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The Cryosphere Discussions

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 #1,

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: An idea to increase the novelty of this study would be to process the original aerial imagery (to which the authors state that they have access) with new software solutions to obtain better surface elevations and ortho-images from the mid-1960s.

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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. They were not acquired with new software solution, but the accuracy of topographic maps is very high. According to the photogrammetric Chinese National Standard (2008) issued by the Standardization Administration of the People's Republic of China, the nominal vertical accuracy of these topographic maps is within 3-5 m for flat and hilly areas (with slopes of $< 2^\circ$ and 2-6°, respectively) and within 8-14 m for the mountainsides and high mountain areas (with slope of 6-25° and >25°, respectively). The horizontal accuracy of the topographic maps is within 0.5 mm for flat and hilly areas and with 0.75 mm for the mountainsides and high mountain areas. Hence, glacier area and mass balance result from topographic maps should be reliable.

Specific comments:

(1) Page 3 line 6-23: I am wondering if the authors are aware of the study of Loibl et al., 2014 who give a thorough overview of the study area.

Answer: I have already revised the section of study area. "The CNR (30°9âĂš∼ 30°53âĂšN, 94°0âĂš∼ 95°30âĂšE) lies in south-eastern Tibet, north of Linzhi County, east of Jiali County and west of Bomi County, extending about 130 km from west to east. South of this region is the Yigong Tsangpo River, a tributary of the Purlung Tsangpo River and a secondary tributary of the Yarlung Tsangpo River (Fig. 1). The altitudinal differences between mountain peaks and valley bottoms often reach 3000-3500 m. The rugged topography with steep valleys and slopes results from the interplay of a still ongoing tectonic uplift and erosion (Li et al., 1986). High precipitation amounts during the summer monsoon season (May to September) are the main reason for the intense erosion. The CNR is characterized by a strong climatic influence of the Indian summer monsoon entering through the Yarlung Tsangpo valley (Loibl et al., 2014). More than 80% of annual precipitation falls from June to September, while winter months are characterized by cold and dry conditions (Molnar et al., 2010). According to the climatic classification of local meteorological station data, the CNR marks a transition zone between warm-wet subtropical and cold-dry plateau conditions (Leber et al., 1995). Previous studies showed that average annual precipitation in most high-elevation areas in the CNR exceeds 2000 mm. Farther north, the east-west striking ranges act as barriers forcing heavy orographic rainfalls (Böhner, 2006; Maussion et al., 2014). This results in a distinct precipitation gradient from south toward north slope of the CNR (Shi et al., 1988). Due to the high elevation, the monsoonal summer precipitation accumulates as snow in the upper reaches of the mountain range, a large number of maritime (temperate) glaciers developed (Shi et al., 2008; Shi and Liu, 2000). The first Chinese Glacier Inventory (CGI) determined that glaciers covered 2537.7 km2 of our study region, with a total volume of 454.2 km3 in 1968 (Mi et al., 2002; Pu, 2001); about 8% of the area was covered by debris. Three glaciers in the CNR are larger than 100 km2, the Xiaqu (CGI code: 5O281B0702), Kyagqen (CGI code: 5O281B0729) and Nalong (CGI code: 5O281B0768). The Kyagqen, on the south slope of the CNR, 35.3 km long and 206.7 km2, with a terminus at 2900 m a.s.l., is the largest of these (Li et al., 1986). Above 4000 m a.s.l. it has a broad basin in which several ice streams converge to form a large accumulation zone (165 km2) that accounts for over 80% of the glacier's total area. Below this, the glacier enters a narrow ice-filled valley where its velocity increases; the resultant great driving force pushing the glacier terminus to a subtropical elevation at 2900 m a.s.l. The narrow glacier tongue, 1000 m wide and 17 km long, passes through the subalpine shrub-meadow zone, the mountain dark coniferous forest zone and the mixed broadleaf-conifer forest zone (Li et al., 1986)."

(2) Page 5 line 36-Page 7 line 8: I am also wondering in how far this processing scheme differs to the one applied by Wu et al., 2018? I think it would be better to explain the differences to Wu et al, 2018 rather than rewriting everything. This applies not only for this section but for large parts of the manuscript.

Answer: Actually 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.

(3) Page 7 line 14-18: this is probably a reasonable assumption, however surface properties could still have been different in both years.

Answer: Surface properties have been different in both years, it is reflected in precipitation in acquired dates of SRTM and TerraSAR-X/TanDEM-X. Given that the SRTM and TerraSAR-X/TanDEM-X were observed mostly in February, winter months are characterized by cold and dry conditions in study area, and the carrier frequencies of the TerraSAR-X/TanDEM-X and the SRTM X-band satellites are almost the same, it is assumed that no penetration warranting consideration exists between these two datasets.

(4) Page 7 line 23-24: was this mean value used for a correction? Not clear. I strongly suggest to read the above studies (Vijay, S. et al., 2016 and Neelmeijer, J. et al., 2017) as radar penetration is clearly a function of altitude and surface properties. The authors need to account for this.

Answer: I have already revised the section of "4.4 Penetration depth". "The penetration depth differences were analysed and corrected in each 100 m elevation bin. Because the penetration difference should not exceed 10 m (Gardelle et al., 2012a), all of the difference values greater than ±10 m were defined as outliers and did not consider for the penetration estimation. The median values of each elevation bin were used to correct the SRTM C-band DEM but only for areas with elevations below 6200 m a.s.l. In the CNR, the penetration depth difference for clean ice/firn/snow was about 0.88 m below

5200 m, and 1.28 m between 5200 and 6200 m. There have no enough pixels per elevation bin were available to generate reliable results at higher elevations. Glacier area above 6200 m occupies about 0.78% of the total glacier area in this study. According to the linear trend calculated for the several highest bins in Fig. 3, a value of 2.26 was assumed for the area above 6200 m. Interestingly, some of the lower elevation bins in debris-covered area show negative correction values. Because the stable areas were also partly covered with snow, the radar penetration difference due to this snow cover was removed during the vertical matching of SRTM C-band and X-band DEMs., Low-elevation bins in debris-covered area have less snow cover than the stable areas, and this will result in negative radar penetration differences. Hence, penetration corrections were not applied for the debris-covered regions. In total, the average penetration depth of the SRTM C-band radar is 1.16 m for clean ice/firn/snow in the CNR. This value is consistent with previous studies finding an average penetration depth of 1.1 m in Yigong Tsangpo (Zhou et al., 2018)."

(5) Page 8 line 1-4: I have the feeling that this sentence is rather related to DEM processing than to accuracy assessment. How did the authors find that the accuracy of both DEMs is similar? Not clear.

Answer: Page 8 line 1-4: "For the InSAR-derived TerraSAR-X/TanDEM-X DEM, the GCPs that converted the unwrapped interferogram into absolute heights were selected from the off-glacier regions of the SRTM C-band DEM; the accuracy of TerraSAR-X/TanDEM-X DEM are similar to those of the SRTM C-band DEM." In section of "4.3 Glacier elevation changes", I have already introduced that "The unwrapped differential phase could be transformed to absolute elevation changes from the computed phase-to-height sensitivity and select ground control points (GCPs) of the off-glacier regions of the SRTM C-band DEM" . It can assume that the off-glacier regions of TerraSAR-X/TanDEM-X DEM are similar to those of SRTM C-band DEM. The accuracy of DEMs were assessed by off-glacier elevations, so the accuracy of TerraSAR-X/TanDEM-X DEM are similar to those of the SRTM C-band DEM.

(6) Page 8 line 10: it might also be interesting to see the sinusoidal relationship between vertical bias and aspect (Page 6 line 36-Page 7 line 3, before and after the correction). Further it would be interesting if any systematic bias is remaining in the off-glacier regions. See for example Neelmeijer, J. et al., 2017 on this issue.

Answer: I have already added the sinusoidal relationship between vertical bias and aspect. "Based on the relationship between elevation difference, slope and aspect, relative horizontal and vertical distortions between the two datasets were corrected statistically (Nuth and Kääb, 2011). At first, a difference map was constructed with the TOPO DEM and SRTM C-band DEM. Before adjustments, histogram statistics for off-glacier regions showed elevation differences concentrated at 6.73 m. Outliers are usually found around data gaps and near DEM edges and can be excluded using 5% and 95% quantile thresholds based on statistical analysis (Pieczonka et al., 2013). Then, based on the substantial cosinusoidal relationship between standardized vertical bias and topographical parameters (slope and aspect), the vertical biases and horizontal displacements could be rectified simultaneously (Fig. 2). The biases, caused by different spatial resolutions between the two datasets, could be refined using the same relationship between elevation differences and maximum curvatures for both on- and off-glacier regions (Gardelle et al., 2012a)." For the systematic bias in the off-glacier regions, the iterations continued until the change of the magnitude of the shift vector was less than 0.3 m.

(7) Page 11 line 26-28: and what did they find? Please explain or remove. There is also a recent study of Ji et al., 2018 which might be of interest in this context. I am not sure if Table 7 is really necessary. I have the feeling that it makes things more confusing.

Answer: In this section, we concluded that the glaciers in the study area have shrunk continuously since 1968 (1.23% a-1 from 1970–1999, 0.82% a-1 from 1999–2011 and 0.62% a-1 from ∼2010 to 2016), although the rate has eased during the most recent decade. The study of Ji et al., 2018 present the change of glaciers in whole eastern

Nyainqentanglha Range, the mean glacier size in eastern Nyainqentanglha Range is smaller than that in central Nyainqentanglha Range. In this and previous studies a greater relative loss has been measured for the smaller glaciers. In order to analysis the tendency of glacier area change in CNR, the study of Ji et al., 2018 cannot be discussed in this study. I have already deleted the Table 7.

(8) Figure 3: I assume that the colored dots represent the median elevation of each glacier, but how did the authors calculate the relative amount of debris cover? E.g. has every glacier with a yellow dot a relative debris cover of 10%? Please explain.

Answer: The relative amount of debris cover is the ratio of the area of debris cover to the total glacier area per elevation class.

(9) Page 13 line 13-41: I am not a climate modeler, however when looking at Figure 8 I am wondering how well this dataset is resolved in mountainous areas such as the study area and how well this dataset fits to other estimates in the region. I think such points need to be discussed in more detail. Are there any other glacier related studies relying on this dataset?

Answer: I have already revised this section. "To analyze 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° × 0.5° Grid-based Temperature/ Precipitation in China (V2.0) (Dataset2.0). Dataset2.0 was produced using the thin plate smooth spline method, and a 50 year (1961 to 2010) quality controlled observational daily climate data series based on 2472 gauges (http://data.cma.cn/data/cdcindex/cid/00f8a0e6c590ac15.html) for Mainland China. Dataset2.0 is exact describing the climate characteristic of the Tibetan Plateau, the Tienshan Mountains and Tarim Basin (Zhao and Zhu, 2015). Fig. 8 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 2015, while 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."

There have no other glacier related studies relying on this dataset, but this dataset was produced by the Climate Data Center, National Meteorological Information Center, China meteorological Administration and has excellent reliability.

(10) Figure 5: I think that at this scale the reader is not able to detect any details in the elevation change maps. I therefore suggest to additionally zoom in into several subsections which could be shown in a supplement. As mentioned before it would be of great value to also see the elevation changes in the off-glacier regions. I also found the limits of the color bar rather strange. Is 7.69 m really the maximum value? Furthermore I have the feeling that the TOPO DEM has several regions with unreliable

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interpolation artifacts. As mentioned above, generating DEMs from the original aerial images could possibly improve the results.

Answer: Thank you for your valuable suggestions and I have already added more details in a supplement, including several subsections and the elevation changes in the off-glacier regions. For the maximum value, elevation differences with values exceeding $\pm$100 m were defined as outliers and omitted, so the 7.69 m a-1 is the maximum elevation difference. As mentioned above, 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. They were not acquired with new software solution, but the accuracy of topographic maps is very high.

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-AC2-supplement.zip

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