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Interactive comment on "Remote-sensing estimate of glacier mass balance over the central Nyainqentanglha Range during 1968 – ∼2013" *by* Kunpeng Wu et al.

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Dear Referee #2,

Thank you for your valuable suggestions and I have already revised the article according to your suggestions. The following are a few answers to some questions.

General comments: By quantifying the rates of ice loss in the region over several decades, this study has potential to improve our understanding of multi-decade glacier changes and water resources in an important region. However, a primary concern with this paper is the large degree of overlap with a previously published work covering the

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same topic in a nearby area (https://doi.org/10.5194/tc-12-103-2018). Many aspects of the methodology are nearly identical, except that a 1968 topographic map is used instead of a 1980 topographic map. I recommend the authors summarize all similar aspects, then simply cite their previous work. This will allow the new manuscript to focus on the unique portions, such as the different time intervals and the quantification of the acceleration of ice loss. This will require a significant revision by the authors. However, in its current form I feel the manuscript is too similar to the previous work for publication in TC.

Answer: Thank you for your valuable suggestions and I have already revised the article according to your suggestions. The data processing in this study was almost simultaneous with that one in Wu et al. (2018). The only difference is that the two-dimensional first-order polynomial fitting in off-glacier regions removes the residual in the differential interferogram. This study area is closed to the study area in Wu et al., 2018, and this processing scheme is similar with previous study, but the Result and Discussion have big differences, such as the distribution of debris covered region, the effect of debris-cover to mass balance, and the difference of land-and lake-terminating glacier mass balance. It is indicated that this study has great scientific value and it is definitely worth to study.

Specific comments:

(1) Page 1 line 26: The uncertainties for the 1968-2000 interval ($\pm$ 0.05) seem rather small, especially when viewing the vertical error statistics in Table 3, where the standard deviation of vertical error between TOPO and SRTM ranges from 20 to 27 meters. Figure 5a (elevation difference between 1968 and 2000) also shows large areas with significant vertical error over both ice and ice-free terrain, which may be due to interpolation procedures used when the topographic map was originally created. The limits of the color scaling (-7.69 to 7.69 meters) also seem too narrow - a wider elevation range should be used in this figure so that larger elevation changes are not saturated at the endpoints of the color bar. Based on these, I would expect uncertainties larger

than ± 0.05. I recommend careful revisit of the uncertainty estimation procedure, to ensure that the results are representative of the vertical error associated with using the historical topographic maps.

Answer: Thank you for your valuable suggestions and I have already revisited the uncertainty estimation procedure carefully and revised the result of uncertainty in manuscript and tables. For the maximum value of the color scaling, elevation differences with values exceeding ±100 m were defined as outliers and omitted, so the 7.69 m a-1 is the maximum elevation difference and can be considered reasonable.

(2) Page 2 line 40: I am wondering if the authors drew the topographic maps themselves? The wording is unclear here.

Answer: The topographic maps were compiled by the Chinese Military Geodetic Service from air photos acquired in April 1968. Based on scanned and well-georeferenced topographic maps, the outlines of glaciers in the CNR in 1968 were digitized manually by authors.

(3) Page 3 line 3: Most readers will not be as familiar with the region, thus using county names may not be the best way to describe the location.

Answer: Thank you for your valuable suggestions and I have already added the latitude and longitude range of study area.

(4) Page 4 line 25: Not sure what is meant here by "higher quality images could not be acquired in 2000-2010". There are several Landsat 7 scenes obtained in the early 2000's which are cloud-free and available over the region of study (Landsat scene LE71350392001335BJC00 acquired on Dec 01 2001 for example). What is this referring to?

Answer: Thank you for your valuable suggestions and I checked Landsat 7 scenes obtained in the early 2000's in USGS, scenes with cloud-free indeed exist, but most scenes with extensive snow cover. Due to the influence of the Indian monsoon and westerly winds, the CNR was almost permanently covered by cloud in summer and covered by snow in winter in 2000–2010, so higher quality images could not be acquired.

(5) Page 4 line 29: “No horizontal shift was observed”. What is the horizontal shift being measured relative to?

Answer: I have already revised this section. “Acquired from the United States Geological Survey (USGS), the Landsat OLI images are orthorectified with the SRTM. We selected a Landsat OLI scene from 2016 as reference. For the OLI scenes no horizontal shift was observed, whereas the topographic maps had small systematic shifts of 6 to 12 m.”

(6) Page 4 line 33: Do the authors have access to the original aerial photographs? If so, it would be useful and interesting to create a figure showing a sample aerial image for some of the glaciers. Also, later in in the paper, it states that Corona satellite images were used to estimate the uncertainty of glacier outlines (Page 10 line 5). Were the Corona images used in the creation of glacier outlines as well? Please clarify exactly how the aerial photographs, topographic maps, and Corona images were used to derive the glacier outlines.

Answer: I am sorry that I did not make it clear due to the mistake in the English language. I didn’t have access to process the original aerial imagery but the topographic maps. Topographic maps were compiled by the Chinese Military Geodetic Service from aerial images acquired in April 1968. Based on scanned and well-georeferenced topographic maps, the outlines of glaciers in the CNR in 1968 were digitized manually by authors. For Corona image, it was used to evaluate the accuracy of glacier outlines in the western Nyainqentanglha Range (Wu et al., 2016). The image was orthorectified based on ASTER GDEM V2 and a pan-sharpened Landsat OLI image. Before digitising the glacier outlines and comparing them temporally, topographic maps had done co-registration with Corona image. After eliminating the impact of cloud and seasonal snow, an accuracy of less than half a pixel was achieved. Then the offset in the pixels between topographic maps and Corona image was 2.8 m. Upon careful examination, the dark portions of the image that are included as part of the outlines, are those shadow of mountains on the glacier surface. The average offset between the topographic-map and Corona-image outlines was ±6.8 m, calculated as the average distance between points taken every 10 m along the map outline and the nearest points on the corresponding Corona image outline. Hence, average offsets between topographic-maps outlines and Corona image in CNR can be considered as the same offsets of ±6.8 m, and then mean relative error was calculated for glacier area in 1968.

(7) Page 5 lines 5-9: The logic in this statement is unclear to me. How are the ±0.8% and ±3.0% values derived?

Answer: Compared glacier outlines derived from Landsat-images with real-time kinematic differential GPS (RTK-DGPS) measurements, average offsets of ±10 m and ±30 m were acquired for the delineation of clean and debris-covered ice (Guo et al., 2015), whereas average offsets between topographic-maps outlines and Corona images was ±6.8 m (Wu et al., 2016). For glacier outlines in 1968, a buffer with ±6.8 m was generated in ArcGIS software. The difference between the area of new polygon and 1968 glacier area is the error of 1968 glacier area. Then divided the error by 1968 glacier area, mean relative error of ±0.8% was determined for glacier areas in 1968. The same method was employed for 2016 glacier area and mean relative error of ±3.0% was determined for glacier areas in 2016.

(8) Page 5 lines 25-34: A more detailed and clear description is required to understand how the glacier centerlines were derived. In what way are the glaciers divided into two polygons? Also I do not understand how and for what purpose the derived centerlines are compared with high-resolution aerial imagery. How are the uncertainties of 6 and 7.5 meters obtained? Perhaps a figure helping to illustrate this process would be helpful.

Answer: Based on a glacier-axis concept derived from glacier morphology that only requires glacier outlines and a digital elevation model (DEM) as input, glacier centerline was derived semi-automatically in this study (X. Yao et al., 2015). The glacier-axis concept assumes the main direction of any given glacier can be defined as a curved line. The glacier outline is divided initially into two curved lines based on its highest and its lowest elevation. Using these, the glacier polygon is then divided by Euclidean distance into two regions. The common boundary of these two regions is the glacier axis or glacier centerline. An error estimation of the resulting centerlines was performed, comparing the semi-automatically generated results to high-resolution aerial imagery at the terminus. A Corona image, with a resolution of 4 m, and Google EarthTM images, with a resolution better than 1 m, were used to evaluate the accuracy of these centerlines. In a comparison with topographic maps and Landsat images, the uncertainties in centerline location were no more than 6 m and 7.5 m, respectively.

(9) Page 8 line 9: Regarding the statement "probably overestimate the uncertainty of the larger sample". What "larger sample" is being referred to here?

Answer: "Larger sample" refers to the larger off-glacier regions. Because averaging in larger regions reduces the error, the standard deviation (SD) in off-glacier regions will probably overestimate the uncertainty of the larger off-glacier regions. Hence, the uncertainty can be estimated by the standard error of the mean ($SE = SD/\sqrt{N}$, N is the number of the included pixels).

(10) Page 8 line 13: How do the decorrelation lengths factor into the uncertainty estimates? An additional equation showing exactly how they are used would be helpful.

Answer: To minimize the effect of autocorrelation, a decorrelation length based on the spatial resolution is recommended. From previous studies, decorrelations of 600 m and 200 m were employed for different DEMs with the spatial resolution of 30 m and 10 m (Bolch et al., 2011; Paul et al., 2015). Utilization of the decorrelations of 600 m and 200 m, regular network were created in whole study area. Then the included pixels in off-glacier area were counted and used to estimate the standard error of the mean (Table 3). The overall errors of derived surface-elevation changes can then be estimated using mean standard error and average elevation difference in off-glacier regions.

(11) Table 3: Using MED as an abbreviation for mean may be confusing, as MED is commonly used to abbreviate median.

Answer: Thank you for your valuable suggestions and I have already changed “MED” into “AED”. (AED as an abbreviation of Average Elevation Difference)

(12) Page 8 Line 33: How were debris-covered portions of the glaciers delineated?

Answer: I have already introduced how to separate the debris-free and debris-covered regions in the section of 4.1. Glacier outlines in 2016 were delineated using a ratio threshold method, a division of the visible or near-infrared band and shortwave infrared band of Landsat OLI images (Paul et al., 2009; Racoviteanu et al., 2009). A 3 $\times$ 3 median filter was applied to eliminate isolated ice patches $<$ 0.01 km2 (Bolch et al., 2010b; Wu et al., 2016). In order to discriminate proglacial lakes, seasonal snow, supraglacial boulders and debris-covered ice, scenes without snow, or cloud-free image scenes acquired at nearly the same time, were used for reference when making manual adjustments. Generated from the SRTM-C DEM automatically, topographical ridgelines (TRLs) were used to divide the final contiguous ice coverage into individual glacier polygons (Guo et al., 2015). Due to a small proportion of debris-covered regions in study area, the debris-free and debris-covered regions were separated manually using Landsat OLI images.

(13) Page 9 line 14: The magnitude of this length change seems extremely large. Is this a lake-terminating glacier? Can the authors show images of the glacier in 1968 and 2016 to confirm this? On another note, it is difficult in this paper to determine which glacier ID corresponds to which glacier in the figures. For example, the numbers in Figure 1 should correspond to the numbers in Table 6, as currently this does not

seem to be the case.

Answer: Thank you for your attention and I made a mistake in this paragraph. Glacier 5O281B0575 experienced the most recession, not Glacier 5O281B0668. And Glacier 5O281B0575 is a lake-terminating glacier. I have already added a supplementary figure S2 to show more detail of glacier length change. “Glacier 5O281B0575 experienced the most recession (105.1 m a-1), its length decreasing from 24703 m to 19657 m. The terminus elevations of these selected glaciers rose an average of 113 m, varying from 23 m (3759 to 3782 m a.s.l.) to 323 m (3981 to 4304 m a.s.l.).”

(14) Page 13 line 13: It is interesting to see the 0.5 x 0.5 degree temperature and precipitation trends derived from the Grid-based China v 2.0 dataset. However, it seems rather tenuous to base conclusions on a single climate dataset at very course spatial resolution over a region of extreme mountain topography. As the authors summarize in the paragraph starting on page 13 line 14, different climate datasets give widely varying results. The authors have chosen this particular climate dataset to base their conclusions on - is there sufficient reasoning for why this dataset is more accurate than any of the other cited ones? Some justification is required for using this climate dataset instead of others. In turn, more details regarding how the actual trends were computed would be helpful. Did the authors calculate the trends, or are they from prior studies? Overall, while this section provides a good overview of a particular climate dataset, it may not be robust enough to attribute glacier changes. Page 13 line 27: Where are the weather stations located to derive this climate dataset? Were any high altitude stations used which are located nearby the glaciers? Page 13 line 28: How were the temperature and precipitation trends derived? Page 13 line 37: Figure 8 does not show the climate changes separated into the 1961- 2000 and 2000-2013 intervals. Do you have any data suggesting that the warming rate has increased after 2000?

Answer: I have already revised this section. “To analyse the response of glaciers in the CNR to climate change, relevant air temperature and precipitation datasets were taken from the Dataset of Daily $0.5^{\circ} \times 0.5^{\circ}$ Grid-based

Temperature/ Precipitation in China (V2.0) (Dataset2.0). Using the thin plate smooth spline method, and a 50 year (1961 to 2010) quality controlled observational daily temperature and precipitation data series based on 2472 gauges (http://data.cma.cn/data/cdcindex/cid/00f8a0e6c590ac15.html), Dateset2.0 was produced by the Climate Data Center, National Meteorological Information Center, China meteorological Administration for Mainland China. Previous study showed that the mean bias error of precipitation in large part gauge is between -1 mm d-1 and 1 mm d-1. Dataset2.0 reduced the rain intensity when heavy rain or moderate rain comes. Over the light rain, it has more veracity. Dataset2.0 is exact describing the climate characteristic of the Tibetan Plateau, the Tienshan Mountains and Tarim Basin (Zhao and Zhu, 2015). Linear regression analysis was performed in each grid for temperature and precipitation during 1961-2010, 1961-2000 and 2000-2010. Fig. 10 shows the horizontal distribution of surface temperature and precipitation changes from May to September since 1961. It is clear that increasing surface temperatures and decreasing precipitation have been dominant in the CNR in recent decades. The changes in surface temperature and precipitation were confirmed with data from the three nearest meteorological stations, Jiali (30°40âĂšN, 93°17âĂšE, 4488 m a.s.l.), Linzhi (29°40âĂšN, 94°20âĂšE, 2992 m a.s.l.) and Bomi (29°52âĂšN, 95°46âĂšE, 2736 m a.s.l.). Surface temperature at these stations increased slightly from 1961 to 2000 and then significantly after 2000, the average temperatures at the three stations after 2000 increased 0.44 $\sim$ 0.50°C than those before 2000. The trend of precipitation is not evident at the three stations and present large interannual precipitation fluctuations. Dataset2.0 shows average precipitation decreasing by more than 40 mm per decade since 1961, resulting in less glacier accumulation. The reduced precipitation on the N slope is smaller than on the S slope, but glaciers on the N slope experienced a more intense mass loss than the S slope. This suggests the influence of precipitation is much less on glacier mass loss in the CNR. The average surface temperature increased by more than 0.2°C per decade in the CNR (with a confidence level <0.05), higher than the rate of global warming (0.12°C per decade, 1951–2012) (IPCC, 2013). The warming rate on the N slope is slightly larger than that on the S slope. Furthermore, a lesser warming rate was present from 1961 to 2000, becoming greater after 2000. The changes of average surface temperature are consistent with the changes of glaciers. The mean mass deficit in the 5O28 drainage basin (on the S slope) was smaller than that in the 5N22 drainage basin (on the N slope) during the investigated periods. Glacier mass loss in the CNR can be attributed to climate warming."

This dataset was produced by the Climate Data Center, National Meteorological Information Center, China meteorological Administration and has excellent reliability. I have already added the location of weather stations in Figure 10. There have no other high altitude stations can be used which are located nearby the glaciers. The temperature and precipitation trends were derived from linear regression analysis in each grid during 1961-2010. Fig. 10 shows the horizontal distribution of surface temperature and precipitation changes from May to September since 1961.

(15) Figure 7: It would be nice to see the locations where each photo was taken on the map image of the glacier (in panel a).

Answer: Thank you for your valuable suggestions and I have already added the locations where each photo was taken on the map image of the glacier (in panel a).

Best Regards, Wu Kunpeng and other authors

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2018-90/tc-2018-90-AC3-supplement.zip

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2018-90, 2018.