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 and the title of manuscript has been revised to be "Recent variations of a partially debris-covered glacier in Mt. Tomor, Tian Shan, China". We hope it will be able to meet with your approval.

Best wishes!

Yours sincerely,

Puyu Wang

Response to review 2:

Review of manuscript: "Characteristics of an avalanche-feeding and partially debriscovered glacier and its response to atmospheric warming in Mt. Tomor, Tien shan, China" by P. Wang, Z. Li and H. Li submitted to the Cryosphere

This paper presents a description of measurements of different type over one glacier in the Chinese Tian Shan (Qingbingtan glacier no. 72 in the Mt. Tomoro area). The measurements include: 1) mass balance observations in a section of the glacier tongue, starting from 2008; 2) GPS observations of surface velocities conducted once every year starting in 2008; 3) measurements of surface elevation obtained with the same GPS setup; 4) a topographic map from 1964 and a SPOT5 satellite image from 2003 used to assess changes in the glacier terminus position and in glacier area; 5) Ground Penetrating Radar (GPR) measurements of ice thickness at five transverse and four longitudinal transects; 6) measurements of ice temperature at three boreholes (two on clean ice and one at a debris-covered location) (four readings over two years); 7) manual measurements of debris thickness at various points; and 8) an Automatic Weather Station (AWS) installed on the glacier in 2008, complemented by three more after 2009. This is a relatively abundant data set, spanning the period from 2008 until 2013, in a region where data are scarce, and it would be worth of publication. However, the paper has many serious flaws, and lacks a coherent structure and clearly defined goal beyond the description of the many data sets (this in itself lacking key details). The analysis and methods of data processing are poorly explained (see general comment below).

The conclusions and some of the authors' main results are speculative, and inferred from assumptions or values taken from literature somehow extrapolated to the study site. This is a major criticism to the paper. In particular, it regards: i) the assessment of the position of the ELA, which has a clear meaning and cannot be estimated from extrapolation of the linear variation above 4020m, obtained from very few points (not clear how many and which one because of the bad quality of Figure 5 and the associated description); ii) vague statements about the precipitation amount on the glacier which is determined "From meteorological observations in the ablation zone and the observation data from other glaciers in the same region " (lines 348-350) – no details of either is provided and yet the authors come up with a number of 700 mm for the annual precipitation in the ablation area; iii) the same holds for the estimates of precipitation in the accumulation area, which the authors estimate from value from "an expedition to Mt Tomor in the 1970s" and considerations of a general increase in precipitation in the region (lines 345-360) which seem to allow the authors to derive a value of "no less than 1000 mm" for the accumulation area; iv) the corresponding estimates of total annual accumulation – which the authors come up with in a mysterious way. They state: "the total annual accumulation could be 4-10 *106 m3" (my italic and bold); v) the entire section regarding ice temperature, all based on speculations with no support from data or any analysis: "Therefore, temperature at the glacier bottom must be at the melting point" (lines 455-457), or the following discussion on lines 458-464; vi) the entire reasoning on the behaviour of the debris cover portions of the glacier is also highly speculative (in particular from line 557 onwards until at least 569) and is based on general arguments existing in the literature on the general behaviour of debris covered glaciers that are then somehow bent to derive an assumed behaviour of the glacier studied here. Similar vague statements that are not supported by any evidence or derived rigorously from any analysis can be found throughout the paper, including in the Conclusions (e.g. lines 583-593). This is an unacceptable approach to estimate values of interest or determine mass balance quantities, and should be corrected throughout the paper. Statements are made throughout, but especially so in the Results and Discussion sections, which are made with no support, it is not clear if they are backed by the authors' evidence and results, or are common sense assumptions that the authors extrapolate from literature to then however infer future behaviour and characteristics of this specific glacier that are presented as findings of the paper. This needs to be thoroughly and carefully amended throughout the manuscript.

REPLY: Thanks for the comments and suggestions of the reviewer. According to this, we have made major revision and tried our best to improve our manuscript. We hope it can be meet with your approval. In addition, because the suggestion mentioned above has also been included in the general comments mentioned below. Therefore, we will make detailed response as following.

Comments from reviewer 2:

GENERAL COMMENTS

These are substantial comments that I would encourage the authors to follow.

1) ENGLISH and SCIENTIFIC WRITING The English is poor (both grammar and style) and needs to be substantially improved. I refrain here from making detailed suggestions because these concern the entire paper and the majority of sentences and paragraphs and would take a huge amount of time, but I suggest the authors ask for professional support. More importantly, the authors use often a colloquial language that is not appropriate for a scientific publication and should be removed and the paper style improved accordingly (e.g. glaciers that "inevitably" influence water resources, Introduction; "As we all know, climate is the essential factor determining glacier variation", Discussion). Even more importantly, however, the authors should change substantially the way they infer and then describe several of their major results and conclusions: these are too often only speculative, as I have discussed in details in my general evaluation above. All the instances detailed there should be addressed and corrected, and evidence provided for those statements and the corresponding so-called

results changed or removed. The list above is not exhaustive and so the authors should carefully search their manuscript for other instances of the same way of writing and deducing results. This is a key comment that I encourage the authors to address. In places, text that belongs to the Discussion is included in the Results (e.g. lines 260-268).

REPLY: Thanks for these comments. We have asked an English expert to modify the English language and in the revised manuscript all parts have been rewritten according to reviewer's comments.

2) LACK of a CLEAR AIM and FOCUS The authors have a large amount of potentially interesting data but it is not clear what the main goal of this paper is. If it is to describe general changes of the glacier, some of the data are not well interpreted/exploited and I would recommend the authors from trying to establish the "glacier response to climate change" but only try to document as best as they can recent glacier variations. They should provide much sounder evidence for their analysis to back up their results.

REPLY: Thanks for these comments. In the revised version, we put emphasis on the recent glacier variations shown by field observations, and then we give some discussions on influences of climate change and topographic factors including debris cover. For example, the revised part of "Introduction" is as following.

1. Introduction

In the past decades, atmospheric warming has caused the majority of the glaciers to recede on a global scale, with the acceleration of the recession remarkably (Haeberli et al., 2002; Oerlemans, 2005; Meier et al., 2007; Arendt et al., 2012; IPCC WGI, 2013; WGMS,2008a,b,2012,2013; Farinotti et al., 2015; Zemp et al., 2015). Because glacial recession plays important roles in affecting sea level, water resources and the environment, glacier variation has become the attention focusing on not only scientific communities, but on the all publics (Raper and Braithwaite, 2006; Kehrwald et al., 2008; Berthier et al., 2010; IPCC WGII, 2014; Bliss et al., 2014). However, glacier variation is affected by multiple factors. Beside climatic conditions, glacier morphology and physical properties are also important, so that glacier variation differences arise between various regions and different types of glaciers (Haeberli et al., 2000; Bolch, 2007; Cogley, 2009; Kutuzov and Shahgedanova, 2009; Narama et al., 2010; Bolch et al., 2011; Huss, 2012; Leclercq et al, 2012; Marzeion et al., 2012; Sorg et al, 2012; Yao et al, 2012; IPCC WGI, 2013; Radic et al, 2013; Bliss et al., 2014; Fischer et al., 2014; Neckel et al., 2014; Farinotti et al., 2015).

There are a number of glaciers in the Tian Shan, Central Asia and their changes have been reported on regional scale by many researchers (Aizen et al, 1997; Li et al., 2010; Wang S et al., 2011; Yao et al, 2012; Farinotti et al., 2015; Pieczonka and Bolch, 2015). Mt. Tomor, the highest peak of the Tian Shan (elevation 7439 m; Kyrgyz name: Jengish Chokosu; Russian name: Pik Pobedy), is the largest glaciated region in the Tian Shan (location shown in Fig. 1). Glaciers in the Mt. Tomor region are commonly covered by debris with different extents and melt-water originating from the glaciers in this region is the major water source for the Tarim Basin (Hagg et al., 2007; Chen et al., 2008; Pieczonka et al., 2013). Therefore, it is important to understand response of different topographic glaciers with debris coverage to climate change in this region. Up to date, field investigations and monitoring have been conducted for several glaciers in the China's territory of this region. For example, in 1977–1978, a mountaineering expedition team conducted summer observations on Xiqiongtailan Glacier, a large valley glacier covering 164 km^2 (Mountaineering and Expedition

Term of Chinese Academy of Sciences, 1985). Since 2003, continuous observations have been conducted for the Koxkar Glacier, a large valley glacier covering 83.56 km^2, on the southern side of the Mt. Tomor (Zhang et al, 2006; Xie et al., 2007; Han et al., 2008, 2010; Juen et al, 2014). More recently, field observations have been carried out on a relatively small glacier covering 5.23 km^2, named Qingbingtan Glacier No. 72 and some of these observations on the terminus and thickness change have been reported (Wang et al., 2011, 2013). In this paper, we would comprehensively present the recent variations of Qingbingtan Glacier No. 72 based on more observation data, and then make an attempt to discuss on the influences of climate change and topographic factors including the debris cover.

3) METHODS Methods need in general to be substantially improved. The paper is poor in many respects, and important details are not provided.

REPLY: Thank for the comments. The methods and uncertainties are described more in detail in the revised manuscript as followings:

3. Datasets and methods

Table 1. Observation items on the Qingbingtan Glacier 72

Observation items	location	instrument/method	period
Mass balance	21 stakes in the ablation area	Stake measurement	30 July to 28 August, 2008; at least once in every summer of 2009–2013
	6 ablation stakes in debris-covered area	Stake measurement	30 July to 28 August, 2008
	a snow pit at 4482 m	Stratigraphic observation	August 2008
Ice flow velocity	The ablation stakes	RTK-GPS	every summer of

			2008–2013
Glacier surface elevation	The ablation area	RTK-GPS	August 2008
Glacier terminus position	The glacier terminus	RTK-GPS	Once in each summer of 2008–2013
Ice thickness	5 transverse and 4 longitudinal sections with a total of 824 measurement points in the glacier tongue	EKKO PRO 100A enhanced GPR	August 2008 and July 2009
Ice temperature	~3950 m; ~4200 m; ~3950 m	3 boreholes	July 2008
Debris thickness	at the spacing of ~5 m on both lateral debris-covered areas	Digging the debris	August 2008

3.1 Mass balance

Since the upper part of Qingbingtan Glacier No. 72 is steep, fragile and associated with frequent snow/ice avalanches (Fig. 1b and 1c), the most observations of mass balance were only feasible below ~4200 m (Fig. 1b), except for once observation of a snow pit at 4482 m. During the first investigation in 2008, total 21 stakes were installed at 10 elevations of the ablation area (Fig. 1b). The mass balance measurement contains the vertical height of stakes over the glacier surface and thickness and density of the superimposed ice and snow layers. From the end of July to the beginning of September 2008, the stake mass balance measurement was carried out once almost every two days. In the following periods, the observation was conducted during the summer at least once a year.

The mass balance of a single point (b_n) can be obtained by

$$b_n = b_{ice} + b_s + b_{si} \tag{1}$$

where b_{ice}, b_s and b_{si} are the mass balance of glacier ice, snow and superimposed ice, respectively. In late August, a snow pit deeper than 2 m was observed at an elevation of 4482 m. For this snow pit, different type snow layers were identified and described for their grain size, color and hardness and density of each layer was measured. Since the reading of stakes and thickness of snow and ice layers are in order of 1 cm, error of the obtained mass balance at each site is between 1 and 2 cm.

3.2. RTK-GPS survey

3.2.1. Ice flow velocity

A real time kinematic global positioning system (RTK-GPS) (Unistrong E650) manufactured by Beijing UniStrong Science and Technology Co., Ltd. Beijing, China was used to measure the positions of the ablation stakes. One GPS receiver was installed at a fixed base point on a non-glaciated area to the southeast of the glacier margin. Another was used to survey simultaneously the ablation stakes on the glacier. The displacement vectors could be obtained based on two measurements within a certain period, which were then taken as the ice flow velocity at each corresponding position. In this way, the ice flow velocity provided here was actually the surface velocity, and, therefore, could be decomposed into two components, horizontal and vertical velocities. The positions of 21 ablation stakes (Fig. 1b) were measured in August 2008 and every summer in the following years. Because the ablation stakes were rearranged after every measurement, the measurement result in 2008–2009 was used as an example. The GPS measuring in RTK differential mode results in a horizontal error of 0.02 m and a vertical error of 0.02–0.04 m, which is larger than the horizontal value. Accordingly, errors in the computed velocity were within 8% of the input data.

3.2.2. Surface elevation

The surface elevation on and around the glacier was measured at a sampling spacing of 20–50 m using RTK-GPS during the investigation in 2008, allowing the preparation of a large scale (1:50 000) topographic map. Accordingly, the ice surface elevation changes of the glacier tongue can be obtained by comparing with 1964 topographic map (1: 50 000). First, the 1964 topographic map was digitized into a 5 m resolution digital elevation model (DEM). Then, the variations in ice surface elevation during the period from 1964 to 2008 could be derived. From 1964 topographic map and 2008 GPS data, ten discrete independent control points in the surrounding non-glaciated area were selected to perform the accuracy of ice surface elevation (σ_{DEM}) using the equation:

$$\sigma_{DEM} = \frac{\sum_{1}^{n}\left(Z_{DEM1964} - Z_{DEM2008}\right)}{n} \tag{2}$$

where n is the number of non-glacierized DEM grid cells. The results indicated that the error of surface elevation variations was within ± 6 m.

3.2.3. Glacier terminus and area changes

To determine glacier terminus and area changes, various data were used, including a topographic map in 1964 (1:50 000), a SPOT5 image (resolution: 5 m) in 2003, and the glacier terminus position measured by RTK-GPS during the investigation in 2008 and in summer of each following year from 2009 to 2013. All these data were put into the same coordinate system, which is an important precondition for precisely calculating changes in glacier terminus, area and surface elevation. Glacier boundaries for the different periods were digitized manually in the software ARCGIS. For the period 1964–2008, according to Williams et al. (1997), Hall et al. (2003), Silverio and Jaquet (2005), and Ye et al. (2006), the uncertainty in the glacier area and terminus changes for an individual glacier can be estimated by

$$U_T = \sqrt{\sum \lambda^2} + \sqrt{\sum \varepsilon^2} \tag{3}$$

$$U_A = \sum \lambda^2 \times \frac{2 \times U_T}{\sqrt{\sum \lambda^2}} + \sum \varepsilon^2 \tag{4}$$

where U_T is the uncertainty of the glacier terminus and U_A is the uncertainty of glacier area. λ is the resolution of each individual image, and ε is the registration error of each image to the 1964 topographic map. For the accuracy of glacier terminus and area changes during 2008–2013, it mainly depends on the GPS measuring error, although the error using a seven-parameter space transform model for transforming coordinate of GPS data that is less than 0.002 m (Wang et al., 2003), cannot be ignored. Values of variables in Equations 3 and 4 are listed in Table 2. Integrated evaluation indicated that the resulting uncertainties of glacier terminus and area variation are 26 m and 1.3×10^{-3} km^2 in 1964–2008, and 5 m and 0.037×10^{-3} km^2 in 2008–2013, respectively.

Table 2 Values of variables in Equation 3 and 4 to estimate uncertainty in glacier area and terminus change

Variables	Period			
	1964 (m)	2003 (m)	2008 (m)	2013 (m)
λ	25	5	2.5	2.5
ε	0	1	1	1

3.3. Ice thickness

In August 2008 and July 2009, a pulse EKKO PRO 100A enhanced ground penetrating radar (GPR; Sensors & Software Inc., Mississauga, Canada) in combination with RTK-GPS was adopted to measure the glacier thickness. As shown in Fig. 3a, the ice thickness survey was conducted along five transverse and four longitudinal sections with a total of 824 measurement points. Since there is a crevasses area above 3950 m, the longitudinal cross section along the centerline was divided into two segments (B–B and D–D). Horizontal survey was conducted along an east-west direction, while the longitudinal survey started from the high elevation. Surveyors were unable to extend some survey lines to the glacier margins because of its steep slopes. The spatial coordinates of survey points were recorded simultaneously, thereby achieving terrain correction for every survey point. The GPR data were then processed in the software EKKO_View Deluxe. The ice thickness (*h*) can be calculated by the equation 5, and the relative error of ice thickness measurement can be estimated by the equation 6 (Sun et al. (2003)):

$$h = \frac{t_s}{2} \times v \tag{5}$$

$$\frac{dh}{h} = \frac{dv}{2v} \tag{6}$$

where t_s is the radar wave two-way travel time and v is the velocity of radar signal in glacier. In this study, the velocity was set at 0.169 m $(ns)^{-1}$ after field trial for many times and the value is within the range of 0.167–0.171 m $(ns)^{-1}$ for the velocity of radar signal in mountain glaciers (Glen and Paren, 1975; Robin, 1975; Narod and Clarke, 1994). The estimation result indicated that the relative error of ice thickness measurement was within 1.2%. Moreover, the estimated uncertainty of the ice thickness was also according to previous studies (Fischer, 2009; Navarro and Eisen, 2010; Andreassen et al., 2015). Commonly, uncertainties for all ice thickness measurements are related to the propagation velocity of electromagnetic waves in snow, firn and ice, inaccuracies when picking reflectors, and the radar system resolution.

Ice thickness distribution map was eventually obtained by Ordinary Kriging Interpolation assuming the thickness at the glacier margin to be zero. The variogram in this study was estimated as the variance of the difference between field values at two locations (x and y) across realizations of the field (Cressie, 1993). And the spherical variogram model was fitted. The spherical variogram model is

$$r(h) = (s-n)\left(\left(\frac{3h}{2r} - \frac{h^3}{2r^3}\right)1_{(0,r)}(h) + 1_{[r,\infty)}(h)\right) + n1_{(0,\infty)}(h) \tag{7}$$

where s is sill, n is nugget, r is range, and h is lag distance.

3.4. Ice temperature and thickness of debris cover

At the end of July 2008, three ice temperature measurement boreholes were respectively drilled by a thermal steam drill in the bare ice at ~3950 m (T1; near to stake D2) and ~4200 m (T2), and in the debris covered area at ~3950 m (T3) (see Fig. 1b). The holes were 10 m deep in bare ice area and 2 m deep in debris covered area with the debris thickness of 13 cm. Thermistor temperature probes were buried at a depth interval of 0.5 m in bare ice area and 0.2 m in debris-cover. Ice temperature from the three boreholes (T1, T2, and T3) were measured respectively at the beginning of August 2008, and May, July, and September of 2009. The error of observed temperatures is within 0.1 ^{o}C according to similar works previously.

In August 2008, the thickness of debris cover is measured by digging the debris at the spacing of ~5 m on both lateral debris-covered areas. Moreover, six ablation stakes were installed in debris-covered area to observe the ablation difference under debris-covers with different thickness.

In addition, an automatic weather station was set at ~3950 m during the investigation in 2008. A hydrologic section was placed ~2 km down from the glacial terminus. Since their short observation period, the Aksu Meteorological Station (80°14′ E, 41°10′ N; 1104 m a.s.l.) and Xiehela Hydrologic Station (79°37′ E, 41°34′ N; 1487 m a.s.l.) were selected for long-term meteorological data analysis. These two stations are ~75 km southeast and ~30 km southwest to Qingbingtan Glacier No. 72, respectively. Because the Xiehela Hydrological Station has not been included in China's meteorology station network, only data before 2000 could be collected.

The location of the AWSs is not indicated in the map, nor is it clear from the paper if these were installed on or off glacier. In general, one or more tables with the details of all measurements (setup, location, instruments, temporal resolution, etc) should be provided. As an example, we do not know where the AWSs were located, the location of the boreholes, etc.

REPLY: An AWS was installed at 3950 m on the glacier and precipitation was observed during the 2008 expedition. But due to glacier movement, the AWS was not stable. So this one and two more AWSs were installed off glacier in during 2009 expedition. Since no more precipitation measurement, we have not used data from these AWSs and thus have not mentioned more about AWSs.

We accepted the reviewer's suggestion and added a table (Table 1; see below) in which all observation items were listed with their methods, instruments, observation time, etc.

Table 1. Observation items on the Qingbingtan Glacier 72

Observation items	location	instrument/method	period
Mass balance	21 stakes in the ablation area	Stake measurement	30 July to 28 August, 2008; at least once in every summer of 2009–2013
	6 ablation stakes in debris-covered area	Stake measurement	30 July to 28 August, 2008
	a snow pit at 4482 m	Stratigraphic observation	August 2008
Ice flow velocity	The ablation stakes	RTK-GPS	every summer of 2008–2013
Glacier surface elevation	The ablation area	RTK-GPS	August 2008
Glacier terminus	The glacier terminus	RTK-GPS	Once in each summer

position			of 2008–2013
Ice thickness	5 transverse and 4 longitudinal sections with a total of 824 measurement points in the glacier tongue	EKKO PRO 100A enhanced GPR	August 2008 and July 2009
Ice temperature	~3950 m; ~4200 m; ~3950 m	3 boreholes	July 2008
Debris thickness	at the spacing of ~5 m on both lateral debris-covered areas	Digging the debris	August 2008

Other methodological aspects/sections that need to be improved include: - The kriging method used to interpolate the observations of ice thickness: no details about the method, which kriging approach is used (there are many: simple kriging, ordinary kriging, kriging with drift, etc), how the variogram was estimated, which theoretical variogram was fitted, etc.

REPLY: Thanks for the comments of the reviewer. The Ordinary Kriging method was adopted for the interpolation of the observation of ice thickness. The variogram in this study was estimated as the variance of the difference between field values at two locations (x and y) across realizations of the field (Cressie, 1993). And the spherical variogram model was fitted. These have been added in the revised manuscript as following:

3.3. Ice thickness

In August 2008 and July 2009, a pulse EKKO PRO 100A enhanced ground penetrating radar (GPR; Sensors & Software Inc., Mississauga, Canada) in combination with RTK-GPS was adopted to measure the glacier thickness. As shown in Fig. 3a, the ice thickness survey was conducted along five transverse and four longitudinal sections with a total of 824 measurement points. Since there is a crevasses area above 3950 m, the longitudinal cross section along the centerline was divided into two segments (B–B and D–D). Horizontal survey was conducted along an east-west direction, while the longitudinal survey started from the high elevation. Surveyors were unable to extend some survey lines to the glacier margins because of its steep slopes. The spatial coordinates of survey points were recorded simultaneously, thereby achieving terrain correction for every survey point. The GPR data were then processed in the software EKKO_View Deluxe. The ice thickness (*h*) can be calculated by the equation 5, and the relative error of ice thickness measurement can be estimated by the equation 6 (Sun et al. (2003)):

$$h = \frac{t_s}{2} \times v \tag{5}$$

$$\frac{dh}{h} = \frac{dv}{2v} \tag{6}$$

where t_s is the radar wave two-way travel time and v is the velocity of radar signal in glacier. In this study, the velocity was set at 0.169 m $(ns)^{-1}$ after field trial for many times and the value is within the range of 0.167–0.171 m $(ns)^{-1}$ for the velocity of radar signal in mountain glaciers (Glen and Paren, 1975; Robin, 1975; Narod and Clarke, 1994). The estimation result indicated that the relative error of ice thickness measurement was within 1.2%. Moreover, the estimated uncertainty of the ice thickness was also according to previous studies (Fischer, 2009; Navarro and Eisen, 2010; Andreassen et al., 2015). Commonly, uncertainties for all ice thickness measurements are related to the propagation velocity of electromagnetic waves in snow, firn and ice, inaccuracies when picking reflectors, and the radar system resolution.

Ice thickness distribution map was eventually obtained by Ordinary Kriging Interpolation assuming the thickness at the glacier margin to be zero. The variogram in this study was estimated as the variance of the difference between field values at two locations (x and y) across realizations of the field (Cressie, 1993). And the spherical variogram model was fitted. The spherical variogram model is

$$r(h) = (s-n)\left(\left(\frac{3h}{2r} - \frac{h^3}{2r^3}\right)1_{(0,r)}(h) + 1_{[r,\infty)}(h)\right) + n1_{(0,\infty)}(h) \qquad (7)$$

where s is sill, n is nugget, r is range, and h is lag distance.

The references cited for this is:

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

Uncertainty in glacier area and terminus change: the authors indicate a formula they use to calculate this, but it is not clear how they come up with the actual values from that formula "Integrated evaluation indicated that the resulting uncertainties: : : etc" (lines 192: : :). They should provide the values for each of the variables/terms in equation 3 and 4. In general, their methods should be reproducible, which is not the case at present for most of their approaches.

REPLY: According to the suggestion of the reviewers, the uncertainty has been re-evaluated referring to previous studies and the variables used have been shown in Table 2. The revised part was as following:

3.2.3. Glacier terminus and area changes

To determine glacier terminus and area changes, various data were used, including a topographic map in 1964 (1:50 000), a SPOT5 image (resolution: 5 m) in 2003, and the glacier terminus position measured by RTK-GPS during the investigation in 2008 and in summer of each following year from 2009 to 2013. All these data were put into the same coordinate system, which is an important precondition for precisely calculating changes in glacier terminus, area and surface elevation. Glacier boundaries for the different periods were digitized manually in the software ARCGIS. For the period 1964–2008, according to Williams et al. (1997), Hall et al. (2003), Silverio and Jaquet (2005), and Ye et al. (2006), the uncertainty in the glacier area and terminus changes for an individual glacier can be estimated by

$$U_T = \sqrt{\sum \lambda^2} + \sqrt{\sum \varepsilon^2} \tag{3}$$

$$U_A = \sum \lambda^2 \times \frac{2 \times U_T}{\sqrt{\sum \lambda^2}} + \sum \varepsilon^2 \tag{4}$$

where U_T is the uncertainty of the glacier terminus and U_A is the uncertainty of glacier area. λ is the resolution of each individual image, and ε is the registration error of each image to the 1964 topographic map. For the accuracy of glacier terminus and area changes during 2008–2013, it mainly depends on the GPS measuring error, although the error using a seven-parameter space transform model for transforming coordinate of GPS data that is less than 0.002 m (Wang et al., 2003), cannot be ignored. Values of variables in Equations 3 and 4 are listed in Table 2. Integrated evaluation indicated that the resulting uncertainties of glacier terminus and area variation are 26 m and 1.3×10^{-3} km^2 in 1964–2008, and 5 m and 0.037×10^{-3} km^2 in 2008–2013, respectively.

Table 2 Values of variables in Equation 3 and 4 to estimate uncertainty in glacier area and terminus change

Variables	Period			
	1964 (m)	2003 (m)	2008 (m)	2013 (m)
λ	25	5	2.5	2.5
ε	0	1	1	1

- Ice thickness estimation: I am not an expert in GPR, but there must be a more appropriate reference for the equation to estimate the ice thickness and associated uncertainty than a paper published in a Chinese journal. It would also be useful to associate an uncertainty to the ice thickness values estimated, or provide a sensitivity analysis. It is not clear where does Eq. 6 come from.

REPLY: We have already referred to many previous international studies and estimated the uncertainty of the ice thickness. Moreover, an uncertainty of the ice thickness value was added in the manuscript. The revised part of "3.3 Ice thickness" and "4.2. Changes in glacier thickness and surface elevation" were as following.

3.3. Ice thickness

In August 2008 and July 2009, a pulse EKKO PRO 100A enhanced ground penetrating radar (GPR; Sensors & Software Inc., Mississauga, Canada) in combination with RTK-GPS was adopted to measure the glacier thickness. As shown in Fig. 3a, the ice thickness survey was conducted along five transverse and four longitudinal sections with a total of 824 measurement points. Since there is a crevasses area above 3950 m, the longitudinal cross section along the centerline was divided into two segments (B–B and D–D). Horizontal survey was conducted along an east-west direction, while the longitudinal survey started from the high elevation. Surveyors were unable to extend some survey lines to the glacier margins because of its steep slopes. The spatial coordinates of survey points were recorded simultaneously, thereby achieving terrain correction for every survey point. The GPR data were then processed in the software EKKO_View Deluxe. The ice thickness (*h*) can be calculated by the equation 5, and the relative error of ice thickness measurement can be estimated by the equation 6 (Sun et al. (2003)):

$$h = \frac{t_s}{2} \times v \tag{5}$$

$$\frac{dh}{h} = \frac{dv}{2v} \tag{6}$$

where t_s is the radar wave two-way travel time and v is the velocity of radar signal in glacier. In this study, the velocity was set at 0.169 m (ns)$^{-1}$ after field trial for many times and the value is within the range of 0.167–0.171 m (ns)$^{-1}$ for the velocity of radar signal in mountain glaciers (Glen and Paren, 1975; Robin, 1975; Narod and Clarke, 1994). The estimation result indicated that the relative error of ice thickness measurement was within 1.2%. Moreover, the estimated uncertainty of the ice thickness was also according to previous studies (Fischer, 2009; Navarro and Eisen, 2010; Andreassen et al., 2015). Commonly, uncertainties for all ice thickness measurements are related to the propagation velocity of electromagnetic waves in snow, firn and ice, inaccuracies when picking reflectors, and the radar system resolution.

Ice thickness distribution map was eventually obtained by Ordinary Kriging Interpolation assuming the thickness at the glacier margin to be zero. The variogram in this study was estimated as the variance of the difference between field values at two locations (x and y) across realizations of the field (Cressie, 1993). And the spherical variogram model was fitted. The spherical variogram model is

$$r(h)=(s-n)\left(\left(\frac{3h}{2r}-\frac{h^3}{2r^3}\right)1_{(0,r)}(h)+1_{[r,\infty)}(h)\right)+n1_{(0,\infty)}(h) \tag{7}$$

where s is sill, n is nugget, r is range, and h is lag distance.

4.2. Changes in glacier thickness and surface elevation

As shown in Fig. 3b, the maximal ice thickness of the glacier tongue is 148±2 m, m, occurring in the upper part of the tongue close to the centerline. Around an elevation of ~4200 m, the thickness and its spatial variation are relatively large. Fig. 3c and 3d illustrate the glacier cross section from the a–a radar image profile and longitudinal section from B–B and D–D radar image profiles, respectively, which could reflect the basic characteristics of horizontal and longitudinal changes of the ice thickness and elevations of the glacier surface and the bedrock. From these figures it can be seen that the maximum thickness in longitudinal section occurs above ~4000 m a.s.l., and the thickness in the horizontal sections is larger in the central. Compared to the surface elevations, the bedrock exhibits large undulations, especially at ~4000 m a.s.l., where persistent undulations occur on the same level.

The references cited for this are:

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.

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

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.

Eq.6 referred to Sun et al. (2003).

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.

- Discussion of the character of the glacier (continental or maritime): no elevation is given for the boreholes, so comparison with temperature at other sites is not very meaningful.

REPLY: Thanks for the comment of the reviewer. It is true that it is not useful to compare temperatures at different elevations on different glaciers because ice

temperature is different at different elevations on a same glacier. So we have deleted the content about this.

4) Mass balance equation I am not sure that equation makes sense, with its three terms. What is the “affiliated” ice (line 132)? It is much more common to show the mass balance as the sum of its accumulation or ablation components. Even considering only the annual mass balance, it is not clear how the authors can identify the one of snow and ice (and of “affiliated” ice) at the same location from stake readings.

REPLY: Yes, it is well known that the mass balance is usually shown as the sum of its accumulation or ablation components. But at a single point, it also can be shown the sum of changes in snow and ice within a given time interval. Since in mountains of West China, snowfall is frequent in summer, it is often that there are a snow layer and a superimposed ice layer beneath the snow layer on surface in the ablation area of a glacier. This paragraph has changed in the revised manuscript as follows:

3.1 Mass balance

Since the upper part of Qingbingtan Glacier No. 72 is steep, fragile and associated with frequent snow/ice avalanches (Fig. 1b and 1c), the most observations of mass balance were only feasible below ~4200 m (Fig. 1b), except for once observation of a snow pit at 4482 m. During the first investigation in 2008, total 21 stakes were installed at 10 elevations of the ablation area (Fig. 1b). The mass balance measurement contains the vertical height of stakes over the glacier surface and thickness and density of the superimposed ice and snow layers. From the end of July to the beginning of September 2008, the stake mass balance measurement was carried out once almost every two days. In the following periods, the observation was conducted during the summer at least once a year.

The mass balance of a single point (b_n) can be obtained by

$$b_n = b_{ice} + b_s + b_{si} \tag{1}$$

where b_{ice}, b_s and b_{si} are the mass balance of glacier ice, snow and superimposed ice, respectively. In late August, a snow pit deeper than 2 m was observed at an elevation of 4482 m. For this snow pit, different type snow layers were identified and described for their grain size, color and hardness and density of each layer was measured. Since the reading of stakes and thickness of snow and ice layers are in order of 1 cm, error of the obtained mass balance at each site is between 1 and 2 cm.

5) TREATMENT of DEBRIS COVER This also needs substantial improvements. First, a lot of text in the results belong to a general discussion on the topic and not actual results (e.g. lines 375-383), and should be either included in the Introduction or removed. Second, the authors do not map debris cover (either manually or from satellite images) and a map of debris cover should be provided in Figure 1. We see the possible location of debris from the map of reconstructed debris thickness in Figure 7. Thirdly, and importantly, it is not clear how the authors come up with a critical thickness of 4cm (line 385). This should be justified in a convincing manner. The same is valid for the statements in lines 388-389, where the authors say that below 0.4-0.5 m the ice melting becomes negligible, but do not show any figure, data or evidence for this. Fourth, it is not clear how they calculate the area of debris cover thicker than the critical thickness– indeed they never mention any estimate or calculation of the debris cover area before in the methods or data section (was it mapped manually, derived from satellite images?). Do they infer the area from the point measurements of thickness? This does not seem to be the case since the thickness point measurements are interpolated, so the area of the interpolation must be prescribed before. Details are needed here. Fifth, and importantly, also this section is affected by the vague and speculative statements typical of the paper, with a lot of assumptions about what will happen to the glacier debris-covered area and to the melt that are not in the least supported (lines 392-400). The authors themselves admit they

have no observations of what they are describing (line 394).

REPLY: Thanks for these comments. In the revised manuscript, this part has been rewritten. The description for the debris cover extent and thickness distribution map is given. We have added a figure (Fig. 8) to show the relationship between the debris thickness and observed ablation rates, from which the critical thickness can be seen. The sentences contain the inferring meanings have been deleted. Some sentences on studies of other glaciers and effect of debris cover on glacier change are removed to the discussion part. In the part related to debris cover, one more figures (Fig. 12) is added, from which it can be seen the ablation is very weak when the debris thickness is exceeds 0.5 m. The new paragraph is as following:

4.4. Debris cover and its influence on glacier ablation

Generally, the debris-cover within a few centimeter of thickness is believed to promote glacier ablation, and the debris cover starts to inhibit ablation when its thickness reaches a certain value (Han et al., 2010; Bolch et al., 2012; Pieczonka et al., 2013; Pellicciotti et al., 2015; Pieczonka and Bolch, 2015; Pratap et al., 2015). Fig. 7 shows debris-covered extent and its thickness distribution manually drown from the point measurements described above. Firstly, the point thickness values from 5 m spacing measurement were put on the glacier map and then the thickness isogram map was drawn manually. Figure 8 shows the observed daily ablations of six measuring points across the debris-covered area at an elevation of ~3950 m. From these figures, the critical thickness of debris cover is about 4 cm on this glacier, and the debris-covered area was 0.87 km^2 and the area of debris cover thicker than 4 cm was 0.66 km^2. So the debris cover on this glacier has an alleviating ablation effect.

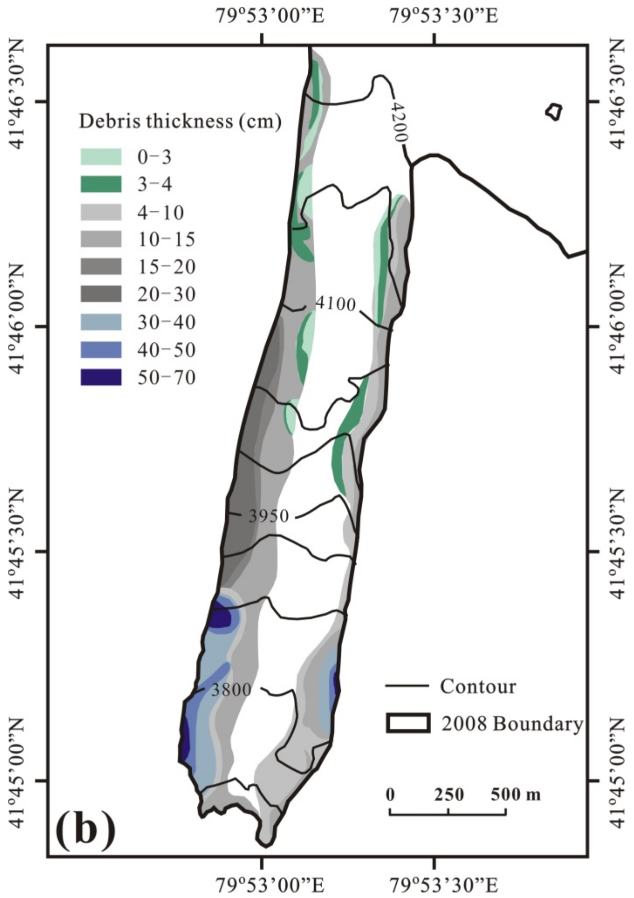

Figure 7. Distribution of debris thickness on Qingbingtan Glacier No. 72.

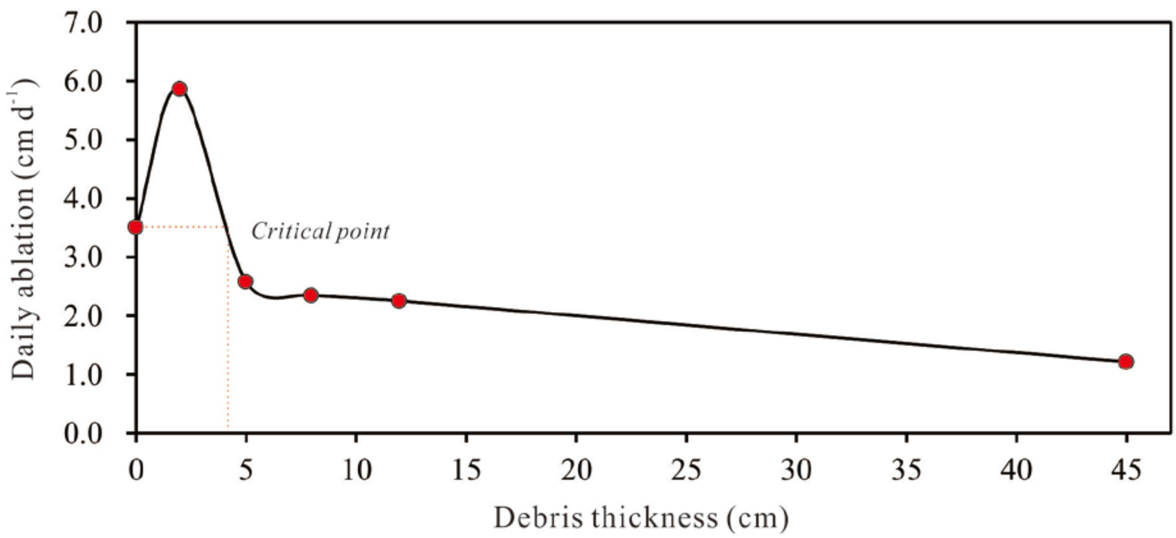

Figure 8. Correlation between the debris thickness and daily ice ablation. The red points represent the observation of six ablation stakes.

6) ABSTRACT The abstract needs to be entirely rewritten, both for English and

content.

REPLY: Thanks for this comment. Yes, we have rewritten the Abstract as following.

Abstract. Qingbingtan Glacier No. 72 in Mt. Tomor region is a cirque-valley glacier with complex topography and debris-covered areas. In-situ measurements from 2008 to 2013 and digitized earlier topographic maps and satellite images indicate that the glacier has been in retreating and experienced thinning during the past decades. Between 1964 and 2008, its terminus retreat was 41.16 $\pm$ 0.6 m a^{-1}, area reduction was 0.034$\pm$ 0.030$\times10^{-3}$ km^2 a^{-1}, and its thickness decreased at an average rate of 0.22 $\pm$ 0.14 m a^{-1} in the ablation area. The strongest ablation and terminus retreat occurred at the end of the last century and the beginning of this century rather than in most recent years, seeming to be related to increase in the debris coverage and thickness. The debris-covered area was 0.87 km^2, 0.66 km^2 of which was thicker than the critical thickness of 4 cm, and thus the debris cover on this glacier has an alleviating ablation effect. Based on a comprehensive analysis of climate change, glacier response delay, glacial topographic features and debris-cover influence, the glacier would continue to retreat in the upcoming decades, yet with a gradually decreasing speed.

7) INTRODUCTION The Introduction needs to be rewritten. In its current form it does not provide a clear rationale for the paper nor states a well-defined goal, and importantly the literature cited is not appropriate. For example, the studies cited as references for differential response of glaciers do not seem nearly comprehensive

enough.

REPLY: Thanks for this comment. We have rewritten the Introduction. In it some sentences have deleted since they are not related closely, and several new references have been added. It is mentioned that this paper is comprehensively present the recent variations of Qingbingtan Glacier No. 72 based on field observation data, and then discuss on influences of climate change and topographic factors including the debris cover.

The revised "Introduction" is as following.

1. Introduction

In the past decades, atmospheric warming has caused the majority of the glaciers to recede on a global scale, with the acceleration of the recession remarkably (Haeberli et al., 2002; Oerlemans, 2005; Meier et al., 2007; Arendt et al., 2012; IPCC WGI, 2013; WGMS,2008a,b,2012,2013; Farinotti et al., 2015; Zemp et al., 2015). Because glacial recession plays important roles in affecting sea level, water resources and the environment, glacier variation has become the attention focusing on not only scientific communities, but on the all publics (Raper and Braithwaite, 2006; Kehrwald et al., 2008; Berthier et al., 2010; IPCC WGII, 2014; Bliss et al., 2014). However, glacier variation is affected by multiple factors. Beside climatic conditions, glacier morphology and physical properties are also important, so that glacier variation differences arise between various regions and different types of glaciers (Haeberli et al., 2000; Bolch, 2007; Cogley, 2009; Kutuzov and Shahgedanova, 2009; Narama et al., 2010; Bolch et al., 2011; Huss, 2012; Leclercq et al, 2012; Marzeion et al., 2012; Sorg et al, 2012; Yao et al, 2012; IPCC WGI, 2013; Radic et al, 2013; Bliss et al., 2014; Fischer et al., 2014; Neckel et al., 2014; Farinotti et al., 2015).

There are a number of glaciers in the Tian Shan, Central Asia and their changes have been reported on regional scale by many researchers (Aizen et al, 1997; Li et al., 2010; Wang S et al., 2011; Yao et al, 2012; Farinotti et al., 2015; Pieczonka and Bolch, 2015). Mt. Tomor, the highest peak of the Tian Shan (elevation 7439 m; Kyrgyz name: Jengish Chokosu; Russian name: Pik Pobedy), is the largest glaciated region in the Tian Shan (location shown in Fig. 1). Glaciers in the Mt. Tomor region are commonly covered by debris with different extents and melt-water originating from the glaciers in this region is the major water source for the Tarim Basin (Hagg et al., 2007; Chen et al., 2008; Pieczonka et al., 2013). Therefore, it is important to understand response of different topographic glaciers with debris coverage to climate change in this region. Up to date, field investigations and monitoring have been conducted for several glaciers in the China's territory of this region. For example, in 1977–1978, a mountaineering expedition team conducted summer observations on Xiqiongtailan Glacier, a large valley glacier covering 164 km^2 (Mountaineering and Expedition Term of Chinese Academy of Sciences, 1985). Since 2003, continuous observations have been conducted for the Koxkar Glacier, a large valley glacier covering 83.56 km^2, on the southern side of the Mt. Tomor (Zhang et al, 2006; Xie et al., 2007; Han et al., 2008, 2010; Juen et al, 2014). More recently, field observations have been carried out on a relatively small glacier covering 5.23 km^2, named Qingbingtan Glacier No. 72 and some of these observations on the terminus and thickness change have been reported (Wang et al., 2011, 2013). In this paper, we would comprehensively present the recent variations of Qingbingtan Glacier No. 72 based on more observation data, and then make an attempt to discuss on the influences of climate change and topographic factors including the debris cover.

8) RESULTS

Several statements are made in the paper's Results section but it is not clear where that evidence or specific results come from (see general comment above), a lot of it is speculative and this hinders an assessment of the soundness and validity of the authors' findings. - In general, Section on Changes in Glacier Mass balance and Volume (4.3) needs to be substantially improved, including the description of Figure 5 and the actual Figure 5 needs improvements: see points i) to v) in my general evaluation above and comment below about Figure 5. The extrapolation of the thickness reduction to the entire area (lines 370 on) is questionable and I would remove this part, or justify it in a sounder way. As the authors themselves recognise, the results are very rough (line 372).

REPLY: Thanks for these comments. In the revised manuscript, the Result section has been rewritten almost. Some sentences have been removed to the Discussion and unclear sentences have been deleted. The part of mass balance has been changed completely according to the reviewer's comments and a table (Table 3) has been added for observed values of the annual net mass balance at each stake point. Fig. 5 has been improved according to the comments.

Yes, the extrapolation of the thickness reduction to entire area and estimations of the average precipitation and accumulation from very limited data are questionable. So these sentences as well as the estimation of total mass balance have been deleted.

The revised part of "Results and analyses" is as following.

4. Results and analyses

4.1. Change in glacier terminus and area

From comparison of 1964 topographic map and 2008 RTK-GPS survey data, the elevation of the glacier terminus increased from 3560 m to 3720 m and the terminus position had retreated by 1811 ± 26 m at an average rate of 41.16 ± 0.6 m a^{-1}. By comparing the SPOT5 remote sensing images of 2003 with on-site investigation in 2008, the recession was 240 ± 7 m or 48 ± 1.4 m a^{-1} during the five years. The following field investigations show that the annual recession rates during 2008–2013 were 40.8 ± 1.0 m a^{-1}, 41 ± 1.0 m a^{-1}, 30 ± 1.0 m a^{-1}, 27 ± 1.0 m a^{-1}, and 22 ± 1.0 m a^{-1}, respectively. Thus, a general outline of the glacier terminus variations was obtained (Fig. 2). These observed results, show that the glacier terminus has been retreating during the past 50 years and the most intensive retreat occurred at the end of 20th century and the beginning of this century. More recently, i.e. after 2009, the recession has slowed down because the debris cover enhanced the inhibition of glacier ablation, which will be discussed more later on.

In addition, by comparing various topographic maps, remote sensing image, and field survey data, the glacier tongue area had also shrunk beside recession of the terminus. The obtained glacier area shrinkage was 1.53 ± 1.3×10^{-3} km^2 at a rate of 0.034 ± 0.030×10^{-3} km^2 a^{-1} between 1964 and 2008 and was 0.165 ± 0.08×10^{-3} km^2 or 0.033 ± 0.016×10^{-3} km^2 a^{-1} between 2003 and 2008. The area declined by 0.124 ± 0.037×10^{-3} km^2 from 2008 to 2013 with a rate of 0.025 ± 0.007×10^{-3} km^2 a^{-1}. The results indicated that the area reduction was large before 2008 and was alleviated afterwards, a similar trend to the terminus retreat.

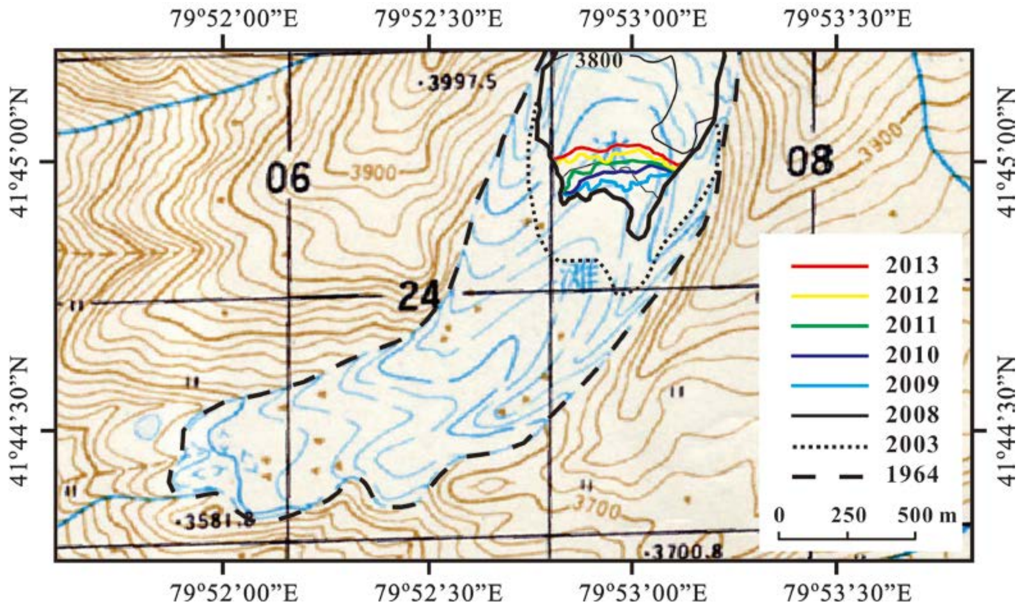

Figure 2. Schematic graph of boundary changes of the tongue area of Qingbingtan Glacier No. 72. The background is the topographic map in 1964.

4.2. Changes in glacier thickness and surface elevation

As shown in Fig. 3b, the maximal ice thickness of the glacier tongue is 148±2 m, m, occurring in the upper part of the tongue close to the centerline. Around an elevation of ~4200 m, the thickness and its spatial variation are relatively large. Fig. 3c and 3d illustrate the glacier cross section from the a–a radar image profile and longitudinal section from B–B and D–D radar image profiles, respectively, which could reflect the basic characteristics of horizontal and longitudinal changes of the ice thickness and elevations of the glacier surface and the bedrock. From these figures it can be seen that the maximum thickness in longitudinal section occurs above ~4000 m a.s.l., and the thickness in the horizontal sections is larger in the central. Compared to the surface elevations, the bedrock exhibits large undulations, especially at ~4000 m a.s.l., where persistent undulations occur on the same level.

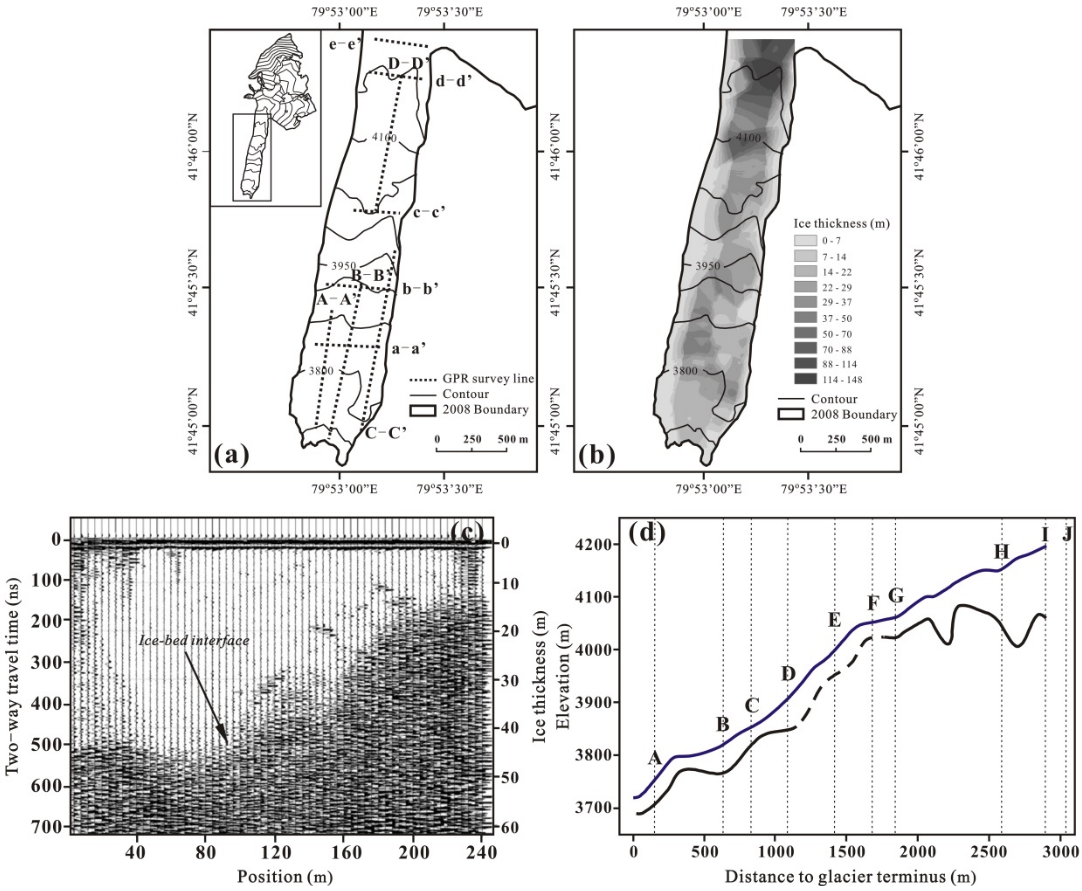

Figure 3. (a) Ground penetrating radar survey sections of Qingbingtan Glacier No. 72; (b) Ice thickness distribution map of the glacier tongue; (c) An example of the radar image showing the cross section profile (a–a); (d) variations of the surface and the bedrock elevations along the centerline (based on radar image section B–B and D–D).

Since lack of earlier thickness measurements, temporal changes of the ice thickness could be obtained only from the variations in the surface elevation. The derived surface elevation variations are shown as Fig. 4. This result reveals that the ablation area of the glacier was generally in a thinning tendency. Between 1964 and 2008, the reduction in thickness was 9.59 ± 6 m, with an average reduction rate of 0.22 ± 0.14 m a^{-1}. A small area at ~4200 m exhibited a slight amount of thickening, meaning a positive net difference between upper stream feeding and ablation around this elevation. Meanwhile, it was also found that the variation in the surface elevation in the central was more obvious than onto the two lateral sides, probably related to debris-cover effect.

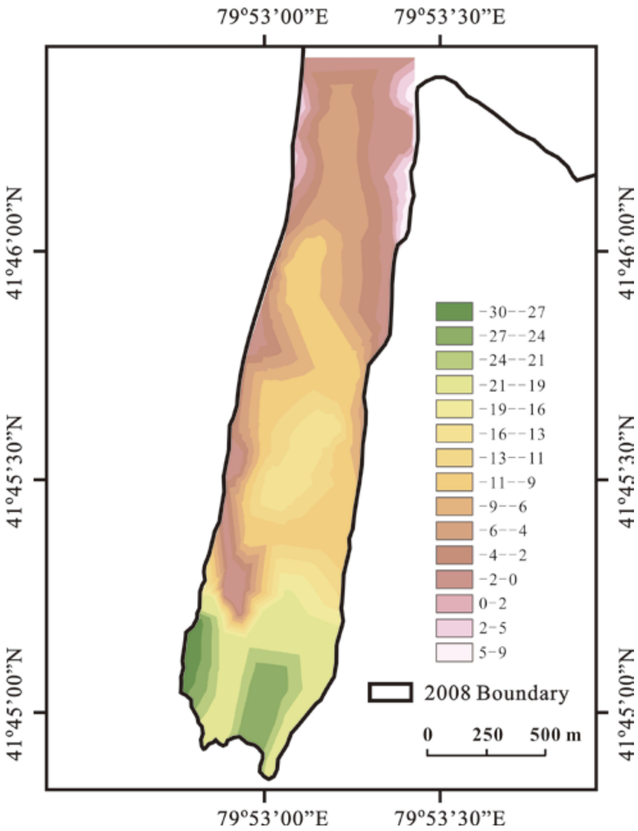

Figure 4. The isogram map of the surface elevation variations in the tongue area of Qingbingtan Glacier No. 72 during 1964–2008.

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

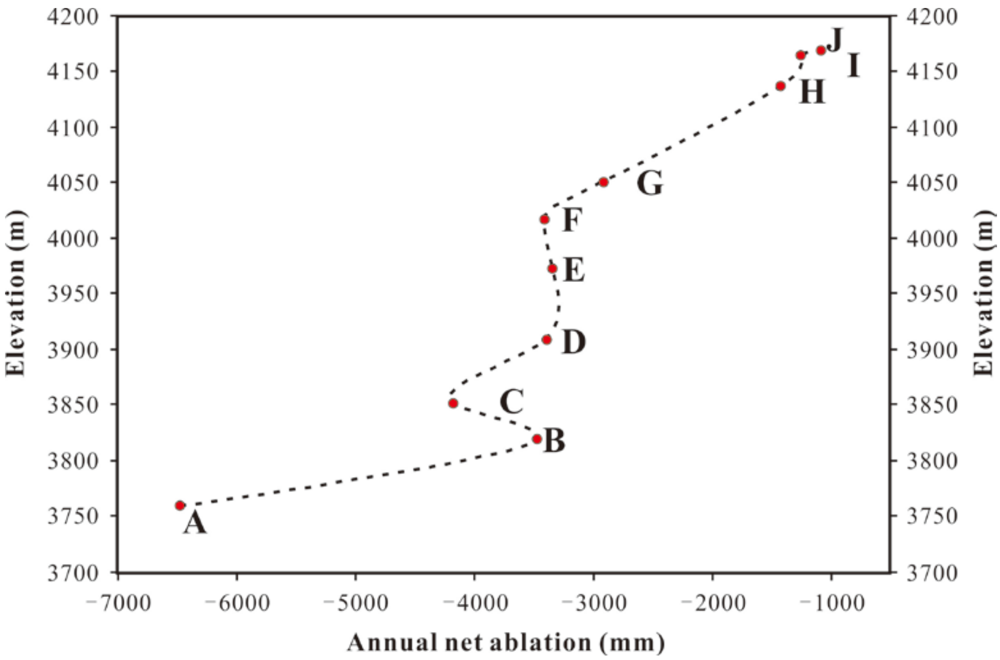

Figure 5. Variation of the annual net ablation along with elevation of Qingbingtan Glacier No. 72.

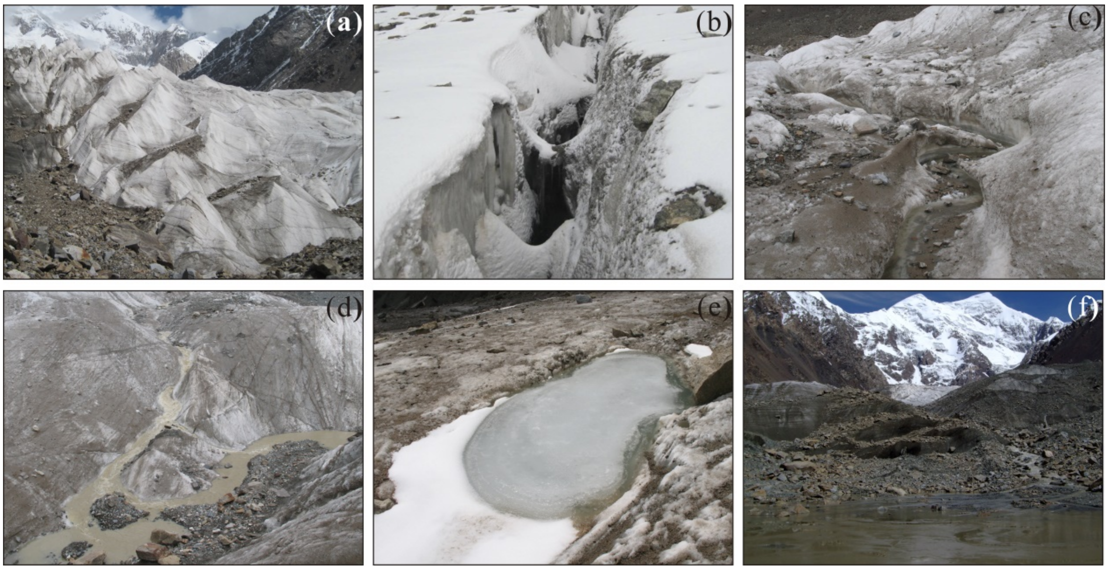

Figure 6. Photos showing the surface features of Qingbingtan Glacier No. 72.

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.

4.4. Debris cover and its influence on glacier ablation

Generally, the debris-cover within a few centimeter of thickness is believed to promote glacier ablation, and the debris cover starts to inhibit ablation when its thickness reaches a certain value (Han et al., 2010; Bolch et al., 2012; Pieczonka et al., 2013; Pellicciotti et al., 2015; Pieczonka and Bolch, 2015; Pratap et al., 2015). Fig. 7 shows debris-covered extent and its thickness distribution manually drown from the point measurements described above. Firstly, the point thickness values from 5 m spacing measurement were put on the glacier map and then the thickness isogram map was drawn manually. Figure 8 shows the observed daily ablations of six measuring points across the debris-covered area at an elevation of ~3950 m. From these figures, the critical thickness of debris cover is about 4 cm on this glacier, and the debris-covered area was 0.87 km^2 and the area of debris cover thicker than 4 cm was 0.66 km^2. So the debris cover on this glacier has an alleviating ablation effect.

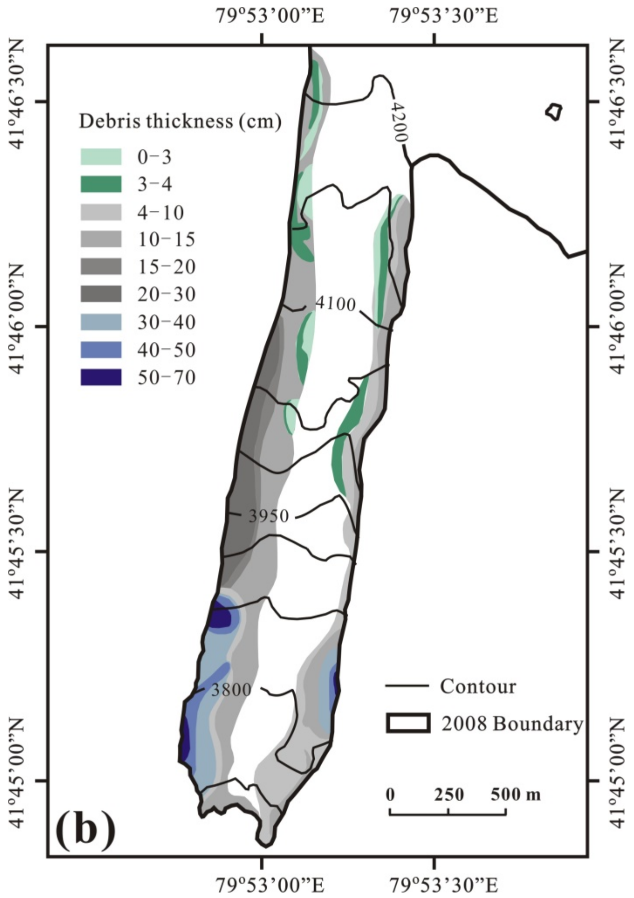

Figure 7. Distribution of debris thickness on Qingbingtan Glacier No. 72.

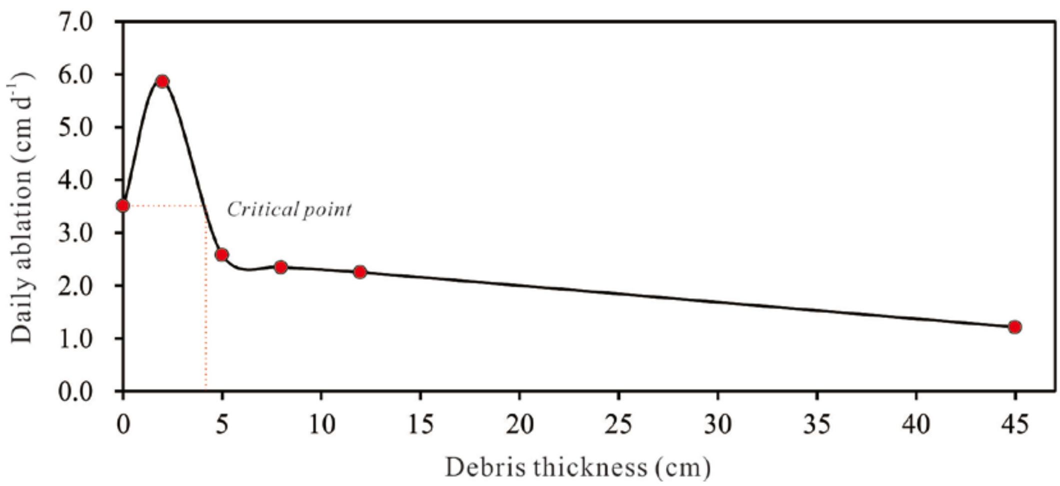

Figure 8. Correlation between the debris thickness and daily ice ablation. The rhombuses represent the observation of six ablation stakes.

4.5. Ice flow velocity

Since the stakes at a same section were relatively near to each other, the velocity difference between adjacent stakes was small. The stake close to the centerline moved faster than others in the same section. Fig. 9a shows the annual average horizontal velocity of every section between August 2008 and August 2009. The minimal horizontal speed, 18.6 m a^{-1}, appeared at the J cross section at an elevation of ~4170 m, where the surface slope was rather gentle, and the bedrock had large undulations around a roughly same elevation as well as ice thickness was relatively very large (see Fig. 3 for longitudinal profiles of ice thickness, elevation and slope). The maximum speed, 70 m a^{-1}, was observed at the G cross section at an elevation of ~4050 m, where there was a turning point of changes in surface slope and ice thickness since slope increased and ice thickness decreased sharply downstream from this section. Below the elevation of ~3900 m, the surface slope gradually decreased, ice thickness had no change almost and the ice velocity decreased continuously. At the B cross section at an elevation of ~3820 m, the velocity decreased to 20 m a^{-1}. At the A cross section with the lowest elevation, the annual ablation depth was approximately 7 m. Because the stakes fell down, the velocity was only available for a short period. When compared with the B' cross section, the velocity at A’ was slightly elevated, which corresponded to the increase of the terminus slope. The change in vertical velocity with elevation was similar to the horizontal velocity (Fig. 9b); the maximal value, 15 m a^{-1}, was present at the F cross section at an elevation of ~4016 m, which was a little lower than the G cross section where the maximal horizontal velocity occurred. From the results, one can conclude that surface slope was the main factor controlling the velocity distribution. Based on the results of all measuring points, the annual average horizontal velocity over the entire observed area was 47.61 m a^{-1}, which was higher than most cirque-valley glaciers observed in the Tian Shan (Jing et al., 2002, 2011; Zhou et al., 2009; Wang et al., 2016). This suggests that the basal sliding has an important contribution to the glacier movement.

Furthermore, Fig. 9 gives the comparison of the average monthly velocity in ablation season (June–August) with the average monthly velocity of every section. It can be seen that average monthly velocity was lower than that in the ablation season. By averaging the values of all points, the average monthly horizontal velocity was 3.95 m per month and 6.46 m per month in the ablation season, and the average monthly vertical velocity was 0.58 m per month and 1.54 m per month in the ablation season. The higher velocity during the ablation season should be attributed to the meltwater lubricating at the bedrock, which has an enhancing effect on the glacial sliding.

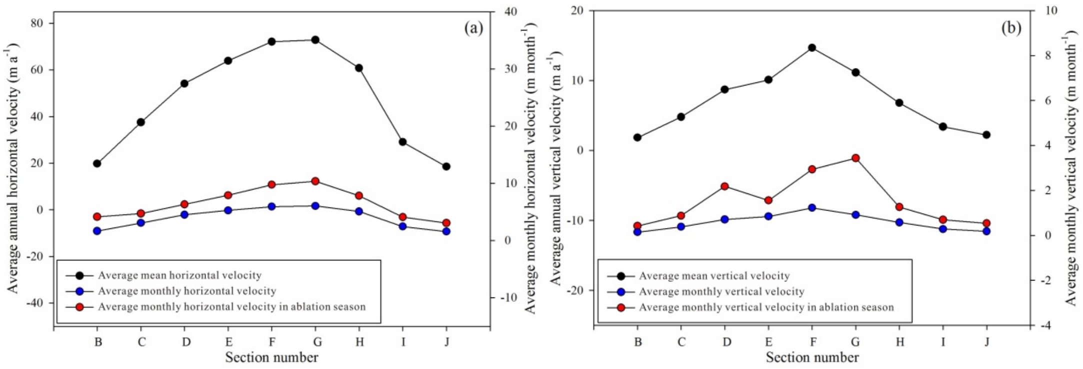

Figure 9. The surface velocity in the ablation area of Qingbingtan Glacier No. 72 between August 2008 and August 2009. (a) and (b) show the variation of horizontal and vertical velocity with elevation increasing, respectively.

4.6. Ice temperature

Ice temperature is an important index of the physical characteristics of a glacier. The measurement results in the boreholes drilled in the bare ice at the elevation of ~3950 m (T1) and ~4200 m (T2) show that the ice temperature within a depth of 10 m in the ablation area was higher than −2°C in summer and was −1.2°C at 10-m depth. In the debris-covered area at the elevation of ~3950 m (T3), ice temperature within a depth of 2 m was higher than −1°C. Fig. 10 illustrates the temperature of three boreholes observed in the early August of 2008. Although no observations were conducted in winter, one can speculate that the temperature will drop below −2°C within only a few meters of depth. In the Mt. Tomor region, the annual precipitation is 600–800 m at elevations between 3700–4200 m, 40% of which fell during the non-ablation season (Han et al., 2008) and so the surface snow layer could be deeper than 1 m during winter. Thus, according to the simple model of heat conduction in the near surface layer of a glacier (Paterson, 1994), the propagation depth of a cold wave in winter was within 5 m. Moreover, the heat released from refreezing of the meltwater stored in summer will offset the cold wave propagation. When the depth was greater than 10 m, the temperature would increase further. Usually, temperature gradient in ice is about 2.4 K per a hundred meters in a glacier only under effect of the normal geothermal flux (50 mWm^{-2}) (Paterson, 1994). For mountain glaciers, due to effects of melting water and ice movement (deformation and sliding), the temperature gradient is larger. Therefore, temperature at the bottom of the ablation area of this glacier is easy to be at the melting point, which benefits to the glacier sliding.

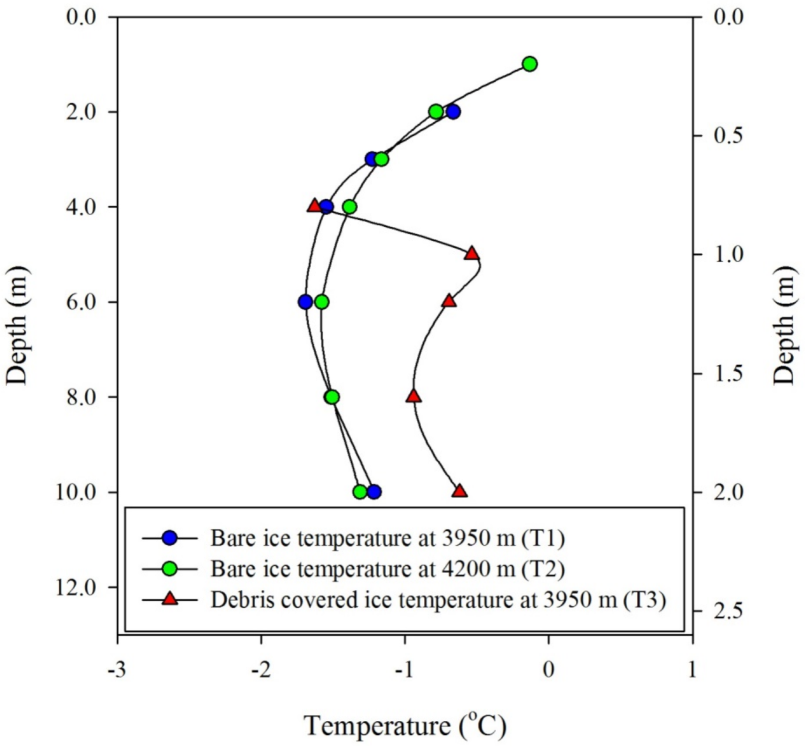

Figure 10. The measured temperatures in 10 m–depth boreholes in the bare ice at ~3950 m (T1) and ~4200 m (T2), and in a 2 m-depth borehole with debris covered (T3) of Qingbingtan Glacier No. 72 in the early August 2008.

Values of terminus and area changes in Table 1 should all be accompanied by uncertainty estimates (which in some cases the authors have derived and are provided in the text) to be able to make a meaningful comparison between the three periods (1964-2008; 2003-2008; 2008-2013) and across case studies.

REPLY: Thanks for the comment. In the revised manuscript, this table has been removed to the Discussion as Table 4, in which, uncertainties of values of terminus and area changes for the three periods are given.

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	Terminus change	Area change	Source

			length					
		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 covered in a lower part	83.6	26	1976–1981	0.0		—	Wang and Su, 1984
				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

9) FIGURES The quality of most figures needs to be improved, both graphically and

in terms of content. - Figure1: missing key locations of observations, e.g. the position of the AWSs. - Figure 2 needs to be improved, it is not clear if it is real or a scheme. There should be a background to the lines, be it the map or the SPOT image, or a DEM of the area. - Figure 4 should be replaced with a surface figure based on colours (also shades of grey are fine), not isograms. - Figure 5: the authors have to show the points here of their observations, not a continuous like that it is not clear how it was drawn. As it is, it seems that the authors have continuous observations in space

REPLY: Thanks for these comments. We have checked all figures and changed them according to these comments. Fig. 1 has been changed according to two reviewers' comments.

10) LITERATURE and REFERENCES Often the authors' literature is limited to Chinese papers (sometimes not available in English), also for issues for which there are ample literature in international, peer-reviewed journals. They should make an effort to expand that.

REPLY: Thanks for this comment. We accepted the reviewer's suggestion and added several new references from international journals. The revised references are as following.

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