geophysical investigations (ERT and GPR) that ensure different resolution scales can fill the gap of knowledge regarding the spatial variability of the permafrost, potentially uncovering features that have not been discovered so far.

The four piezometers (P1, P2, P3, P4) drilled as part of the I2F project (see the "Piezometer Area" in Fig. 1c) were placed in a dominantly mineral soil in order to continuously monitor the water level, temperature and electrical conductivity of water, and to sample water for analyzing chemical and isotopic features. High density polyethylene pipes (with a diameter of 63 cm and a length of 3 m) were inserted in predrilled holes down to 200 cm into the soil. Each tube is screened by 3 mm slits in the lower 200 cm to allow water to enter the tube. Once piezometers were installed, caps were placed on top, again preventing outside material from entering the tube. The gravel (2-5 cm of diameter) collected locally to avoid external effects on the chemical features of the water was placed between the tube and the soil to fill the space around the tube and creating a pre-filter respect to the screened part. The piezometer metadata and data sets are available under request from the Italian Arctic data Center webpage (https://metadata.iadc.cnr.it/geonetwork/srv/eng/catalog.search;jsessionid=D5D17204B9DE391F0E3A72C26CE9AC6F#/metadata/5e0ba64e-71a7-4949-8752-9fb57b38b4fa) and the I2F webpage (https://www.icetoflux.eu/data/). Meteorological and climatic data (air temperature and precipitation) can be downloaded from the Ny-Ålesund weather station (SN99910, https://seklima.met.no)."

The new added references are:

- Orr, E., Hansen, G., Lappalainen, H., Hübner, C., and Lihavainen, H.: SESS report 2018, Svalbard Integrated Arctic Earth Observing System, Longyearbyen, 2019. https://sios-svalbard.org/SESS_Issue1
- Haldorsen, S., Heim, M., and Lauritzen, S.-E.: Subpermafrost Groundwater, Western Svalbard, Hydrology Research, 27, 57–68, https://doi.org/10.2166/nh.1996.0019, 1996.
- Haldorsen, S., Heim, M., Lefauconnier, B., Pettersson, L.-E., Røros, M., and Sandsbråten, K.: The water balance of an arctic lake and its dependence on climate change: Tvillingvatnet in Ny-Ålesund, Svalbard, Norsk Geografisk Tidsskrift - Norwegian Journal of Geography, 56, 146–151, https://doi.org/10.1080/002919502760056477, 2002.
- Van der Ploeg, M. J.: Simulation of coupled groundwater flow and transport of heat in the groundwater system under Vestre Lovénbreen, with the model METROHEAT; a surveying study, 2002. https://repository.tudelft.nl/islandora/object/uuid%3A8889c4d7-5ad4-489d-9e1e-82b5cf67ab34
- Haldorsen, S., Heim, M., and Van der Ploeg, M. J.: Impacts of climate change on groundwater in permafrost areas: case study from Svalbard, Norway, in: H. Treidel, J. L. Martin-Bordes, & J. J. Gurdak (Eds.), Climate change effects on groundwater resources: a global synthesis of findings and recommendations, IAH-International Contributions to Hydrogeology (pp. 323-338). (IAH - International Contributions to Hydrogeology)., 323–338, 2011. https://www.researchgate.net/publication/254839230_Impacts_of_climate_change_on_groundwater_in_permafrost_areas_Case_study_from_Svalbard_Norway

- Haldorsen, S., Heim, M., Dale, B., Landvik, J. Y., Van Der Ploeg, M., Leijnse, A., Salvigsen, O., Hagen, J. O., and Banks, D.: Sensitivity to long-term climate change of subpermafrost groundwater systems in Svalbard, Quat. res., 73, 393–402, https://doi.org/10.1016/j.yqres.2009.11.002, 2010.
- Pälli, A., Moore, J. C., Jania, J., Kolondra, L., and Glowacki, P.: The drainage pattern of Hansbreen and Werenskioldbreen, two polythermal glaciers in Svalbard, Polar Research, 22, 355–371, https://doi.org/10.3402/polar.v22i2.6465, 2003.
- Putkonen, J.: Soil thermal processes and heat transfer processes near Ny-Ålesund, northwestern Spitsbergen, Svalbard, Polar Research, 17, 165–179, https://doi.org/10.3402/polar.v17i2.6617, 1998

4. ***Geophysical Surveys:*** *The authors could provide additional insights into the rationale behind the chosen survey configurations, such as the use of electrode spacing of 1 and 10 meters. e.g., whether the smaller spacing is intended for active layer characterization and larger spacing for permafrost? Moreover, detailing the challenges encountered during the surveys using ERT and GPR conducted in this region, data noise and uncertainties, modelling error would not only assist researchers to understand the limitations of data but also benefit those engaged in geophysical prospecting in polar and remote areas for potential improvement.*

Thank you for the opportunity to clarify these aspects. As regards the reasons behind the chosen survey configurations, we have revised **Section 3.1**: "The transmitter and the receivers can be placed in several relative positions or configurations. … (Martorana et al., 2017). The distance between the electrodes affects the depth of investigation of a measurement, the vertical penetration of the injected current, the lateral resolution of the data and the field logistic. The more the electrode spacing, the more the depth of investigation and the less the data resolution in the near surface (Oldenburg and Li, 1999). We chose the electrode spacings of 1 and 2 m to characterize the active layer, and of 10 m to characterize the permafrost or deep aquifers at the expense of high resolution in the near surface.".

New reference: Oldenburg, D. W., & Li, Y. (1999). Estimating depth of investigation in dc resistivity and IP surveys. Geophysics, 64(2), 403-416.

As regards the logistic challenges, we have added more information in **Section 3.3**:

"… and iii) the mine area on the east (close to the Ester spring).

The geophysical survey had to be planned to overcome some specific logistic difficulties owing to the study area placed in a remote polar region and to the long duration of the survey, split into two different campaigns during the thaw season. First, the whole equipment (14 boxes with a total weight of around 450 kg) had to be shipped two months before the survey and returned back three months after the survey ended. Second, the whole crew had to obey the health and safety protocols, required, respectively, to be hosted in the Italian Arctic Station and to carry out field operations in a region where polar bears may approach humans. Globally, field logistics and fieldwork conditions were largely affected by the isolation and asperity of the study area. For example, most of the survey sectors were not directly accessible from the road and hiking with the equipment was necessary. Moreover, since safety was of primary concern, operators had to work nearby to monitor the presence of wildlife (polar bears) in the surroundings, thus extending the time required for the surveys.

The ERT survey…".

We have addressed the topic of data uncertainties and modelling error in the following reply.

5. ***ERT:*** *Further information regarding contact resistance data would be valuable if available. This could include typical values observed during ERT surveys, the efficacy of bentonite solution in mitigating contact resistance, and any experimentation with other alternatives such as salt water. Additionally, details on electrode type and dimension, the establishment of threshold values for contact resistance filtering, and the extent of data filtered based on each criterion (e.g., negative values, contact resistance, outlier) and in total would be useful. Such insights contribute to our understanding of best practices for ERT surveying and data processing in permafrost regions. See for example*

   Herring, T., Lewkowicz, A.G., Hauck, C., Hilbich, C., Mollaret, C., Oldenborger, G.A., Uhlemann, S., Calmels, F., Farzamian, M., Calmels, F., and Scandroglio, R. 2023. Best practices for using electrical resistivity tomography to investigate permafrost, Permafrost and Periglacial Processes, 34, 4, 494-512, https://doi.org/10.1002/ppp.2207.

   While acknowledging that this is primarily a data-based publication, I suggest that the authors go a bit deeper into the interpretation of ERT examples. This includes presenting how resistive values are interpreted (based on available data), their lateral and vertical variability, quantifying average resistivity changes across different sites and depths of investigation, and exploring potential subsurface factors influencing and explaining variability. While direct measurements of electric resistivity in the investigated area seems not be available, some additional information such as borehole data (if available) can help with interpretations of resistivity data and facilitate broader utilization of this dataset.

Thank you for your comment. We have revised **section 3.3** to add the requested details about ERT acquisition. We have also added the suggested reference:

"The receiver was multichannel with a maximum of 10 measurements at a time and a maximum number of 48 electrodes for each acquisition. Standard stain steel electrodes were used. The configurations of the acquisition were DD (both in direct and reverse configurations), WS and WE. … The details about the acquired ERT profiles are schematized in Table 1. Soil conditions were generally fair in terms of electrical contact resistance, allowing to easily achieve contact resistance values lower than 10 KΩ. This was not surprising because the thaw season is generally the best season for ERT data quality because the contact resistances are expected to be low (Herring et al., 2023). Not favorable conditions were encountered in areas where stones and gravels covered the ground surface, such as in the Bayelva catchment and in the mine area. The bentonite was used there to improve the ground-electrode contact if necessary.

For some of the profiles (ERT7, 8, 9,10 and ERT_P1, P2, P3, P4), the contact resistance values were stored together with the WS geoelectrical data to enhance a posteriori control of the data quality and monitoring of the measuring conditions. The contact resistance was stored only for the WS acquisitions due to the negative influence that this procedure has on the multichannel acquisition (i.e., the DD acquisition) in terms of time consumption.".

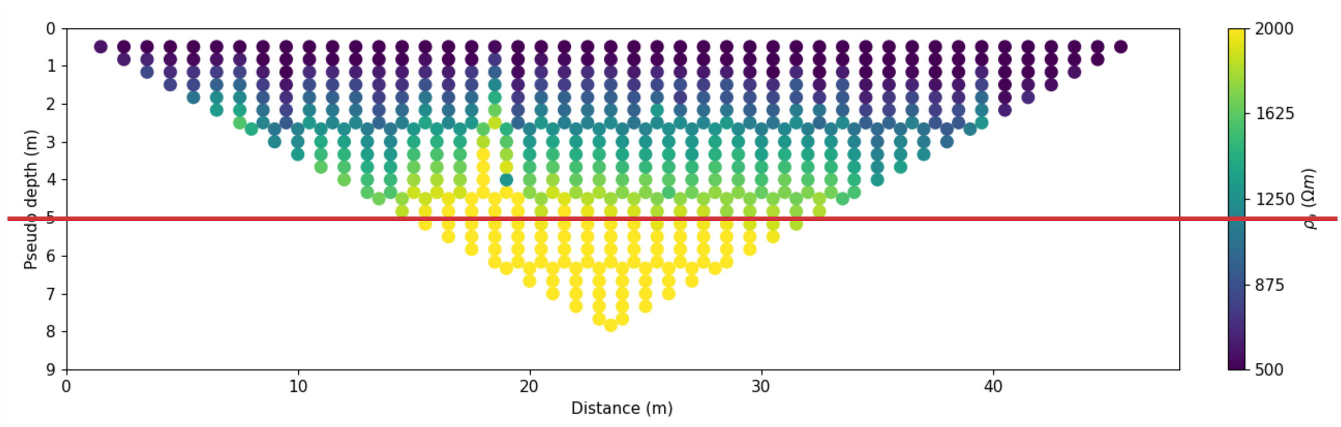
Regarding the contact resistance we have added two new figures showing the pseudo-sections of R (kΩ) for ERT_P1_Par and ERT9. Please see new Figs. 4 and 8. **Section 4.2** has been revised:

"The ERT data were pre-processed by using the software Prosys-III (Iris instruments). The filtering procedure of ERT data was based on the verification of some general criteria. For each geoelectrical profile the preprocessing consisted of discarding the following data:

- electrodes with anomalous values of contact resistance ("RS check"), when available,
- negative resistivity values,
- ~~electrodes with anomalous values of contact resistance ("RS check"),~~
- isolated extremely high or low resistivity values (i.e., outliers).

An example of ERT data~~, i.e., a~~ with the pseudo-sections of apparent resistivity and contact resistance, measured…. repository (see Section 6 for details).

The apparent resistivity pseudo-section (Fig. 4 top) is characterized by relatively smooth variations and no outlier data as expected considering the good contact resistances (Fig. 4 bottom). The filtered ERT data were then ready to be inverted to create 2D geoelectrical models of the subsoil (see Section 5.1).



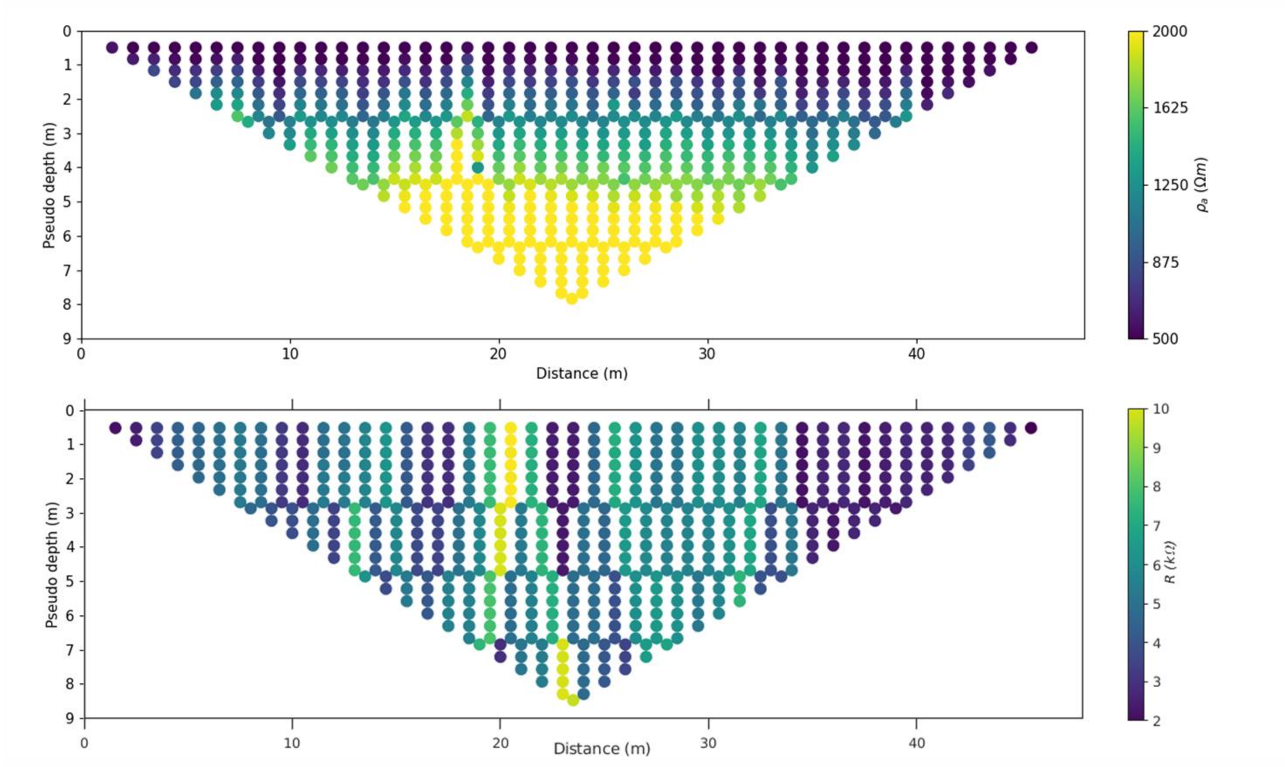


Figure 4: Example of experimental pseudo sections of the ERT_P1_Par profile. The acquisition configuration is WS: top) showing the spatial distribution of the measured apparent resistivity (ρ_a) values (in Ωm); bottom) contact resistance values (in kΩ)recorded for each current electrodes pair involved in the data acquisition sequence. The acquisition configuration is WS.".

We have revised **Section 5.2** to add the representation of the contact resistance of ERT9 (new Fig. 8):

"The reliability of the inversion results is hence derived not only from the similarity of the three geoelectrical models of Fig. 7 but also from the pseudo sections of the contact resistance (stored with the WS data), as shown in Fig. 8 top, and of the percentage reciprocal error (derived by measurements in DD direct and reverse configuration), as shown Fig. 8 bottom.

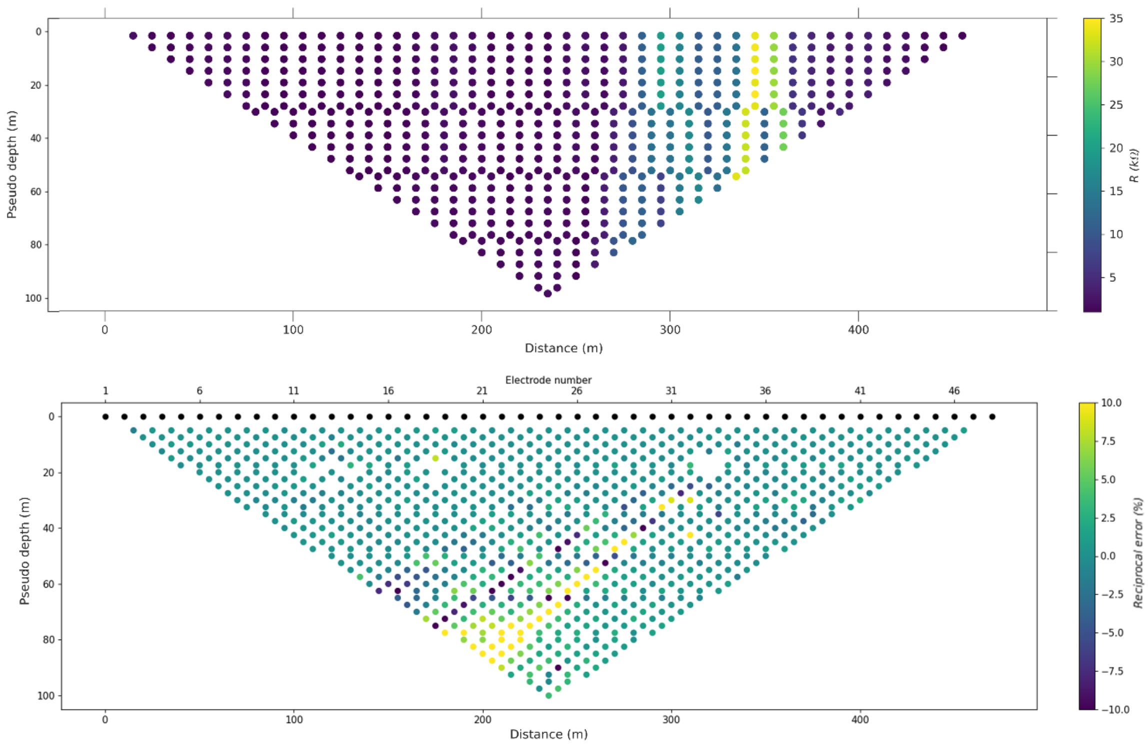


Figure 8: Pseudosections of ERT9 for: top) contact resistances stored during the WS acquisition; bottom) percentage reciprocal errors derived from the DD acquisitions performed in direct and reverse configurations.".

As regards the possible interpretation of the ERT examples and the availability of borehole data, we have added more information in the new section "**7 Discussion**":

"We presented a new set of geophysical data from the remote site of Ny-Ålesund in High Arctic environment. The multi-method geophysical survey was designed to image the subsurface at different scales and resolutions. A comprehensive and integrated interpretation of the presented data set is beyond the scope of this paper but some thought for food can be proposed to stimulate future discussions and applications among the scientific community active in polar studies as well as in climate changes studies.

A significant variability was observed in the measured ERT and GPR data. This implied various degrees of heterogeneity in the distribution of the imaged physical parameters, both electrical resistivity and dielectric permittivity. To explain this heterogeneity, several factors should be considered by the users and modelers of the data set. As is widely known, the electrical resistivity of the subsurface is usually controlled by lithology, the occurrence of liquid phase (that rules electrolytic conduction) and the amount of clay (that enhances surface conduction). The peculiar conditions of the study area strongly affected the geophysical response. The occurrence of ice in the permafrost and intermittently in the active layer plays a relevant role in increasing the bulk resistivity of the subsurface. The data set can be modelled and interpreted in terms of percentage of ice content at depth, thus solving the challenge of a distinction between different solid and fluid phases involved in the system under investigation.

Moreover, given that Ny-Ålesund is a former coal mining town, the occurrence of various coal seams as well as the past anthropic activity should be considered (Orvin, 1934). A dense and tangled mining tunnelling system which supposedly develops from the surface down to several tens of meters could play an important role in the distribution of electrical resistivity in the mine area at the foot of Mt. Zeppelin.

In the whole study area, the interpretation of the geophysical data (and models) in terms of liquid phase of the ground should consider different origin, evolution, physico-chemical properties and hence different values of the electrical resistivity of the aqueous solutions.

The presented data set can be used for several scientific purposes. First, the ERT data can support studies on the interplay between groundwater and permafrost, thus improving knowledge about possible deep circulation of water supra, intra and sub-permafrost. Second, the integrated ERT and GPR data can offer the opportunity to identify both the interface between active layer and permafrost at very high latitudes and even the continuity of the permafrost in terms of ice percentage. The time series of various parameters directly measured in the four piezometers will be delivered as outcomes of the project that funded this research (I2F project). Therefore, various schemes of joint and/or petrophysical inversion could be tested in the future by using these data.

The geological data of the study area are available from the literature and could be useful to interpret the data set and geophysical models. The different sectors of the study area have different coverage of geological data. Poor coverage of direct borehole data is available in the Bayelva catchment so that it was challenging to reliably interpret the data measured in this sector (ERT1 and ERT2). A few geological data about the piezometer area are available in the literature. In addition to the aforementioned I2F piezometers, some borehole data are available from Orvin (1934) and few geological data can be accessed for borehole "DBNyÅlesund" (Orr et al., 2019; https://sios-svalbard.org/node/648; http://gtnpdatabase.org/boreholes/view/1837/).

The mine area presents a completely different situation because decades of coal mining exploitation produced a great amount of direct data from a dense network of tunnels, boreholes and pits in a number of mines. To the knowledge of the authors, these data of the mine area are neither organized nor available, except for few information reported in Orvin (1934)."

6. ***GPR:*** *From the text It's unclear whether the surveys were conducted continuously or manually, and whether the antenna was pulled or measured at specified distances (for both antennas). Given that these antennas are not typically designed for rough terrains, it's worth discussing if the authors encountered any additional challenges during data collection and processing, particularly regarding ensuring proper surface contact and if those challenges impacted data quality.*

   Additionally, it's unclear whether the same processing steps discussed apply to both antennas or specifically to the 400 MHz frequency. Furthermore, there is an absence of example presentations of GPR data from the low frequency of 40 MHz. Incorporating such examples would offer a more comprehensive understanding of the collected GPR data and also comparison with deeper ERT surveys with 10m electrode spacing.

   A preliminary interpretation of the GPR results presented in Figure 8 would be beneficial, particularly considering that the surveys were conducted in a piezometer area. I miss any information about piezometer area and if they are available and how they could guide on survey design and interpretations afterward.

   Is there any available information from the site that could assist in estimating the dielectric constant, even if only roughly, to enable estimation of the depth of reflections? Alternatively, has there been any calibration conducted over known buried targets? Could piezometer data from the study area be used for this purpose?

   Thank you for your comment. We have revised sections 3.3, 4.2, 5.3 and 6.1 following your suggestions. We have added requested information and a figure (new Figure 11) showing the GPR data at 40 MHz. The details about the piezometers drilled as part of the I2F project were included in Section 2 "Study area" (please, see the reply to comment n.3). We have provided the links to the webpages where the piezometer data can be accessed and downloaded. These data are going to be updated in the next steps of the I2F project.

   The revised **Section 3.3** is: "The GPR data were acquired with the GSSI SIR-3000 GPR System coupled with two different antennae working at the frequencies of 40 (SUBECHO AB Sweden air-coupled antenna) and 400 MHz (GSSI ground-coupled antenna). The … time-samples. Since the acquisitions were carried out without a survey wheel, ~~and~~ the data were acquired in time domain and ~~to assign the right coordinates to each recorded trace,~~ several marks were placed every 5 meters in order to assign the right coordinates to each recorded trace.

The surface investigated close to the piezometer area was regular and the few ground irregularities encountered did not affect the quality of the acquired data always ensuring a proper surface contact for the ground coupled antenna. The use of the 400 MHz antenna was limited to transect line where it was possible to guarantee and adequate contact between the ground and the antenna avoiding unwanted “jumps” of the antenna itself. This limitation was not affecting the use of the 40 MHz antenna which performs well even in absence of direct contact with the ground.”.

The revised **Section 4.2** is:

“- A subtract-mean, or "dewow" filter was used with a time window of 2 ns and 8 ns for 400 MHz and 40 MHz data respectively, to remove possible instrumental voltage shift in the data.

- A manually selected gain function, based on subjective choice and experience, was applied to contrast the effects of signal attenuation and geometric dispersion.

- A bandpass filter removed the frequencies under about 150 MHz and above about 550 MHz for 400 MHZ data and between 20 and 100 MHz for 40 MHz data

- Only for the 40 MHz data, an automatic control gain (AGC) with a time window of 100 ns was applied in order to better detect deeper reflectors.

The data processing chain is shown in Fig. 5.

For visualization, all the GPR data were ~~the~~ topographically ~~correction of the data was performed~~ corrected by using the topographic…”.

The revised **section 5.3** is:

“Fig. 10 shows GPR_P1_Par, a representative GPR line that is parallel to ERT_P1_Par and acquired with the 400 MHz antenna. The radargram is acquired close to piezometer P1 and shows unequivocally the presence of a reflective layer placed in a time window ranging between 50 and 55 ns. In order to convert the data from the time domain to the spatial domain it is necessary

~~To calculate the depth of the reflections,~~ to determine the propagation speed of the radar waves in the investigated levels. This is mainly related to the physical–electrical characteristics of the investigated medium. In particular, in a low-loss material, it is inversely proportional to the square root of the dielectric constant (ε_r) and is estimated or calculated through various possibilities of signal analysis or with experimental calibration tests. ~~The data processing enables the conversion of the propagation speed of the radar waves into the subsoil depth. Finally, the digital acquisition allows the representation of the acquired data in 2D-profiles, as can be seen in Fig. 8. It shows GPR_P1_Par, a representative GPR line that is parallel to ERT_P1_Par and acquired~~

~~with the 400 MHz antenna.~~ From the analysis and fitting of the hyperbolae characterizing the radargrams (Rønning, 2023), generated by punctual elements present in the subsoil (i.e., stones), it was possible to determine that the velocity value can be assumed equal to 0.10 mns^{-1}. This assumption is also validated by the comparison of the most reflective layer detected by the GPR data with the most interesting electrical anomalies detected by ERT at a similar depth. Further efforts are required to constrain the interpretation with the direct data that will be collected in the close piezometer.

~~The 2D GPR profiles can be finally filtered and enhanced to detect and locate geological features.~~

…

Fig. 11 shows the results obtained with the 40 MHz antenna. The radargram was acquired with an antenna that does not require ground contact. Although the recorded signal is noisier than that acquired with the 400 MHz antenna and the resolution is not comparable to that provided by the 400 MHz antenna, some reflective layers can be detected in the upper 300 ns. After such time, the presence of attenuation phenomena seems not to provide the possibility of identifying hydro-geological features. However, some discontinuities seem to characterize the radargram in particular at the distance of 450 meter from the starting point of the radargram.

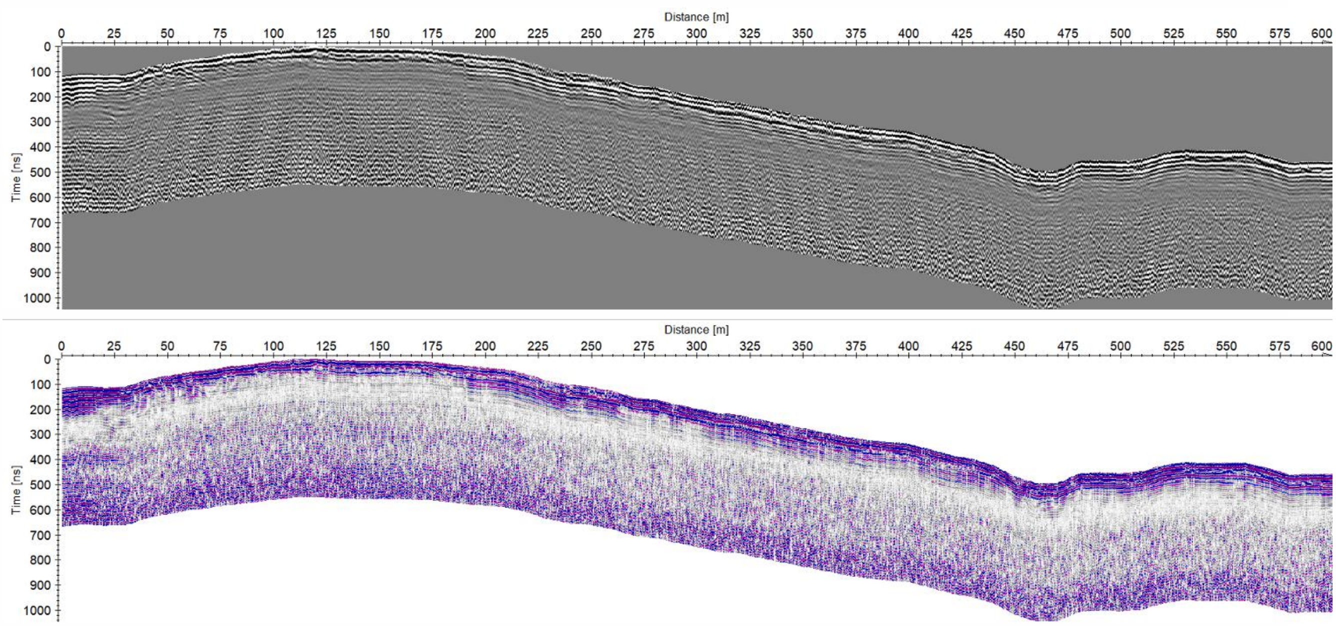


Figure 11: Example of a processed 2D radargram for GPR_long_40 MHz radargram. The radargram is shown in two different color scales.".

A new reference was added:

- Rønning, J.S. (2023) Finetuning ground penetrating radar velocity analysis from hyperbola fitting using migration. Near Surface Geophysics, 21, 171–181

Finally, the revised **section 6.1** is: "~~An example~~ Two examples of processed data ~~is~~ are provided for profile GPR_P1_Par (Fig. ~~8~~10) and profile GPR_Long_40MHz (Fig. 11), inside folder Example result in GPR. The data were processed according to the workflow explained in Fig. 4 and saved in Reflex-w format and in SEGY format. The files following the Reflex-w format are named ~~"GPR_P1_Par_processed.04R" and~~ "GPR_P1_Par_processed.04~~T~~(T-R)" and "GPR_Long_40MHZ_processed.01(T-R)", while the remaining files are ~~is~~ "GPR_P1_Par_processed.SGY" and "GPR_ Long_40MHZ_processed.SGY". The processed files in Reflex-w …".

The "01(T-R)" and ".SGY" files were added to the Zenodo data repository in "/GPR /Example_results /GPR_Long_40MHz".

7. ***MT:*** *The current statement about MT may not offer significant insight into the source of the problem. Thus, I recommend either including more information about the equipment, survey design, and even including datasets or removing this section and briefly mentioning it in the introduction.*

Thank you for your comment. We have revised Section 3.2, by adding the requested details and a new figure (Figure 3) showing the corrupted MT signal:

"The MT method is a natural-source electromagnetic method that measures the Earth's response to the low-frequency EM waves coming from the magnetosphere and ionosphere. The measurement of the electrical and magnetic fields allows determining the electrical resistivity of the Earth at depths ranging from some meters to hundreds of kilometers (Chave et al., 2012). The acquisition of MT data is performed with no transmitters since the signal has a natural origin. Two components (horizontal and perpendicular) of the electric field and ~~three components~~ of the magnetic field are measured on the ground surface. The electric field is measured by means of two pairs of dipoles (grounded non-polarizable electrodes), being usually the direction of one pair parallel to the magnetic North (x-direction for MT convention). The magnetic field components are usually measured by means of two horizontally buried magnetometers (induction coils). An additional magnetometer can be deployed to measure the vertical component of the magnetic field.

The Audio-MT method (AMT) refers to the measurements of MT signals in the frequency range from 10^5 to 10 Hz. AMT is devoted to the shallow characterization of geoelectrical structures. The broadband MT method refers to measurements of both low and high frequencies usually in the range of 10^3 to 10^{-4} Hz with deeper investigation depths than AMT.

~~An MT survey was planned in the Bayelva area as part of the I2F project, but a first attempt had with no success.~~ Two different systems were adopted for Audio-MT and ~~Broad-Band~~ broadband MT acquisitions. The Audio-MT equipment was composed of the Geometrics StrataGem system, two G100K magnetometers and four steel electrodes. The Broad-Band MT equipment was tailored by Zonge International Inc. and consisted of one ZEN receiver (high-resolution, multi-channel 32-bit receivers) which record broadband time-series from 10^3 to 10^{-4} Hz, three magnetometers (type ANT/4) and six non-polarizable electrodes (Pb-PbCl) devoted to geophysical resistivity measurements.

The MT and AMT surveys were planned to be carried out during the I2F project because they have different resolution and depth of investigation with respect to ERT and GPR. MT and AMT were deemed to be ideal for the deep characterization of permafrost and sub-permafrost aquifers since they are more sensitive than ERT and GPR to electrically conductive formations and have a larger depth of investigation than ERT and GPR. Moreover, the MT and AMT methods were supposed to overcome the possible difficulties of the ERT method related to the injection of a direct current into a highly resistive subsoil. There are several MT and AMT applications that study the ice sheet and glacial dynamics in the polar regions (Hill, 2020), both Arctic (e.g., Beka, 2016; Beka et al., 2015, 2016, 2017a, 2017b) and Antarctic regions (e.g., Wannamaker et al., 1996, 2017).

The MT and AMT surveys were planned in the Bayelva and mine areas, but every attempt of acquisition had no success. The planned MT and AMT surveys had to be stopped after the acquisition of 5 soundings due to an unexpected high level of anthropic electromagnetic noise. The first MT acquisition was scheduled with three different sampling rates for a total of 2.5 hours. The estimated impedances ranged in the frequency band from 0.01 to 1280 Hz but were affected by noise. Then, four AMT soundings were acquired, but again the data were corrupted by noise. The AMT time series were processed by using different window lengths and filtering stages in three frequency bands resulting in impedance estimates in the frequency range from 15.8 Hz to 63 kHz.

The MT data would have been useful for the deep characterization of the permafrost and potential sub-permafrost aquifer. However, the MT and AMT data processing performed after the first acquisition revealed a wide-band and energetic noise source whose presence prevented the possibility of acquiring good-quality ~~MT~~ data. This was completely unexpected because Ny-Ålesund is a radio silent and geographically remote settlement, where wireless equipment is not allowed to ensure a high signal-to-noise ratio for the data measured. ~~This restriction is probably duly working for very high frequency signals (in the order of giga Hz).~~ Even though any equipment emitting radio signals is limited and several scientific instruments take advantage of the radio silence, a few exceptions are permitted for safety, operational and scientific reasons. The equipment transmitting and receiving radio frequencies in Ny-Ålesund is supposed to be authorized and listed in the "NySMAC frequency list" (https://nyalesundresearch.no). Although the listed equipment operates in the frequency range from kHz to GHz, it directly or indirectly affected the quality of our acquired MT signals ~~The most corrupted MT signals were~~ in the frequency bands > 1 Hz. As an example, this low quality can be appreciated from Fig. 3, where the power spectra are dominated by a 50 Hz noise and its harmonics. The signal in Fig. 3 was analyzed in Matlab® Signal Processing Toolbox. The presence of this kind of noise ~~in the recorded MT time series~~ resulted in the impossibility of obtaining reliable MT estimates.

Figure 3: Time series (top panel) and power spectra (bottom panel) related to the Electric (Ex and Ey) and Magnetic (Hx and Hy) field components sampled at 4096 Hz. Ex is plotted in ochre, Ey in purple, Hx in green and Hy in cyan. The components were measured in the (magnetic) N-S and E-W directions. The signal was analyzed in Matlab® Signal Processing Toolbox.

Note that in Fig. 3 the time series of the magnetic components are not deconvolved for the instrumental response.

The MT and AMT surveys were ~~was~~ shut down and the data were not included in the repository published along with this work due to the impossibility to process and interpret them. However, ~~but~~ our experiment can be of help as a lesson learned for future geophysical expeditions in Ny-Ålesund."

New references:

- Hill, G. J.: On the Use of Electromagnetics for Earth Imaging of the Polar Regions, Surv Geophys, 41, 5–45, https://doi.org/10.1007/s10712-019-09570-8, 2020.
- Wannamaker, P., Hill, G., Stodt, J., Maris, V., Ogawa, Y., Selway, K., Boren, G., Bertrand, E., Uhlmann, D., Ayling, B., Green, A. M., and Feucht, D.: Uplift of the central transantarctic mountains, Nat Commun, 8, 1588, https://doi.org/10.1038/s41467-017-01577-2, 2017.
- Wannamaker, P. E., Stodt, J. A., and Olsen, S. L.: Dormant state of rifting below the Byrd Subglacial Basin, West Antarctica, implied by magnetotelluric (MT) profiling, Geophysical Research Letters, 23, 2983–2986, https://doi.org/10.1029/96GL02887, 1996.