Dear editor and reviewers,

Thanks for your comments concerning our manuscript. Based on the suggestions and comments of the reviewers, the paper has been made major revision carefully. We hope it will be able to meet with your approval.

Best wishes!

Yours sincerely,

Puyu Wang

Response to review 1:

Review for the paper of Puyu Wang et al titled "Characteristics of an avalanche-feeding and partially debris-covered glacier and its response to atmospheric warming in Mt. Tomor, Tian Shan, China".

This paper presents observation results of a glacier partially covered by debris in the central Tian Shan. The observations include the glacier changes in terminus, area, thickness, mass balance, debris-cover, ice velocity and temperature. Although some observations are short, it is very value of understanding this type glacier response to climate change. After describing all field works and characteristics of this glacier, the paper gives a comprehensive analysis and discussion on glacier change process and its influence factors such as climate, debris cover and geomorphology. Generally it is a thorough work and both data and results are suitable and worthwhile for publication. Therefore, I support publication of this paper in TC after some revisions.

To my understanding, the following comments need consideration of the authors for revision.

REPLY: Thanks for the comments of the reviewer. We have made major revision of the manuscript and will response point by point as following.

1. English language throughout the paper must be improved. The language is a common problem to Chinese people and to me also. So I strongly suggest the authors give attention more on this.

REPLY: Thanks for this comment. Yes, we know our English language is a problem. Therefore, the revised version has been polished by an English expert in order to improve the English language. See the revised manuscript.

2. Debris cover is a very important factor influencing the glacier melting. It is mentioned in the paper that with the melting enhancing, the proportion of the debris-covered area and thickness increased as well as inhibition of debris cover to melting. Because the authors have large scale maps surveyed in 1964 and 2008, it is possible to check if the debris cover expanded from comparison of these maps. If it is true, the conclusion becomes more believable.

REPLY: Very good suggestion! We have tried but unfortunately the 1964 topographic map does not show the debris cover extent. Then, we made the comparison between remote sensing images in the recent periods, and it was found that the change of debris coverage cannot be seen very clearly.

3. According to higher surface velocity compared to other glaciers in Tian Shan and to that the temperature at 10m depth is quite near the melting point, the authors say that the glacier is analogous to a temperate or a monsoon maritime glacier. I think it should be cautious since this region is in far inland under the continental climate. For a temperate glacier, ice velocity is almost attributed to the basal sliding. In this paper, proportion of siding velocity has no given. Perhaps the basal sliding exists but not everywhere in the ablation area.

REPLY: Thanks for this comment. Another reviewer has a similar comment. We agree with your comment. In the revised manuscript, the part has been deleted. Moreover, the part of discussion has been rewritten as following.

5. Discussion

5.1 Glacier change

Table 4 compares the terminus and area variation between this glacier and other glaciers in the Mt. Tomor region. We can see that Qingbingtan Glacier No. 72 has the highest shrinkage rate although its area is the smallest. The major potential reason for this is that the other glaciers are covered by debris completely in their lower parts and thus have smaller terminus recessions. Among those glaciers, the Koxkar Glacier was observed relatively well. The Koxkar glacial terminus was basically stable before 1989, and then started to retreat. Since 2003, the recession was alleviated due to the enhanced inhibition of ablation by the debris-covered expansion (Xie et al., 2007 and personal communication with Haidong Han).

The glacier mass balance over the past decades could be evaluated via the variation in glacier volume change, i.e. geodetic mass balance (Zemp et al., 2010). According to the variation of glacier thickness mentioned above, the volume reduction caused by tongue area thinning (only the measured area of 1.47 km^2) between 1964 and 2008 was (14.1 ± 8.8) × 10^3 km^3, i.e. a water equivalent of (12.7 ± 7.9) × 10^3 km^3 if assuring ice density of 900 kg m^{-3}. Thus, the average annual mass loss was (288.6 ± 179.5) × 10^3 m^3.

Table 4 Comparison of the terminus and area variations between the Qingbingtan Glacier No. 72 and other glaciers in the Mt. Tomor region.

Glacier	Debris cover	Glacier area	Glacier length	Terminus change		Area change		Source
		km^2	km	Period	m a^{-1}	Period	km^2 a^{-1}	
Qingbingtan Glacier No. 72	Partially covered	7.27	7.4	1964–2008	−41.16±0.6	1964–2008	−0.034±0.030×10^{-3}	This study
				2003–2008	−48.00±1.4	2003–2008	−0.033±0.016×10^{-3}	
				2008–2013	−32.16±1.0	2008–2013	−0.025±0.007×10^{-3}	
Keqikar Glacier	Completely	83.6	26	1976–1981	0.0		—	Wang and Su, 1984

	covered in a lower part			1981–1985	−4.0		—	Zhu, 1982; Wang, 1987
				1985–1989	0 or 2		—	Xie et al., 2007
				1989–2003	−18–−20		—	Xie et al., 2007
				2003–2010	−11–−15		—	Han, Personal communication
Qingbingtan Glacier No. 74	Completely covered in a lower part	9.55	7.5	1964–2009	−30.0	1964–2009	−0.031	Wang et al., 2013
Keqikekuzibayi Glacier	Completely covered in a lower part	25.77	10.2	1964–2007	−22.9	1964–2007	−0.041	Wang et al., 2013
Tomor Glacier	Completely covered in a lower part	310.14	41.5	1964–2009	−3.0	1964–2009	−0.021	Wang et al., 2013
Qiongtailan Glacier	Completely covered in a lower part	164.38	23.8	1942–1976	−17.6		—	Su et al., 1985

5.2. Glacier response to climate change

It is well known that climate is the essential factor determining glacier variation. The combination of temperature and precipitation is most important for the glacier mass balance, which will consequently cause dimensional changes of a glacier. Many studies have investigated the relative importance of temperature and precipitation for glacier mass balance and they have demonstrated that the mass balance is more sensitive to temperature than to precipitation, although the quantitative relation depends on regional climate and topographic conditions (Oerlemans and Reichert, 2000; Bolch et al., 2012; Carturan et al., 2012; Yu et al., 2013; Baral et al., 2014). Some studies on glaciers in the Tian Shan also proved the dominant role of temperature for changes in mass balance (Duethmann et al., 2015). As shown in Fig. 11, the records of both stations revealed that the temperature in the region has tended to increase during the last several decades. The Aksu Meteorological Station has also recorded an obvious increasing trend for precipitation, while the increasing trend was weak at the Xiehela Hydrological Station. However, the inter-annual variability was larger at Xiehela Hydrological Station than that at the Aksu Meteorological Station. Although precipitation is generally much different between high mountains and low elevations, the overall long-term trend should be similar. In view of the significant recession of this and other glaciers in the Tomor region during the last decades (Xie et al., 2007; Wang et al., 2013), one can conclude that temperature increase played a decisive function, and precipitation increase was insufficient to offset the effects of increasing temperatures. According to regional meteorological estimates (Qin, 2012), the temperature in the Tian Shan is expected to continue increasing in the next decade or more. It is not certain if precipitation will continue to increase, despite of the large inter-annual variability. At least, possibility of continuous large increase in precipitation is less. Hence, considering the influence of climate change, the glacier will keep a tendency of net mass loss during the next decade, and the corresponding glacier terminus recession is expected to last much longer. Based on the simplest model of glacier response to the mass balance disturbance caused by climate change (Paterson, 1994), this type of small size valley glacier would be expected to experience a delay of several years and a response time of several decades. For this glacier, if taking the average thickness of 70 m in the ablation area, the ablation rate of 5~7 m a^{-1} at the terminus, the estimated response time is about 15 to 21 years. Since ablation rate may decrease with expending debris-covered area and ice thickness would be larger in the upper part of this glacier, the response time should be longer than 20 year.

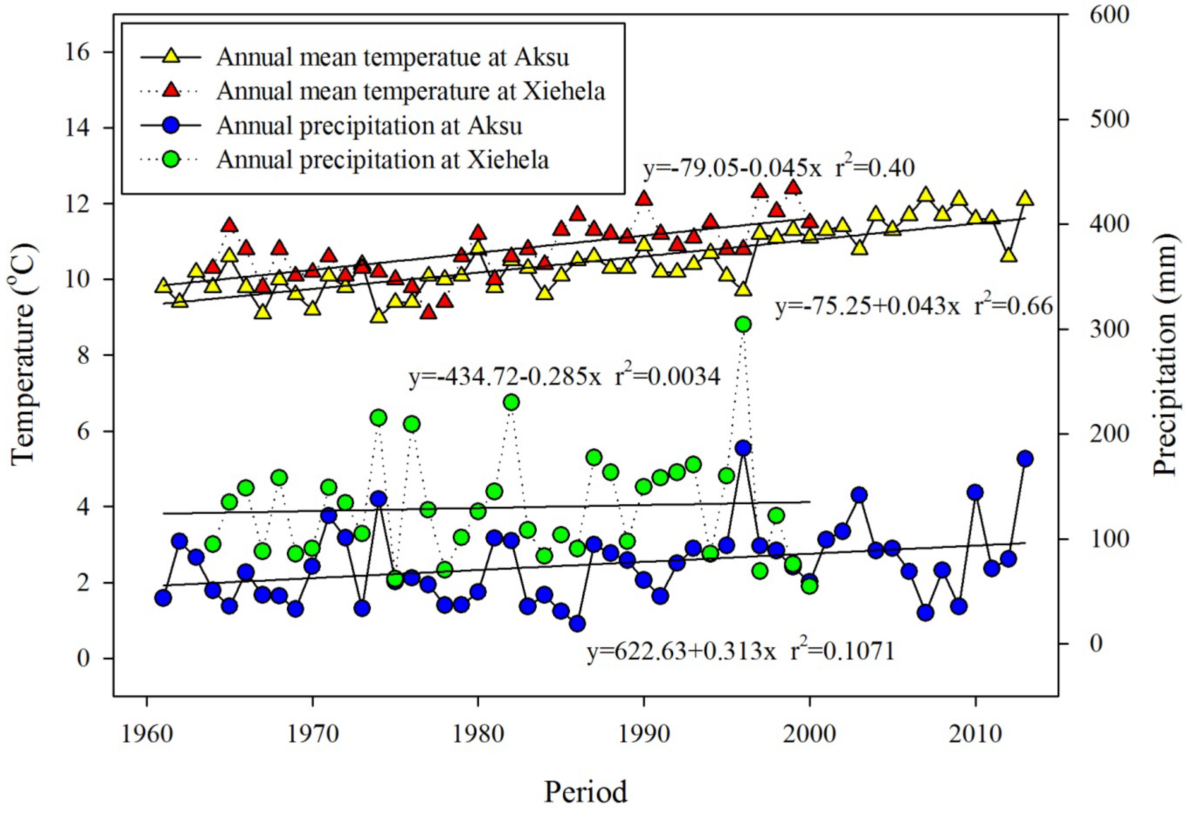

Figure 11. The temperature and precipitation variations recorded at Xiehela Hydrological Station and Aksu Meteorological Station since 1960.

5.3. Influences of topographic factors and debris cover

Qingbingtan Glacier No. 72 has an irregular accumulation area and extremely steep slopes occur in the northern part in a wide range from ~4300 m up to about ~6000 m at the peak and snow/ice avalanches happen frequently. Since the snow fall at high elevations could be rapidly transferred to the lower elevations, the size of the accumulation area was generally stable. This can be partially evidenced by that the aerial photos used for mapping in 1964 and the recent remote images show the snowline has been at around 4300 m a.s.l..

Many studies have revealed that thicker supraglacial debris covers act as a protecting carapace, which insulates the underlying ice and significantly reduces ablation (Han et al., 2010; Bolch et al., 2012; Pieczonka et al., 2013, 2015; Pellicciotti et al., 2015; Pratap et al., 2015; Juen et al, 2014). For the Qingbingtan Glacier 72, as mentioned in the result part (Fig. 8), the debris alleviation of ice melting is enhancing with increasing thickness of debris cover after exceeding the critical thickness of 4 cm. In Figure 12 a scatter diagram shows the relationship between log10 mean daily ablation and debris cover thickness. We can see that when the debris cover thickness exceeds 0.5 m, the ice melting beneath became very weak.

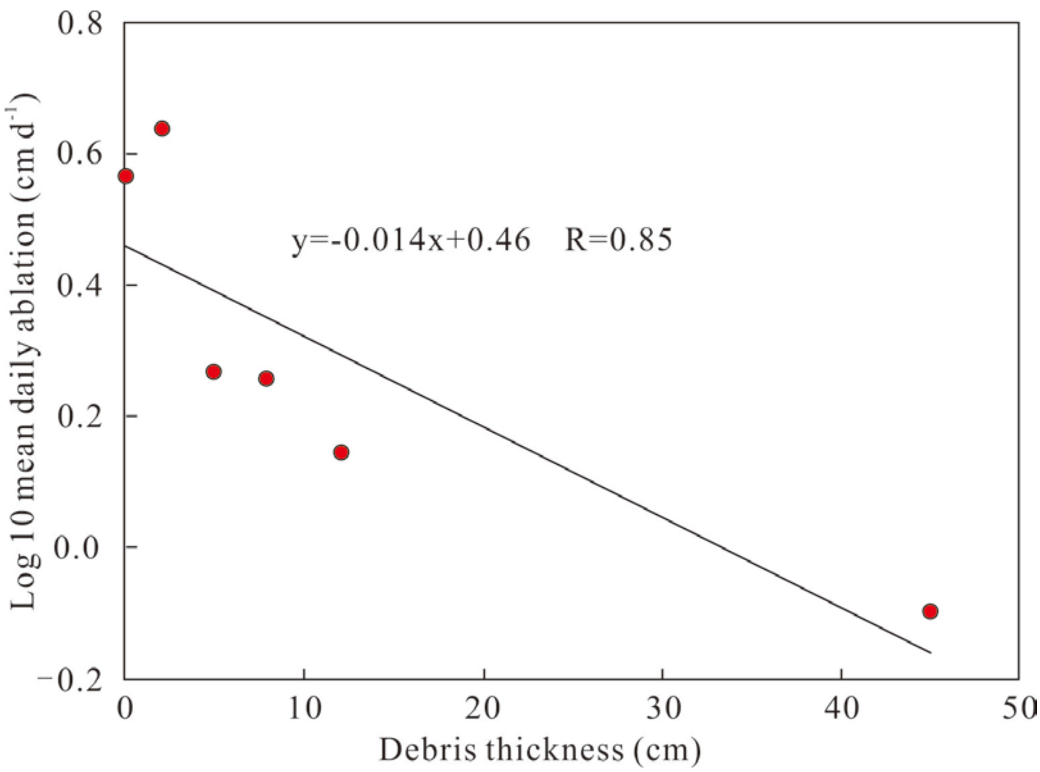

Figure 12. Scatter diagram relating log10 mean daily ablation and debris cover

thickness

The ablation area seems a regular rectangle on the plane and the debris-covered belts on both edges were generally thicker than the critical value required for the inhibition of ablation. Therefore, in the background of atmospheric warming, the bare ice area is expected to experience enhanced ablation and continuously thinning, and the debris coverage and thickness will increase further. Because the bare ice area is narrow at the elevation ~4000 m, the debris-covered belts may be merged firstly at this elevation and then in the downstream area. If so, the glacier terminus retreat would be relatively stable.

4. The ice thickness data is very good because GPR measurement sections covered the ablation area very well. However, the presented transverse section (Fig.3c) is not clear to show the valley shape. If the basal sliding is strong, the glacier valley should be U shape and can be seen clearly from the sounding profiles. So I suggest the authors give more clear thickness profiles.

REPLY: Thanks for comments. We have checked all profile images but have not selected the better one.

5. As mentioned in the section 3.1, snow pits at 4400 and 4600 were observed despite of the fragile surface and frequent snow/ice avalanches. But the result of these snow-pits was not presented. Since no any other data has been obtained in the accumulation area, this snow-pit observation is very important for estimates of the accumulation rate.

REPLY: Thanks for this very good comment. In the revised version, the snow-pit result has been added. The revised part is as following.

4.3. Mass balance

4.3.1. Ablation characteristics

Despite the small scale of Qingbingtan Glacier No. 72, its complex morphology in upper part makes it difficult to conduct mass balance observation. Table 3 lists the annual net ablation at each stake position from observations of August 2008 to August 2009. The lowest row of stakes (~3760 m) showed an annual net ablation of 6000−7000 mm, and the highest row demonstrated 1100 mm of annual ablation. Taking the average value of stakes in every row as the net ablation of the corresponding elevation, the net annual ablations at different elevations are shown in Fig. 5. It can be seen that the relationship between net annual ablation and elevation seems to be linear when elevation is below ~3820 m and above ~4020 m and is irregular between ~3820 m and ~4020 m. From the topographic map (Fig. 1b) and on-site observations (Fig. 1c and Fig. 6), the surface is relatively flat and the mount shelter influence is weak below ~3820 m so that the ablation was extremely strong near the terminus and decreased linearly with increasing elevation. Between ~3820 and ~4020 m, the glacier surface was uneven and so the ablation was complex. Between ~3820 − ~3850 m, the surface is very rugged with undulations as high as 10−20 m, and there were surface streams as well as scattered debris composed of black and brown rock, which contributed to the tendency of increasing ablation with rising elevation. Between ~3850 − ~3930 m, the surface became smooth again, showing similar ablation conditions as observed at the glacial terminus. Between ~3930 − ~4020 m, because of shielding and shades of high mountains on both sides, only a small area received direct sunlight. Meanwhile, the glacier surface undulations reached more than 20 m and surface lakes formed. The ablation amount increased slightly with increasing elevation. Above the elevation of ~4020 m, the glacier surface became smooth and even, and the ablation was weak and decreased with increasing elevation. In addition, high amounts of precipitation fell in the area above ~3950 m during the field observations, mainly in the form of sleet.

Table 3. Observed net annual ablations of 2008−2009 at each stake position on the Qingbingtan Glacier No.72.

Stake	Number	Mass balance (mm w.e.)	Altitude (m)	Stake	Number	Mass balance (mm w.e.)	Altitude (m)
A	1	-6109	3759	F	1	-3313	4013
	2	-6844	3760		2	-3516	4021
B	1	-4494	3810	G	1	-2958	4046
	2	-4355	3819		2	-2890	4058
	3	-1697	3821	H	1	-1434	4153
C	1	-4646	3852		2	-1484	4119
	2	-3778	3855	I	1	-1263	4159
D	1	-3671	3905		2	-1287	4170
	2	-3259	3904	J	1	-1056	4163
E	1	-3175	3960		2	-1120	4275
	2	-3498	3967	K	-	-	4482

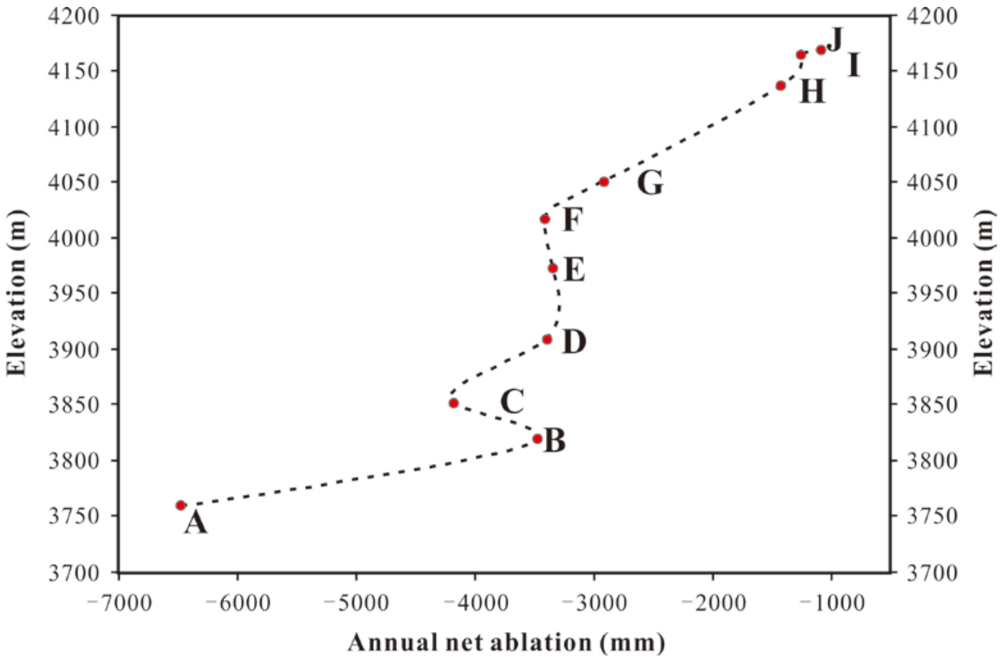

Figure 5. Variation of the annual net ablation along with elevation of Qingbingtan Glacier No. 72.

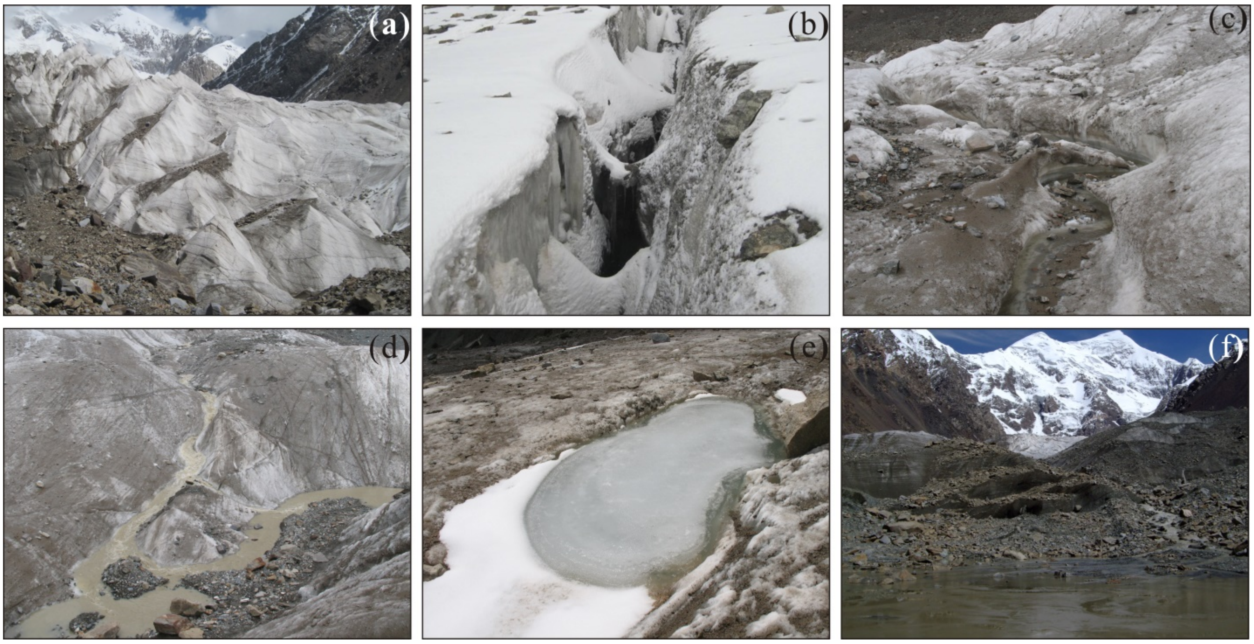

Figure 6. Photos showing the surface features of Qingbingtan Glacier No. 72.

4.3.2. Equilibrium-line altitude (ELA)

Since no measurement data above 4020 m a.s.l., it is difficult to determine the ELA. If simply extrapolating the linear decrease rate of annual ablation between 4020 and 4130 m a.s.l. to higher elevations, the ELA could be roughly estimated to be at ~4250 m. However, the satellite images showed that the snowline is ~4400 m in the sun-facing eastern and middle ice feeding areas and ~4200 m in the western mountain shade area. Because ELA is usually a little lower than the snowline, we assume ELA to be about 4300 m on average.

4.3.3. Precipitation and accumulation

The manual meteorological observation at an elevation of 3950 m was only conducted from 30 July to 28 August, 2008 during the field expedition and the observed precipitation is 91 mm. No precipitation data from automatic weather stations can be available yet. The observation data from the Koxkar Glacier shows that the average annual precipitation is about 700 mm in the ablation area with elevations of 3009 m to 4300 m (Han et al, 2010). To some extent this can be regarded as a reference precipitation value in this region. The complex terrain of the accumulation zone makes the net accumulation hard to estimate, even though observation of a snow pit had been conducted in the eastern firn basin at 4482 m. According to the snow stratigraphic observation down to 225 cm depth, two annual layers were identified and their mass values estimated at 621 mm and 673 mm respectively.

Other minor points:

1. Please check references cited correctly.

REPLY: Thanks for this comment. We have checked the references and added some new references. The references in the revised manuscript are as following.

References

Andreassen, L. M., Huss, M., Melvold, K., Elveh, Øy., and Winsvold, S. H.: Ice thickness measurements and volume estimates for glaciers in Norway, Journal of Glaciology, 61(228), 763–775, 2015.

Aizen, V. B., Aizen, E. M., Melack, J. M., and Dozier, J.: Climatic and Hydrologic Changes in the Tien Shan, Central Asia, J. Climate, 10, 1393–1404, 1997.

Arendt, A. A. and 77 others: Randolph Glacier Inventory [v2.0]: A Dataset of Global Glacier Outlines. Global Land Ice Measurements from Space, Boulder, CO http://www.glims.org/RGI/randolph.html, 2012.

Baral, P., Kayastha, R. B., Immerzeel, W. W., Pradhananga, N. S., Bhattarai, B. C., Shahi, S., Galos, S., Springer, C., Joshi, S. P., and Mool, P. K.: Preliminary results of mass-balance observations of Yala Glacier and analysis of temperature and precipitation gradients in Langtang Valley, Nepal, Annals of Glaciology, 55(66), 9–14, 2014.

Berthier, E., Schiefer, E., Clarke, G. K. C., Menounos, B., and Rémy, F.: Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery, Nature Geosci., 3(2), 92–95, 2010.

Bliss, A., Hock, R., and Radić, V.: Global response of glacier runoff to twenty-first century climate change, J. Geophys. Res.: Earth Surf., 119(4), 717–730, 2014.

Bolch, T.: Climate change and glacier retreat in northern Tien Shan (Kazakhstan/Kyrgyzstan) using remote sensing data, Global and Planetary Change, 56, 1–12, 2007.

Bolch, T., Pieczonka, T, Benn, D. I.: Multi-decadal mass loss of glaciers in the Everest area (Nepal Himalaya) derived from stereo imagery, The Cryosphere, 5, 349–358, 2011.

Bolch, T. and 10 others: The state and fate of Himalayan glaciers, Science, 336(6079), 310–314, 2012.

Carturan, L., Cazorzi, F., and Fontana, G. D.: Distributed mass-balance modeling on two neighbouring glaciers in Ortles-Cevedale, Italy, from 2004 to 2009, Journal of Glaciology, 58(209), 467–486, 2012.

Chen, Y. N., Xu, C. C., Hao, X. M., Li, W. H, Chen, Y. P, and Zhu, C. G.: Fifty-year climate change and its effect on annual runoff in the Tarim River Basin, China, Journal of Glaciology and Geocryology, 30(6), 921–929, 2008.

Cogley, J. G.: A more complete version of the World Glacier Inventory, Annals of Glaciology, 50(53), 32–38, 2009.

Cressie, N.: Statistics for spatial data. Wiley, New York, 1993.

Duethmann, D., Bolch, T., Farinotti, D., Kriegel, D., Vorogushyn, S., Merz, B., Pieczonka, T., Jiang, T., Su, B., and Güntner, A.: Attribution of streamflow trends in snow and glacier melt-dominated catchments of the Tarim River, Central Asia, Water Resour. Res., 51, 4727–4750, 2015.

Farinotti, D., Longuevergne, L., Moholdt, G., Duethmann, D., Mölg, T., Bolch, T., Vorogushyn, S., and Güntner, A.: Substantial glacier mass loss in the Tien Shan over the past 50 years, Nature Geoscience, DOI: 10.1038/NGEO2513, 2015.

Fischer, A.: Calculation of glacier volume from sparse icethickness data, applied to Schaufelferner, Austria, J. Glaciol., 55(191), 453–460, 2009.

Fischer, M., Huss, M., and Hoelzle, M.: Surface elevation and mass changes of all Swiss glaciers 1980–2010, Cryosphere Discuss., 8(4), 4581–4617, 2014.

Glen, J. W., and Paren, J. G.: The electrical properties of snow and ice, J. Glaciol., 15, 15–38, 1975.

Haeberli, W., Cihlar, J., and Barry, R. G.: Glacier monitoring within the Global Climate Observing System, Ann. Glaciol., 31, 241–246, 2000.

Haeberli, W., Paul, F., and Maisch, M.: Mountain glaciers in global climate-related observation networks, World Meteorological Organization Bulletin, Geneva, 51(1), 1–8, 2002.

Hagg, W., Braun, L. N., Kuhn, M., Nesgaard, T. I.: Modelling of hydrological response to climate change in glacierized Central Asian catchments. Journal of Hydrology, 332(1–2): 40–53, 2007.

Hall, D. K, Bayr, K., Schöner, W., Bindschadler, R. A., and Chien, J. Y. L.: Consideration of the errors inherent in mapping historical glacier positions in Austria from ground and space (1893–2001), Remote Sensing of Environment, 86, 566–577, 2003.

Han, H. D., Wang, J., Wei, J. F., and Liu, S. Y.: Backwasting rate on debris covered Koxkar glacier, Tuomuer mountain, China, J. Glaciol., 56(196), 287–296, 2010.

Han, H. D. and 13 others: Near-surface meteorological characteristics on the Koxkar Baxi Glacier, Tianshan, Journal of Glaciology and Geocryology, 30(6), 967–975, 2008.

Huss, M.: Extrapolating glacier mass balance to the mountainrange scale: the European Alps 1900–2100, Cryosphere, 6(4), 713–727, 2012.

IPCC: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535, 2013.

IPCC: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132, 2014.

Jing, Z. F., Liu, L., Zhou, Z. M. and Deng, Y. F.: Analysis on the influencing factors of glacier flow velocity: a case study of Qiyi Glacier in Qilian Mountains, Journal of Glaciology and Geocryology, 33(6), 1222–1228, 2011.

Jing, Z. F., Ye, B. S, Jiao, K. Q., Yang, H. A.: Surface velocity on Glacier No. 51 at Haxilegen of the Kuytun River, Tianshan Mountains, Journal of Glaciology and Geocryology, 24(5), 563–566, 2002.

Juen, M., Mayer, C., Lambrecht, A., Han, H., and Liu, S.: Impact of varying debris cover thickness on ablation: A case study for Koxkar Glacier in the Tien Shan, The Cryosphere, 8, 377–386, 2014.

Kang, E. S., eds.: Runoff of snow and ice meltwater and mountainous rivers, In: Shi Yafeng. Glaciers and their environments in China—The present, past and future, Science Press, Beijing, 2000.

Kehrwald, N. M., Thompson, L. G., Yao, T. D., Thompson, E. M., Schotterer, U., Alfimov, V., Beer, J., Eikenberg, J., and Davis, M. E.: Mass loss on Himalayan glacier endangers water resources, Geophys. Res. Lett., 35, dOI: 10.1029/2008GL035556, 2008.

Kutuzov, S., and Shahgedanova, M.: Glacier retreat and climatic variability in the eastern Terskey-Alatoo, inner Tien Shan between the middle of the 19th century and beginning of the 21st century, Global and Planetary Change, 69, 59–70, 2009.

Leclercq, P. W., and J. Oerlemans: Global and hemispheric temperature reconstruction from glacier length fluctuations, Climate Dynamics, 38, 1065–1079, 2012

Li, Z. Q., Li, K. M., and Wang, L.: Study on recent glacier changes and their impact on water resources in Xinjiang, North Western China, Quaternary Sciences, 30(1), 96–106, 2010.

Marzeion, B., Jarosch, A. H., and Hofer, M.: Past and future sealevel change from the surface mass balance of glaciers, The Cryosphere, 6(6), 1295–1322, 2012.

Meier, M. F., Dyurgerov, M. B., Rick, U. K., O’Neel, S., Pfeffer, W. T., Anderson, R. S., Anderson, S. P., and Glazovsky, A. F.: Glacier dominate eustatic sea-level rise in the 21st century, Science, 317(5841), 1064–1067, 2007.

Mountaineering and Expedition Term of Chinese Academy of Sciences: Glacial and Weather in Mt. Tuomuer District, Tianshan, Xinjiang Peoples Publishing House, Urumqi, 1985.

Narama, C., Kääb, A., Duishonakunov, M., Abdrakhmatov, K.: Spatial variability of recent glacier area changes in the Tien Shan Mountains, central Asia, using Corona (~1970), Landsat (~2000), and ALOS (~2007) satellite data, Global and Planetary Change, 71(1), 42–54, 2010.

Narod, B. B., and Clarke, G. K. C.: Miniature high-power impulse transmitter for radio-echo sounding, J. Glaciol., 40, 190–194, 1994.

Navarro, F., and Eisen, O.: Ground-penetrating radar in glaciological applications. In: Pellikka, P., and Reese, W. G., eds. Remote sensing of glaciers: techniques for topographic, spatial and thematic mapping of glaciers. Taylor & Francis, London, 195–229, 2010.

Neckel, N., Kropácek, J., Bolch, T., and Hochschild, V.: Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements, Environ. Res. Lett., 9(1), 014009, 2014.

Oerlemans, J.: Extracting a climate signal from 169 glacier records, Science, 308, 675–677, 2005.

Oerlemans, J., and Reichert, B.K.: Relating glacier mass balance to meteorological data by using a seasonal sensitivity characteristic, J. Glaciol., 46(152): 1–6, 2000.

Paterson, W.S.B.: The physics of glaciers, 3rd edn, Elsevier, Oxford, 1994.

Pellicciotti, F., Stephan, C., Miles, E., Herreid, S., Immerzeel, W. W., Bolch, T.: Mass-balance changes of the debris-covered glaciers in the Langtang Himal, Nepal, from 1974 to 1999, Journal of Glaciology, 61(226), 373–386, 2015.

Pieczonka, T., and Bolch, T.: Region-wide glacier mass budgets and area changes for the Central Tien Shan between ~ 1975 and 1999 using Hexagon KH-9 imagery, Global and Planetary Change, 128, 1–13, 2015.

Pieczonka, T., Bolch, T., Wei, J. F., and Liu, S. Y.: Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery, Remote Sensing of Environment, 130, 233–244, 2013.

Pratap, B., Dobhal, D. P., Mehta, M., and Bhambri, R.: Influence of debris cover and altitude on glacier surface melting: a case study on Dokriani Glacier, central Himalaya, India, Annals of Glaciolgy, 56(70), 9–16, 2015.

Qin, D. H.: Climate and environment changes in China, vol 1, Meteorology Press, Beijing, 2012.

Radic, V., Bliss, A., Beedlow, A. D., Hock, R., Miles, E., and Cogley, J. G.: Regional and global projections of the 21st century glacier mass changes in response to climate scenarios from global climate models, Clim. Dyn., 42, 37–58, 2013.

Raper, S. C. B. and Braithwaite, R.J.: Low sea level rise projections from mountain glaciers and icecaps under global warming, Nature, 439, 311–313, 2006.

Robin G. de. Q.: Velocity of radio waves in ice by means of a bore-hole interferometric technique, J. Glaciol., 15, 151–159, 1975.

Silverio, W. and Jaquet, J.M.: Glacial cover mapping (1987–1996) of the Cordillera Blanca (Peru) using satellite imagery, Remote Sens. Environ., 95(3), 342–350, 2005.

Sorg, A., Bolch, T., Stoffel, M., Solomina, O., and Beniston, M.: Climate change impacts on glaciers and runoff in Tien Shan (Central Asia), Nature Climate Change, doi: 10.1038/nclimate1592, 2012.

Su, Z., Sun, G. P., Wang, L. L., Zhang, W. J., Zhang, H. Y, Yang, C. T, and Liang, D.: Modern glacier in Mt. Tuomuer district. In: Su, Z., Kang, E.S., eds., Glacial and Weather in Mt. Tuomuer District, Tianshan, Xinjiang Peoples Publishing House, Urumqi, 32–88, 1985.

Sun, B., He, M. B., Zhang, P., Jiao, K. Q., Wen, J. H., and Li, Y. S.: Determination of ice thickness, subice topography and ice volume at Glacier No. 1 in the Tianshan, China, by ground penetrating radar, Chinese Journal of Polar Research, 15(1), 35–44, 2003.

Wang, J. X., Wang, J., and Lu, C. P.: Problem of coordinate transformation between WGS-84 and BEIJING 54, J. Geod. Geodyn., 23(3), 70–73, 2003.

Wang, P. Y., Li, Z. Q., Li, H. L., Wang, W. B., and Wang, F. T.: Ice surface-elevation change and velocity of Qingbingtan glacier No.72 in the Tomor region, Tianshan Mountains, central Asia, Journal of Mountain Science, 8, 855–864, 2011.

Wang, P. Y., Li, Z. Q., Li, H. L., Wang, W. B., Wu, L. H., Zhang, H., Huai, B. J., Wang, L.: Recent evolution in extent, thickness and velocity of Haxilegen Glacier No. 51, Kuytun River Basin, eastern Tianshan Mountains, Arctic Antarctic and Alpine Research, 48(2), 241–252, 2016.

Wang, P. Y., Li, Z. Q., Wang, W. B., Li, H. L., Zhou, P., and Jin, S.: Changes of six selected glaciers in the Tomor region, Tian Shan, Central Asia, over the past ~50 years, using high-resolution remote sensing images and field surveying, Quaternary International, 311, 123–131, 2013.

Wang, S., Zhang, M., Li, Z., Wang, F., Li, H., Li, Y., Huang, X.: Glacier area variation and climate change in the Chinese Tian shan Mountains since 1960, Journal of Geographical Sciences, 21(2), 263–273, 2011.

Wang, Z. T.: Influence of supraglacial moraine on surface ablation and ice temperature of glaciers. In: The Lanzhou Institute of Glaciology and Geocryology, CAS. Proceedings of the 2nd National Conference on Glaciology of the Geographical Society of China, The People's Publishing House of Gansu, Lanzhou, 131–139, 1987.

Wang, Z. T., Su, Z.: A road on the glacier, Journal of Glaciology and Geocryology, 6(3), 95–96, 1984.

World Glacier Monitoring Service (WGMS): Global glacier changes: facts and figures. UNEP, World Glacier Monitoring Service, Zürich http://www.grid.unep.ch/glaciers/, 2008a.

World Glacier Monitoring Service (WGMS): Fluctuations of glaciers 2000–2005 (Vol. IX). ICSU (FAGS)/IUGG–(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zürich, doi: 10.5904/wgms-fog-2008-12, 2008b.

World Glacier Monitoring Service (WGMS): Fluctuations of glaciers 2005–2010 (Vol. X). ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zürich, doi: 10.5904/wgms-fog-2012-11, 2012.

World Glacier Monitoring Service (WGMS): Glacier Mass Balance Bulletin No. 12 (2010–2011). ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zürich, doi: 10.5904/wgms-fog-2013-11, 2013.

Williams, R. S., Hall, Jr, D. K., and Chien, J. Y. L.: Comparison of satellite-derived with ground-based measurements of the fluctuations of the margins of Vatnajökull, Iceland, 1973–92, Ann. Glaciol., 24, 72–80, 1997.

Xie, C. W., Ding, Y. J., Chen, C. P., and Han, T. D.: Study on the change of Keqikaer Glacier during the last 30 years, Mt. Tuomuer, Western China, Environ. Geol., 51, 1165–1170, 2007.

Yang, Z. N.: Glacier water resources in China, Gansu Science and Technology Press, Lanzhou, 1991.

Yao, T., Thompson, L., Yang, W., Yu, W. S., Gao, Y., Guo, X. J., Yang, X. X., Duan, K. Q., Zhao, H. B., Xu, B. Q., Pu, J. C., Lu, A. X., Xiang, Y., Kattel, D. B., and

Joswiak, D.: Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings, Nature Climate Change, doi: 10.1038/NCLIMATE1580, 2012.

Ye, Q. H., Kang, S. C., Chen, F., and Wang, J.: Monitoring glacier variation on Geladandong mountain, central Tibetan Plateau, from 1969 to 2002 using remote sensing and GIS technologies, Journal of Glaciology, 52(179), 537–545, 2006.

Yu, W. S., Yao, T. D., Kang, S. C., Pu, J. C., Yang, W., Gao, T. G., Zhao, H. B., Zhou, H., Li, S. H., Wang, W. C., Ma, L. L.: Different region climate regimes and topography affect the changes in area and mass balance of glaciers on the north and south slopes of the same glacierized massif (the West Nyainqentanglha Rang, Tibetan Plateau), Journal of Hydrology, 495, 64–73, 2013.

Zemp, M., Jansson, P., Holmlund, P., Gärtner-Roer, I., Koblet, T., Thee, P., Haeberli, W.: Reanalysis of multi-temporal aerial images of Storglaciären, Sweden (1959-99)–Part 2: Comparison of glaciological and volumetric mass balances, The Cryosphere, 4, 345–357, 2010.

Zemp, M., and 38 others: Historically unprecedented global glacier decline in early 21st century, Journal of Glaciology, 61(228), 745–762, 2015.

Zhang, Y., Liu, S., Ding, Y., Li, J., and Shangguan, D.: Preliminary study of mass balance on the Keqicar Baxi Glacier on the south slopes of Tianshan mountains, J. Glac. Geocry., 28, 477–484, 2006.

Zhou, Z. M., Li, Z. Q., Li, H. L., and Jing, Z. F.: The flow velocity features and dynamic simulation of the Glacier No. 1 at the headwaters of Urumqi River, Tianshan Mountains, Journal of Glaciology and Geocryology, 31(1), 55–61, 2009.

Zhu, G. C.: Type B-1 experimental radar instation for measuring the thickness of

glaciers, Journal of Glaciology and Geocryology, 4(2), 93–95, 1982.

2. In Fig.1a, a thick black line in the upper seems to be the country boundary. And there are two black patches, seemingly lakes. They should be marked clearly.

REPLY: Thanks for this comment. The Fig. 1 has been revised according to this comment.

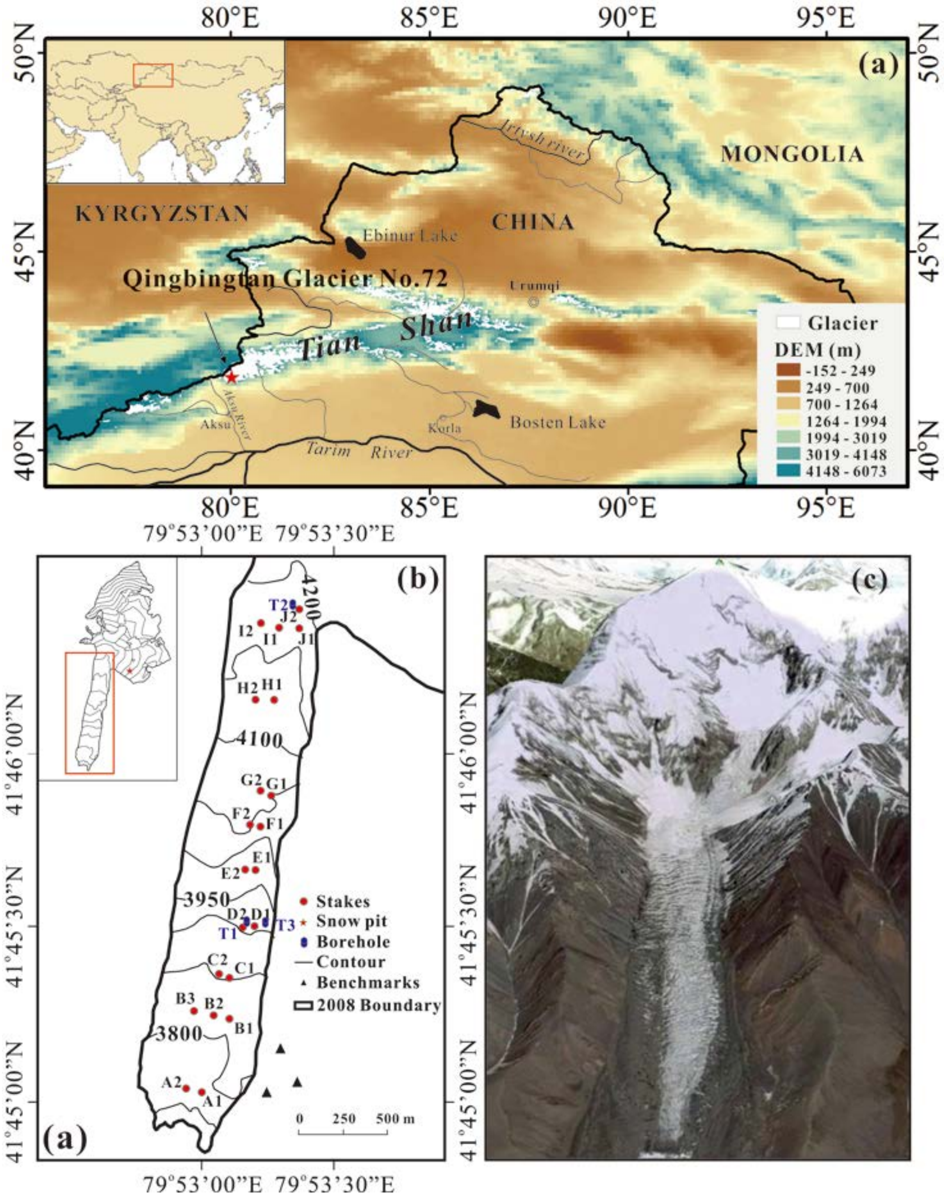

Figure 1. (a) The geographic location of Qingbingtan Glacier No. 72 in Mt. Tomor, Tian Shan, China; (b) Topographic map of Qingbingtan Glacier No. 72 and the surveyed area. Red points are ablation stakes and red star indicates the snow pit.

Triangles are benchmarks for the GPS ground survey that are the national trigonometric reference points. Blue cylinders represent three ice temperature boreholes (T1 and T2: bare ice at 3950 m and 4200 m, respectively; T3: debris covered at 3950 m); (c) A satellite image of Qingbingtan Glacier No. 72 (data source: Google Earth).

3. Since most valley glaciers in the Tomor region have debris cover on their surface to different extents and the debris-covered area accounts for a half of the ablation area, to say "debris-covered" may be better in my opinion.

REPLY: Thanks for this comment. Since some people think that "debris-covered glacier" should be fully covered by debris across, we are not sure if could delete "partially" from the partially debris-covered".

4. In the paper, "debris cover", "debris-cover", "debris covered area" and "debris-covered area" occurred at different places. Please check these.

REPLY: Thanks for this comment. We have checked these words throughout the revised manuscript.