Response to Referee #1

We appreciate you very much for your comments concerning our manuscript entitled "Permafrost temperature baseline at 15 meters depth in the Qinghai-Tibet Plateau (2010–2019)" (MS No.: essd-2024-114). Those comments are valuable and helpful for improving our manuscript. We followed all comments and made revision and responses carefully. Revised portions are marked in red in the revised manuscript. The line, and figure numbers refer to our revised manuscript. And, a point-by-point reply to the comments are listed below.

Main comments

1. Overall, the paper is well presented based on outstanding field and model works. The data and metadata as well as methodology presented in the paper are very helpful to the geoscientists and engineering in cold regions. We all know that data sharing in permafrost temperature study has been rather difficult. These ground temperature data are thus invaluable in evaluating the thermal state of permafrost and for validating many geocryological, hydrological, ecological and land-surface processes models, and for engineering design and construction in elevational permafrost regions.

   The structures of the paper are well thought out and basically follow the ESSD mandates. However, the authors are encouraged to tell more on the methods of air and ground temperature measurements and their evolutionary paths, since different measurements methods can result in false trends in climate or permafrost changes. For example, your FDD or TDD or your MAGT@DZAA is based on ground or air temperature measurements, and the methods have been advancing rapidly. In the same time, the authors should be more explicit on the criterion selection as why 15 m can be regarded as the DZAA, for which it is evidently illogical. In the meantime, positive MAGT does not necessarily means absence of permafrost because of extensive and increasing presence of supra-permafrost subaerial talik, especially to the east of the QTEC from Golmud-Lhasa and along the engineering lines. Thus, a criterion of subzero MAGT for judging the occurrence of permafrost may underestimate the permafrost extent. That means, you have to be cautious of areas with rapidly or chronically degrading permafrost. Lithology and soil moisture contents are key in defining local or regional DZAA, ALT and MAGT. Thus, using a given depth of either 10 or 15 m as DZAA seems not so reasonable. Thus, if you chose 15 m as the DZAA, you'd better convince readers that your choice is acceptable.

Response:

We sincerely appreciate your thorough and insightful review of our manuscript. After carefully considering your comments, we have provided detailed responses to each of the concerns and suggestions you raised.

1. The measurement methods of FDD/TDD and MAGT and their evolution.

In early studies, the calculation of Freezing Degree Days (FDD) and Thawing Degree Days (TDD) primarily relied on air temperature (AT). However, the presence of buffering layers, e.g., snow cover and vegetation, introduces significant discrepancies between AT and ground surface temperature (GST) across different permafrost regions. To account for these variations, the relationship between AT and GST is often expressed using n-factors (Riseborough et al., 2008). With the development of remote sensing techniques and ground-based observations, more and more permafrost mapping studies are utilizing GST as a substitute for AT in model inputs, particularly with the widespread application of MODIS land surface temperature (LST) data (Zou et al., 2017; Obu et al., 2019). Additionally, some studies have demonstrated the superiority of GST in simulating the thermal state of deep permafrost (Luo et al., 2018). Therefore, based on the MODIS LST product, this study utilizes ground-measured GST data for calibration to obtain regional GST data, which is then used as input variables for the model. To more clearly express this evolution, we have taken the manuscript context into account and added the following description in the manuscript (Line 121-122):

"*GST, corrected based on MODIS LST, was selected in this study due to its superior performance over air temperature in permafrost modeling (Luo et al., 2018).*"

For the measurement of ground temperature at various depths in the Qinghai-Tibet Plateau (QTP) permafrost regions, are predominantly conducted using thermistors chains assembled by the National Key Laboratory of Frozen Soil Engineering (SKLFSE, CAS). All the $MAGT_{15m}$ data utilized in this study, encompassing both data collected by our own observations and data obtained from the literatures during the 2010-2019, were measured using the same thermistors chains. This methodology is explicitly documented in the cited references. The chains used for these measurements employ thermistor temperature sensors with an accuracy of ±0.05 °C. These sensors are configured using a cable equipped with a string of thermistors at various depths. The standardized use of the same observational equipment provides a robust foundation for the comparability of $MAGT_{15m}$ data across different regions. We have further elaborated on this in the manuscript as follows (Line 73-74):

"*All ground temperature measurements were obtained using the same equipment, ensuring the comparability of $MAGT_{15m}$ across various permafrost regions.*"

2. Considering 15m as DZAA and the issue of talik.

We fully agree with your comment that interpreting 15 m as DZAA is evidently illogical. This misunderstanding may have arisen from unclear description in our writing as below:

"*The data of MAGT at 15 m in depth are used for spatialization, considering that DZAAs generally ranges from 10 to 15 m in the QTP (Zhao et al., 2010).*"

However, the intention of our study was not to produce a distribution map of $MAGT_{DZAA}$. To the best of our knowledge, Ran et al. (2021 and 2022) have conducted several mapping of $MAGT_{DZAA}$ across various regions, including the QTP and the Northern Hemisphere. These studies have made significant contributions to the spatial analysis of $MAGT_{DZAA}$. In contrast, our study aims to provide a fixed-depth deep ground temperature map to facilitate the estimation of permafrost thickness, thereby avoid the spatial variability issues associated with DZAA.

The selection of a depth of 15 m is based on two primary considerations. Firstly, it corresponds with the observed DZAA depth range of 10-15 m in the QTP, with the choice of the lower end of this range aimed at enhancing the stability of ground temperature readings, this particularly beneficial in areas with limited observational depth and data availability. Secondly, this depth corresponds with the extent of existing boreholes, thereby facilitating the integration of a larger dataset into the mapping process.

Although our $MAGT_{15m}$ map exhibits similar spatial patterns to existing $MAGT_{DZAA}$ map, it is fundamentally distinguished by its theoretical framework within permafrost research. The key difference lies in depth: DZAA varies spatially, whereas $MAGT_{15m}$ represents a constant depth.

The adoption of $MAGT_{DZAA}$ as a reference for our $MAGT_{15m}$ mapping is due to the relative scarcity of research on deep permafrost temperatures. $MAGT_{DZAA}$ stands out as one of the few indexes with notable advancements in this area. In contrast, there is a lack of comprehensive studies on deeper ground temperatures based on observed data, largely due to the challenges associated with obtaining such observations. We have undertaken considerable efforts to collect and compile the $MAGT_{15m}$ data during 2010-2019 to support the completion of this study.

To avoid any ambiguity, we have revised the sentence as follows (Line 58-61):

"*This study aims to establish a fixed-depth deep permafrost temperature baseline using data from the QTP for a decade (2010-2019) and a machine learning approach to address the limitations associated with the use of $MAGT_{DZAA}$. Considering the availability of ground temperature records, the data of MAGT at 15 m in depth are used for spatialization.*"

"*In the meantime, positive MAGT does not necessarily means absence of permafrost because of extensive and increasing presence of supra-permafrost subaerial talik, especially to the east of the QTEC from Golmud-Lhasa and along the engineering lines. Thus, a criterion of subzero MAGT for judging the occurrence of permafrost may underestimate the permafrost extent. That means, you have to be cautious of areas with rapidly or chronically degrading permafrost.*" Your suggestions above indeed highlight one of the key challenges faced in the mapping work of this study. Initially, we considered keeping some positive $MAGT_{15m}$ values to ensure coverage of most permafrost exist regions. However, due to the high variability in geothermal gradients of the permafrost base, determining an appropriate positive MAGT threshold proved challenging. After carefully reviewing your comments, we have followed the conventions of previous studies and retained regions with MAGT < 0.5 °C in the revised manuscript, to encompass areas where talik is more likely to be widespread. To ensure the reliability of permafrost temperature analysis, we did not reanalyze data with $MAGT_{15m}$ > 0°C in the *Result section* of the revised manuscript. As an alternative, we have included a discussion of regions with $MAGT_{15m}$ > 0 °C, as outlined below (Line 255-257):

"*Additionally, permafrost may still persist in areas where $MAGT_{15m}$ exceeds 0 °C. Statistical analysis reveals that the areas with $MAGT_{15m}$ within the ranges of 0-0.1 °C and 0-0.2 °C cover approximately $0.05×10^6$ km^2 and $0.10×10^6$ km^2, respectively.*"

In addition, ESSD papers should try to avoid over-interpret the patterns or trends of data. It is supposed to tell the integral story of the data structure and functions. Please make the paper concise and on the point, avoiding unnecessary details as possible.

Response:

Thank you for your insightful suggestions. To avoid over-interpreting patterns or trends in the data, and after thoroughly reviewing your annotations, we have decided to remove certain sections of the discussion related to permafrost degradation. This adjustment ensures that the manuscript maintains a clear focus on the data structure and functionality. The specific changes are detailed in *Minor Comment 7*.

Other minor issues regarding editing of the MS are provided on the marked MS in the attached document. This is a very quick editing. It is up to authors to ensure the presenting quality to suffice the ESSD standards based on meticulous efforts.

Response:

We have thoroughly reviewed and carefully addressed each of your proposed revisions, while also correcting similar issues throughout the manuscript. We greatly appreciate your detailed feedback and constructive insights.

Minor comments

1. This sentence is problematic!!!One can hardly imagine that the Tarim Basin and the Amu Darya Basin have lowest MAGTs? Do they belong to the QTP? Are you including the Tianshan Mountains and surrounding basins, as well as the intermontane basins, in the extent of the QTP? Should the title of the paper be changed to that of the Third Pole?

Response:

The study area of this research is the Qinghai-Tibet Plateau (QTP), a natural geographical unit that spans both domestic and international regions, excluding the Tianshan Mountains and surrounding basins. The delineation of basins used in this study is derived from research conducted by the Institute of Tibetan Plateau Research, Chinese Academy of Sciences, and has been categorized into 12 major river basins. Some of these basins encompass only the headwater regions. For improved clarity, we have revised the sentence as follows (Line 20-22):

"*The $MAGT_{15m}$ was the lowest in the headwater areas of the Amu Darya, Indus, and Tarim river basins (-2.9 to -2.7 °C) and the highest in the headwater areas of the Yangtze and Yellow river basins (-0.9 to -0.8 °C).*"

2. Tarim RB is wrongly located. There should be a space between Amu Darya RB

Response:

The Tarim river basin is a major basin that includes several smaller sub-basins. In this study, it primarily refers to the headwater areas of the Yarkant River and Hotan river. To improve the figure, we have relocated the label "*Tarim*" to more precisely reflect the Tarim River's headwater region. Additionally, we have updated the label "*Amu Darya*" in *Figure 1*.

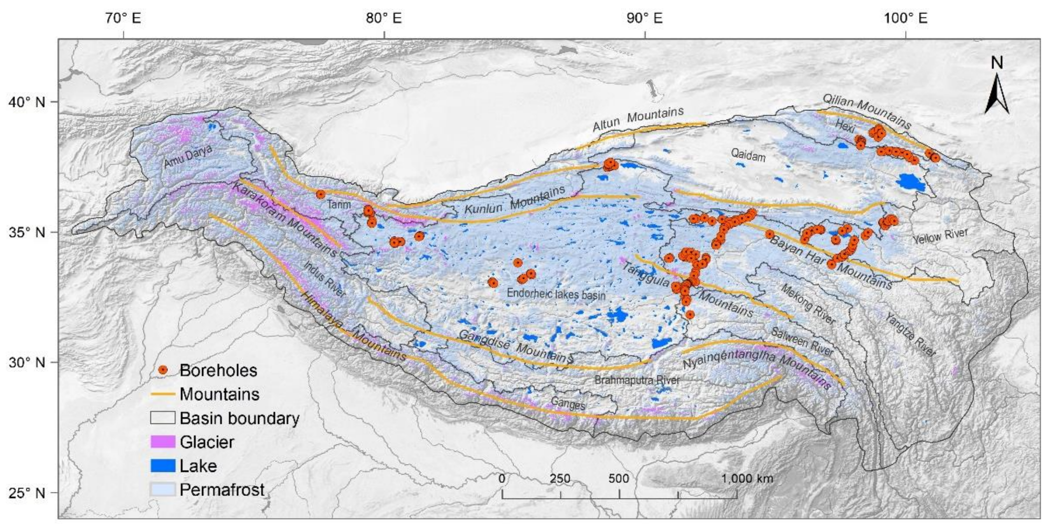

Figure 1: *Distribution of boreholes (n=231) for monitoring mean annual ground temperature at 15 m in depth (MAGT15m) on the Qinghai-Tibet Plateau.*

3. Legend items are hard to distinguish because of similar colors and the same shape. Right lower inset, Ground warming rate?

Response:

To clearly distinguish the legend items, we have updated *Figure 2* using a darker color palette, ranging from dark blue to dark red, representing the gradient of permafrost temperature from low to high. The right lower inset illustrates the relationship between warming rates and average $MAGT_{15m}$ values.

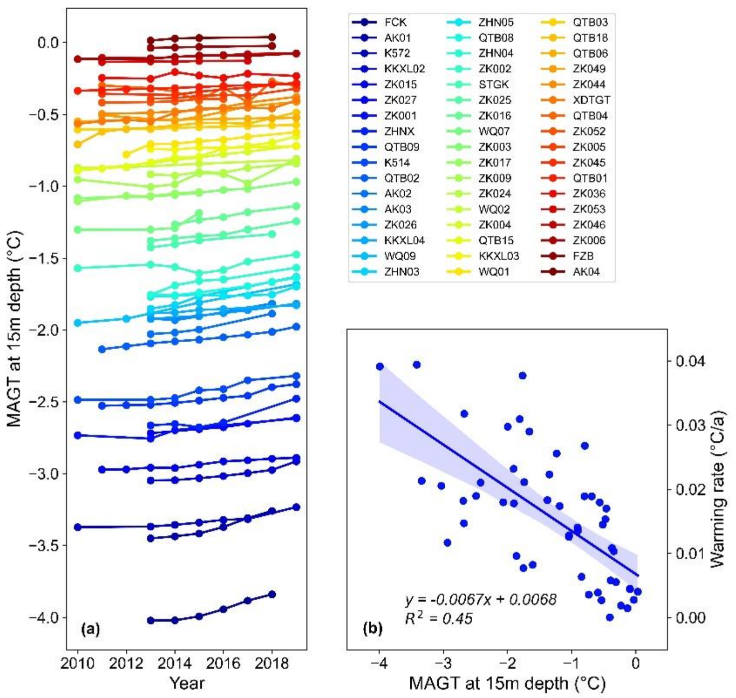

Figure 2: *Warming rates of $MAGT_{15m}$ during 2010-2019 (a) and the relationship between warming rates and the average $MAGT_{15m}$ (b).*

4. Maybe you should mark out major mountain ranges in the lowest inset.

Response:

We greatly appreciate your suggestions. In response, we have marked out the major mountain ranges to facilitate a more precise interpretation of the spatial distribution patterns of $MAGT_{15m}$.

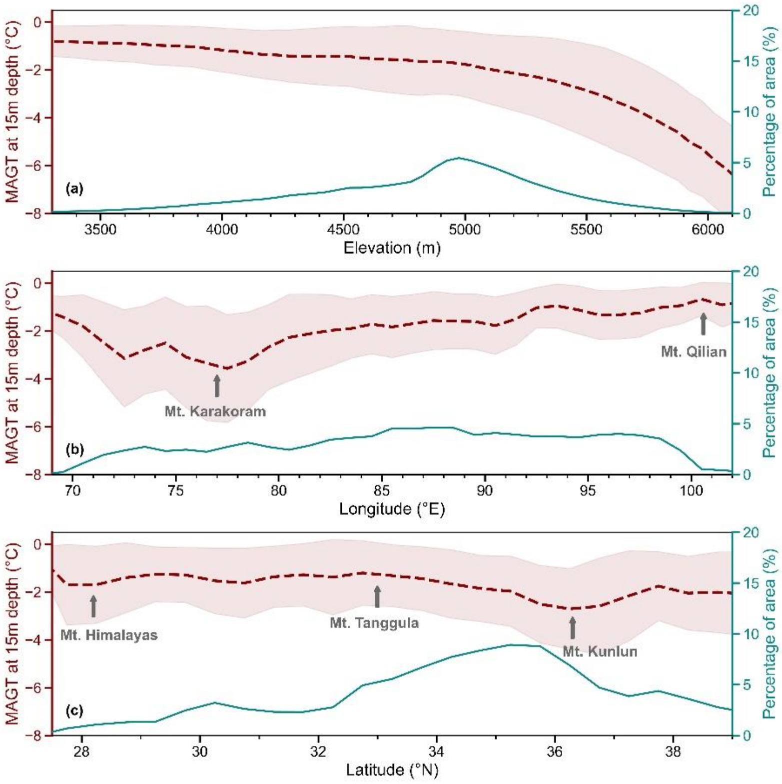

Figure 5: *Variations of mean annual ground temperature at 15m depth ($MAGT_{15m}$) along elevation (a), longitude (b), and latitude (c) transects on the Qinghai-Tibet Plateau (the dashed red line represents the mean $MAGT_{15m}$, and the light-red shaded area indicates its standard deviation; the cyan dashed line shows the areal percentage).*

5. Legend needs unit and name

Response:

We have added the legend name and unit in the revised manuscript.

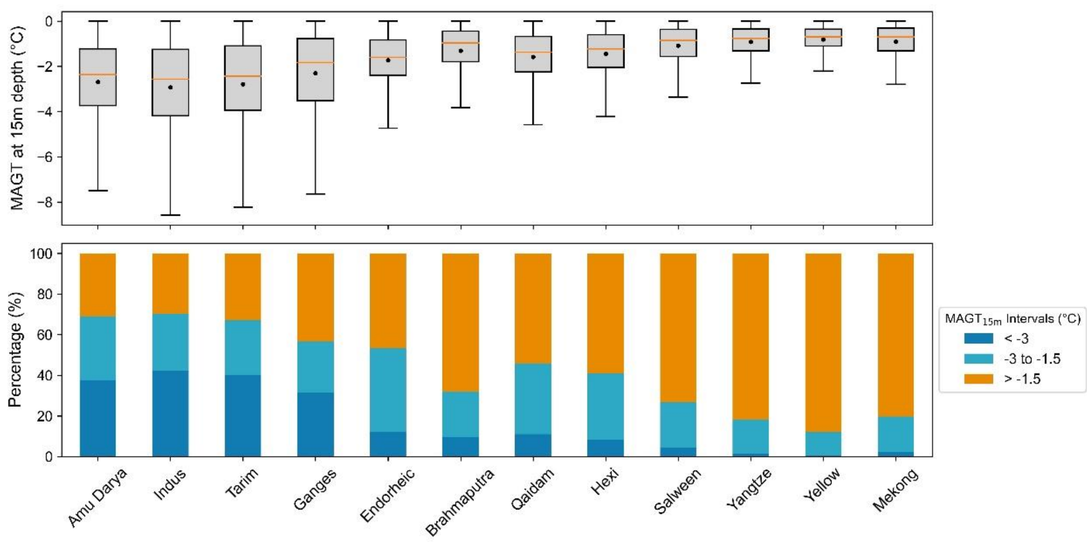

Figure 7: *Distribution (a) and percentage of area in three intervals (b) of MAGT at 15 m depth ($MAGT_{15m}$) in 12 basins of the Qinghai-Tibet Plateau during 2010-2019.*

6. Traditionally and internationally, -1.0C is regarded as the divide. If you use -1.5C, you have to logically persuade readers why would you challenge this criterion. Does Dr. Ran have the clout/right to define warm permafrost, or who else, to deviate from the tradition? Especially, on the QTP or in China, where warm permafrost dominates, why would you define warm permafrost at a lower MAGT? Would that indicate that you do not have enough proportion of cold or warm permafrost? why not -3 or -5C as have done by some Russians and Canadians?

Response:

Our initial use of -1.5 °C was aimed at maintaining consistency with the previously defined temperature ranges, facilitating a coherent discussion based on earlier figures and descriptions. After reviewing your feedback in detail, we revisited the literature and found that the -1.5 °C threshold was derived from roadbed deformation assessment studies on the QTP, where Liu et al. (2002) established this threshold based on observed pavement deformation and MAGT. However, for natural permafrost on the QTP, a threshold of -1.0 °C is more commonly used to differentiate between cold and warm permafrost (Wu et al., 2010). In the revised manuscript, we have recalculated the distribution of cold and warm permafrost using -1.0 °C as the threshold and have updated the relevant descriptions accordingly (Line 258-261).

"*Based on the classification criteria established by $MAGT_{DZAA}$, the permafrost can be categorized into cold (≤ -1.0 °C) and warm (> -1.0 °C) permafrost (Wu et al., 2010). Using the predicted $MAGT_{15m}$ data, we analyzed the distribution characteristics of permafrost on the QTP based on this classification. Cold permafrost was the dominant type, covering 63.7% of the permafrost regions, while warm permafrost accounted for 36.3% during the period from 2010 to 2019.*"

7. This is not necessarily true! Warm permafrost may have rich ice content and is slow in thawing, why colder permafrost, generally rocky and found at very high locations. In addition, the thermal inertia would work out, ans apparent head is negligible in comparison with latent heat for ice-rich permafrost regarding the thermal stability.

   ibid. This is simply not true. Many locations in Arctic and Boreal zones and on Uplands (of course on the QTP and in Central Asian mountains), permafrost has been persisted at about the freezing temperatures (close to negative zero) for a long, long time, and has not shown the trend of thaw. This is called the zero geothermal degree mode of permafrost degradation or ground temperature curve. Instead of quoting those authors working in regions from other different zones, we may look at more from those working in nearby zones of the QTP.

Response:

"Cold permafrost is characterized by rapid increased in ground temperature and slow permafrost thawing, whereas warm permafrost undergoes rapid thawing with a slower ground temperature increase (Biskaborn et al., 2019; Smith et al., 2022). This phenomenon can be attributed to the higher apparent thermal diffusivity in colder permafrost layers, where temperatures near 0 °C led to latent heat consumption by ground ice melts, resulting in lower diffusivity and less energy required to raise ground temperatures (Isaksen et al., 2011; Nicolsky and Romanovsky, 2018)."

Considering the incomplete conclusions, regional misalignment, and the style of the ESSD journal (also recommended by the other reviewer), we have decided to remove this section of text. This revision aims to maintain a clear focus on the QTP region and the data structure and functionality presented in the manuscript.

8. Compared to the thickness of the QTP, permafrost, generally a few meters to a kilometer to the best, is very shallow and on the surface of the plateau. In the QTP is generally more often used in geology and geophysics of the QTP studies. For most geographical and geocryological, glacial studies, on the QTP is more proper.

Response:

We have expanded on the significance of this study's findings in the context of geology and geophysics research on the QTP as follows (Line 277-278):

"*These validations are crucial for enhancing our understanding of QTP permafrost responses to environmental drivers and climate change. Additionally, the* $MAGT_{15m}$ *data offers critical insights for understanding geological processes and ecosystem dynamics, thereby supporting related studies in the QTP permafrost regions.*"

References:

Riseborough, D., Shiklomanov, N., Etzelmüller, B., Gruber, S., and Marchenko, S.: Recent advances in permafrost modelling, Permafr. Periglac., 19, 137–156, doi:10.1002/ppp.615, 2008.

Zou, D., Zhao, L., Sheng, Y., Chen, J., Hu, G., Wu, T., Wu, J., Xie, C., Wu, X., Pang, Q., Wang, W., Du, E., Li, W., Liu, G., Li, J., Qin, Y., Qiao, Y., Wang, Z., Shi, J., and Cheng, G.: A new map of permafrost distribution on the Tibetan Plateau, Cryosphere, 11, 2527–2542, doi:10.5194/tc-11-2527-2017, 2017.

Obu, J., Westermann, S., Bartsch, A., Berdnikov, N., Christiansen, H. H., Dashtseren, A., Delaloye, R., Elberling, B., Etzelmüller, B., Kholodov, A., Khomutov, A., Kääb, A., Leibman, M. O., Lewkowicz, A. G., Panda, S. K., Romanovsky, V., Way, R. G., Westergaard-Nielsen, A., Wu, T., Yamkhin, J., and Zou, D.: Northern Hemisphere permafrost map based on TTOP modelling for 2000–2016 at 1 km^2 scale, Earth-Sci. Rev., 193, 299–316, doi:10.1016/j.earscirev.2019.04.023, 2019.

Luo, D., Jin, H., Marchenko, S. S., and Romanovsky, V. E.: Difference between near-surface air, land surface and ground surface temperatures and their influences on the frozen ground on the Qinghai-Tibet Plateau, Geoderma, 312, 74–85, doi.org/10.1016/j.geoderma.2017.09.037, 2018.

Ran, Y., Li, X., Cheng, G., Nan, Z., Che, J., Sheng, Y., Wu, Q., Jin, H., Luo, D., Tang, Z., and Wu, X.: Mapping the permafrost stability on the Tibetan Plateau for 2005–2015, Sci. China Earth Sci., 64, 62–79, doi:10.1007/s11430-020-9685-3, 2021.

Ran, Y., Li, X., Cheng, G., Che, J., Aalto, J., Karjalainen, O., Hjort, J., Luoto, M., Jin, H., Obu, J., Hori, M., Yu, Q., and Chang, X.: New high-resolution estimates of the permafrost thermal state and hydrothermal conditions over the Northern Hemisphere, Earth Syst. Sci. Data, 14, 865–884, doi:10.5194/essd-14-865-2022, 2022.

Liu, Y., Wu, Q., Zhang, J., and Sheng, Y.: Deformation of highway roadbed in permafrost regions of the Tibetan Plateau, Journal of Glaciology and Geocryology, 01, 10-15, 2002 (in Chinese).

Wu, Q., Zhang, T., and Liu, Y.: Permafrost temperatures and thickness on the Qinghai-Tibet Plateau, Glob. Planet. Change, 72, 32–38, doi:10.1016/j.gloplacha.2010.03.001, 2010.