## Revisions and responds to reviewer 1's comments

This is a review of the manuscript titled "Thermokarst lakes disturb the permafrost structure and stimulate through-talik formation in the Qinghai–Tibet Plateau, China: A hydrogeophysical investigation" by X. Ke et al. This manuscript details an investigation primarily focused on geophysical measurements related to permafrost properties around lakes in the Qinghai Tibet Plateau. The main objective is to characterize permafrost structure and the morphology of sublake taliks using direct current electrical measurements and time-domain electromagnetic measurements of permafrost electrical properties. Overall, the text is written clearly and English usage is good. The manuscript lacks a clearly articulated science question, and therefore it is challenging to determine if the main objective of the research was achieved. Additionally, concerns are raised below about geophysical data acquisition, processing, and presentation – while it is not clear that there are detrimental issues with the methods at this point, insufficient information was provided to fully evaluate these issues.

*Response: We sincerely thank Reviewer 1 for taking the time to review our manuscript again and providing valuable suggestions and comments, which helped us to improve this article considerably. We are very sorry that your comments and suggestions were not fully dealt with in the last round of revision. Meanwhile, we also admit that there are some shortcomings in our research and look forward to their resolution in future studies. Here, we have made every effort to respond to your comments and revise our manuscript. Following are point by point responses to his/her comments. Reviewer 1's comments are written in normal fonts and our responses are presented in italics and blue.*

**Specific Comments:**

1. The research question remains unclear. In the manuscript, I was unable to locate the word "question" nor any use of a question mark "?" – a question has not been posed here, and therefore it is difficult to determine if the authors have answered the research question. Furthermore, there is no evidence of a hypothesis that is stated or tested.

*Response: We thank the Reviewer for pointing out the missed research question in the introduction section. Reviewer 3 mentioned this, too. Following the Reviewer's comments, we* *have added the research questions that need to be solved in this paper at the beginning of the fourth paragraph of the introduction. The corresponding text was rephrased as "Given the widely distributed thermokarst lakes and the paucity of information about permafrost degradation under their influence, we aim to answer the following questions: (1) What is the characteristic of permafrost structure (spatial distribution and thickness)? (2) How do thermokarst lakes affect the permafrost distribution? To answer these questions, we combined ERT, TEM, and GTM methods to obtain the characteristics of sublake taliks and permafrost structures in the Qinghai–Tibet engineering corridor. ERT and TEM measurements were used to map the permafrost distribution, whereas GTM helped record the thermal state of the sublake taliks and was used to verify the ERT and TEM results".*

2. Line 151: The measurement parameters for TEM are confusing. The authors state that a 40,000 m^2 loop was used for transmitting, however, this is an unusually large loop size for such shallow measurements. Typical loop areas for TEM within the top 400 m would be in the range of 1,600 m^2 to 10,000 m^2 (the vast majority being towards the lower end of this range). I was unable to retrieve any information from the manufacturer about this instrument to confirm if 40,000 m^2 is indeed correct, and if so, why such a large loop size would be used in shallow investigations (in the context of TEM, I consider anything <200 m to be a shallow target).

*Response: Thanks for your valuable comments. We understand your concerns regarding the TEM results and acknowledge the limitations of the transmitting loop size used in our field investigation. The 40,000 $m^2$ loop was selected to enhance detection capability, as the high resistivity of permafrost was expected to restrict signal penetration. Given the research constraints, we used the MSD-1, an early-generation TEM instrument developed in China, where a larger loop was also necessary to improve signal strength and signal-to-noise ratio. However, data processing revealed a greater investigation depth than initially intended. To obtain reliable shallow subsurface information, we applied a 1D inversion approach and validated the resulting model against the acquired data.*

3. Line 158: The use of the approach in Constable et al 1987 is acceptable, however, the authors do not reference (either in the manuscript or supplement) which codebase or commercial software was used for the inversions. If the authors created their own implementation of the inversion detailed in Constable et al 1987, I would encourage them to share the codebase in

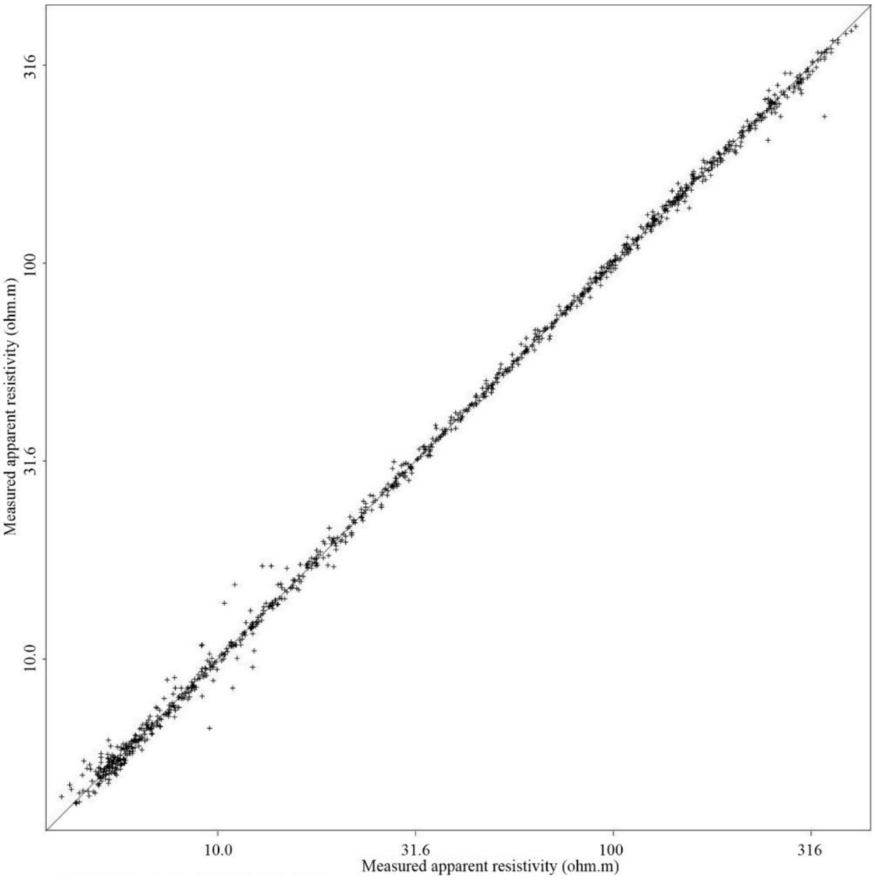
accordance with open data policies and benchmarks should be provided to demonstrate that their code produces consistent results with existing free and paid software that is available. Furthermore, key data pre-processing details are omitted.

*Response: Thanks for your attention to the details of the inversion method and for your valuable comments. We confirm that a 1D inversion based on the method proposed by Constable et al. (1987) was employed in this study. The 1D inversion was carried out in collaboration with Professor Li Xiu's team from Chang'an University, who have developed a dedicated inversion code based on this method. However, following our collaborative agreement, the code is currently not publicly available. We sincerely apologize for this limitation. We fully recognize the importance of code and data transparency in scientific research and appreciate your understanding.*

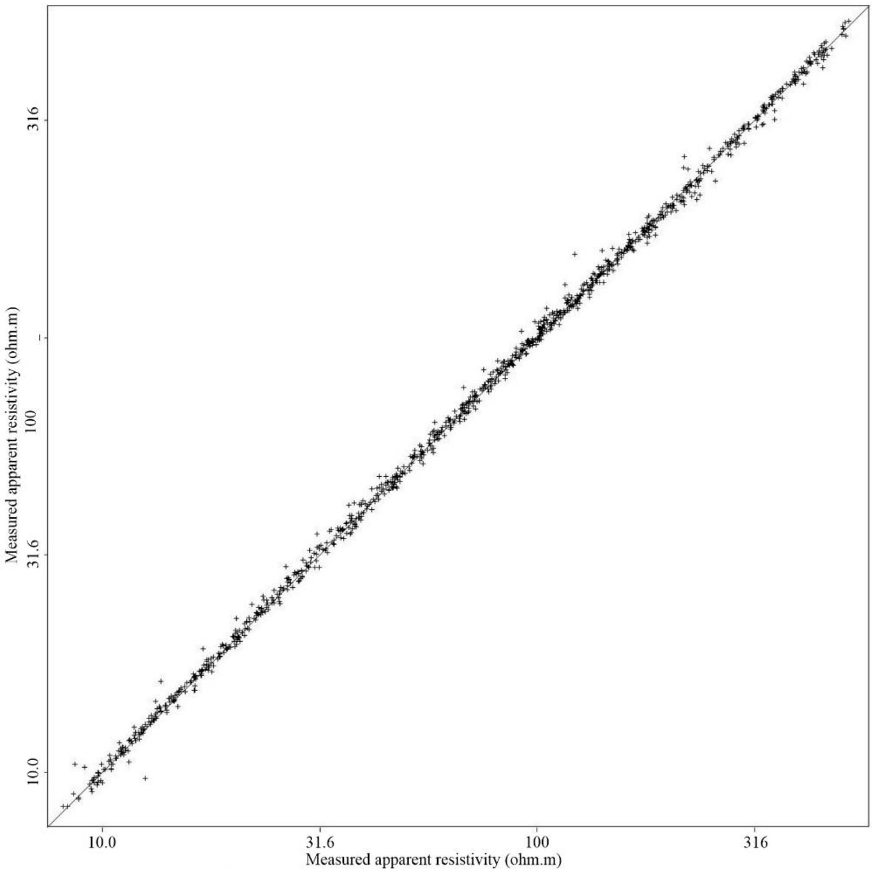
4. I appreciate that the measured and modeled TEM data are provided in Figure 6 (the same should be done for pseudosections of the ERT data), however these figures seem to reveal that much of the apparent electrical structure has not been fit during the modeling. This is evidenced by the spread of the data and non-linearity of the relationships shown in Figure 5 particularly (but also in Figure 6). In conjunction with the sparse information on TEM pre-processing and inversion make me concerned about the reliability of the TEM results.

*Response: Thanks for your valuable comments. We have used the same processing for pseudosections of the ERT data, and added the relevant figure (provided by RES2DINV software ) and clarifications in the supplementary material and revised manuscript, respectively. Unfortunately, the RES2DINV software cannot export these data for plotting. Therefore, we used and processed pictures printed by RES2DINV, which might result in a relatively low clarity of the pictures.*

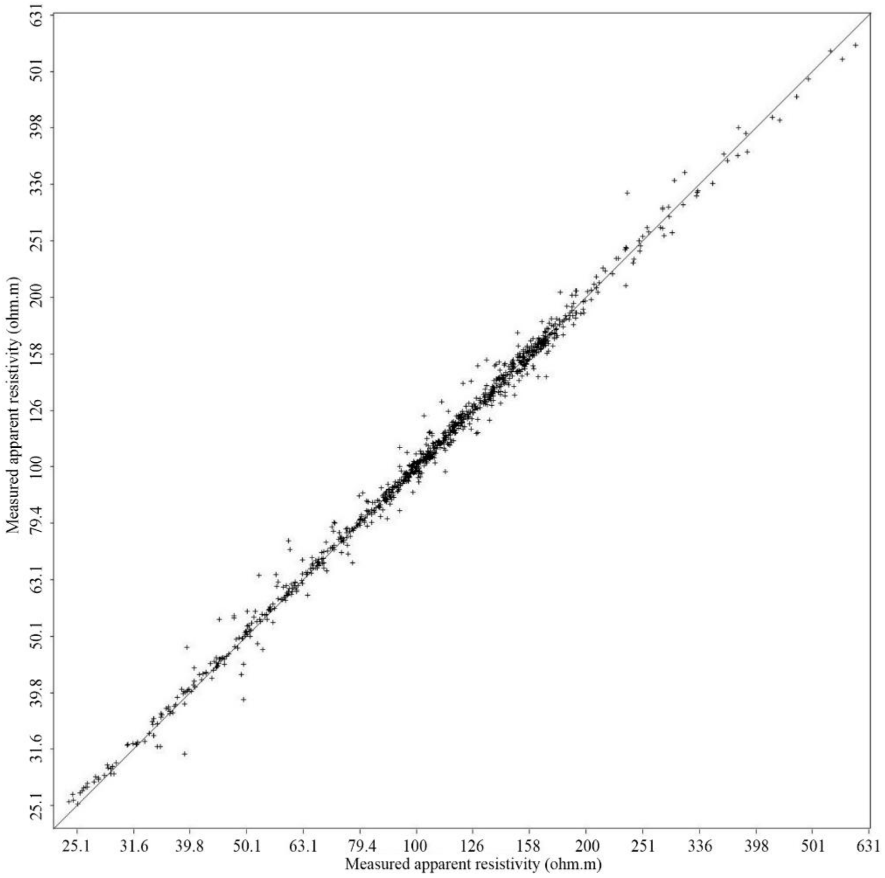
*We also sincerely appreciate your continued attention to the reliability of the TEM results. We fully understand your concerns and acknowledge the limitations of our study. In the revision, we have added explanations regarding possible sources of errors and the constraints of our survey strategy. Investigating permafrost structures in the QTP presents significant challenges. To the best of our knowledge, this is the first study in which GPM and GTM are employed to obtain information on deep permafrost and sublake taliks in the QTP. We are grateful that your thoughtful feedback helped reveal these shortcomings, which will be highly valuable for improving future research. Thank you again for your understanding and constructive* *suggestions.*



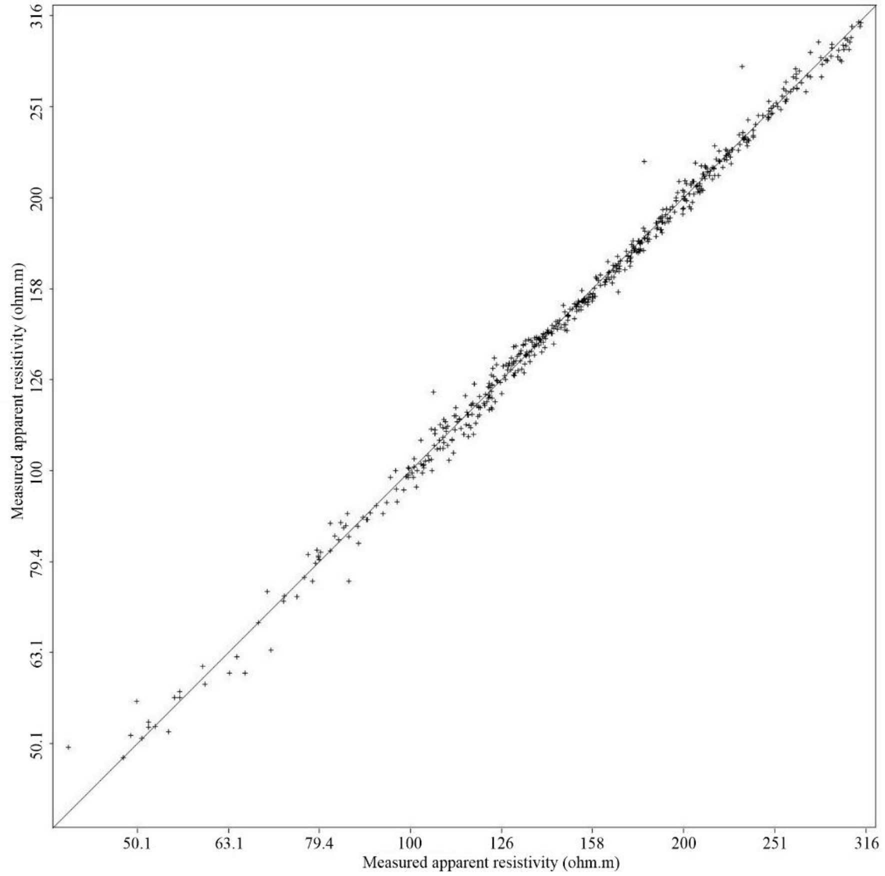

ER1



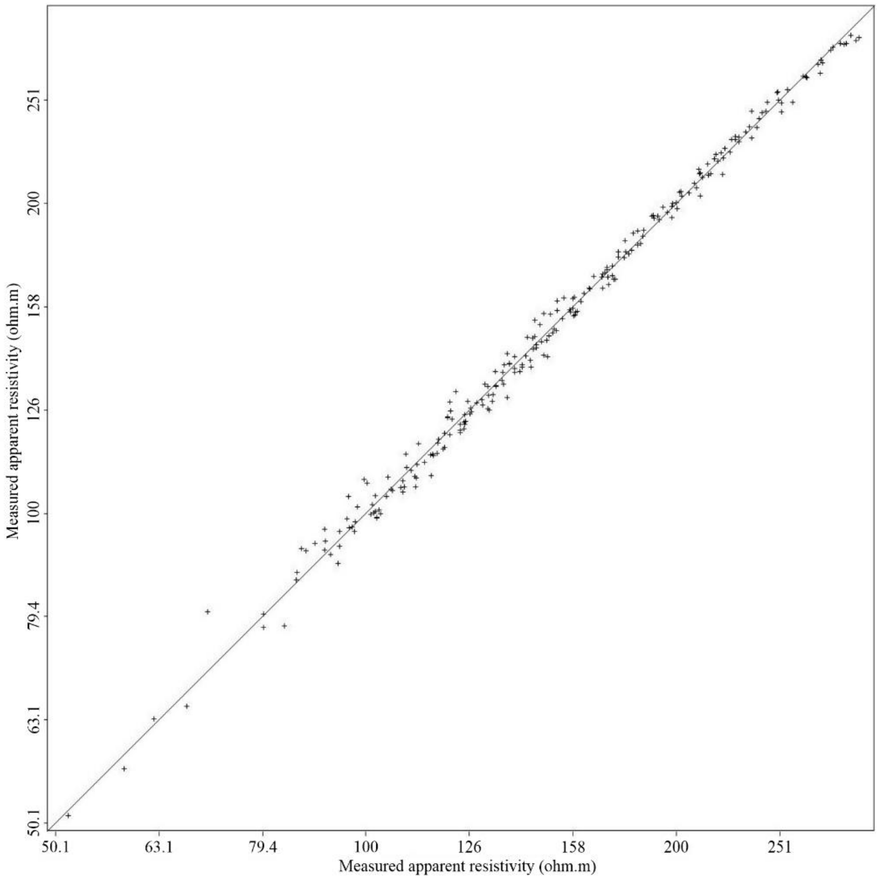
ER2


Measured apparent resistivity (ohm.m)
25.1
31.6
39.8
50.1
63.1
79.4
100
126
158
200
251
336
398
501
631
Measured apparent resistivity (ohm.m)

ER3


Measured apparent resistivity (ohm.m)
50.1
63.1
79.4
100
126
158
200
251
316
Measured apparent resistivity (ohm.m)

ER4



ER5

***Figure S1: Comparison between calculated and measured apparent resistivities for ER1 to ER5. In the supplementary information, it is presented as two side-by-side images.***

5. Line 190: The method to calculate the maximum detection depth is not stated.

*Response: Thanks for your comment. We acknowledge that the method for estimating the maximum detection depth was not explicitly stated in the previous version. We have clarified this in the revised manuscript. Generally, the maximum detection depth is 1/5 to 1/6 of the transect length (790m), that is, 132 to 158m. The calculated depth of 141 m was determined by RES2DINV based on the electrode configuration and maximum spacing used in the data acquisition. This depth ensures a balance between sensitivity coverage and numerical stability during inversion.*

6. Line 193: "lack of borehole temperature measurements" I don't understand this, ground temperature to >50 m is presented in figure 3, and can easily be modeled to greater depths. Temperature correction should be considered for all geoelectrical images given that large

temperature gradients may be present in the subsurface (e.g., Figure 3), particularly within the top 5-10 meters.

*Response: Thanks for your valuable comment. Temperature gradients can be used to estimate ground temperatures at greater depths. We have deleted this statement. Moreover, we have estimated the thawing depth (depths of 0℃) below lake BLH–A by using ground temperature and temperature gradients, which helped us to judge whether there was a through-talik below lake BLH–A. We fully agree that temperature correction for geoelectrical images is important. Although we wanted to make this beneficial improvement based on your suggestions, we gave up due to the time difference between temperature and resistivity measurements. We will be very glad to carry it out if you have any better suggestions. Nevertheless, we will benefit greatly from these valuable comments in our future work.*

7. Line 324: How was ALT interpreted from this image? It is unwise, if not impossible, to reliably interpret ALT from ERT data because 1) at any reasonable electrode spacing, the ALT will be too close to the surface to image because the layer thickness is ~1x – 4x the electrode spacing and may only occupy 1 or 2 vertical elements in the mesh, and 2) ERT images are inherently smooth and do a poor job of resolving sharp interfaces such as encountered at the ALT.

*Response: We agree with the reviewer that ERT has limitations in resolving shallow features such as the active layer thickness (ALT). To improve near-surface resolution, we used a 2 m electrode spacing. We inferred the ALT using a consistent resistivity threshold that was used in inferring the lower boundary of the permafrost, and the ground temperature information was referred to.*

8. Section 3.3: What is the purpose of this section? It does not appear to play a role in the Discussion section (i.e., Figure 9 is not referenced in the discussion, nor are observations from GTM explicitly discussed in the context of the geophysical measurements and previous research), and if not, why is it included? Presumably the authors would want to consider all of their presented work in the context of other results.

*Response: Thanks for your comments. Ground temperature monitoring is the most effective method to determine the state of permafrost. We hope to determine the permafrost structure and* *talik by using the thermal state below the thermokarst lake. Moreover, the temperature below the lake BLH–B decreased first and then increased, suggesting the complete disappearance of the permafrost and the formation of a through-talik. Unlike lake BLH–B, the temperature below lake BLH–A continued to decrease with increasing depth, implying the possible existence of permafrost or a permafrost-free zone below the borehole bottom. We have added the calculation of the thawing depth in the supplementary information (reach 73.38-87.21 m) below the lake BLH–A using the ground temperature gradient. As the depth increases, the geothermal gradient decreases. Therefore, the thawing depth may be greater than 87.21 m. The lower limit depth of the permafrost estimated by the borehole temperature (Lin et al., 2010) and by the hydrogeophysical investigation are 85 m and 84-100 m, respectively. Therefore, we infer that a through-talik had also formed below lake BLH–A (formed 800 years ago determined by the $^{210}$Pb and $^{137}$Cs). Additionally, we want to use the temperature data of the active layer to correspond to the thickness of the active layer revealed by the ERT. Therefore, Section 3.3 (Ground temperature below and around thermokarst lakes) existed.*

*Lin, Z., Niu, F., Ge, J., Wang, P., Dong, Y., 2010. Variation characteristics of the thawing lake in permafrost regions of the Tibetan Plateau and their influence on the thermal state of permafrost. Journal of Glaciology and Geocryology 32(2), 341-350. (in Chinese)*

| *Selected depth (m)* | *Temperature at the selected depth (℃)* | *Ground temperature gradient (℃ m$^{-1}$)* | *Permafrost lower boundary depth (m)* |
|---|---|---|---|
| *31.4* | *4.16* | *-0.095* | *73.38* |
| *41.4* | *3.05* | *-0.084* | *77.67* |
| *51.4* | *2.05* | *-0.057* | *87.21* |

9. Section 3.4 may be better suited for the Discussion section, and if moved, should be augmented with appropriate references.

*Response: This is a good suggestion, and we appreciate the reviewer's contributions to enhancing the readability and fluency of the paper. We have moved Section 3.4 to the Discussion section to become the new Section 4.1 and augmented some appropriate references. The revised texts are as follows:*

**4.1 Comparison and unification of detection results**

*The maximum lower limit depths of the permafrost for ER3 and TE2 (in the distance range of*

*250–525 m) were 93 and 96 m (Figs. 4h and 8b), respectively, suggesting they describe a similar permafrost structure. However, the results of ER1 and TE1 in the distance range of 341–734 m were different, with the maximum lower limit depths of the permafrost for ER1 and TE1 being 34 m and 85 m (Figs. 4b and 8a), respectively. Similar differences were also found for shallow detection along ER3 and TE2. These differences may be attributed to the transmitting frequency (25 Hz) used in the TEM survey and simplified inversion model. A high transmitting frequency can capture shallow information; however, the lower limit of the permafrost may be difficult to obtain (Xu, 2014). Therefore, a low transmitting frequency was used, in which case the shallow layer information may be ignored (Zhu et al., 2017). Although inversion can reconstruct geological features to some extent, the simplified model cannot fully capture the complexity of geological structures. Moreover, the TEM inversion models tended to smooth abrupt resistivity changes, leading to smoothed or displaced boundaries. Additionally, the highly heterogeneous geoelectrical structure of permafrost, driven by strong freeze–thaw dynamics, may further amplify discrepancies between inversion results. The ERT method exhibited a higher resolution and accuracy for shallow layers (Li et al., 2021b), and its results were more consistent with the influence of thermokarst lakes, streams, and groundwater on the permafrost. Therefore, the maximum lower limit depths of ER1 or TE1 in the distance range of 341–734 m were determined to be 34 m. Additionally, the maximum lower limit depth of the permafrost for ER2 was 100 m, which was close to those for ER1 (84 m), ER3 (93 m), and TE2 (96 m). As compared above, the maximum lower limit depth of the permafrost (less disturbed) was in the range of 84–100 m. The ALT inferred from the ERT was in the range of 0.9–4.0 m (the average level was 2.45 m), which was close to the result of the borehole temperature ($S_1$ and $S_2$ in September 2019 were 2.45 and 2.76 m, respectively) (Xu et al., 2023). Based on the ER of ER1 (Fig. 4b) and borehole temperature measurements in lakes BLH-A and BLH-B (Figs. 9a and b), it can be inferred that a through-talik had formed below lake BLH-C. The temperature monitoring results of lake BLH–A indicated the formation of a through-talik below lake BLH–A (Fig. 9a) (Lin et al., 2017). Similarly, the ground temperatures ($L_B$) and the results of ER2 jointly revealed the complete degradation of the permafrost below lake BLH–B, forming a through-talik (Figs. 4f and 9b). Overall, the hydrogeophysical investigations clarified the permafrost structure and the effect of thermokarst lakes and groundwater on permafrost.*

*Li, M.N., Zeng, Y.J., Lubczynski, M.W., Roy, J., Yu, L.Y., Qian, H., Li, Z.Y., Chen, J., Han, L., Zheng, H., Veldkamp, T., Schoorl, J.M., Franssen, H.J.H., Hou, K., Zhang, Q.Y., Xu, P.P., Li, F.,* *Lu, K., Li, Y.L., Su, Z.B.: A first investigation of hydrogeology and hydrogeophysics of the Maqu catchment in the Yellow River source region. Earth System Science Data., 13(10), 4727-4757. doi: 10.5194/essd-13-4727-2021.*

*Lin, Z.J., Niu, F.J., Fang, J.H., Luo, J., Yin, G.A.: Interannual variations in the hydrothermal regime around a thermokarst lake in Beiluhe, Qinghai-Tibet Plateau. Geomorphology., 276, 16-26. doi: 10.1016/j.geomorph.2016.09.035.*

*Xu, J. The study and application of transient electromagnetic sounding on the theoretical depth of investigation. Master's Thesis, East China University of Technology, Fuzhou, China. (in Chinese)*

*Xu, Z.D., Jiang, L.M., Guo, R., Huang, R.G., Zhou, Z.W., Niu, F.J., Jiao, Z.P.: Interaction of permafrost degradation and thermokarst lakes in the Qinghai-Tibet Plateau. Geomorphology., 425. doi: 10.1016/j.geomorph.2023.108582.*

*Zhu, X.G., Fu, Z.H., Su, X.F., Qin, S.Q.: Frequency-domain analysis for pulse current sources in transient electromagnetic method. Near Surface Geophysics., 15(2), 155-162. doi: 10.3997/1873-0604.2016051.*

10. Figure 1: It is unacceptable to have the tomograms on different color scales because it makes unbiased interpretation impossible. Each tomogram in this figure must be presented on the same colorscale. Also, I suggest considering the current consensus on colormaps for the presentation of scientific results, and pick one that is more accessible: Crameri, F., Shephard, G. E., & Heron, P. J. (2020). The misuse of color in science communication. Nature communications, 11(1), 5444.

*Response: Yes, the Reviewer is right! We thank the Reviewer for pointing out this error again. We agree with Reviewer 1 that each tomogram in this figure must be presented on the same color scale. Following the Reviewer’s comment, we have redrawn the figures and attached them below. First of all, we used the same color scale and the same threshold for all transects. However, for the ER1 transect, the maximum depth of permafrost is less than 40 m (Figure A), which is quite different from the results of borehole temperature, TEM, and other sections. There are significant differences in the range and spatial distribution of their resistivity due to the different environments (water bodies and permafrost distribution) in each transect. We comprehensively considered resistivity and its variations to infer the permafrost boundaries.*

*Therefore, we also consider using the same color scales but with different thresholds for ER1 and other sections (Figure B) to determine the permafrost structure of each transect. We think the second plan is more reasonable.*

*To fully address the Reviewer's concern, we present both options for consideration. While both approaches have merits, we believe that Figure B provides a more accurate representation of the permafrost structure. However, we would greatly appreciate the Reviewer's opinion on this matter and are happy to revise accordingly.*

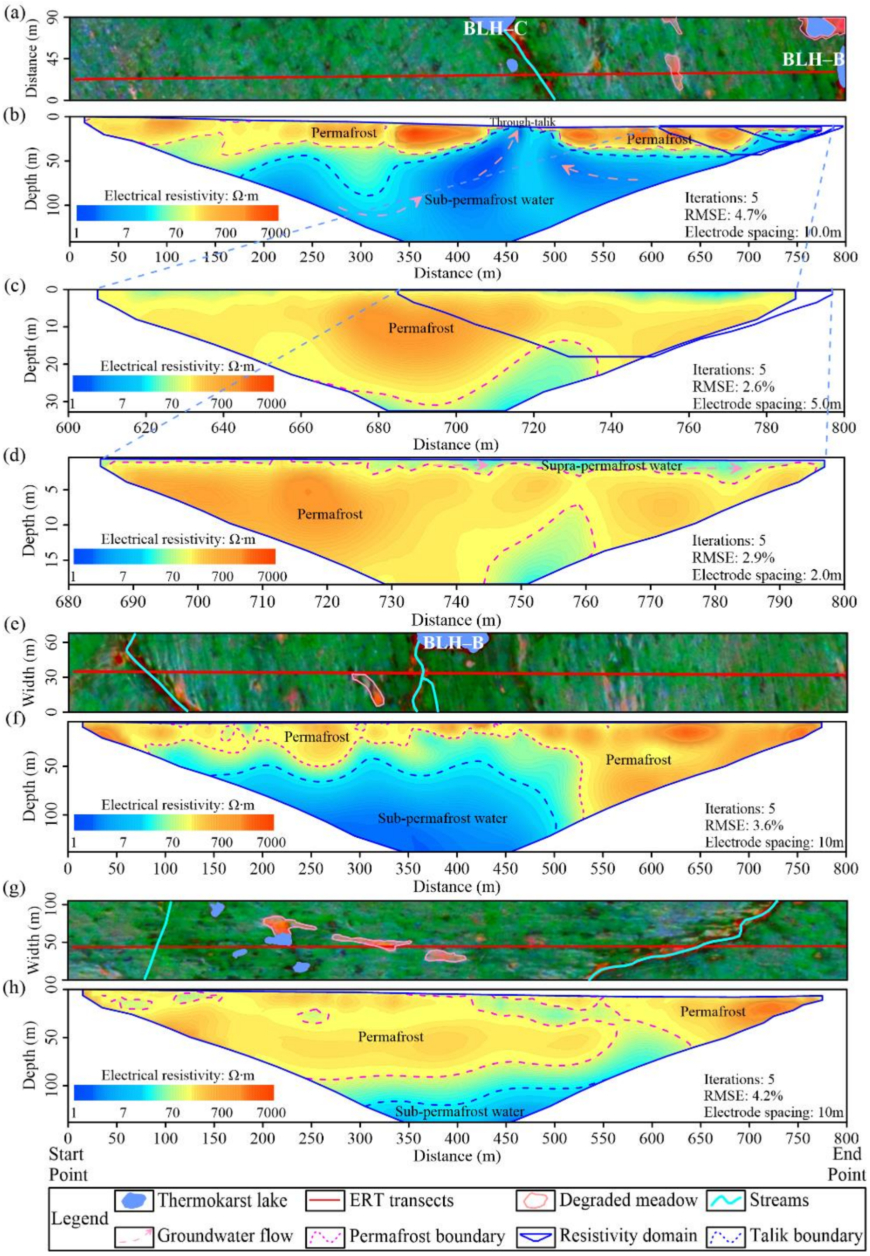



***Figure A: Inversion results of ER1 (b), ER4 (c), ER5 (d), ER2 (f), and ER3 (h) that used the same threshold.***

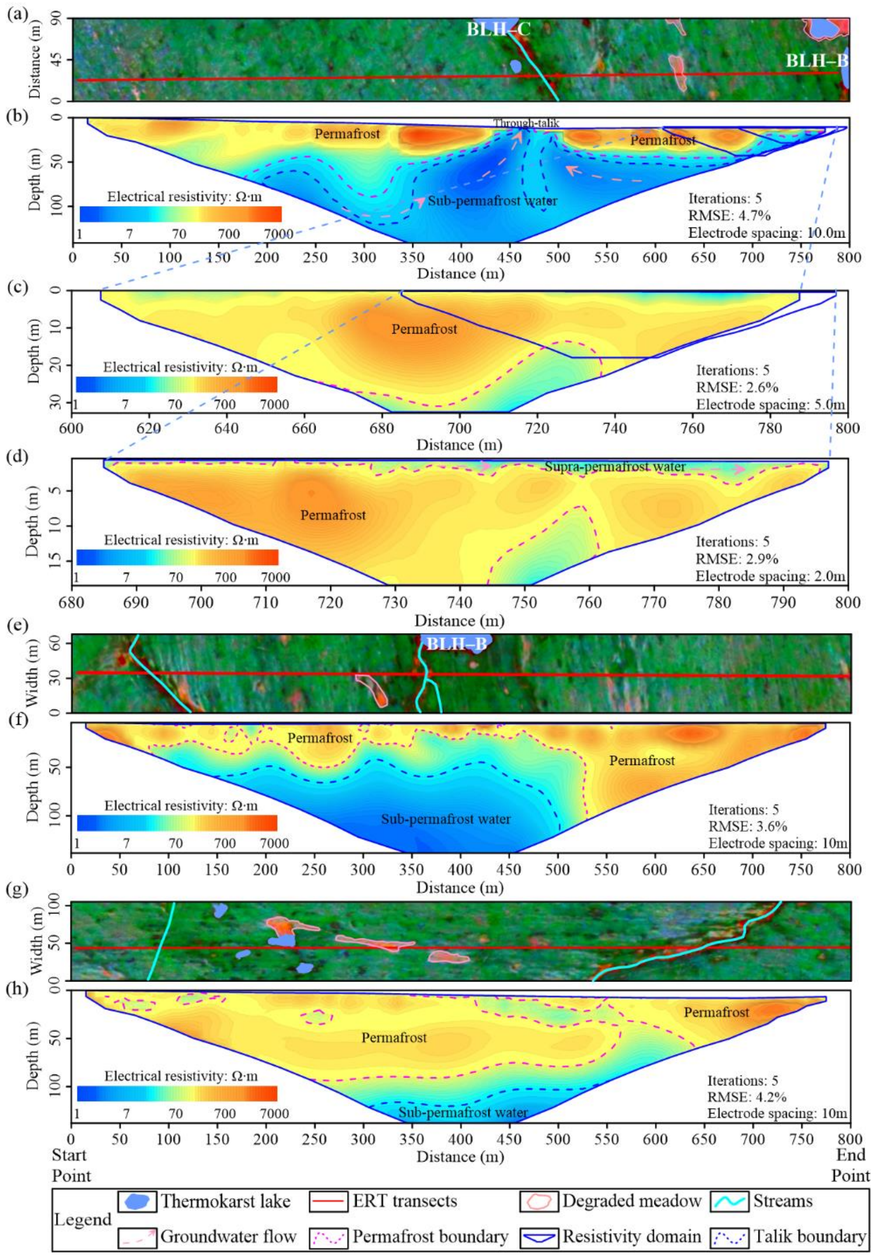



***Figure B: Inversion results of ER1 (b), ER4 (c), ER5 (d), ER2 (f), and ER3 (h). The threshold of ER1 is different from that in other sections.***