Response to Reviewers' Comments

We would like to thank the reviewers for their comments and suggestions. We have revised the manuscript as possible. Comments from the referees are rearranged and responded one by one as follows, with the responses presented in blue.

Response for referee 1

Comment 1

Many times, the authors provided the permafrost temperature and active layer change rate based on the in-situ measurements. My major concern is that are the trends significant, i.e., p-value < 0.05? This is important as permafrost temperature at some sites seems "maintained" without a trend, right? Please clarify.

I also suggest authors use the unit of °C dec^{-1} or m dec^{-1} for the estimated trend. In such a case, authors at least could avoid so many "0".

***Response*:** Thank you for your comments and suggestions. First of all, the ground temperature at the depths deeper than 8 m at most sites except YTLH1 has significant warming trends. According to your suggestion, we have made the trending analysis by using the Man-Kendall method with p values tested. Results show that most of the MK p-values for the warming trend of ground temperature are less than 0.001 (as indicated in figures from Figure 4 to Figure 7) except for the d) panel in Figure 7. We also made a MK trend analysis for the variables in Figure 9 and presented the MK p values in the figure. In addition, in the revised manuscript, we have recalculated all the intercept values for the equations in figures from Figure 4 to Figure 7, by respecting the initial observing date as the original point, which is more meaningful.

Secondly, we have used °C dec^{-1} instead of °C/a for the estimated trend in the revised manuscript according to your suggestion.

Comment 2 Ground temperature amplitude

It is not surprising that ground temperature amplitude decreased with increased depth if groundwater is absent. I suggest authors provided the depth of zero annual amplitude (ZAA), its annual ground temperature is also often taken as permafrost MAGT.

***Response*:** Thank you for your suggestion. We have revised the manuscript and added Table 2 to fully present the thermal states of permafrost in the study area.

Comment 3 Data availability

The authors mentioned the data used in this study are public open via TPDC, but it seems the link does not really work. Could you please double-check the link? This will also be required by the ESSD journal if the paper is accepted for final publication.

***Response*:** We have revised the DOI link (https://doi.org/10.11888/Geocry.tpdc.271752), and it works now.

Specific Comment 1

- P1, L34: about "one quarter"
- P1, L36: In this case, the permafrost region over the TP was about 1.59 - 0.31 = 1.28? Could you please update the statistics based on the latest results from Cao et al., 2019, or Zou et al., 2017?

***Response*:** Thank you for your comments. According to Ran et al. (2012) and Zhang et al. (2021) the areal extent of permafrost in China and Northeast China is about 1.59×10^6 km^2 and 0.31×10^6 km^2 respectively. However, the area of permafrost over the TP cannot be calculated simply by a subtraction

of these two area numbers, i.e., 1.59 - 0.31=1.28, because the subtraction result actually includes the permafrost in some mountainous areas in northwestern China, e.g., Tian Mountain, Qilian Mountain, and Altai Mountain. That is, the area of permafrost over the TP should be less than 1.28 $\times 10^6$ km^2, as reported to be about 1.06-1.17$\times 10^6$ km^2 by Cao et al. (2019) and Zou et al. (2017). Therefore, we think the various reported numbers are not conflict to each other as so far, although we cannot make a further judgment on their accuracy advantages and disadvantages.

Specific Comment 2

- P5, L196: Please check if the estimate is significant.

***Response*:** we have made the significant tests by using the Man-Kendall method with p values listed in the figures. Results show that most of the trend estimation is significant.

Specific Comment 3

Tables & Figures

Table 1: Could you also please provide the last measured MAGT and ALT? This would then provide clear TSP info at the measured sites to readers.

***Response*:** Thank you very much. We have provided Table 2 in the revised manuscript to show clear TSP information.

Figure 1: Is the permafrost distribution from IPA map? Please clarify.

***Response*:** Actually, the permafrost distribution in Figure 1 is from Jin et al. (2007), and it has been clarified in the revised manuscript.

Response for referee 2

General Comments:

It's my pleasure to review "Permafrost changes in the northwestern Da Xing'anling Mountains, Northeast China in the past decade" by Chang et al. Despite meeting the problems of the logger damage, lost in mailing, borehole damage and traffic control, the soil temperature including seven boreholes has been observed continuously for nearly 10 years, which is a valuable data set for understanding the hydrological process of regional permafrost. The manuscript is generally well organized and written. The manuscript can be accepted after addressing my following comments.

***Response*:** First of all, thank you for your positive evaluation.

Specific comments:

Comment 1 Please strictly unify the font and serial number of the main title and sub-title in the manuscript according to the template of ESSD. In addition, keywords do not appear to be necessary.

***Response*:** As requested, we have modified typesetting of the manuscript strictly according to the ESSD WORD template, including the font style and title system. We also removed the keywords in the revised manuscript.

Comment 2 Please check the acronyms in the full-text to ensure that each is defined when it first appears. For example, GH, MG, YTLH, etc. must be defined by Genhe, Mangui, Yituli'he, etc. in appropriate places; ALT must be defined at the first occurrence, not at Line 209; Is YT in Table 1 equivalent to YTLH? Please add one note after the Table 1.

***Response*:** Thank you very much. In the revised manuscript, GH, MG, YTLH, etc. have been defined by Genhe, Mangui, Yituli'he at Line 22-23 and Line 72-73, and ALT by active layer thickness at Line 132 when they first appear in the full-text. Actually we have made a mistake to use two acronyms (i.e., YT and YTLH) for the same site (i.e., Yituli'he), and we have replaced YH with YTLH in Table 1 in the revised manuscript.

Comment 3 Please add a north arrow to the left sub panel of Figure 1. Full name of all boreholes shall be included in the description of Figure 1.

***Response*:** According to you suggestion, we have added a north arrow for the left panel and give all the boreholes full names in the description.

Comment 4 Ground temperatures at the Borehole GH4 were automatically collected hourly by the Micrologger CR3000 (USA), whereas at other sites were manually measured with a multi-meter (Fluke 189®). Can the deviation of the two different recording methods be quantified? Please clarify their possible uncertainties.

***Response*:** The ground temperatures at GH4 were automatically collected by a CR3000 Micrologger. Because the hourly data was recorded as the mean value of samplings in every ten minutes, the collected data were steady and smooth. In contrast, the ground temperatures at other sites were manually measured with a Fluke 189®, and the data was collected once at an instantaneous time over a week or a month. Results show that the deviation of this two methods are obvious. With a more severe fluctuation, the manually collected data is not as steady as the automatically collected data. However, because there are

no overlapping data collected between these two different methods at the same boreholes, we did not figure out how to quantify the deviation between the data collected by these two different methods for now, and the uncertainties are also hard to be assessed. We planned to install automatic data logger for the boreholes gradually in future.

Comment 5 Please add the factors (temperature, precipitation, etc.) of climate change from 1980 to 2020 in Figure 9 to better reveal the relationship between the maximum thaw depth and climate change.

Response: The following figure presents the maximal thaw depth of permafrost at YTLH. However, we did not have meteorological data at YTLH. Therefore, the mean annual air temperature (MAAT) at Gehe (about 18 km away from YTLH) and Tulihe (about 30 km away from YTLH) was compared with the maximal thaw depth at YTLH here (Figure r1). The MAAT from 1980 to 2020 at Tulihe is calculated based on the daily observation of a national weather station. At Genhe, we only collected the MAAT from 1996 to 2020. We did not have the data on precipitation at Genhe before 2010. The MAAT at Genhe and Tulihe shows an obvious warming trend. In contrast, the maximal thaw depth of permafrost takes a decreasing trend from 2004 to 2020 at YTLH. It seems inconsistent at first glance. However, the thaw depth of permafrost is mainly subject to the positive air temperature, and MAAT is the mean of all negative and positive air temperatures. The annual mean of positive air temperature at Genhe from 2010 to 2020 shows a slight decreasing trend, at least not warming, although MAAT from 2010 to 2020 warmed up, which was mainly caused by the warming negative air temperature. In addition, the maximal thaw depth was also subject to other conditions, such as soil moisture and vegetation cover, both of which are related to precipitation. Visual inspection can tell that the increased thaw depth (2012~2014) is coincidentally connected to the low level of precipitation (Figure r2). Of course, the influencing paths of precipitation on thaw depth through the soil moisture and vegetation are complex and indirect, even with significant non-linear relationship. We cannot simply clarify them completely here. However, we will give them more insight investigation in future.

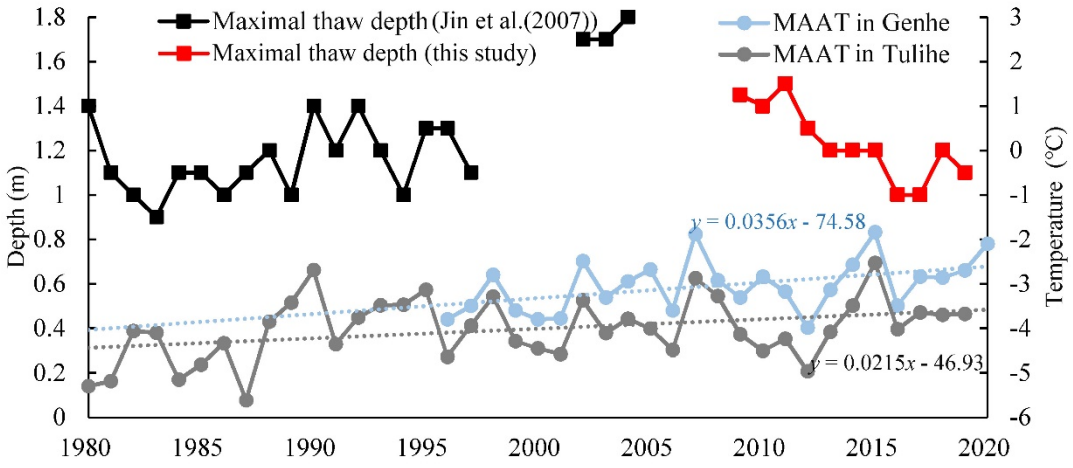

Figure r1 The maximal thaw depth (1980-2019) in Yituli'he and MAAT in Genhe and Tulihe on the northwestern flank of the northern Da Xing'anling Mountains in Northeast China

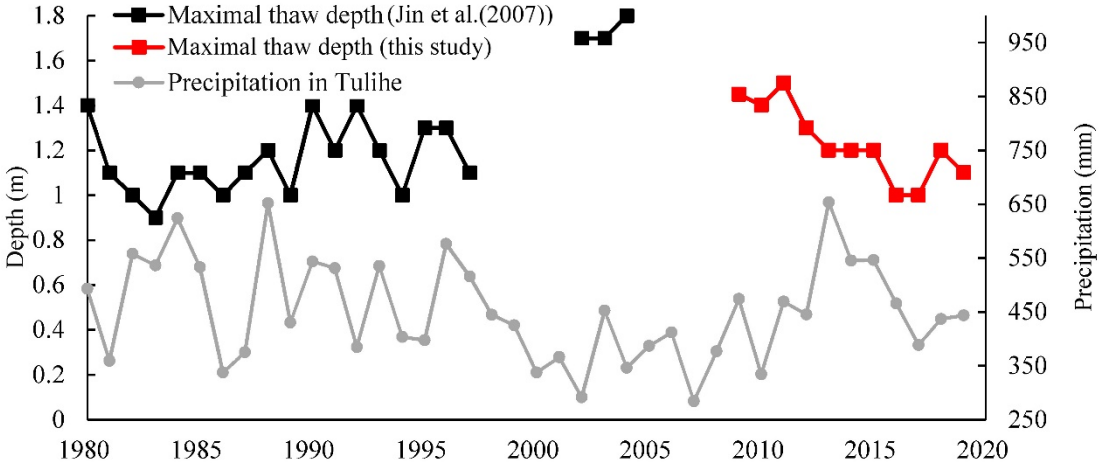

Figure r2 The maximal thaw depth (1980-2019) in Yituli'he and Precipitation in Tulihe on the northwestern flank of the northern Da Xing'anling Mountains in Northeast China

Comment 6 In discussion, please consider the possibility of hiatuses recovery and the possibility of increasing the frequency of observation (MG1, MG2, and MG3) from month to week. Because it is probably to enhance the comparability between these borehole data or with borehole data in other regions on monitoring frequency.

***Response*:** On data hiatuses recovery at MG1, MG2, and MG3, data users could use a linear interpolation method to generate weekly series from monthly series for the observed ground temperatures at depths, because the fluctuation is not much severe except some outliers. We planned to install automatic data loggers for some boreholes as soon as possible to guarantee the data logging accuracy and time resolution.

The dataset (https://doi.org/10.11888/Geocry.tpdc.271752):

Comment 7 What represents the difference between two and nine decimal places in the observed value? What determines it? Why do they alternate in all sites except for the MG3 (two decimal places)?

***Response*:** We are sincerely sorry that we did not pay attentions to the format (i.e., decimal places) of the released data. Actually, the ground temperatures are calculated from the resistance observed by thermistor cables, and the decimal places of output are not set uniformly. Data users can take the first two decimal digits.

Response for comment

General comment

This study investigated the changes in thermal regime of permafrost on the northwestern Da Xing'anling Mountains, Northeast China in the past decade based on a ten-year observation of permafrost and active-layer temperatures. The topic of this study is hot, the results have potential benefit for understanding responses of permafrost to climate change. However, there are some flaws and concerns that should be clarified. I recommend a major revision.

***Response*:** First of all, thank you for your general positive evaluation for our work. We also appreciate your comments and suggestions. We revised the manuscript as possible as we can, and here we give the responses one by one according to your comments.

Specific comment 1

In my opinion, one scientific value of this study is to provide valuable long time series data for other permafrost and related studies, such as, statistic analysis, model evaluation and development, reanalysis dataset validation, etc., however, current version didn't emphasize this point.

***Response*:** Thank you for your suggestion. We have emphasized the potential scientific contribution to the related studies in the introduction section (L54-58, and L78-81), especially for the study of model validation in future.

Specific comment 2

As authors stated, many studies have been analyzed the permafrost changes (e.g., Jin et al., 2000; Jin et al., 2007; Shanshan Chen, 2020; Zhang et al., 2019; Jin et al., 2021), new insights that is expected are few. For example, how the frozen soil has changed in the last decade and how it is different from the past were not clear.

***Response*:** Actually, most of the mentioned literatures are review articles. The permafrost distribution estimation in northeast China by Zhang et al. (2019) was derived from meteorological data without vigorous validation. In the past decades, the studies on permafrost in northeast China is fragmentary and rare, lacking persistent and systematic observation, until Jin et al. established the long-term observing system since 2009. Even up to now, the permafrost in the Qinghai Tibetan plateau is still the main focus, attracting far more attention, although the mechanism for permafrost evolution in northeast China is much complex due to its interactions with snow, forest canopy, and wetland. The immediate consequence is that the in-situ observations on permafrost in this region is rare, let alone long-term observations. To fill this gap, we gradually established the ground temperature observing network for permafrost, including 7 boreholes from Mangui to Gen'he, to monitor the permafrost thermal dynamics under the warming climate expected at the beginning. However, in the progress of study, we found that the thermal state of permafrost in northeast China was regulated by the vegetation, snow, and wetland in a complicated way. In addition, the ground temperature in the shallow soil took an apparent decreasing trend (i.e., referred to as permafrost cooling in the manuscript) in the recent years when there is no decreasing trend in the mean air temperature or even when the mean air temperature is warming, which was completely out of our expectation. This "permafrost cooling" also occurred in some experimental sites nearby, e.g., Nanwen station. This phenomenon has never been reported in the last decades and still remains incompletely understood. More attention should be paid to its mechanisms. Unfortunately, because this phenomenon was totally out of our expectation and the funding was not sufficient enough at the beginning, systematic observing systems aiming at the influences of vegetation, snow, and moisture condition on the permafrost was not established synergistically. We plan to complement some

related observation in future and investigate this “permafrost cooling” comprehensively with the help of some physically based models.

Specific comment 3

The data at Gen’he has large missing values (Figure 5, 6), the linear trend was calculated on base of intermittent series that should be not robust.

***Response*:** Indeed, there exists some long periods with missing data at Gen’he, where the data was collected by a data logger (CR3000). In such a harsh environment, the data collecting system is prone to failure. Without GPRS signal at the observing site, we cannot monitor the system status in time and take a repair. Unfortunately, there is no remedy for these missing data. It is reluctant for us make the trend analysis with these missing data. However, at the surface layers, although the fluctuation of ground temperature is relatively huge, the collected data has generally captured the maximal and minimal ground temperature in years with observing data. Simply by a visual inspection, the minimal or maximal ground temperature has an apparent warming trend from 2012 to 2020, which has a good coincidence with the trend analysis in our manuscript. That is, although the missing values could make some loss for the accuracy of trending analysis, or make it less robust, they will not change the trend in an antipodal way. In addition, in depths greater than 8 m, the annual fluctuation of ground temperature was much less than the surface layers, as shown in Figure 5 and 6. The missing values will not vary too much from the collected values. Therefore, we speculate the influence of missing values on trending analysis for deep layers will be smaller than that in the surface layers, and it will decrease with depth, which can be inferred from Figure 5 and 6.

Specific comment 4

The possible reasons for cooling permafrost in the last decade on the northwestern slope of the Da Xing’anling Mountains should be further investigated, its relations to winter precipitation, snow cover and maximal snow depth are just appearances, how snow affect the soil temperature of permafrost through surface energy budget (e.g., albedo effect, insulation effect, etc.) should be clarified.

***Response*:** Actually, the observed permafrost cooling is out of our expectation at the beginning, and the mechanisms still remains incompletely understood. We speculated that it could be related to the thriving vegetation and declining winter precipitation or snow cover in this area during the observational period. In the last decade, although the mean positive air temperature (MPAT) in this region barely changed, precipitation in warm seasons increased slightly, leading to a wetter condition in favor of vegetation thriving. For example, the maximum vegetation height of Carex tato at YTLH1 and YTLH2 grew significantly from 2009 to 2014. Bushes have also emerged recently near the borehole. Thriving vegetation will reduce the solar irradiance incident onto the soil surface in summer and cast a cooling effect on the ground temperature. On the contrary, the winter precipitation (Figure 9a) and snow cover, including the maximal snow depth (Figure 9c) and snow duration (Figure 9d), declined slightly. The thermal insulation effect of snow cover will be weakened when the snow the depth of snow cover decreased, which will lead to a larger heat removal from the permafrost to air in winter and drive the permafrost cooling. The detail mechanisms for the cooling permafrost will be further investigated with the help of some physically based models after complementing observations on the interactions of energy balance between the permafrost, vegetation, and snow cover.

Specific comment 5

Uncertainties of some quantitative results should be discussed, for example, line 183 “warming at an average rate of 0.004-0.020 °C /yr”, its magnitude is much small than the observation error.

***Response*:** Yes, the observed ground temperature by the thermistor has an error within ±0.05 °C when the ground temperature ranges from -30 to +30 °C. However, we cannot conclude that the warming rate is meaningless because its magnitude is smaller than the observing error, because the warming rate was a statistic number derived from a large sample of observation. Its uncertainty should be inferred based on the law of large numbers or central limit theorem, instead of based on the observation error. For example, according to the law of large numbers, the variance of the mean of the distribution of a random variable can be calculated as,

$$Var(\bar{X}_n) = \frac{1}{n^2} Var\left(\sum_{i=1}^{n} X_i\right) = \frac{\sigma^2}{n}$$

where σ^2 is the variance of random variable X_i.

That is, although every single observation of ground temperature by using a thermistor may has an error within ± 0.05 °C, the uncertainty of the calculated mean ground temperature was much reduced when the observing sample was large enough, although the magnitude of the mean ground temperature could be very small, i.e., smaller than 0.05 °C. Similarly, we cannot judge the significance of the calculated warming rate by comparing its magnitude directly with the observation error.

For the sake of simplicity, we assume that an ordinary least squares (OLS) estimator was used in the trend analysis, and a general linear regression equation for predicting the ground temperature changing with time could be descripted as follow,

$$\mathbf{y} = \beta_0 + \beta_1 \mathbf{t} + \boldsymbol{\epsilon}$$

where **y** is the ground temperature (°C), and **t** is time (d) in this case. β_1 is the regression coefficient, which could stand for the warming rate of ground temperature with time. β_0 is the intercept. $\boldsymbol{\epsilon}$ is the error term.

According to DeGroot and Schervish (2011), the regression coefficient β_1, i.e., the warming rate or trend of ground temperature, could be estimated as,

$$\widehat{\beta_1} = \sum_{i=1}^{n} (y_i - \bar{y})(t_i - \bar{t}) / \sum_{i=1}^{n} (t_i - \bar{t})^2$$

and the variance of β_1, which could be used to weight its uncertainty, could be calculated as,

$$var(\widehat{\beta_1}) = \frac{var(y_i)}{\sum_{i=1}^{n} (t_i - \bar{t})^2}$$

Because the random variables $y_1,...,y_n$ at each observing time are independent and each has variance σ^2,

$$var(\widehat{\beta_1}) = \frac{\sigma^2}{\sum_{i=1}^{n} (t_i - \bar{t})^2}$$

where the σ^2 can be estimated as,

$$\widehat{\sigma^2} = \frac{1}{n} \sum_{i=1}^{n} \left(y_i - \widehat{\beta_0} - \widehat{\beta_1} t_i\right)^2$$

The calculated variances of β_1 at GH4 were listed in Figure 6 as follow, which tells that the uncertainties of warming rate were not great. In addition, significance test has been done for all the trending analysis by using the Man-Kendall method in the revised manuscript, such as Figure r3. Most pvalues are smaller than 0.001.

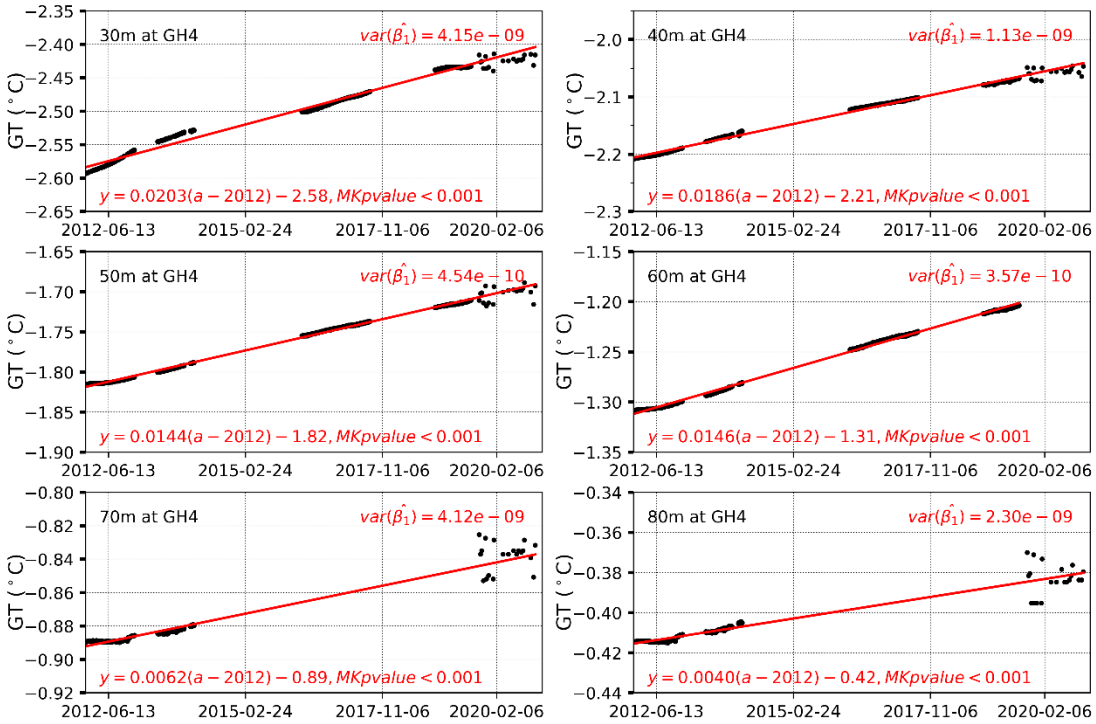

Figure r3 Variability of deep permafrost temperatures at depths of 30 – 80 m for Borehole GH4

References:

DeGroot MH and Schervish MJ. Probability and statistics (4th edition), 2011, publisher: Addison-Wesley, Boston.

Specific comment 6

Linear trend should be made significant test.

***Response*:** Thank you very much. According to your suggestion, we have made the trending analysis by using the Man-Kendall method with significant test done, and p-values are shown in figures in the revised manuscript. Results show that most of the MK p-values for the warming trend of ground temperature are less than 0.001 except for the d) panel in Figure 7, which means that the warming trend of ground temperature are significant although some of the warming rates are a little small in magnitude.

Comment 8 The number of hiatuses in dataset far exceeds the described in the manuscript. Please add the interruption causes, including the sensor changes before and after the interruption (if any).

***Response*:** We are sorry for this mistake. Yes, there are there long hiatuses in the datasets and some short. Actually, there are no sensors change in the entire observation period until CR3000 data logger is totally damaged and the data are collected manually. Except the hiatus between 2014 and 2016, other data interruptions are mainly caused by the problems of power-supply system and expansion board that connects the sensors and data logger. Because there is no GPRS signal at most sites, wireless transmission module was not used in the observing system, and we cannot monitor the system status in time and take a repair. The hiatus between 2014 and 2016 was also caused by the power-supply system, but the system maintenance was totally suspended due to personnel transfer.

Comment 9 GH5 and YTLH2 data have repeated the column of date. Does it make a special meaning? Please unify the format of observation data.

***Response*:** Sorry for another mistake. They repeated columns are just a duplicate. We will contact the data center and update the datasets as soon as possible.