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Ice Surface-Elevation Change and Velocity of Qingbingtan Glacier No.72 in the Tomor Region, Tianshan Mountains, Central Asia

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Abstract: Glaciers in the Tomor region of Tianshan Mountains preserve vital water resources. However, these glaciers suffer from strong mass losses in the recent years because of global warming. From 2008 to 2009, a large-scale scientific expedition has been carried out in this region. As an individual reference glacier, the tongue area of Qingbingtan glacier No. 72 was measured by the high precise Real Time Kinematic-Global Position System (RTK-GPS). In this paper, changes of the tongue area of Qingbingtan glacier No.72 has been studied based on topographic map, remote sensing image and the survey during 2008-2009 field campaign. Results indicated that the ice surface-elevation of the tongue area changed -0.22±0.14 m a^{-1} from 1964 to 2008. The estimated loss in ice volume was 0.014±0.009 km^3, which represented a ~20 % decrease from the 1964 volume and was equivalent to average annual mass balance of -0.20±0.12 m water equivalent for the tongue area during 1964-2008. Terminus retreated by 1852 m, approximately 41 m a^{-1}, with the area reduction of 1.533 km^2 (0.034 km^2 a^{-1}) from 1964 to 2009. Furthermore, the annual velocity reached to ~70 m a^{-1}. Comparing with the other monitored glaciers in the eastern Tianshan Mountains, Qingbingtan glacier No.72 experienced more intensive in shrinkage, which resulted from the combined effects of climate change and glacier dynamic, providing evidence of the response to climatic warming.

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Introduction

Mountain glaciers are considered to be a sensitive indicator of climatic variations (e.g. Houghton et al. 2001) and important because of their contribution to sea-level change (Meier et al. 2007). The glaciated area in the central Asia is 114,800 km^2 (Dyurgerov 2002), among which more than half (52% of the total) are in China (SHI et al. 2005). The IPCC Report (2007) indicated that warming has increased since the 1910s, global annual mean temperature increases by 0.74°C from 1906 to 2005, and that it is likely to increase by 1.1-6.4°C by 2100. In China, the temperature increases by 0.4-0.5°C from 1860 to 2005, and the rise of winter temperature has been apparent since 1951; nineteen “warm winters” have been experienced since 1986/1987 (Climate and Environment in China 2006). From a worldwide study of the mass balance, equilibrium-line altitude, accumulation area ratio and ablation volume of 300 mountain glaciers from 1961 to 1998, Dyurgerov (2003) concluded that glacier area and volume had decreased at an increasing rate and the speed of the water cycle had accelerated as a result of global warming since the 1980s. The worldwide extent of glacier retreat between 1884 and 1978 was proportional to the extent of global warming (0.66±0.1 K) in the same period, and it is estimated that the total area of the world's mountain glaciers will decrease by 1/3-2/3 in the 21st century (Oerlemans and Fortuin 1992; Oerlemans 1994). In Western China, most glaciers have experienced a strong reduction in the mass because of global warming since the early 20th century, and the significant glacier retreat have been reported since the 1980s (ZHANG and YAO 1998; LIU and KANG 1999; SHI and LIU 2000; SHI 2001, LIU et al. 2003; SHANGGUAN et al. 2008; LI et al. 2010).

Located in the western part of the eastern Tianshan Mountains (China), Tomor Peak (7435 m a.s.l.) is the highest peak in Tianshan Mountains and fosters the largest glaciated region, Tomor region. According to the Glacier Inventory of China Ⅲ (LIGG 1987), 1858 glaciers are located in this region with a total area of 4195.42 km². There are six glaciers with an individual area larger than 100 km². Glacial runoff from the Tomor region is the main water sources of Aksu River that accounts for about 70% of the surface runoff of Tarim River and plays an important role in the sustainable development of the ecological environment, industry and agriculture, especially in the arid and semi-arid region of the northwestern China (KANG et al. 2002; SHI et al. 2005). As the major water resources of Tarim River, glaciers in the Tomor region are experiencing rapid recession in the past several decades. However, glacier field observation was sparse in this region.

Taking this into account, it is important to document, and to account for, glacier changes in the Tomor region, Tianshan Mountains. Understanding the evolution and spatial variability of glaciers can contribute to better knowledge of impact, trends and rates of ongoing climate change. To investigate the current situation of glaciers and glacier changes in the Tomor region, a field campaign has been carried out by Tianshan Glaciological Station during 2007-2009 and Qingbingtan glacier No.72 (Glacier No.72) was surveyed by RTK-GPS (Real Time Kinematic-Global Positioning System). Qingbingtan glacier No.72 (41.75°N, 79.9°E; Figure 1), located at upper reaches of Aksu River, had an area of 7.27 km² and was 7.4 km long in 1964. The glacier extends from 5986 m to 3560 m a.s.l. at the terminus and faces towards the south, which is mainly nourished from icefall and avalanche. Glacier No.72 can be considered as representative of many "cirque-valley" glaciers with debris-cover in the Tomor region, which account for 80% of the total number of glaciers in the Tomor region (SHI et al. 2005).

The main objective of the paper is to understand the glacial changes process of this type by analyzing ice, surface-elevation, volume, area and terminus changes, during the 1964-2009 period by comparing topographic maps, remote sensing data and field survey data. Furthermore, the relation of glacier changes with ice velocities measured at 21 stakes during the summer of 2008 and 2009, and regional trends in temperature and precipitation data were analyzed.

1 Methodology and Data

A variety of datasets used in this study are included: topographic map in 1964, SPOT 5 image in 2003, GPR survey data in 2008, RTK-GPS surveying and surface velocity data in 2008 and

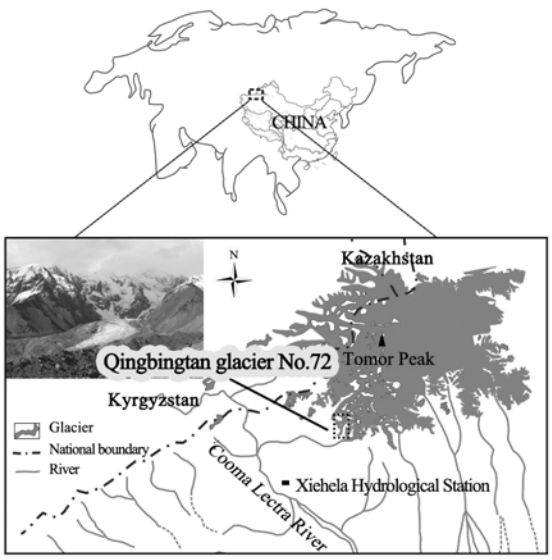

Figure 1 Location of Qingbingtan glacier No.72, which is at upper reaches of Aksu River (including Cooma Lectra River and Tuoshigan River in the headwaters), Tomor region, eastern Tianshan. The figure in the upper left corner shows the topography of Qingbingtan glacier No.72 (photographed by Li Zhongqin in 2008). The rectangle indicates the location of the Xiehela Hydrological Station.

2009, and temperature and precipitation data from the Xiehela Hydrological Station. For the purpose of analyzing glacier changes (e.g. ice surface-elevation, volume, area and terminus change), data of different periods are computed comparison. The ice surface-elevation change, i.e. ice thickness or volume change can be derived from repeated comparison of the surface topography over different periods.

1.1 RTK-GPS survey and data processing

In August 2008, (RTK-GPS) (Unistrong E650; Figure 2) was carried out in and around the tongue area over an altitude range of 3700-4200 m a.s.l. at a sampling spacing of 20-50 m with a precision better than 1 cm. In August 2009, survey was repeated at the glacier terminus. GPS survey concentrated in the tongue area due to the steep slope, crevasses and icefall in the upper part. All GPS data, measured with respect to the Universal Transverse Mercator (UTM) World Geodetic System 1984 ellipsoidal elevation (WGS84), were re-projected and transformed to the 1954 Beijing Geodetic Coordinate system (BJ54) GEOID using LandTop software version 2.0.5.1. The datum level is the mean sea level of the Yellow Sea, namely, Qingdao Tidal Observatory in 1956. The error using a seven-parameter space transform model is <0.002 m (WANG et al. 2003). A 21-stake network was set up with ten transects to measure ice velocity (Figure 2). To study the annual and seasonal ice-velocity, the stakes were measured in August 19th 2008, July 19th and August 20th 2009, respectively.

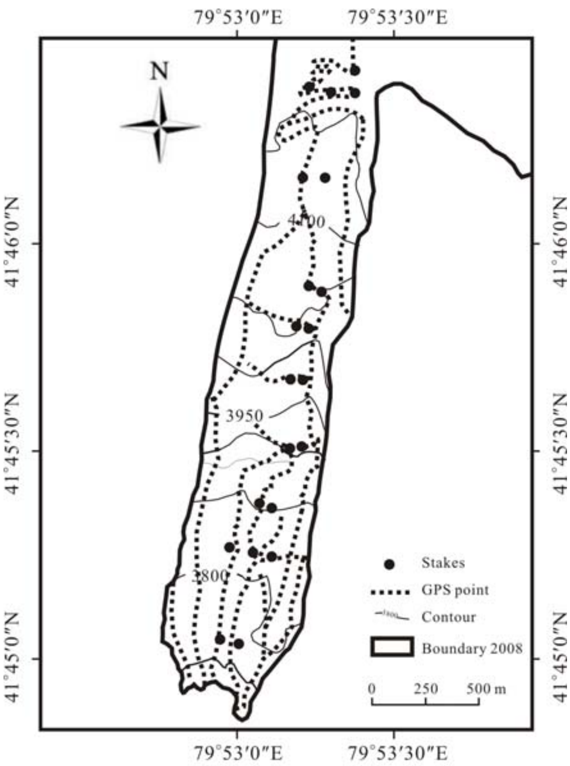

Figure 2 The GPS measuring trajectory denoted by the dashed lines. The red circles are the survey stakes, with the total number of 21 in the ten transects (A-J).

1.2 Changes of terminus, area and ice surface-elevation for the period 1964-2009

Terminus and area changes can be calculated by comparing data of different periods. The outlines and terminus position were determined from digitized topographic map in 1964, SPOT 5 image in 2003, GPS surveying data in 2008 and the repeated measuring data in 2009, respectively. The SPOT 5 image used in this study was obtained in September 2003 with the resolution of 5 m. It was co-registered with the topographic map using ERDAS Imagine 9.0 software. Ground-control points were selected that were easily identified on both topographic map and the remote sensing image. Enough points were selected to reduce the RMS error of the co-registered remote sensing image and topographic map to 0.8 pixels (Richards 1993).

The map of 1964-2008 ice surface-elevation, or ice thickness changes was obtained by subtracting the DEM-2008 and DEM-1964. The lowest variation range was set at 3 m, with the aim of filtering noise arising from inaccuracies in the DEMs, and to only highlight relevant fluctuations. The 1964-2008 ice-volume changes were computed from the ice surface-elevation change map in ArcMap™, supported by Geographic Information System (GIS)-based methodology. DEM-2008 was generated from the GPS data acquired in 2008 with a pixel resolution of 5 m. Another DEM for 1964 (DEM-1964) was produced by digitizing the 20 m interval contours and spot heights from the topographic map in 1964, and interpolated to a 5 m×5 m grid size. The topographic map for 1964 was constructed by the Chinese Military Geodetic

Service, using plane table mapping technique. The scale was 1:50 000. A total of 20 ground-control points (GCPs) with good spatial distribution were obtained from field measurements with GPS. These were taken, with centimeter accuracy, on exposed rock or non-glacierized areas. The map was then geo-referenced and rectified with the acquired equally distributed reference points. The systematic errors of the DEM are <±11 m over slopes <15° and <±19 m over slopes >25° (State Bureau of Surveying and Mapping 2007). Both DEMs were referenced to Bejing geodetic coordinate system 1954. Non-glacier land elevation differences are used to quantify the errors associated with the glacial elevation changes. It was estimated that the accuracy of ice surface-elevation changes are within ± 6 m by using 10 independent points in the surrounding non-glaciated area and the differences are within the expected accuracy (Raymond et al. 2005; Bauder et al. 2007; Rivera et al. 2007; Vanlooy and Forster 2008).

1.3 Temperature and precipitation

Meteorological data for the period 1964-2000 was observed by Xiehela Hydrological Station (1487 m a.s.l.) in Aksu River Basin, Xinjiang Uygur Autonomous Region. And it is the closest station to the terminus of Glacier No.72 in the Tomor region. Temperature and precipitation data used in this study are derived from the observed daily data of this station. The average annual temperature and precipitation in Xiehela Hydrological Station are 10.8°C and 105 mm respectively, for the period 1964-2000.

2 Results

2.1 Terminus, area, ice surface-elevation and volume changes, 1964-2009

Remarkable changes are observed for all parameters of the terminus, area, ice surface-elevation and volume. During 1964-2009, glacier terminus had retreated by 1852 m (41 m a^{-1}) with the area shrinkage of 1.533 km^2 (0.034 km^2 a^{-1}), as shown in Figure 3. To monitor glacier change, long-timescale (decades) observations of terminus and area changes are required to separate short-term fluctuations from changes that may reflect secular trends. Terminus and area changes were estimated for different periods: (1) 1964-2003 by comparing topographic map in 1964 and SPOT 5 image in 2003, (2) 2003-2008 by comparing SPOT 5 image in 2003 and RTK-GPS data in 2008, and (3) 2008-2009 from survey during field campaign. Estimates indicated that the glacier had experienced accelerated retreat and area shrinkage in the past few decades. Field survey showed that the glacier retreated by 40.8 m along the main flowline during 2008-2009 resulted in the area shrinkage of 0.023 km^2. It seemed that the glacier melting was slowing down comparing with the previous retreat rate. In fact that was not the case. Seen from Figure 3, the southeast corner of the terminus had been separated from the glacier tongue by the meltwater in one year, which is the direct evidence of serious ablation. Moreover, the glacier narrowed from both sides with different extent, probably related to the differences of the terrain.

In Figure 3 the spatial distribution of the thickness change in the ice tongue is shown. In the tongue area, a typical pattern was found. There is a good correlation between the areas of largest thickness decreases and those of lowest surface elevation, showing a gradual increase of ice

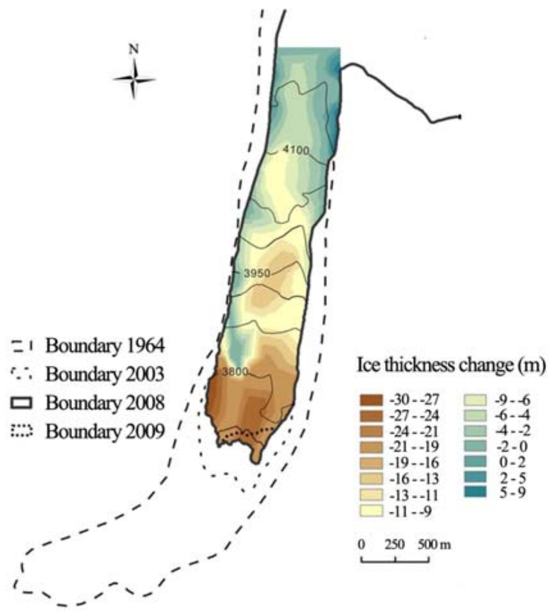

Figure 3 Ice surface-elevation changes for the period 1964-2008, together with the terminus changes of Qingbingtan glacier No.72 in 1964-2009. Different types of the lines represent glacier boundary of different periods.

thickness changes toward the terminus. This effect is rather common for glaciers in retreat (Huss et al. 2010). A significant common characteristic over the period considered (1964-2008) is that the ablation area underwent dramatic thinning. Changes in the ice-surface elevation of the order of -30 to 9 m between 1964 and 2008 were observed on the ice tongue with the average value of -0.22±0.14 m a^{-1}. The largest decrease of 30±6 m is concentrated at the terminus, providing powerful evidence of intensive ablation. The only positive changes, of the order of 0-9 m, are found close to the altitude of 4200 m, where a large local accumulation of ice has been observed and the flow is strongly compressive along the main flowline as a result of the change in slope and narrowing of the valley. The thinning pattern described for Glacier No.72 is very similar to many glaciers in Patagonia (Rignot et al. 2003) and Chilean Lake District (Bown and Rivera 2007), suggesting high ablation in a negative mass balance context. The change in ice volume is -0.014±0.009 km^3 for the tongue area with ice density 0.9×10^3 kg m^{-3}. In the past 44 years, the ice volume has decreased by ~20 % from the 1964 volume of ~0.070 km^3, estimated using combined ice-volume in 2008. On the whole, Glacier No.72 shows an even large reduction in ice volume, due to its dramatic terminus retreat and reduction in ice thickness.

2.2 Morphologic changes

With the intensive ablation, the morphologic feature of the glacier changed correspondingly. Field investigation found that the glacier tongue is debris-covered (Figure 4a). Ice pillars are widespread on the glacier tongue as a result of differential ablation (Figure 4b). Streams are common on the glacier tongue (Figure 4c) because of the high rate of ablation, and these will cause further ablation, erosion and disintegration of the glacier surface (e.g. the disintegration of the southeast corner from the glacier terminus during 2008-2009). There is a large meltwater pool on the tongue of Glacier No.72 (Figure 4d). It was also found at the summit of East Branch of Ürümqi glacier No.1 in 2004 (Li 2005). Although the two meltwater pools occur at the different part of the two glaciers, the altitude of their locations are close (4200 m for Glacier No.72; 4225 m a.s.l. for Ürümqi glacier No.1). Amount of crevasses are widely distributed on the surface of the glacier. Based on the field investigation, the crevasses are broadening heavily, especially for the one shown in Figure 4e, with greatest broadening over 2 m in 2008-2009. It was caused by intensive ablation at the glacier surface accompanied by substantial erosion by englacial water. A large amount of water is found to surge from sub-glacier channels, and braided streams have been well developed near the glacier tongue. Changes of englacial flow within the glacier result in further erosion (Figure 4f).

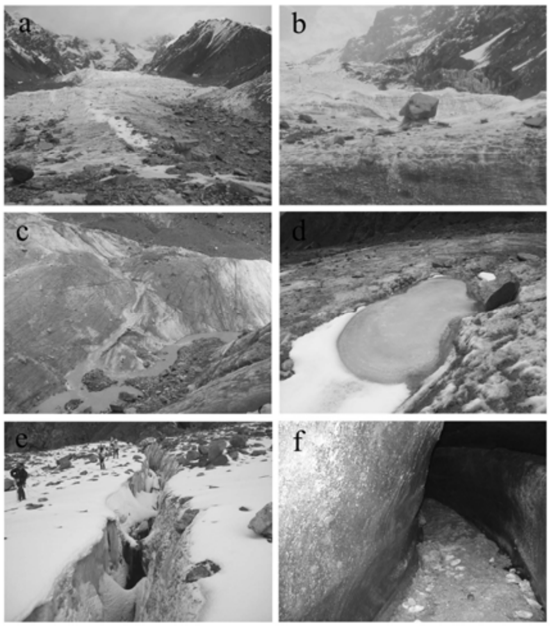

Figure 4 **G**eomorphologic features of the glacier under the intensive melting in the recent years: (a) debris-cover on the glacier tongue; (b) ice pillar on the glacier; (c) ice streams on the Qingbingtan glacier No.72, 2008; (d) meltwater pool on the surface of Glacier No.72, 2008; (e) Ice crevasse on the tongue of the glacier, 2009; and (f) Englacial water channels, 2008.

2.3 Annual and seasonal ice-velocity

Ice velocities measured in August 2009 at the 21 stakes in the tongue area, which are shown in the form of ten transects (Figure 5). In general, ice-velocity at the ablation area of Glacier No.72 shows larger fluctuation. The maximum velocity of 73.4 m a^{-1} occurs at transect G (4050 m a.s.l.), where the ice flow is dominated by rapid extending flow. The velocity then decreases to the minimum of 18.6 m a^{-1} at transect J (4170 m a.s.l.), where the flow is strongly compressive. The large variation of ice-velocity between 4050 m and 4170 m are indicative local changes in the flow pattern due to bedrock irregularities. In the region below 4050 m, the velocity decreases towards the glacier terminus, reaching to a lowest point of transect B (20.0 m a^{-1}),

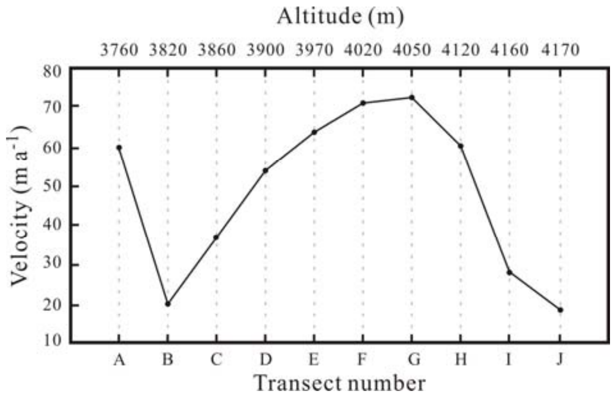

Figure 5 Ice velocities along the ten transects (A-J) indicated in Figure 2 in the tongue area of Qingbingtan glacier No.72 in August 2009.

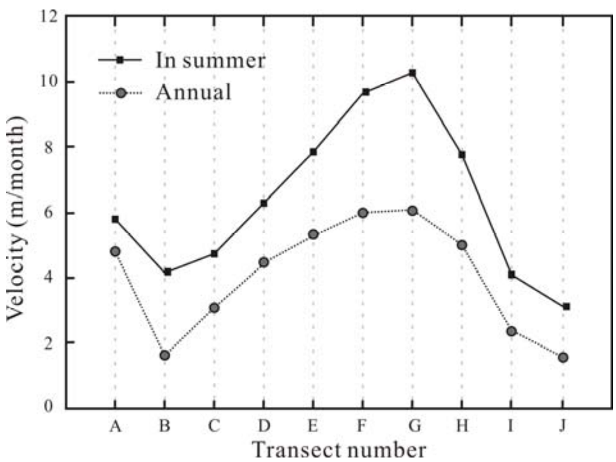

Figure 6 Comparison of the ice velocity in summer and the annual average value under monthly scale for the ten transects in the tongue area of Qingbingtan glacier No.72.

and then increases, closely related to the steep gradients. Analysis of the ice-velocity from stakes shows that the glacier reaches its maximum velocity near the central flowline, and the velocity decreases towards both lateral margins. The velocity vectors show directional consistency down to the glacier terminus. This would be expected for a glacier experiencing basal sliding in the glacier tongue. Furthermore, the glacier exhibits a significant seasonal variation in ice velocity, with the velocity in summer higher than the annual average value (Figure 6), due to the enhanced sliding by rapid migration of surface meltwater to the ice bedrock interface.

3 Discussion

Since the early 20th century, global warming drove a strong reduction in the mass balance of most glaciers, resulting in remarkable retreat in China (SHI et al. 2006; YAO et al. 2007). From 1980s to 1990s, glaciers retreated rapidly and only 10% of glaciers were advancing, but after the 1990s, glacial retreat appeared to be an accelerating trend (SHI et al. 2006). Glaciers in China are categorized into three types-extremely continental, sub-continental and monsoonal maritime, based on climatic conditions, especially regional annual precipitation (SHI and LIU 2000). However, different types of glaciers have shown different behaviors responding to climate change. Although Glacier No.72 is categorized to sub-continental glacier from the location, it is more similar to monsoonal maritime glacier in characteristics of glacier changes and ice-velocity. The ablation of Glacier No.72 is more intensive comparing with other monitored glaciers in eastern Tianshan Mountains (JING et al. 2002; LI et al. 2007; LI et al. 2008) and larger glacier velocity shows a faster dynamic response to climatic warming.

Extremely continental glaciers are developed in the western and inner parts of the Tibetan Plateau, including the Qiangtang and Pamir Plateaus. Cold and dry climate dominates these regions. The basal layer of the glaciers is normally frozen to bedrock, making ice flow slowly. This type of glacier is insensitive to climate warming. For example, the Xiao Dongkemadi glacier in the Tanggula Mountains has experienced two main change phases during the period 1969-2007. The elevation increased by an average of ~4.60 m, or 0.19 m a^{-1}, corresponding to a tongue advance of 16.9 m from 1969 to 1993 (PU et al. 1998; YAO et al. 2007). After 1993, the ice surface elevation decreased ~1.62 m (0.54 m a^{-1}) from 1993 to 1996 and decreased by ~11.0 m (1.1 m a^{-1}) from 1996 to 2007, corresponding to a tongue retreat of 93.9 m between 1993 and 2007 (SHANGGUAN et al. 2008). Referred to LIU et al. (1999), 1°C temperature rise could lead a rise of the ELA of only 58 m. It seems that glaciers of this type are more sensitive to precipitation change. The sub-continental glaciers are distributed in Tianshan Mountains, northern and northeastern parts of the Tibetan Plateau, and the northern slop of the western Himalaya, which are usually more sensitive to temperature than precipitation. Taking Ürümqi glacier No.1, eastern Tianshan as an instance, the glacier has an overall shrinkage since 1959 and separated to the two independent glaciers (East Branch and West Branch) in 1993. The average retreat rate was 4.5 m a^{-1} in 1959-1993. From 1993 to 2004, the East Branch retreated at the rate of 3.5 m a^{-1} and the West Branch retreated at the rate of 5.8 m a^{-1}. The ice-velocity is 7.2 m a^{-1} and 5.3 m a^{-1} for the West Branch and East Branch, respectively during 1962-1973. After 1980, ice velocity of the glacier was within the range of 4-12 m a^{-1} (LI et al. 2003). The observation data of Daxigou Meteorological Station in the headwater of Ürümqi River shows that the average annual temperature increased by 0.8°C (0.017°C a^{-1}) during 1958-2004 and changes of the glacier were mainly controlled by temperature, but had no correlation with precipitation since 1986 (LI et al. 2008). Monsoonal maritime glaciers are mainly located in southeastern part of the Tibetan Plateau, including the southern slope of the Himalaya. For example, the terminus of Hailuogou glacier, Mt. Gongga, China shows a very strong response, with an accelerated retreat rate. Since the 1960s the retreat of the glacier terminus has accelerated from 12.7 m a^{-1} (1966-1989; SU et al. 1992) to 27.4 m a^{-1} (1998-2008). The rate of ice surface-elevation change of the ablation area over the period 1966-2009 is -1.1±0.4 m a^{-1} and the ice velocity ranges from 41.0 m a^{-1} to a maximum of 205.0 m a^{-1} (ZHANG et al. 2010). Data observed at the Gongga Alpine Ecosystem Observation and Research Station indicates the mean temperature over the period 1998-2004 was 0.42°C higher than for the period 1988-1997. The glacier is more sensitive to air temperature that a small rise of temperature could result in a large uplift of ELA and prominent shrinkage of glacier area.

As shown in Figure 7, the annual temperature variation has a fluctuation manner recorded by Xiehela Hydrological Station in Aksu River Basin and a rising temperature trend with the average rate of 0.45°C $(10a)^{-1}$ appears in the record. The difference between the high and low annual temperatures was 3.3°C. The linear trend analysis of mean temperature indicated that the average rate of summer temperature rising, which prominently influenced glacier changes, was 0.55°C $(10a)^{-1}$. Especially, the duration of the high summer temperature was longer than that of the low temperature, which had potentials to accelerate the glacier melting. During the corresponding period, the record displayed a slight increase in annual precipitation, with the average rate of 2.85 mm $(10a)^{-1}$. The rapid increase in temperature, especially for summer temperature,

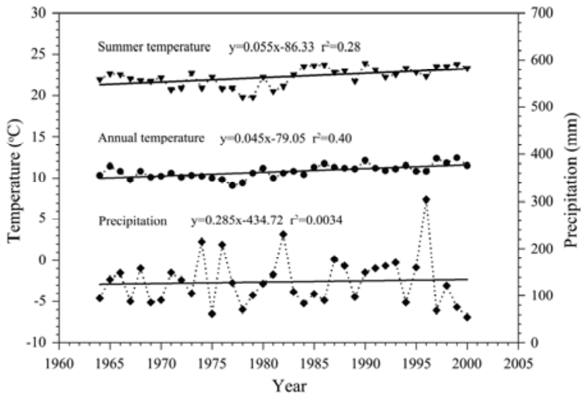

Figure 7 Variation of summer temperature (June-September), annual temperature and precipitation recorded at Xiehela Hydrological Station in the Aksu River Basin for the period 1960-2000 and the linear fit to the data.

together with a relative slow increase in precipitation arises as the most significant regional climatic trends, and therefore it is possible to presume that both the accumulation and ablation area of the glacier must be significantly affected, with smaller amount of snowfall and higher ablation. Although the precipitation increases with slow trend, it is insufficient to compensate for mass loss owing to temperature rise. Moreover, the cold-energy store of the glacier will diminish quickly with a sustained rise of temperature, as ablation increases, the ablation area becomes larger and the ablation period lengthens, accompanied by internal and surface morphology changes of the glacier. As the ELA increases, the morphological changes occur further at the up-glacier by massive falls of ice/snow and rock for Glacier No.72.

Furthermore, the topographical factors (e.g.

aspect, altitude, slope, morphology) also have impacts on glacial response to climate change, by influencing glacial dynamic. Exposed bedrock and glacier orientation to the south probably make the Glacier No.72 receive more solar insolation. Moreover, the lower terminus altitude (3560 m) has an important influence on the glacier ablation. As the increased melting related to climate warming has greater effect on the lowest elevations, the resulting increase in surface slope will indicate an increase in driving stress that will contribute to an enhanced transport of excessive mass from accumulation area to ablation area. Haeberli (1990) also stressed the influence of glacial surface slope, and this is illustrated by the terminus behavior of 38 glaciers in the North Cascades mountain, Washington, since 1890 (Pelto and Hedlund 2001). Hoelzle et al (2003) examined size classes of 90 glaciers worldwide and suggested that large flat glaciers have weak fluctuations, while small steep glaciers have high-frequency and large-amplitude variability. In this case, any increase in air temperature is directly translated into ice melting. A part of the generated meltwater percolates into the ice, and a portion of it eventually reach to the glacier bed, contributing to basal sliding (Molina et al. 2007). Also the increase in water content of temperate ice contributes to enhanced flow, due to the strong dependence of the rate factor in Glen's flow on the water content of temperate ice, which implies that a 1% increase in water content results in an increase of the effective strain rate by a factor of 3 (Duval 1977). The morphology is also a key factor to influence glacier melting (Kuhn 1985; Barry 2006). The ice tongue accounted for great proportion of the glacial length with a large part of the glacier exposed to strong ablation. So, it is reasonable to believe that a large ablation area could make the glacier intensive melting and sensitive response to climatic warming. Although Glacier No.72 is debris-covered with an average debris thickness of ~12 cm measured in the field campaign in 2008 it is not enough to minimize its response to climate change, suggesting a delay time even as fast as it is reported for another bare-ice glaciers in Southern Chile (Rivera et al. 1997). All the glacial/topographical factors jointly influence the glacier response to climate change, although we separately analyze each factor.

Summarizing, as Glacier No.72 has been thinning, retreating and shrinking, changes of internal and surface morphology also occurred, even under the effect of the debris protection, showing a faster dynamic response and providing evidence of the response to climatic warming in recent years. These results support the finding that the observed acceleration trend corresponds to similar developments elsewhere and even at a global scale (Haeberli et al. 2007). However, further study and new data (e.g. mass balance) will be necessary in order to fully understand the inter-annual glacier variations and processes taking place in this glacier, especially the impact of glacier dynamics.

4 Conclusions

In this study, ice surface-elevation, volume, terminus and area changes were studied by comparing topographic map, SPOT 5 image and GPS survey data over a long time interval (45 years). Results indicated that the changes of ice-surface elevation was -0.22±0.14 m a^{-1} with the ice volume loss of 0.014±0.009 km^3 for the tongue area from 1964 to 2008. Glacier No.72 experienced mass loss in the period 1964-2009 with the terminus retreat at a rate of 41 m a^{-1}, and the area reduction of 1.533 km^2, or 0.034 km^2 a^{-1}. Ice velocity in August 2009 was also studied and it showed larger fluctuation, ranging from the maximum of 73.4 m a^{-1} to the minimum of 18.6 m a^{-1}. The ablation and ice motion of Glacier No.72 is more intensive than any other monitored glacier in the eastern Tianshan Mountains, which can be attributed to climatic warming and glacial dynamic, controlled by glacial/topographical features. To complete our effort to analyze the probable reasons causing the intensive ablation of Glacier No.72, a more extensive study about the glacier dynamic effect is needed.

Considering that Glacier No.72 has been thinning, retreating and shrinking during recent decades, even under the effect of the debris protection, it can be speculated that in the future the glacier retreat will be enhanced in response to an increase in temperature. As a reference glacier in the Tomor region, the largest glaciated area of Tianshan Mountains, the significant shrinkage of Glacier No.72 represent a serious mass loss in this region and continued decrease of the glaciers will influence the hydrological cycle, impact on water resources and the ecological environment, and increase natural hazards. Thus, it is important and essential to continue to monitor glacier changes in the region.

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