Response to the Editor

16th May 2024

Dear Baptiste Vandecrux,

Topical Editor at ESSD,

Thank you for the opportunity to revise our manuscript entitled "**A new repository of electrical resistivity tomography and ground penetrating radar data from summer 2022 near Ny-Ålesund, Svalbard**" for consideration by the journal Earth System Science Data. We greatly appreciate the suggestions to improve the paper. We have addressed all the comments, as explained below.

The comments are numbered in bold and written in italics. Our responses follow sequentially, including how and where the text has been modified. The text added to the original manuscript has been underlined, while the text deleted has been crossed.

The revision has been developed in agreement with all coauthors, and each author has given approval to the final form of this revision.

We hope that this revision will meet your requests.

Thank you.

Yours sincerely,

Francesca Pace.

Response to the Editor's comments

Dear Dr. Pace,

Thank you for your response to the reviewers and for the revised manuscript.

1. *I want to come back to the reviewer's comment:*

> *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.*

I do agree with this comment and I find that the added material in the discussion does not really provide more information, but rather a list of analysis that could be conducted on the data. Please provide these interpretations as demanded by the reviewer.

Thank you for your comment. We have improved the manuscript following your suggestions. We have added more information and comments regarding: the lateral variability of resistivity in the ERT models (resistivity), the heterogeneity of the ERT data (apparent resistivity), the main differences in the three investigated sectors. Furthermore, we have added information about direct data measured at the four piezometers during the ICEtoFLUX (I2F) project and their relevance with respect to the geophysical data. Comments about the complexity of providing a comprehensive interpretation of the results and about the limitations of our geophysical surveys for the identification of the bottom of the permafrost were included.

At this stage, a comprehensive interpretation of the geophysical results would require an integrated approach, that is, a combined analysis with geology, geochemistry, and hydrogeological modelling because the study area is known to have complex heterogeneities in the subsurface and permafrost distribution (Orvin, 1934). Detailed analyses are ongoing as part of the I2F project, that funded our research, and will consider the geophysical data set as a mosaic tile.

The revised Section 5.2:

"The inversion result for the ERT_P1_Par (WS configuration, 1 m of electrode spacing) is presented in Fig. 6. The resistivity model shows a gradual increase in resistivity with depth. At shallow depth, up to 2 m of depth b.g.l., the resistivity range is 100 – 500 Ωm, while from 2 m of depth down to the bottom of the model the resistivity rises to 1000 Ωm and even up to 8000 Ωm, which can be theoretically correlated with the permafrost. The resistivity model of Fig. 6 does not show a marked lateral variability, that is, the resistivity clearly increases with depth, being characterized by a shallow medium resistive layer and a deep very high resistive layer. This geoelectrical structure is valid for only profile ERT_P1_Par because the measured apparent-resistivity data in the ERT profiles centered in the other piezometers are clearly different. ~~The~~ Further interpretation of the resistivity models goes beyond the scope of this paper and needs multidisciplinary ~~insights~~contributions, given that the resistivity of the frozen rock might be site-specific. To the best of the authors' knowledge there is no direct measurement of electric resistivity in the investigated area, except for few, ~~and~~ old and superficial electric-conductivity sensors installed up to 1 meter of depth in the Bayelva basin (Kodama et al., 1995; Boike et al., 2018; Son and Lee, 2022).".

In the Discussion section, we have rearranged the sentences and added more information, thus expanding the 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 thorough interpretation of all the 2D resistivity models goes beyond the scope of this paper, that was primarily conceived to share with the scientific community a large data set coming from a unique study area. In fact, a comprehensive interpretation would require an integrated approach, that is, further investigations on geology, geochemistry, and hydrogeological modelling because the study area is known to have complex heterogeneities in the subsurface and permafrost distribution (Orvin, 1934). Detailed analyses are ongoing as part of the I2F project and will consider the geophysical data set as a mosaic tile. ~~A comprehensive and integrated interpretation of the presented data set is beyond the scope of this paper but s~~To date, the published data set represents an invite to expand scientific knowledge of the Ny-Ålesund area by means of geophysical proofs. Some food ~~thought~~ for thought ~~food can be~~is here proposed to stimulate future discussions and applications among the scientific community active in polar studies as well as in climate change~~s~~ studies.

A significant variability was observed in the measured ERT and GPR data, that is, in the apparent resistivity pseudosections for ERT and in GPR profiles. 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.

We showed the results from two different inspected sectors, i.e., the piezometer and the mine areas. The profiles ERT_P1_Par (Fig. 6), GPR_P1_Par (Fig. 10) and GPR_long_40 (Fig. 11) are placed in the piezometer area, while profile ERT9 (Fig. 7) is placed in the mine area.

The results from ERT_P1_Par (Fig. 6) and GPR_P1_Par (Fig. 10) regarded the shallow subsurface (maximum depth of investigation 10 m) and revealed a clear change with depth of the correspondent physical parameters. From these results, it can be inferred that there is a clear discontinuity in resistivity at around 1.5-2 m b.g.l and a reflector at 50-55 ns. This may be related to the interface between the active layer and the frozen ground. The physico-chemical parameters measured in the piezometers (P1-P4) during the week of the geophysical survey are useful for further considerations. These measurements consist of continuous data logs (every 15 minutes) of temperature, electrical conductivity and water level and then at specific days water was collected to measure temperature and electrical conductivity. In P1, which is located in the center of ERT_P1_Par, there was no detection of water during the geophysical survey and hence the water conductivity was not measured. In P1, the day of the acquisition of ERT_P1_Par, the bottom-hole temperature was 1.3 °C, while the depth of the frozen level was 132 cm from ground surface one day before the ERT acquisition.

GPR_long_40 is placed in the piezometer area and the acquisition direction was from P1 to P4 towards the glacier Brøggerbreen (Fig. 2). As anticipated in Section 5.3, this profile crosses all the piezometers from P1 (at a distance of 120 m) to P4 (at a distance of 440 m). During the geophysical survey in summer 2022, P1 and P4 were dry, while P2 and P3 had water inside. The water sampling performed the 23rd of July 2022 (four days before the ERT survey in the piezometer area) gave a water level of 95 and 77 cm b.g.l. for P2 and P3, respectively, and water conductivity of 665 and 682 µS/cm, respectively. Moreover, in the days of the ERT acquisitions around P2 and P3, the depth of the frozen level from ground surface was 123 cm in P2 and 200 cm in P3. The ERT data around P2 and P3 reflected in the pseudosections of apparent resistivity the possible presence of water. In fact, the apparent resistivity of the ERTs crossing P2 and P3 was lower than that of ERTs crossing P1 and P4. These ERT data can be used to study groundwater or hydrogeological activity together with the geochemical analyses performed during the I2F project. The piezometer data are in good agreement not only with the ERT data acquired with 1 m of electrode spacing, but also with the GPR data acquired with the 400 MHz antenna. In fact, the radargrams close to P2 and P3 have discontinuous reflectors that can be explained by the presence of water, which attenuates the GPR signal, and by heterogenous properties of the frozen ground. In the whole study area, the interpretation of the geophysical data (and models) in terms of liquid phase ofwithin the ground should consider different origin, evolution, physico-chemical properties and hence different values of the electrical resistivity of the aqueous solutions.

As regards the deep resistive structures (up to 10000 Ωm) in the models of ERT_P1_Par (Fig. 6) and ERT9 (Fig. 7), there is a clear difference in their lateral extent even though the two models have different depths of investigation. While ERT_P1_Par presents a laterally homogeneous deep resistive region, ERT9, which is placed in the mine area, discloses a heterogeneous resistivity distribution that can be explained by complex hydrological dynamics or even by the traces of the past mining activity/tunnels, that are not mapped nor available. The lateral variability of the deep structures of the resistivity model of ERT9 was not surprising because it was already evident in the data, i.e., the apparent resistivity pseudosections of the mine area (see ERT4-9 in the repository) and also because there is evidence of heterogeneous permafrost since Orvin (1934). 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 as a possible source of electrical resistivity anomalies (Orvin, 1934). Decades of coal mining exploitation produced a dense network of tunnels, boreholes and pits in a number of mines. To the knowledge of the authors, information about the mine area is neither well organized in a systematic GIS database nor completely available in English language, except for a report of the mining activities in 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. ERT4 to ERT9 were acquired in the area of the ruins of the past exploited mines, where few abandoned entrances of the past tunnels could be recognized from surface because they are somehow preserved as the cultural heritage of Ny-Ålesund. Therefore, it may be inferred that the mine channels and abandoned empty or saturated tunnels affected the ERT data albeit their maps are not available. 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 mine area hosts Ester Spring, that had a scarce water flux in July 2022 and almost no water in August 2022. The ERT profiles that cross Ester Spring are ERT5-7, where the apparent resistivity pseudosections clearly show an electrically conductive region below the spring.

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 ERT data acquired with the maximum electrode spacing (10 m) provided the largest depth of investigation, i.e., around 100 m. The ERT data set is unlikely supposed to provide clear evidence of the bottom of the permafrost. Increasing the depth of investigation would be of uppermost scientific interest, given the deep heterogeneities that emerged from our data. To do that, future ERT surveys should consider a larger electrode spacing than 10 m or other geophysical techniques, such as time-domain EM.

As regards the quality of ERT data, different levels of noise and error were recognized, ranging from high to very low. The data set provided in the repository includes complete information to allow the user to assess the quality of the data in terms of measurement errors (staking errors) as well as reciprocal errors. The measurements in the Bayelva catchment present the highest measurements errors, whereas the measurements in the piezometers area present very high quality. Future ERT surveys should pay particular attention to the contact resistance that may result high due to the gravelly or dry soil in proximity of the widespread moraine deposits.

We provided piezometer data about depth of the frozen ground, water table depth in the active layer, and water conductivity, measured at the time of the geophysical survey. The time series from a two-years continuous monitoring of various parameters directly measured in the four piezometers will be delivered as outcomes of the I2F 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).".

2. *Since the motivation of the data is to document permafrost and groundwater at your study sites, please detail what (basic) information you already see in your data:*

- What is the depth of the active layer

- What is the potential depth and extent of permafrost

- Is there any evidence of hydrological activity.

Since you have collected these data, you are also the most suited to answer those questions.
"Teasing" what you already see in the data will also increase the reuse of your dataset in the future:
- Hydrologists might want to know whether you see evidence of groundwater in your data, before they decide to reuse it or not
- Geomorphologists might want to hear about your permafrost characterisation (or what makes it impossible with the available data), so that they can design another survey, to be compared to yours.

Thank you for your comment, which gave us the opportunity to improve the manuscript. In the revised Discussion section, we have added the supposed depth/extension of the active-layer and permafrost and more information from the piezometers. We have disclosed the limitations of the current geophysical data set in identifying both the bottom of the permafrost and the evidence of hydrogeological activity. Please see the revised Discussion in the reply of the previous comment.

3. *Please proof-read carefully the revised sections for other language mistakes.*

- change "thought for food" to "food for thought" in the third line of the discussion. This might be removed if these "food for thought" are being replaced by actual interpretations.

- l.166 "an amount of water larger the past is observed to melt and drain to the tongue of the glacier". Is there a word missing?

- l. 168 "abovementioned" change to "above-mentioned"

Thank you for your corrections. Everything has been corrected, as suggested.

4. *Figure 3, 8 and 11 should have larger text. Please provide plots with higher resolution and without background artefacts (gray background in figure 3 and line between panels in figure 11)*

Thank you for your comment. The label text of Figs. 8 and11 was enlarged. The quality of Fig. 3 has been improved as well.

5. *Please label each panel in the multi-panel figure with (a), (b), (c)... Please mention these labels when describing each panel in the caption. Please use these labels in the text whenever a figure is mentioned: e.g. "we can see in fig3a that X and in fig3b that Y". For conciseness, please only show the figures/panels that are actively described in the text. If a figure/panel is an intermediate step but not a crucial result, or if it is just a "nice-to-have" illustration, please move it to the supplementary materials.*

Thank you for your comment. The panels of Figures 3, 4, 7, 8, 9 have been renamed.

6. ***Please add a depth scale (on the right side) to Figure 11 using your estimation of wave velocity. You here give one value. Should that value be used for all transects? Please repeat this estimation for each transect if necessary.***

Thank you for your comment. We decided not to show the depth scale on the right axis of Figs. 10 and 11, but we gave all the processing details in Section 4.2 for both antennas (40 and 400 MHz). The values for the processing reported in Section 4.2 can be used to the transects acquired at 400 MHz as the presence of some hyperbolae allows to estimate the e-m wave velocity. The data acquired at 40 MHz refer to a significantly greater depth of investigation and the absence of obvious reflectors (hyperbolae) and the scarce availability of hydrogeological information do not allow us to assume a single value for the migration of the radargram without carrying out an excessive simplification not consistent with the possible heterogeneity of the subsoil.

We have revised Section 5.3: "Fig. 11 shows the results obtained with the 40 MHz antenna for profile GPR_long_40 which is the only one acquired at low frequency. 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~~Later than this time, the presence of attenuation phenomena seems not~~ to provide~~providing the possibility of identifying hydro~~-~~geological features. However, some discontinuities seem to characterize the radargram ~~in particular~~ at ~~the distance of~~ 450 ~~meter~~ m of distance from the starting point of the radargram, where there is the Bayelva River. Even though Figs. 10 and 11 do not include the depth scale, all the processing details are provided in Section 4.2 for both antennas (40 and 400 MHz). The values for the processing reported in Section 4.2 can be applied to the GPR data acquired at 400 MHz as the presence of some hyperbolae allows the estimation of the EM wave velocity. The GPR data acquired at 40 MHz reach a depth of investigation significantly higher than that at 400 MHz. The absence of clear reflectors (hyperbolae) and the scarce availability of prior hydrogeological information prevented the assumption of a single value for the migration of the radargram, which would have yielded an excessive simplification potentially inconsistent with the expected heterogeneity of the subsurface.".

7. *You provide 5 references from T.I. Beka. One of them is a phd thesis: is there any information in the thesis that does not appear in the other peer-reviewed publications? If not, please prefer peer-reviewed sources. Is that the only team that has applied EMI in Svalbard? If not please diversify your sources.*

Thank you for your suggestion. The reference of the PhD thesis has been removed. The other references were kept because they are pertinent and significant for our study area.

8. *Thank you for the additional information about the mining activities and the springs. Please make clear whether your transects are located over mined channels. If they are not mapped, do you see any evidence of open channels at or nearby your transects? In the discussion, it seems very appropriate to discuss whether you see any evidence of water around Ester Springs.*

Thank you for your comment. We have revised Section 5.2 to highlight that ERT9 is placed close to Ester Spring:

"Another representative example of results is ERT9, that was acquired with 10 m of electrode spacing and with different quadrupole configurations (DD, WS, WE). ERT9 is located in the mine area and close to Ester Spring. The inversion results for ERT9 are presented in Fig. 7. …".

We have revised the Discussion (see the reply to comment n.1) in order to add information about the influence of the past mining activity and of the spring on our ERT data.