Dear Editor and the reviewer,

We are very grateful to your constructive comments and thoughtful suggestions. Based on these comments and suggestions, we have made thorough revisions to the original manuscript. In addition, we polished our language by the highly qualified native English-speaking editors at AJE in the revised manuscript. The changes made to the text are highlighted in blue so that they may be easily identified in the revised manuscript. Above these have led to an improvement of the paper, and we hope the revised manuscript is suitable for publication in the journal.

Yours sincerely,

Tonghua Wu on behalf of all co-authors

Response to comments:

As a staff focusing on model development and application on frozen ground and cold region hydrology, I have read this manuscript with great interest. Permafrost is an indicator of climate change. The response of permafrost to climate change is one of the critical issues in cryospheric science. The 10-year record of permafrost, active layer and meteorological data presented by Tonghua Wu et al. from a relict permafrost site of Mahan Mountain in the northeast of Qinghai-Tibet Plateau is a valuable dataset for permafrost and climate research community, especially important for model development and validation. This is a clearly written paper and the overall structure of the manuscript is well organized. In my opinion, this manuscript and dataset are an important contribution to permafrost science. Therefore I recommend that the manuscript to be accepted after some minor revisions. And I also look forward to an open access for this dataset as soon as possible after protection period.

Here are my major comments:

1 I strongly suggest to add more detailed temporal variations analysis for active layer

hydro-thermal condition and permafrost temperature, particularly for ALT; in addition, the comparison analysis with other permafrost regions is suggested to add.

Response:

Thanks for the suggestion. In the revised manuscript, we have added more detailed temporal variations analysis for active layer hydro-thermal condition and permafrost temperature, and added a section for the comparison analysis with other permafrost regions as follows:

The results revealed that the average warming rate of soil temperature at different depths was 0.056 °C /year at Mahan Mountain from 2010 to 2020 (Fig. 6a). The highest warming rate of soil temperature was 0.107 °C /year at a depth of 30 cm, while the lowest value was 0.019 °C /year at a depth of 120 cm (Fig. 6a). The average changing trend of the volume soil water content was 0.013 m^3 m^{-3}/year from 2010 to 2020, and the highest value was 0.026 m^3 m^{-3}/year at a depth of 120 cm, while the lowest value was 0.005 m^3 m^{-3}/year at a depth of 10 cm (Figure 6b). (Line 305-311)

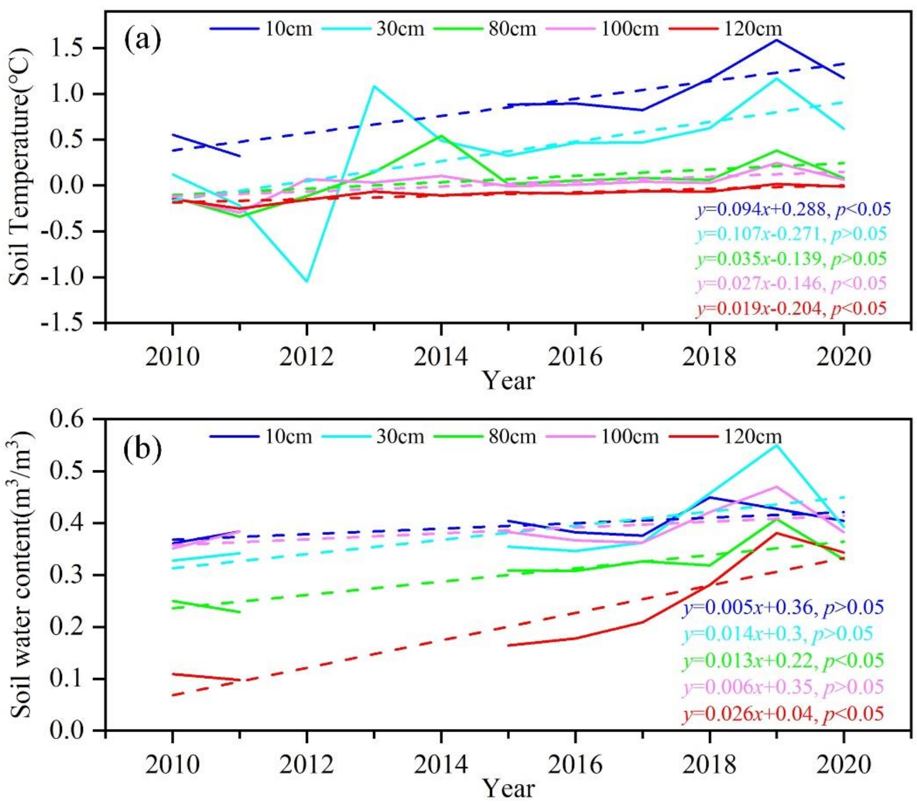

Figure 6. Soil temperature and soil volumetric water content at five depths from 2010 to 2020 at Mahan Mountain permafrost site: soil temperature (a), soil volumetric water content (b).

The active layer thickness (ALT) varied between 107 cm and 150 cm with a mean value of 127 cm from 2010 to 2020 (Fig. 7). The rate of change in ALT was 1.8 cm/year. The increasing rates of ALT in recent decades have varied considerably in different permafrost regions. (Line 315-318)

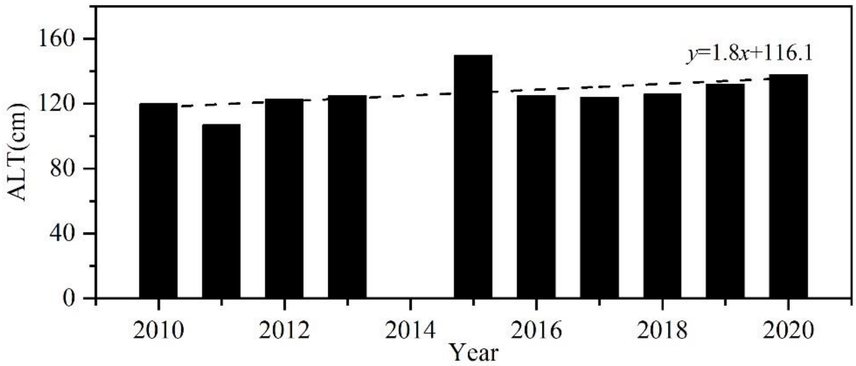

Figure 7. The active layer thickness (ALT) from 2010 to 2020 at Mahan Mountain permafrost site. The ALT data in 2014 were not available.

The permafrost temperature data were not available during 2012–2016 due to the sensor failure. After 2017, a digital multimeter was used to manually measure the permafrost temperature for 2–4 times each month. We calculated the annual average permafrost temperature at depths of 9 m and 15 m. The result shows that the annual mean ground temperature at these depths only showed slight changes during 2010–2020 (Fig. 10). (Line 386-391)

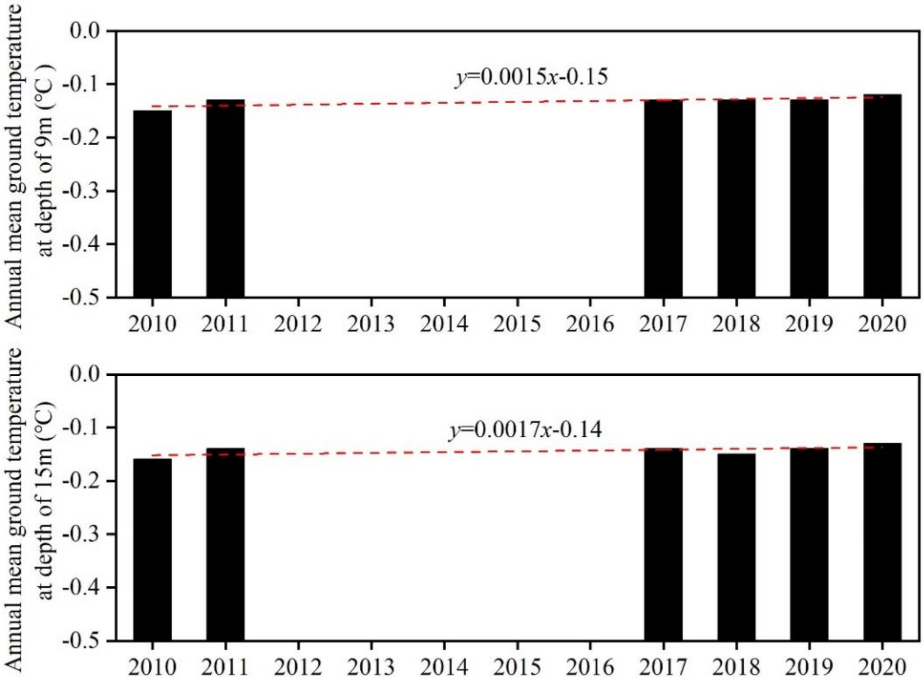

Figure 10. The annual mean ground temperature at depths of 9 m and 15 m during 2010–2020 at the permafrost site.

2.2.4 Comparison of the variation in permafrost characteristics with other regions

There was an obvious regional difference in the variation in the ALT (Table 5). The change rate of ALT since the 1990s was less than 1 cm/a in the permafrost regions of Alaska, northeastern Siberia, and Antarctica, especially in the permafrost in Canada, which was close to 0 cm/a (Smith et al., 2022). The trends in the permafrost regions of Nordic, Russian European north, western and central Siberia, and the Tibetan Plateau are closer to the results of this paper (Smith et al., 2022; Zhao et al., 2019). The ALT showed the greatest change in permafrost regions of the Swiss Alps (Table 5). In addition, the permafrost temperature change on Mahan Mountain is significantly lower than that of other regions, which usually have a warming rate greater than 0.15 °C/decade (Table 5). This pattern can be explained by the existence of a high content of ground ice. The phase change of ground ice can absorb a large amount of heat, and thus, the ground temperature will not change significantly in warm permafrost (Nelson et al., 2001; Biskaborn et al., 2019; Ding et al., 2019). Moreover, the changes in ALT and permafrost temperature varied greatly from different permafrost regions due to the impact of multiple local factors, such as snow cover, slope aspect, vegetation cover, and soil properties (Ding et al.,2019; Smith et al., 2022). It is worth noting that the different study periods, and variability and continuity of the observed data also have an effect on the results. (Line 397-415)

Table 5 Comparison of the change rates of active layer thickness (ALT) and permafrost temperature in different permafrost regions.

Variable	Area	Variation rate	Study period	Reference
Active layer thickness	Alaska North Slope	0.2 cm/a	1990–2020	Smith et al., 2022
	Alaska interior	0.9 cm/a	1990–2020	
	Canada	0.0 cm/a	1991–2018	
	Nordic (including Svalbard and Greenland)	1.3 cm/a	1990–2020	
	Russian European north, western and central Siberia	1.3 cm/a	1993–2020	
	northeastern Siberia (including Chuktoka and Kamchatka)	0.5 cm/a	1994–2020	
	Swiss Alps	10.5 cm/a	1990–2018	
	Antarctica	0.1 cm/a	1999–2019	
	Tibetan Plateau	2.17 cm/a	2004–2018	Zhao et al., 2019
	Mahan Mountain	1.8 cm/a	2010–2020	This study
Permafrost temperature	Arctic continuous permafrost	0.39±0.15 ℃ /decade	2008–2016	Biskaborn et al., 2019
	Arctic discontinuous permafrost	0.20±0.10 ℃ /decade	2008–2016	
	Mountain permafrost	0.19±0.05 ℃ /decade	2008–2016	
	Antarctica permafrost	0.37±0.10 ℃ /decade	2008–2016	
	Tibetan Plateau	0.15 ℃/decade	2005–2017	Cheng et al., 2019
	Mahan Mountain	0.02 ℃/decade	2010–2020	This study

References:

Ding, Y., Zhang, S., Zhao, L., et al., 2019. Global warming weakening the inherent stability of glaciers and permafrost. Science Bulletin, 64(4): 245-253.

Nelson, F.E., Anisimov, O.A. and Shiklomanov, N.I., 2001. Subsidence risk from thawing permafrost - The threat to man-made structures across regions in the far north can be monitored. Nature, 410(6831): 889-890.

Smith, S.L., O'Neill, H.B., Isaksen, K. et al. 2022. The changing thermal state of permafrost. Nat Rev Earth Environ 3, 10–23.

Zhao, L., Zou, D., Hu, G., et al., 2021. A synthesis dataset of permafrost thermal state for the Qinghai-Tibet (Xizang) Plateau, China. Earth System Science Data, 13(8): 4207-4218.

2 In the introduction section, the authors need to state the particularity of the relict permafrost site at this site, including why permafrost could be relict here.

Response:

Thanks for the suggestion. The Mahan Mountain is the only region in the Loess Plateau (China) where permafrost exists. Due to the high mean annual temperature in this region, the permafrost existence can be mainly attributed to two mechanisms. First, the peat layer protects the permafrost from thawing. The organic carbon-rich layer can prevent heating from the air during the warm season as well as the heat loss during the cold season (Du et al., 2012). Second, the high content of ground ice can also favour the presence of the permafrost. It is well known that the phase change of ground ice can absorb a large amount of heat, and thus, the ground temperature will not change significantly in warm permafrost (Biskaborn et al., 2019). In addition, the frequent foggy weather in the area may also decrease the solar radiation and thus favour the presence of permafrost. In the revised manuscript, we added this information in the introduction. (Line 78-88)

3 In Figure 5, some low-values of soil moisture occurred in the depth of 40-80cm, and some high-values occurred near 100cm or so, what's the reason?

Response:

As shown in Fig. 5, there were two higher VWC zones in the upper and lower part of active layer, which were located at around 0–40cm and 90–110cm depths, respectively, and a relatively lower VWC was in the middle part of active layer. There were three possible reasons for the situation, which were as follows:

First, the abundant vegetation and peat layer in shallow soil layer can retain moisture from precipitation infiltration and melting of active layer. In addition, the different soil particle fractions at different depths might influence precipitation infiltration process (Grote et al., 2010; Mathias et al., 2015; Zhu et al., 2017).

Second, the freezing process of active layer is bidirectional. Soil water migrates toward two freezing fronts in this process, then the middle of active layer will become dehydrated and with a low soil moisture content. During the thawing process, soil temperature in the active layer is relatively high in the upper and low in bottom layer, and the temperature gradient will drive soil water to migrate downward. As a result, soil moisture in the deep layers will increase significantly, and soil water at the upper layer will also increase (Zhao et al., 2000; Hu et al., 2014).

Third, some pores, cracks or other water channels probably exist at depths of 40 – 80 cm, which could shape the preferential flows patterns in the soil profile (Xu et al., 2010). These factors may also contribute to the high soil water storage below 80 cm (Greco, 2002; Hincapié and Germann, 2009).

In the revised manuscript, we have added this information, which is as follows:

The distribution of abundant vegetation and peat layers, soil particle fractions, the freeze–thaw process, the ground ice layer, and water channels such as soil pores, and cracks can affect soil water contents. These factors may account for the abnormal features of soil water contents at the depths of 40–80 cm and 100 cm (Hincapié and Germann, 2009; Xu et al., 2010; Hu et al., 2014;

Mathias et al., 2015; Zhu et al., 2017) (Line 287-292).

References:

Greco, R. (2002), Preferential flow in macroporous swelling soil with internal catchment: model development and applications, J. Hydrol., 269(3-4), 150-168, doi:10.1016/S0022-1694(02)00215-9.

Grote, K., C. Anger, B. Kelly, S. Hubbard, and Y. Rubin (2010), Characterization of soil water content variability and soil texture using GPR ground wave techniques, Journal of Environmental Engineering Geophysics, 15(3), 93-110, doi:10.2113/JEEG15.3.93.

Hincapié, I., and P. F. Germann (2009), Impact of initial and boundary conditions on preferential flow, J. Contam. Hydrol., 104(1-4), 67-73, doi:10.1016/j.jconhyd.2008.10.001.

Hu, G., L. Zhao, R. Li, T. Wu, Q. Pang, X. Wu, Y. Qiao, and J. Shi (2014), Characteristics of hydro-thermal transfer during freezing and thawing period in permafrost regions, Soils, 46(2), 355-360. (in Chinese with English abstract)

Mathias, S. A., T. H. Skaggs, S. A. Quinn, S. N. C. Egan, L. E. Finch, and C. D. Oldham (2015), A soil moisture accounting-procedure with a Richards' equation-based soil texture-dependent parameterization, Water Resources Research, 51(1), 506-523, doi:10.1002/2014WR016144.

Xu, X., B. Zhang, and J. Tian (2010), Experimental study on the precipitation-soil water-groundwater transformation in loess hilly region, Adv. Water Sci., 21(1), 16-22. (in Chinese with English abstract)

Zhao, L., G. Cheng, S. Li, X. Zhao, and S. Wang (2000), The active layer freezing and thawing process in the vicinity of Wudaoliang permafrost regions on the Qinghai-Tibetan Plateau, Chin. Sci. Bull., 45, 1205-1210. (in Chinese).

Zhu, X., Wu, T., Li, R (2017), Impacts of summer extreme precipitaton events on the hydrothermal dynamics of the active layer in the Tanggula permafrost

region on the Qinghai-Tibetan Plateau, Journal of Geophysical Research: Atmospheres, 122: 11549-11567.

4 I suggest to add data sources of topographic base in Figure 1a, and to add unit for DEM in Figure 1b.

Response:

Added as follows:

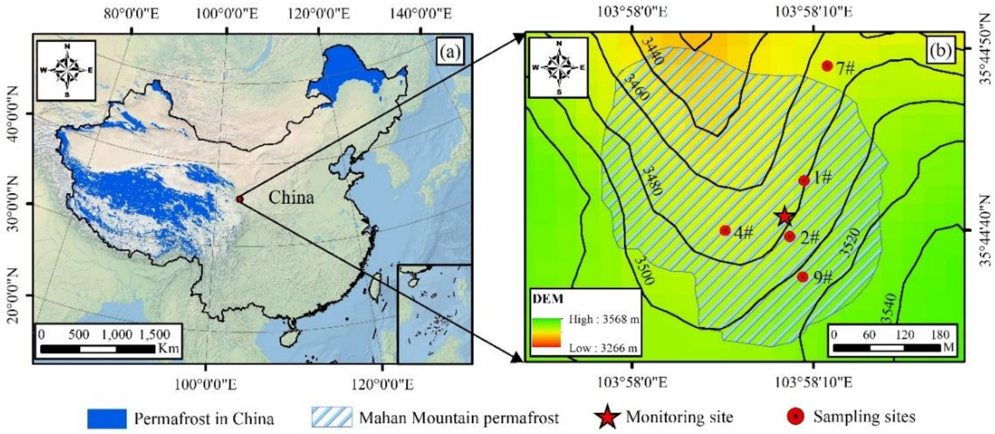

Figure 1. Location (a), topographical map and observation site (b) of Mahan Mountain relict permafrost region. Permafrost distribution data in China are derived from Zou et al. (2017) and Zhang et al. (2019), and the Environmental and Ecological Science Data Center for West China (http://westdc.westgis.ac.cn). The permafrost distribution of Mahan Mountain is derived based on a field survey. The high-resolution satellite-derived land cover map data are provided by Natural Earth (http://www.naturalearthdata.com).

5 The language should be polished by English-native-speakers before its acceptance for publication.

Response:

Thanks for the suggestion. We polished our language by American Journal Experts (https://www.aje.com/) which is a partner of many publishing groups. The changes were highlighted in blue so that they may be easily identified. The editing certificate by AJE were presented as follows:

AJE

Editing Certificate

This document certifies that the manuscript

Permafrost, active layer and meteorological data (2010–2020) from a relict permafrost site at Mahan Mountain, Northeast of Qinghai-Tibet Plateau

prepared by the authors

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