Response to Referee 2

We would like to thank anonymous Referee 2 for reviewing our manuscript. These constructive comments are very important for us to improve the present manuscript. In the following, we address all comments point-by-point according to referee's comments.

General comments:

This article analyses whether elevation-dependent warming (EDW) is present in the Chinese Tianshan Mountains, both overall and at a regional level. The authors present a compelling case for research into this phenomenon, as increased warming in higher regions may have detrimental effects on glacier melt. EDW is judged based on the criteria of regional warming amplification and altitude warming amplification, and these two criteria are assessed for the entirety of the Chinese Tianshan Mountains on a monthly time scale. Furthermore, spatial differences in EDW are assessed across the mountain range. Overall, the paper is well presented and structured, and the discussion and conclusions of this spatially and temporally complicated problem are interesting. However, there are some issues which I think need to be addressed before publication, most importantly the definition of EDW used in the paper and how it relates to the conclusions reached in the paper, and the suitability of the data set used for this analysis, as highlighted below.

Specific comments:

1. Whole paper: The authors have carefully defined elevation-dependent warming (EDW) immediately in the article, namely that two criteria should be met: regional warming amplification and altitude warming amplification. Section 3.1 concludes that regional warming amplification is only present in any of the minimum, mean and maximum daily temperatures in the months

from February to June. However, in section 3.2, warming amplification with altitude is now described as EDW, for example line 183 "The prevalence of EDW is most significant in December...". This is then used for the remainder of the paper, especially in the conclusions. The authors should identify the months which satisfy both regional warming and altitude warming amplification, and these months should be set out clearly as the months where EDW is present.

This needs to be altered throughout the paper, and has substantial implications for the conclusions, as I think there are only one or two months which satisfy both conditions.

-Answer: Thanks a lot for the comments. The reviewer pointed a very important issue. After carefully reviewing the literatures again, we have to admit that our previous definition of EDW were a bit arbitrary. To be precise, regional warming amplification and altitude warming amplification are the two basic characteristics (or "fundamental questions" from Rangwala and Miller, 2012) of EDW. In the previous literatures, although there are many discussions on altitude warming amplification in high mountains, no literature clearly states that regional warming amplification is one of criteria for EDW. We will revise this part through the whole paper in the revision.

2. Methods/CTMD dataset: I think there should be some discussion of the suitability and limitation of the CTMD dataset for this analysis, given that the paper is reliant on it. Two particular points stand out: o Gao et al., 2018 gives an analysis of the data set compared to a number of stations; however they are all under 3000 m asl. I do appreciate the difficulty of finding high elevations stations, but do the authors have any evidence that this data set is suitable at elevations of 5000 m asl and above? In addition, Gao et al., 2018 also indicates that the lapse rate from ERA-interim (the correction term used to downscale ERA-Interim to the 1km scale) is steeper than that seen in the

observations. It is often the case that the free atmosphere lapse rate is steeper than the near-ground lapse rate of temperature with elevation, and this difference may cause errors in the 1 km data set used in this paper.

Gao et al., 2018 acknowledge that the trends in the ERA-Interim data, and therefore the CTMD, do not always follow those of the observations. For example, in the minimum daily temperature, the trend in the CTMD considerably underestimates that of the observations. It is not clear whether this bias is constant with elevation, which is essential to the results presented in this manuscript.

-Answer: Thanks a lot for the comments. The reviewer raised a challenge issue on the quality of CTMD. We must admit that the credibility of data in high-altitude areas is always a huge challenge. In Gao et al., 2018, we used 24 sites to validate the CTMD. It is true that all the sites are lower than 3000 m. We are looking for reliable observation data all the time to further verify the quality of CTMD. We plan to update a more high resolution data V2.0 (100m, 6-hourly) since the CTMD V1.0 that released in 2018. However, as far as we know, there are only very few automatic weather observation stations between 3000-5000m. The time series of these observational data is always short than 10 years with some data gaps. Meanwhile, we have to clarify that these observations data are difficult to access due to permission issues. Therefore, we only could evaluate the credibility of CTMD based on limited observations. In general, we could conclude that the CTMD has a small large-scale bias because of small large-scale errors of ERA-Interim. Previous studies claimed that the large-scale errors of ERA-Interim are acceptable with respect to long-term trends (Gao et al., 2012; Simmons et al., 2010).

To response the question raised by the Referee, we plan to use the Land Surface Data Assimilation System (CLDAS-V2.0) near real-time product data set from China Meteorological Administration to verify the higher areas in the revision. This data set applied multiple resources including more than 2400 surface observations, ECMWF/GFS reanalysis, and remote sensing data. Unfortunately, this data set only begins from 2008. The temporal and spatial resolution is 0.0625°×0.0625° and 1 hour, respectively. We hope we could provide more information on the quality of CTMD via comparing with CLDAS-V2.0.

About the lapse rate, the referee is right that the lapse rate from ERA-interim is steeper than the observations. Figure 4 in Gao et al., 2018 has shown that the lapse rates of ERA-Interim are greater than observations from September to December. Generally, the influence of elevation on temperature is basically unchanged at a smaller spatial resolution of 1km, while slope and aspect of the terrain become the dominant factors at hundreds meters. It is true that the free atmosphere lapse rate is steeper than the near-ground lapse rate of temperature because of the different radiation mechanism. To overcome this limitation, the downscaling model used different spatial spans, that is, from the near surface layer (~925hPa) to the free atmosphere (~500hPa). The selection of the lapse rate (such as Γ_{700_925}) for each grid is completely dependent on its altitude, which reflects a larger elevation range as much as possible for a more real temperature lapse rate as possible. In the downscaling model, we used the ERA-Interim 2-m temperature instead of site temperature. Therefore, the downscaling model is completely independent of ground stations. However, we agree that the ERA-Interim lapse rate may be part of the source of error. Meanwhile, it is a challenge to distinguish this error quantitatively from the ERA-Interim model errors.

The referee is right that the trend of minimum temperature in CTMD does not follow that of observations in Gao et al., 2018. The CTMD in Gao et al., 2018 covers a larger area (818126 km^2), which includes such as the plains on the northern slope of the CTM and the basins on the southern slope of CTM. A “Cold Lake” effect may occur within the basin in winter. The lapse rate may be positive rather than negative. For example, the Turfan Basin (below mean sea level) may have a temperature inversion layer in winter. The present study re-defines the Tianshan boundary according to Deng et al (2019). The CTM contains numerous inter-valley basins and oasis. Thus, the trends of minimum temperature in low terrains may be problematic. However, this study focuses on the trend over the whole CTM, and CTMD may not be good enough on the site scale, but it is still representative on the entire region. Again, we will introduce the CLDAS-V2.0 data set to further valid the reliability of CTMD in the revision.

3. Table 1 and 2: given the variation over time, it would be useful to know which of these trends is statistically significant.

-Answer: Thanks a lot for pointing this out. We will mark the significance levels with asterisk in Table 1 and 2 in the revision.

Table 1. Annual and seasonal temperature trends (°C 10a^{-1}) in the CTM (based on CTMD) and continental China (based on CMA05) from 1979–2016.

	CTMD			CMA05		
	Tmin	Tmean	Tmax	Tmin	Tmean	Tmax
Spring	**0.633** ***	**0.522** ***	**0.640** ***	0.557 ***	0.513 ***	0.518 ***
Summer	0.441 ***	0.342 ***	0.266 **	0.472 ***	0.388 ***	0.378 ***
Autumn	0.302	0.200 *	0.270	0.551 ***	0.458 ***	0.420 ***
Winter	0.014	-0.085	0.115	0.432 ***	0.361 ***	0.327 ***
Annual	0.347 ***	0.245 ***	0.323 ***	0.503 ***	0.430 ***	0.411 ***

Note: the bold and underlined value indicates a greater warming trend in the CTM than continental China. * denotes the significance level p<0.1, ** denotes the significance level p<0.05, and *** denotes the significance level p<0.01.

Table 2. Monthly temperature trends (°C 10a^{-1}) in the CTM (based on CTMD) and the continental China (based on CMA05) from 1979–2016.

	CTMD			CMA05		
	Tmin	Tmean	Tmax	Tmin	Tmean	Tmax
January	-0.133	-0.269	-0.235	0.343 **	0.256	0.212
February	0.313	0.177	**0.605** **	0.558 ***	0.523 ***	0.549 **
March	**0.835** **	**0.818** ***	**1.339** ***	0.651 ***	0.672 ***	0.752 ***
April	0.441	**0.537** ***	**0.664** *	0.547 ***	0.522 ***	0.516 ***
May	**0.624** **	0.211	-0.082	0.475 ***	0.345 ***	0.284 ***

June	**0.752** ***	**0.476** ***	**0.422** ***	0.516 ***	0.390 ***	0.344 ***
July	0.227	0.331 ***	0.280	0.472 ***	0.411 ***	0.416 ***
August	0.342	0.217 *	0.095	0.429 ***	0.363 ***	0.375 ***
September	0.246	0.237	0.330	0.559 ***	0.486 ***	0.495 ***
October	0.273	0.180	0.227	0.524 ***	0.434 ***	0.398 ***
November	0.386	0.183	0.252	0.569 ***	0.455 ***	0.368 **
December	-0.137	-0.164	-0.025	0.394 ***	0.303 **	0.219

Note: the bold and underlined value indicates a greater warming trend in the CTM than continental China. * denotes the significance level p<0.1, ** denotes the significance level p<0.05, and *** denotes the significance level p<0.01.

4. Line 128: How were 6-hourly data aggregated to the minimum and maximum temperature? Was any consideration given to the minimum/maximum temperature not occurring at 00, 6, 12, 18 UTC?

--Answer: Thanks a lot for pointing this out. The minimum and maximum temperatures are calculated from four temperature records. The observation standard of the China Meteorological Administration is also the instantaneous temperature four times a day, from 20 o'clock of previous day to 20 o'clock of current day at local time (UTC+8 Beijing time). The minimum/maximum temperature possible occurs at other time, rather than 00, 6, 12, 18 UTC. However, normally, the maximum temperature occurs around 14 o'clock (06:00 UTC). The minimum temperature occurs around 4 to 5 o'clock in the morning, which is close to 18 UTC (2 o'clock at Beijing time). Therefore, there is only limited effect for minimum and maximum temperature calculation from the 6-hourly data set.

5. Related to points 3 and 4: I'm surprised that in some cases, the warming increase in Tmin and Tmax are both greater than the warming increase in Tmean. This suggests some unusual shift in the shape of the diurnal cycle. Could the authors hypothesise as to why this might be?

--Answer: Thanks a lot for pointing this out. We checked the data carefully again. We found that the header of table does not correspond to the data. It means that the data is in the wrong column. We are very sorry for this kind of mistake that shouldn't be. We correct it in the revision.

Table 1. Annual and seasonal temperature trends (°C $10a^{-1}$) in the CTM (based on CTMD) and continental China (based on CMA05) from 1979–2016.

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Table 2. Monthly temperature trends (°C $10a^{-1}$) in the CTM (based on CTMD) and the continental China (based on CMA05) from 1979–2016.

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6. Section 3.3: This analysis of the spatial variations is interesting, and Figures 5-7 quite well represent the first requirement for EDW, that the warming in the region is greater than the surrounding area. However, it is difficult to see the altitude warming amplification from these plots unless you are well-acquainted with the topography of the region (e.g. from figure 5b it's only really possible to see a north-south gradient in area 1, it's not clear that that corresponds with

high-low). Would it be possible to add (small) plots such as those in figures 2-4 to figures 5-7 for each region? If it’s not possible to fit the graphs on, perhaps the trends and significance could be calculated, such as in figure 2-4? As in point 1, only those areas which fit both criteria should be described as EDW.

--Answer: Thanks a lot for the comment. The reviewer provided a very good suggestion to show the difference in spatial variations. The sub-plot is feasible. We select a certain direction in typical zone 2, and then establish a terrain profile with the corresponding temperature trend. Fox example:

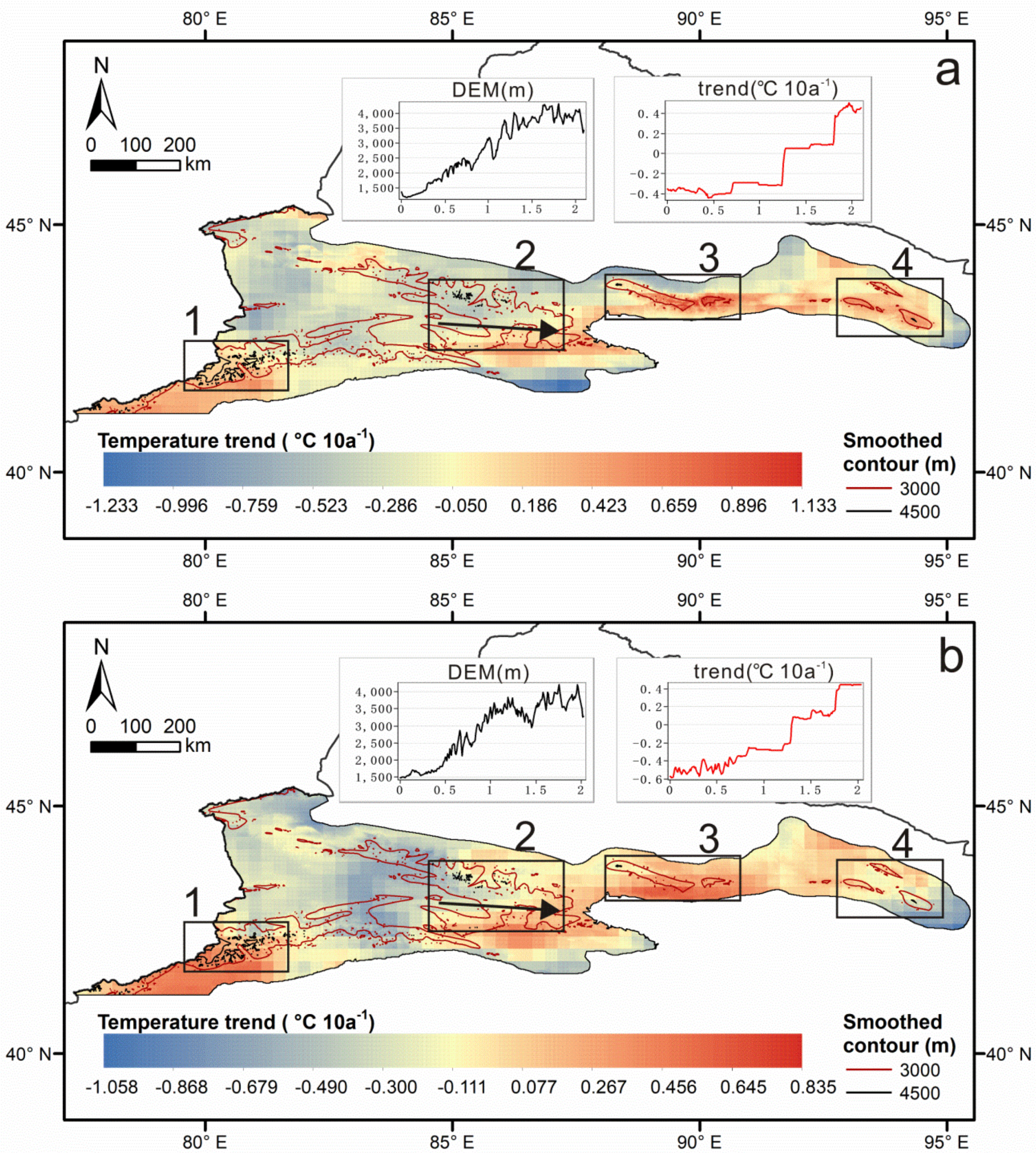

Figure 5: Monthly minimum temperature trends (a) January and (b) December for the

entire CTM from 1979–2016. The top two sub-plots show the elevation and temperature trend along the terrain profile (black arrow) in Zone 2, respectively.

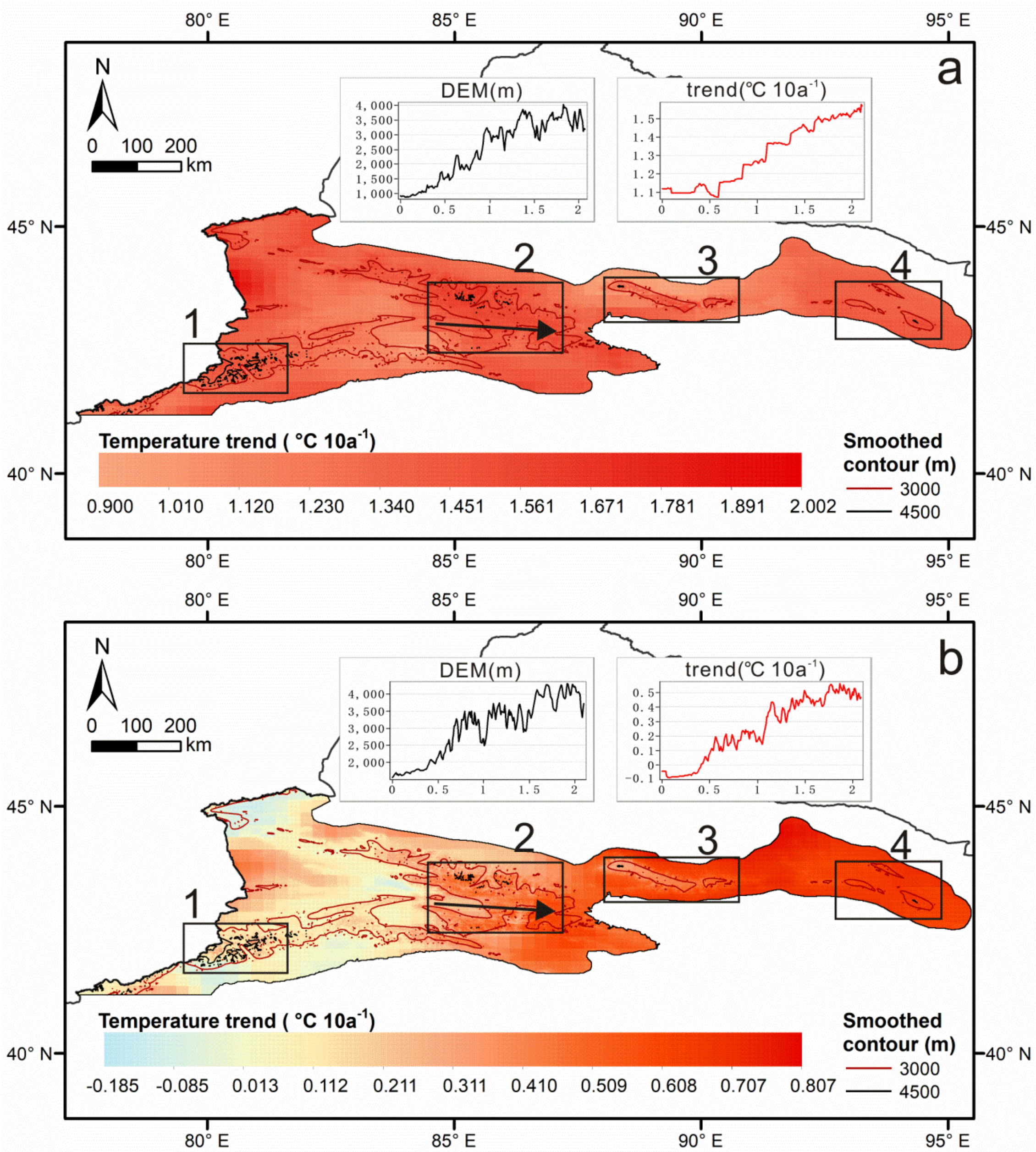

Figure 6: Monthly maximum temperature trends (a) March and (b) September for the entire CTM from 1979–2016. The top two sub-plots show the elevation and temperature trend along the terrain profile (black arrow) in Zone 2, respectively.

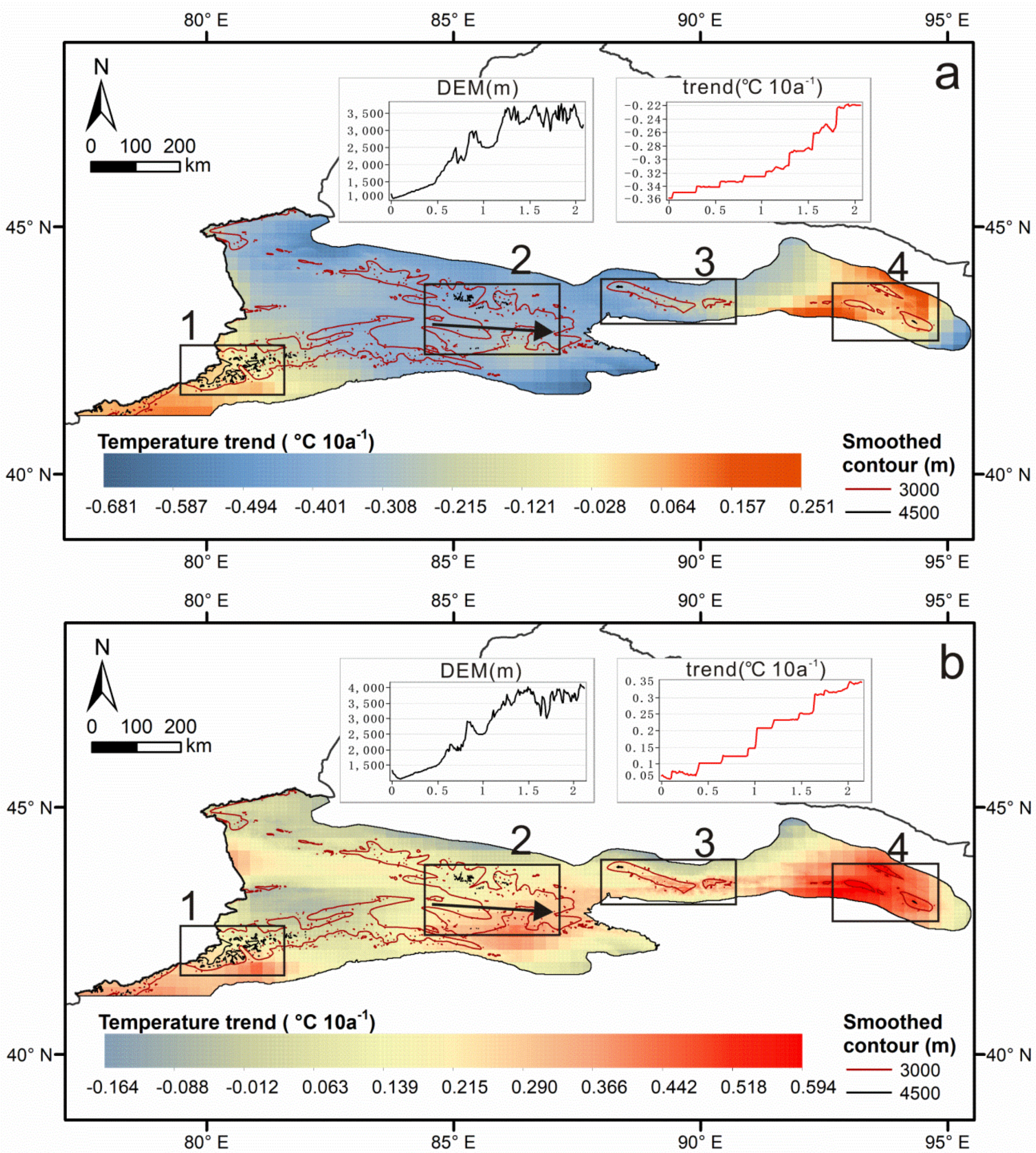

Figure 7: Monthly mean temperature trends (a) January and (b) February for the entire CTM from 1979–2016. The top two sub-plots show the elevation and temperature trend along the terrain profile (black arrow) in Zone 2, respectively.

Smaller remarks, technical comments and suggestions:

7. Figure 1: Does the bottom right hand corner map show the extent of the CMA05 used in this analysis? If so, please add to the caption. If not, could this be altered to show the CMA05 extent?

--Answer: Thanks a lot for pointing this out. We will revise and add the grid points of CMA05 in the Figure 1.

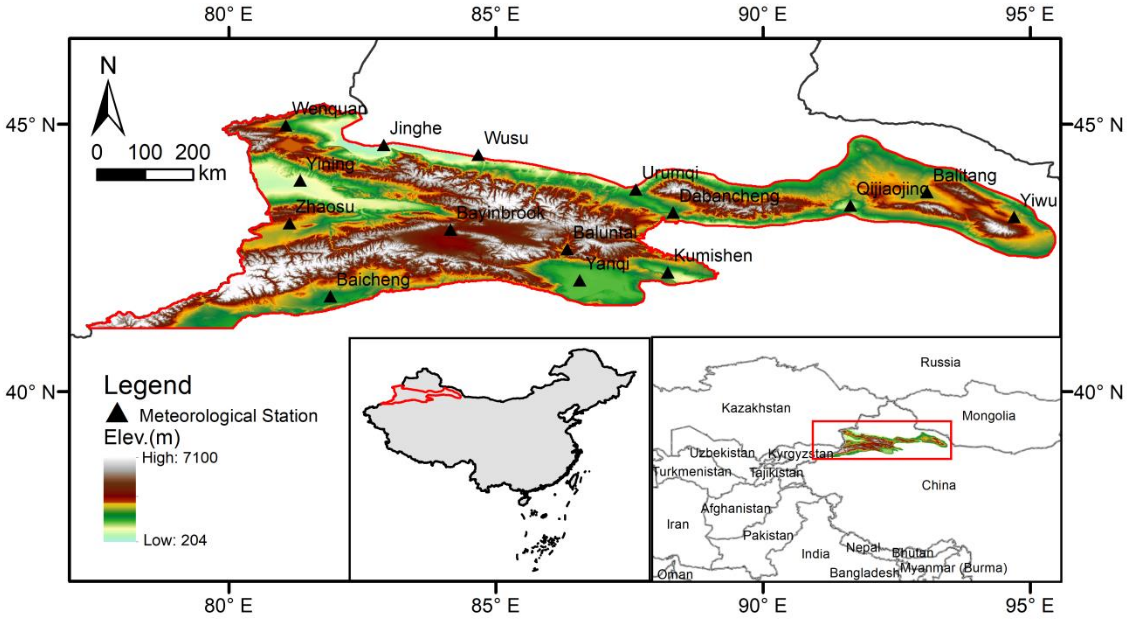

Figure1: Location of the Chinese Tianshan Mountains (CTM).The elevation ranges from 204 m to 7100 m a.s.l., with a DEM resolution of 1 km from SRTM. The grey sub-plot show the extent of the CMA05 at 0.5 °×0.5 °grid.

8. Introduction: It would be useful to make clear earlier on in the paper that EDW is referring to the rate of warming over a multi-annual scale (rather than, say, rate of warming during the day). This is made clear on line 58 with 'warming trend of annual mean temperature' but could be mentioned earlier.

--Answer: Thanks a lot for pointing this out. We will modify the expression for the whole text to clarify the warming trend over a multi-annual scale in the revision.

9. Around line 120 onwards-perhaps mention that the topography comes from SRTM.

--Answer: Thanks a lot for pointing this out. We will clarify the source of DEM that comes from SRTM. It also will be noted in the caption of Figure 1.

10. Line 136-137: it might be sensible to combine the highest two elevation bands, given that the highest only contains 4 points (which may not be

representative in general).

--Answer: Thanks a lot for pointing this out. The referee is right that only four grids above than 7000m. However, we tend to keep these 4 grids because they represent the highest peaks in the entire CTM. Meanwhile, these four grids basically have the similar performance as that of 6500-7000m group.

11. Line 268-270: I think this sentence can be removed as you're only talking about surface albedo here.

--Answer: Thanks a lot for pointing this out. We will revise it in the revision.

12. Line 113: remove 'because' (either 'because the system....,the bias could be' or 'The system bias of.... Thus, the bias...'

--Answer: Thanks a lot for pointing this out. We will revise it in the revision.

13. Please consider changing the colour bars in Figs. 5 to 7 so that they are all the same (and ideally centred around 0, so that red is positive, blue is negative and yellow around zero). At first glance it seems that the maximum temperature trends in March have both positive and negative values, which as you point out in the text is not the case. In addition, please flip the colour bars so that negative values are on the left and positive on the right.

--Answer: Thanks a lot for the comment. The suggestion is excellent for improving the readable of figures. We will revise the color bar in the revision. For example:

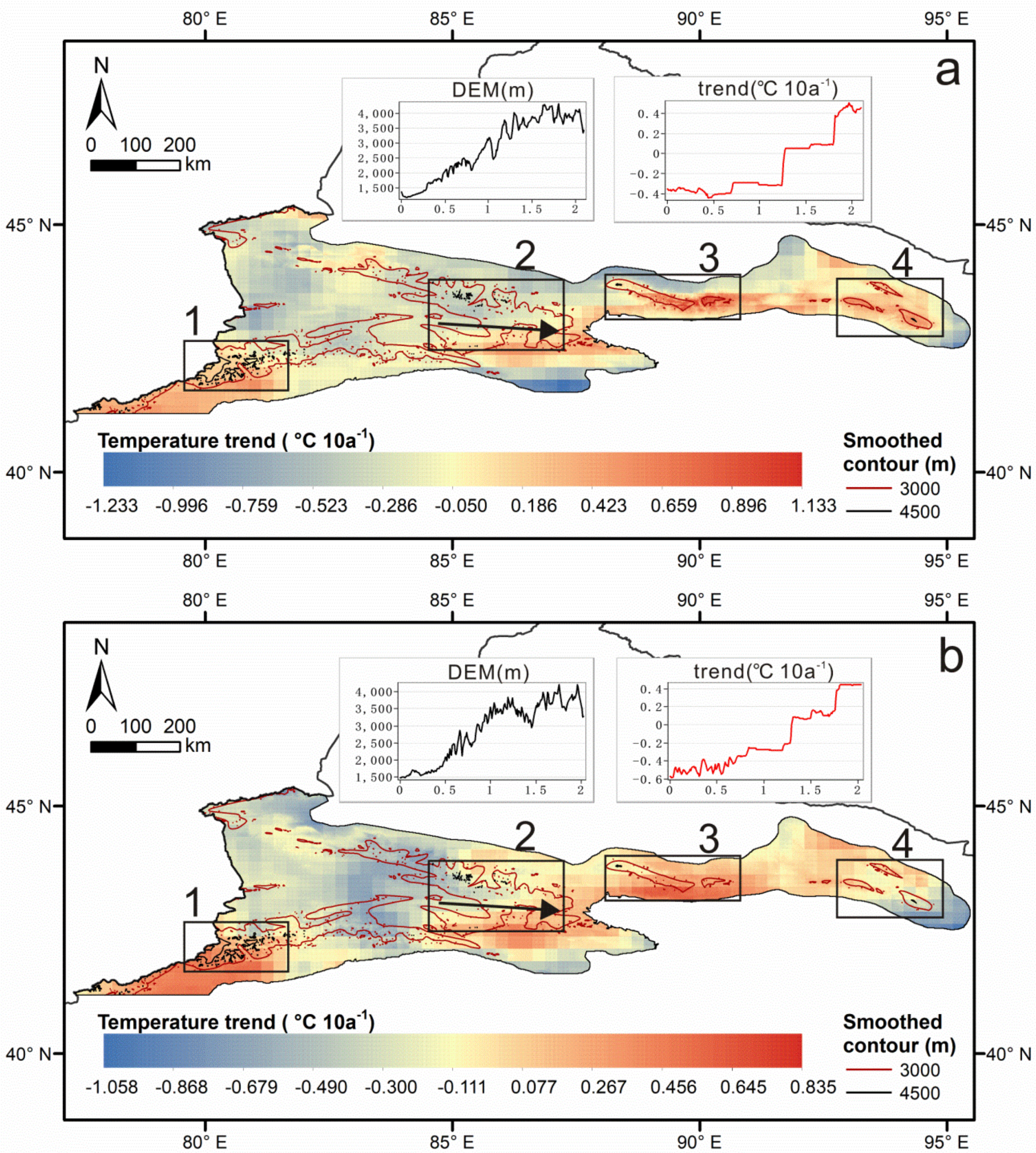

Figure 5: Monthly minimum temperature trends (a) January and (b) December for the entire CTM from 1979–2016. The top two sub-plots show the elevation and temperature trend along the terrain profile (black arrow) in Zone 2, respectively.

14. Give the location of the Ili valley where it first appears on line 208, rather than 210. References Gao, L., Wei, J., Wang, L., Bernhardt, M., Schulz, K., and Chen, X.: A high-resolution air temperature data set for the Chinese TianShan in1979–2016, Earth System Science Data, 10, 2097-2114, 2018.

--Answer: Thanks a lot for pointing this out. We will revise it in the revision.

Reference:

Deng, H., Chen, Y., and Li, Y.: Glacier and snow variations and their impacts on regional water resources in mountains, Journal of Geographical Sciences, 29(1): 84-100, 2019.

Gao, L., Bernhardt, M., and Schulz, L.: Elevation correction of ERA-interim temperature data in complex terrain, Hydrology and Earth System Sciences, 16(12): 4661-4673, 2012.

Simmons, A. J., Willett, K. M., Jones, P. D., Thorne, P. W., and Dee, D. P.: Low-frequency variations in surface atmospheric humidity, temperature, and precipitation: Inferences from reanalyses and monthly gridded observational data sets, J. Geophys. Res.-Atmos., 115, D01110, doi:10.1029/2009jd012442, 2010.