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The Cryosphere
Discussions

Interactive comment on "Recent glacier mass balance and area changes in the Kangri Karpo Mountain derived from multi-sources of DEMs and glacier inventories" *by* Wu Kunpeng et al.

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Dear referee,

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: (1) "The authors point to the possibility for glacier surging and/or increases in precipitation to explain their observations of advancing glacier (Page 11, Lines 20-21) and thickening at glacier termini (Page 12, Lines 27-28). This should be expanded: is there any evidence of glacier surging in the region, e.g. from glacier

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morphological features and patterns? Regarding precipitation, the authors analyze a gridded climate product that shows a mix of increase and decrease in precipitation across the region, but they do not link these results to the inferences about advancing/thickening glaciers. This could be explored further by looking at trends in the accumulation area stake mass balance datasets and exploring more precipitation station data, including a consideration of solid versus liquid precipitation. ”

Answer: I have already provided more discussion for advanced glaciers, and we found that advance of individual glaciers resulted from the increase of high precipitation. “For advanced glaciers, the mean glacier size is about 0.51 km2 and mean glacier surface slope is about 27.9 °, most glaciers have an S or SW aspect, and mean accumulation area ratio (AAR) is 51. Previous studies also found advanced glaciers in Kangri Karpo Mountains (Liu et al., 2006; Shi et al., 2006). Compared with the CGI2 and GAMDAM glacier inventory, the location of most glacier termini in 2000 are very close to that in 2014, indicated that glacier advanced mainly occurs before 2000. Due to the special geographic location and climate feature, the qualities of Landsat MSS/TM images are too low to identify glacier termini. Fortunately, two Landsat Thematic Mapper (TM) scenes (LT51340401994189BKT00 and LT51340401988301BJC00) with high quality can be employed in this study. Compared the glacier termini that acquired from Landsat scenes, such as Glacier 5O282B0111 (Fig. 3B), glacier advanced mainly occurs before 1988, and glacier retreated continuously after that (Fig. 7). Main reason for this phenomenon is probably that the increase of high precipitation (Shi et al., 2006). Annual precipitation dataset from 1980 to 2012, collected from the three nearest meteorological stations (Bomi, Zuogong and Zayu), indicated that maximum precipitation (1153 mm in 1988) is 1.6 times the minimum precipitation (714 mm in 1981) at Bomi (29°52âĂšN, 95°46âĂšE, 2736 m a.s.l.), maximum precipitation (683 mm in 1987) is 2.3 times the minimum precipitation (302 mm in 1983) at Zuogong (29°40âĂšN, 97°50âĂšE, 3780 m a.s.l.), and maximum precipitation (1091 mm in 1988) is 1.7 times the minimum precipitation (624 mm in 1982) at Zayu (28°39âĂšN, 97°28âĂšE, 2423 m a.s.l.). Supposing that the precipitation fluctuation in high elevation glacier area had

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been consistent with that at the three nearest meteorological stations, the change of precipitation or glacier accumulation certainly have significant influence on terminus fluctuation of glaciers. Due to the complicated terrains, the accumulation of glaciers varies greatly, and the response of glacier movement is not quite the same, individual glaciers advanced during 1980 – 1988."

Figure 7. Terminus changes of Glacier 5O282B0111 from 1980 – 2015.

(2) "The authors make inferences about climate controls on the regional glacier mass loss on page 12-13 that are poorly supported."

Answer: I have already provided more discussion for climate controls on the regional glacier mass loss, and we found that climate warming is the primary control on the regional mass balance. "For the rainfall-variation law, a slightly increasing trend was present in the detailed study area of Kangri Karpo Mountains during 1980 – 2012. The increase of precipitation results in more glacier accumulation, while glaciers have experienced an intense mass deficit in the detailed study area of Kangri Karpo Mountains. It can be concluded that other factors are playing a more important role in glacier mass deficit. For the change of temperature, warming was present in the detailed study area of Kangri Karpo Mountains during 1980 – 2012. And the warming rate on the northern slope of the Kangri Karpo Mountains is larger than that on the southern slope slightly. A small warming rate was present from 1980 – 2000, and increased to large warming rate thereafter. This is consistent with the tendency of glaciers change. Glaciers have experienced an intense area reduction and mass deficit in the Kangri Karpo Mountains, and mean mass deficit in the drainage basin of 5O282B (located on the northern slope of detailed study area) was larger than that in the drainage basin of 5O291B (located on the southern slope of detailed study area) during 1980 – 2014. Meanwhile, the rate of glaciers shrinkage and mass loss from 1980 – 2000 were lower than those from 2000 – 2015. Hence, glaciers change in the Kangri Karpo Mountains can be attributed to climate warming. "

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Specific Comments: “Page 2, Lines 16-22: This paragraph is confusing: how was mass deficit established?”

Answer: Thank you for your suggestion and I have already revised this paragraph. “Previous studies have agreed that glaciers in the Kangri Karpo Mountains have experienced mass deficit, nevertheless, the results did differ from each other (Gardelle et al., 2013; Gardner et al., 2013; Kääb et al., 2015; Neckel et al., 2014). Using SRTM DEM and SPOT5 DEM (24 November 2011), glaciers experienced a mean thinning of 0.39 ± 0.16 m a-1 in the Kangri Karpo Mountains (Gardelle et al., 2013). Based on ICESat and SRTM, Kääb et al. (2015), Neckel et al. (2014) and Gardner et al. (2013) acquired different results over the Kangri Karpo Mountains, with glacier thickness loss of 1.34 ± 0.29 m a-1, 0.81 ± 0.32 m a-1 and 0.30 ± 0.13 m a-1 during 2003 to 2009, respectively.”

“Page 3, Line 33: Generally, elevations derived from aerial photography over high elevation, snow covered regions have larger uncertainties due to poor contrast in the imagery. Do the authors have any additional information on this?”

Answer: More information was added in this paragraph. “According to the national photogrametrical standard issued by the Standardization Administration of the People’s Republic of China (GB/T12343.1, 2008), the nominal vertical accuracies of these topographic maps were controlled within 3-5 m for the flat (with slopes < 2°) and hilly areas (with slope 2-6°) and controlled within 8-14 m for the mountain (with slope 6-25°) and high mountain areas (with slope >25°). Since the slopes of the most of the glacierized areas in the Kangri Karpo Mountains were gentle (∼19°), the vertical accuracy of the TOPO DEM is better than 9 m on glaciers.”

“Page 5, Line 18: Is it problematic to rely on Google Earth imagery, since it is not possible to know the dates of the images?”

Answer: Google Earth imagery did not be used in this study. The high-resolution images of Google EarthTM were used to validate the accuracy of the glacier delineation methods in the second Chinese glacier inventory. Google EarthTM images were captured for seven randomly selected regions, where higher-resolution images in Google EarthTM and nearly simultaneous Landsat images are available (Guo et al., 2015). Due to the same data sources and method of glacier inventory between this study and the second Chinese glacier inventory, the study of Guo et al. (2015) was cited to validate the accuracy of the glacier delineation methods in this study.

“Page 5, Line 31: I am unable to access the Yao et al reference: what is a "glacier axis concept"?”

Answer: Thank you for your suggestion and more information about glacier axis concept was added. “In this study, a new strategy based on a glacier axis concept from glacier morphology perspective was applied that requires only glacier outlines and a DEM as input (Yao et al., 2015). As the base for the glacier axis concept we assume that the main direction of any given glaciers can be defined as a curved line from its highest to its lowest elevation. At first, the outline of given glacier is divided into two curved lines by its highest and its lowest point. Using the two curved lines, the polygon of given glacier is divided into two regions by Euclidean distance. Glacier axis is the common boundary of the two regions, and it can be defined as the glacier centerline.”

“Page 6, Lines 1-27: This paragraph is very hard to decipher, especially for a non-expert in SAR processing. Improvement of the grammar should help in this regard.”

Answer: I have already revised this paragraph, and the SAR processing was introduced in detail. “The TerraSAR-X/TanDEM-X acquisitions were processed by differential SAR interferometry (DInSAR) (Neckel et al., 2013a) using GAMMA SAR and interferometric processing software (Werner et al., 2000). The interferometric phase of the single-pass TerraSAR-X/TanDEM-X interferogram could be described by Δ_(âĹĚTSX/TDX) = Δ_(âĹĚorbit) + Δ_(âĹĚtopo) + Δ_(âĹĚatm) + Δ_(âĹĚscat) (1) where Δ_(âĹĚTSX/TDX) is the difference of phases of phases âĹĚTSX and âĹĚTDX simultaneously acquired by TerraSAR-X and TanDEM-X. Δ_(âĹĚorbit) is the

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phase difference induced by the different acquisition geometry of the SAR sensors, and ∆_(âĹĚtopo) is the phase difference induced by topography. ∆_(âĹĚatm) and ∆_(âĹĚscat) are the phase differences induced by atmospheric conditions and different scattering on the ground. As the data of TerraSAR-X/TanDEM-X were acquired simultaneously, the same atmospheric conditions and scattering are assumed for both SAR antennas, which set ∆_(âĹĚatm) and ∆_(âĹĚscat) in Eq. (1) to zero. ∆_(âĹĚorbit) could be removed from the interferogram by subtracting a simulated flat-earth phase trend (Rosen et al., 2000). The DInSAR approach can be described by ∆_(âĹĚdiff) = ∆_(âĹĚTSX/TDX) - ∆_(âĹĚSRTM-C) (2) where ∆_(âĹĚSRTM-C) is the interferometric phase of the February 2000 SRTM-C acquisition. Due to the unavailable of the raw interferometric data of the SRTM-C acquisition, ∆_(âĹĚSRTM-C) was simulated from SRTM-C DEM data using the satellite geometry and baseline model of the TerraSAR-X/TanDEM-X pass. Therefore the differential phase ∆_(âĹĚdiff) is solely based on changes in ∆_(âĹĚtopo) between data acquisitions (Neckel et al., 2013b). In order to improve the phase-unwrapping procedure and minimize errors, the unfilled finished SRTM C-band DEM were employed in this study. Before generating the differential interferogram, precise horizontal offset registration and fitting between the SRTM C-band DEM and the TerraSAR-X/TanDEM-X acquisitions is necessary. Based on the relation between the map coordinates of the SRTM C-band DEM segment covering the TerraSAR-X/TanDEM-X master file, and the SAR geometry of the respective master file, an initial lookup table was calculated. While the areas of radar shadows and layover in the TerraSAR-X/TanDEM-X interferogram would induce gaps in the lookup table, a method of linear interpolation between the gap edges in each line of the lookup table was used to fill these gaps. The offsets between the master scene and the simulated intensity of the SRTM C-band DEM, were calculated using cross correlation optimization of the simulated SAR images employing GAMMA's offset_pwrm module. The horizontal registration and geocoding lookup table were refined by these offsets. The SRTM C-band DEM was translated from geographic coordinates into SAR coordinates via the refined geocoding lookup table, and conversely, the final difference map

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was translated from SAR coordinates into geographic coordinates. Then a differential interferogram was generated by the TerraSAR-X/TanDEM-X interferogram and the simulated phase of the co-registered SRTM C-band DEM. An adaptive filtering approach was used to filter the differential interferogram (Goldstein and Werner, 1998), and then GAMMA's minimum cost flow (MCF) algorithm was employed to unwrap the flattened differential interferogram. According to the computed phase-to-height sensitivity and select ground control points (GCPs) from the respective off-glacier pixel locations in the SRTM C-band DEM, the unwrapped differential phase was converted to absolute differential heights. While, a residual not covered by the baseline refinement would be existed, and can be regarded as a linear trend that estimated by a two dimensional first order polynomial fit in off-glacier regions. The linear trend and a constant vertical offset were removed from the maps of absolute differential heights. Finally, the resulting data sets were translated to a metric cartographic coordinate system with 30 m × 30 m pixel spacing (Neckel et al., 2013a). The same method of DInSAR was employed to acquire the glacier elevation change from 1980 to 2014 with the data sets of TOPO DEM and TerraSAR-X/TanDEM-X acquisitions."

"Page 7, line 12: Specify how this density uncertainty value was chosen."

Answer: The value of density uncertainty was chosen by previous studies of Gardner et al. (2013) and Neckel et al. (2015).

"Page 8, Lines 36-43: It is a bit difficult reading through all of these numbers. Could the authors condense this into a box plot or something similar?"

Answer: Thank you for your suggestion. There have Table 5 and Table 6 that can introduce the length changes of advanced glaciers and retreated glaciers clearly.

"Page 9, Lines 34-37: more information on the percentage of debris cover on individual glaciers and over the entire region would be valuable."

Answer: Thank you for your suggestion and more information about debris cover was added in this paragraph. “Prominent thickening (elevation increase) was found on the termini of two glaciers on the southern slope of the Kangri Karpo Mountains (Fig. 6C, WGI: 5O291B0113 and 5O291B0117). There have 3.79 km2 and 3.70 km2 debris-covered areas on the two glaciers, account for 20.6% and 31.4% of individual glacier areas, respectively. Meanwhile, the lengths of debris-covered regions account for 69.4% and 63.3% of individual glacier lengths. Probably the effect of debris cover, the glacier termini of 5O291B0113 and 5O291B0117 remain stable between October 1980 and October 2015.”

“Page 10, Lines 29-32: How do these results reconcile with the findings of Liu et al., 2006, who found 40% of glaciers were advancing in the region between 1980 – 2001?”

Answer: The findings of Liu et al. (2006) and this study both resulted from Topographic Maps that generated from aerial photos acquired in October 1980. Glacier inventory in other mountains of western China, resulted from Topographic Maps, has fewer mistakes that fewer glacier outlines are not accurate. In order to improve the accuracy of glacier inventory in this study, aerial photographs was employed to check and revise glacier outlines that resulted from Topographic Maps. Hence, the results of this study are more reliable and more accurate.

“Page 12, Lines 11-12: It is unclear how these different thinning rates for debris versus clean ice were calculated? Were entire glaciers classified as debris covered, or specific elevation bands? If so, what was the threshold of debris required to classify it in the debris-covered category?”

Answer: Thank you for your suggestion. These different thinning rates for debris versus clean ice were calculated in specific elevation bands. “Interestingly is the bigger thinning on the debris-covered region of -0.99 ± 0.09 m a-1 on average than clean-ice region of -0.89 ± 0.08 m w.e. a-1 in the 2800 – 5300 m a.s.l. altitude range from 1980 – 2014 (Fig. 8). 2800 m a.s.l. was the lowest altitude of clean-ice region and 5300 m a.s.l. was the highest altitude of debris-covered region.”

Best Regards, Wu Kunpeng and other authors

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2017-153/tc-2017-153-AC2-supplement.pdf

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