

Responses to Editor's Comments and Suggestions **(The answers are shown in blue)**

Minor comments:

P2, L1: "the carbon" becomes "carbon"

[Thank you. This has been modified.](#)

P2, L28: "used index, i.e. MAAT and MAGT, the MAGT is the most direct indicators of the thermal" becomes "used indices (i.e. MAAT and MAGT), MAGT is the most direct indicator of the thermal"

[This has been modified.](#)

P2, L31: "Although the potential problems of the MAAT in predicting permafrost degradation are well known, for example, the performance of the MAAT model is generally affected by the thermal inertia of deep soil layers and geothermal flux (Smith and Riseborough, 2002; Jin et al., 2006; Wu et al., 2010a), the MAAT is easy to measure and has high spatial representativeness" becomes "The potential problems of using MAAT to predict permafrost degradation are well known, such as the neglecting the influences of thermal inertia of deep soil layers or geothermal heat flux (Smith and Riseborough, 2002; Jin et al., 2006; Wu et al., 2010a). However, MAAT is easy to measure and has high spatial representativeness"

[This has been modified.](#)

P3,L1-4: Change to "measurements of MAATs are available. However, MAAT measurement stations are sparse on the QTP, especially in the western region. In previous studies MAAT measurements were interpolated onto grids based on digital elevation models (DEMs), but the uncertainty of the gridded MAAT is substantial because of the locations of weather stations and heterogeneity of the surface characteristics, including snow cover and vegetation (Vancutsem et al., 2010)."

[This has been modified.](#)

P4, L13: "and near surface air temperature and the" becomes "and near surface air temperature, and thus the"

[This has been modified.](#)

P4, L15: "The variation in the uncertainty is mainly related to the underlying surface type such as snow cover and vegetation" becomes "Variation and uncertainty in estimated near surface air temperatures are mainly related to surface conditions such as snow cover and vegetation"

[This has been modified.](#)

P4, L17-20: "Additionally, the highly accurate remote sensing-based snow cover and vegetation products are also available. Overall, the high resolution remote sensing-based LST and the long-term in situ MAAT measurement can be integrated to monitor the permafrost thermal state.

Therefore, the objective of this study is to evaluate the thermal degradation of permafrost including temporal changes, spatial changes in the map plane, and spatial changes with elevation over the QTP from 1960 to 2010 by integrating multi-criterion remote sensing observations and an air temperature observation network" becomes "Highly accurate remote sensing-based snow cover and vegetation products are now available to reduce some of the uncertainty, and solar radiation and cloud cover can be accounted for. Therefore we propose that high resolution remote sensing-based LST and the

long-term in situ MAAT measurement can be integrated to monitor the permafrost thermal state. The objective of this study is to evaluate potential thermal degradation of permafrost including temporal changes, spatial changes in the map plane, and spatial changes with elevation over the QTP from 1960 to 2010 by integrating multi-criterion remote sensing observations and an air temperature observation network.”

[Thank you. This has been modified.](#)

P3, L3 – P4, L3: “The system was proposed based on the MAGT measurement as an index by analysis of the three-dimensional zonation of the high altitude permafrost (vertical, latitudinal, and aridity). It is a high level summary of high altitude permafrost zonation. The MAAT index was given according to the statistical relation between MAGT, elevation, and the in situ MAAT measurement (Cheng, 1984).” Becomes “The system is a high-level summary of the relation between MAGT measurements and the three-dimensional zonation of high altitude permafrost (elevation, latitude, and aridity). Cheng’s (1984) system relates air temperature to permafrost conditions according to the statistical relations between MAGT, elevation, and in situ MAAT measurements.

[Thank you. This has been modified.](#)

P4, L3: Move “On the QTP, a MAAT of $-2\text{ }^{\circ}\text{C}$ has typically been used to distinguish permafrost from seasonally frozen ground (Cheng, 1984; Ran and Li, 2016).” to Line 15, in front of “Additional, a MAAT of $-1\text{ }^{\circ}\text{C}$ is simply used to distinguish likely thawing permafrost from seasonally frozen ground in this paper.” Change “Additional, a MAAT of $-1\text{ }^{\circ}\text{C}$ is simply used to distinguish likely thawing permafrost from seasonally frozen ground in this paper” to “ Here we use a MAAT of $-1\text{ }^{\circ}\text{C}$ is to distinguish likely thawing permafrost from seasonally frozen ground because ...” You need to indicate why your threshold is different.

[Thank you. This has been modified. Here we use a MAAT of \$-1\text{ }^{\circ}\text{C}\$ is to distinguish likely thawing permafrost from seasonally frozen ground based on experience judgment for the region of cave ice and frozen gravel distribution area.](#)

P4, L5: “unstable type in the system” becomes “unstable type in this system”

[This has been modified.](#)

P4, L10-11: “In the extreme case, thawing permafrost appears thermally stable, because heat is used for phase change rather than temperature change and MAGTs appear stable despite being nearly $0\text{ }^{\circ}\text{C}$.” Becomes “In the extreme case, thawing permafrost that is nearly $0\text{ }^{\circ}\text{C}$ may appear thermally stable, because heat is used for phase change rather than temperature change.”

[This has been modified.](#)

P4, L12: “MAAT index,” delete the comma.

[This has been modified.](#)

P4, L24: Italicize “m”, the number of explanatory factors.

[This has been modified.](#)

P4, L29: “(n × m)” becomes “(n × m)”

[This has been modified.](#)

P5, L1: ““(n × 1)” becomes “(n × 1)”

[This has been modified.](#)

P5, L2: Italicize “n”, the number of MAAT observation stations

[This has been modified.](#)

P5, L8-13: This is a mix of results and methods. Also, it is a bit hard to evaluate the outcome of this analysis without knowing about the input data sets (that are introduced later on). Text relating to results should be moved to Page 8, somewhere in the first paragraph after Line 10.

[Thank you very much. Yes, this is a mix. We have moved related text to result section.](#)

P5, L13: If one model has the best explanatory power, why did you use 5 models, and which 5 of the 6 did you use? It is not at all clear.

[Thank you. This is a language error. We have corrected this description.](#)

P5, L14-25: “The SAGA (System for Automated Geoscientific Analyses) (Conrad et al., 2015) is used to implement the GWR. Specifically, the GWR for multiple predictor grids geoprocessing tool is used. The Gaussian weighting function and the global search range are used.

Due to the unavailability of the vegetation, snow cover, and LST datasets during the 1960s to 2000s, the effect of the dynamics of vegetation, snow cover, and LST on MAAT during this period is unknown. This will inevitably cause some errors in the estimation of MAAT. Recent studies show that vegetation is increasing overall during the past 30 years, and the 20 snow cover is decreasing overall during the past 15 years over the QTP (Wang et al., 2016; Huang et al., 2017). The effect of vegetation and snow cover change on MAAT and its feedback process is highly complex. For example, the vegetation-snow interaction effect on MAAT is related to humidity (Zhong et al., 2010; Wang et al., 2013; Wu et al., 2015; Yuan et al., 2017). However, we believe this error mainly occurs at the local level in the nature vegetation dominated areas (Wang et al., 2016; Huang et al., 2017), and it can be partially compensated by the in situ time series MAAT measurement over the QTP for the 25 past 50 years.”

Becomes

“The GWR is implemented in SAGA (System for Automated Geoscientific Analyses) (Conrad et al., 2015), using the GWR for multiple predictor grids geoprocessing tool with a Gaussian weighting function and a global search range.

Due to the unavailability of vegetation, snow cover, and LST datasets during the 1960s to 2000s, the effects of the dynamics of vegetation, snow cover, and LST on MAAT during this period are unknown. This will inevitably cause some errors in the estimation of MAAT. Recent studies of the QTP show overall that vegetation increased during the past 30 years and snow cover decreased during the past 15 years (Wang et al., 2016; Huang et al., 2017). The effect of vegetation and snow cover change on MAAT and related feedback process are highly complex. For example, the vegetation-snow interaction effect on MAAT is related to humidity (Zhong et al., 2010; Wang et al., 2013; Wu et al., 2015; Yuan et al., 2017).

However, we believe that such effects mainly occur at the local level in vegetation dominated areas (Wang et al., 2016; Huang et al., 2017), and they can be partially compensated by in situ time series MAAT measurements over the QTP for the past 50 years.”

[This has been modified.](#)

P5, L27: “50 years. The statistical significance”: becomes “50 years, and the statistical significance”
[This has been modified.](#)

P6, L1: “condition is evaluated from two perspectives” becomes “condition is assessed from two perspectives”
[This has been modified.](#)

P6, L4: “is evaluated at two levels” becomes “is assessed at two levels”
[This has been modified.](#)

P6, L5: “level, the spatial distribution of the degradation is evaluated. At the level of the permafrost types, a transfer matrix” becomes “level the spatial distribution of the degradation is evaluated, and at the level of the permafrost types a transfer matrix”
[This has been modified.](#)

P6, L13 and L25: “(2015; 2017)” becomes “(2015, 2017)” as the authorship is the same.
[This has been modified.](#)

P6, L15: “and the daily” becomes “and that the daily”
[This has been modified.](#)

P6, L21: “Wang, et al.” becomes “Wang et al.”
[This has been modified.](#)

P8, L12: “mean determination coefficient of the model is approximately 0.95” becomes “mean coefficient of determination of the model is approximately 0.95” What is this a mean of? I thought that Model 6 produced the best results? How did you arrive at 0.95, when all values reported in Table 2 are lower?
[Thank you. The mean is the mean of determination coefficient of MODEL 6 for five decadal in the past 50 years. We have removed this sentence to avoid confusion.](#)

P8, L17: “°Ca-1” becomes “°C a-1”
[This has been modified.](#)

P9, L10: “Overall, the warming climate has caused a degradation of permafrost thermal condition.” Delete as it repeats what is said at the beginning of this section.
[This sentence has been removed.](#)

P9, L16: “The degradation of thermal condition has occurred” becomes “Degradation of permafrost thermal condition has likely occurred”
[This has been modified.](#)

P9, L17-18: “The degradation of permafrost condition in the western QTP was serious during the 1960s to the 1970s.” So you mean substantial, instead of serious? You need to make it clear what this sentence means in terms of spatial variation, because it is not clear as written.

Thank you. We have modified this sentence.

P9, L26: “The reduction in the area” becomes “The potential reduction in the area”

This has been modified.

P9, L30: “over a 21×10^4 km² (12.02%) located” becomes “over a 21×10^4 km² area (12.02%) located”

This has been modified.

P10, L1: “has improved” becomes “has likely improved”

This has been modified.

P10, L4: “This is because of the lack” becomes “This relates to the lack”

This has been modified.

P10, L5-11: “The effects of snow or glacier cover may be more important than those of MAAT.” Important to what? What do you mean? What exactly are the effects that glaciers or long-lasting snow pack? Please carefully edit this section so that your point is clear. Are you trying to say that because the glaciers haven’t changed very much, that permafrost has also likely remained about the same?

Thank you very much. This section means that the effects of snow or glacier cover on permafrost may be more important than those of MAAT due to the former has greater latent heat than atmosphere. Also means that the glaciers and snow cover haven’t changed very much. Recent study found that no evidence of widespread decline of snow cover in QTP (Wang et al., 2017). We have clear this in the revised manuscript.

P10, L12: “sensitivity. Of course, these need further investigation in the future” becomes “sensitivity, but this notion requires further investigation”

This has been modified.

P10, L16: “the QTP has increased” becomes “the QTP has likely increased”

This has been modified.

P10, L18-21: “The reduction in elevation is mainly due to the degradation of the very cold permafrost type in the Kailas Mountains. This caused the fluctuation of the mean elevation for very cold permafrost during the 1970s to 1980s and reduced its statistical significance (low R in Table 5) for the increasing rate of mean elevation over the past 50 years.” These statements are not clear. How does permafrost degradation cause a decrease (“reduction”) in elevation. This is contrary to your major findings. Please clarify.

Thank you very much. Yes, this statement is not clear. This is not contrary with my findings. The reduction in elevation during 1960s to 1970s for very cold permafrost is mainly due to the degradation of the very cold permafrost type in the Kailas Mountains. The degradation leads to a decrease in the proportion of very cold permafrost type in high elevation area, and a decreasing mean elevation for very cold permafrost type in 1970s relative to the 1960s. This fluctuation of the mean elevation for very cold permafrost during the 1960s to 1980s reduced its statistical significance for the increasing rate of mean elevation over the past 50 years. We have clearer this in the revised manuscript.

P10, L20: do you mean R2, instead of R?

Thank you. This has been modified. R^2 is used.

P10, L31: “Zou et al., (2016) show that the difference is small. Within permafrost area, the” becomes “Zou et al. (2016) shows that the difference is small. Within permafrost areas, the”

This has been modified.

P11, L10: “which are especially sparse in high mountain areas. First, the response time” becomes “which are especially so in high mountain areas. Beyond these uncertainties, the response time”

This has been modified.

P11, L24-25: “Despite current warming, large permafrost areas may persist due to the thermal inertia of permafrost (Cheng et al., 2012). Second, the thawing of the base of the permafrost induced by the geothermal heat flux leads to the permafrost degrading from bottom to top (Jin et al., 2006; Wu et al., 2010a). The MAAT” becomes “To summarize, despite current warming, large permafrost areas may persist due to the effective thermal inertia of permafrost (Cheng et al., 2012). A final consideration is that the geothermal heat flux leads to thawing of the base of the permafrost (Jin et al., 2006; Wu et al., 2010a). However, the MAAT model”

This has been modified.

P12, L2: “missed geothermal heat flux. Long-term” becomes “missing geothermal heat flux component thermal inertia of permafrost. However, long-term”

This has been modified.

P12, L9: “zones will increase” becomes “zones will likely increase”

This has been modified.

P12, L28: “disappearance” becomes “drainage”. Must be drainage if related to thermokarst.

Thank you. This has been modified.

P12, L29: “which may further affect greenhouse gas emissions and produce a feedback effect on climate change” becomes “which may affect greenhouse gas emissions and feedbacks to climate change”

This has been modified.

P13, L1: “evaluates the permafrost” becomes “evaluates likely permafrost”

This has been modified.

P13, L8: “ $^{\circ}\text{Ca}^{-1}$ ” becomes “ $^{\circ}\text{C a}^{-1}$ ”

This has been modified.

My previous comments on figures were overlooked and are repeated here with a few more minor comments. These changes are required:

In all maps: please move text away from other objects so that the words are clearly legible. Nearly all city and town names are affected.

Thank you. This has been modified in all maps.

Figure 1. Scale bar should span 1000 km as in other figures. Evergreen broadleaf forest, deciduous broadleaf forest, and grasslands are too similar in color to differentiate on the map. Delete the symbols and descriptions in the legend for “Boundary of China” and “Extent of QTP”

[This has been modified.](#)

Figure 2. Change warming rates in map legend from, e.g., “-0.43 - -0.15” to “-0.43 to -0.15”
Also, change (°/decade) to (°decade⁻¹). Delete the symbol and description in the legend for “Extent of QTP”

[This has been modified.](#)

Figure 3. “<3600 m” becomes “< 3600” and “>5800 m” becomes “> 5800”. “Elevation intervals” becomes “Elevation intervals (m)”. Also, change (°/decade) to (°decade⁻¹)

[This has been modified.](#)

Figure 4. Non-permafrost and Unchanged stability are the same color and can be confused. Please indicate areas by a different color such as grey in all panels. Also, if non-permafrost includes seasonally frozen ground and lakes, map out lakes in a different color and add to the legend, and re-name “non-permafrost” to “seasonally frozen”

[Thank you. This has been modified. Non-permafrost includes seasonally frozen and non-frozen. So non-permafrost is still used.](#)

Figure 5. There a lot of white on the maps. Please indicate with a symbol and description what it represents, i.e. seasonally frozen? The color of the lakes is hard to distinguish from the blue permafrost. Consider different colours, or higher contrast between colors.

[This has been modified. Most of the white area indicate the seasonally frozen, and some area in southeast of QTP indicate non-frozen. So non-permafrost is used.](#)