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Mass balance of Kangwure (flat-top) Glacier on the north side of Mt. Xixiabangma, China

LIU Shiyin[1], XIE Zichu[1], SONG Guoping[1], MA Li[2] and Yutaka AGETA[3]

1 Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou, 730000 China

2 Xinjiang Institute of Meteorology, Xinjiang Administration of Meteorology, Urumqi, 830000 China

3 Institute for Hydrospheric-Atmospheric Sciences, Nagoya University, Nagoya, 464-01 Japan

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Abstract

As an experimental glacier, Kangwure Glacier in south Tibet is selected as one of the glaciers in China which are monitored simultaneously together with other glaciers in the world in order to understand the global climatic and environmental change through glacier mass balance observations. Surface mass balance was measured from 1991 to 1993 with intensive observations conducted in the summer, 1993. During these years this flat-top glacier was in a negative mass balance state corresponding to −250 mm water during the period from Sep. 29, 1991 to Oct. 18, 1992 and −640 mm water from Oct. 18, 1992 to Sep. 15, 1993, while a negative balance was also observed in the winter season from Oct. 18, 1992 to Jul. 10, 1993, equal to −160 mm water. This is considered as the sequence of decreasing precipitation in the two years : 1992−1993 as shown by the long term variation of precipitation at Nylam meteorological station, which gives evidence that precipitation exerts an apparent impact on mass balance formation on those glaciers mainly developed under monsoonal climate.

1. Introduction

As an experimental glacier, Kangwure Glacier is selected as one of the glaciers in China which are monitored simultaneously together with other glaciers in the world in order to understand the global climate change through glacier mass balance observations. This glacier was initially observed in 1960s by Xie Zichu (Xie, 1982) and have been reached for some times by several expeditions (Khule and Wang, 1988). In 1991, a joint expedition between China and Russia was organized to conduct a detailed glaciological research when stakes were set up and a temporary meteorological station operated at an elevation about 5300 m a.s.l. in the field season. As proposed by China-Russia joint team, glaciological measurements were continued in 1992. This work was then intensified in the summer, 1993 and observations of glacier mass balance, ice temperature, glacier movement, and meteorological elements, such as air temperature, atmospheric vapour pressure, humidity, wind speed and direction as well as precipitation at the base camp (BC) , 5680 m a.s.l., 100 m north of the glacier terminus were conducted. This paper will discuss glacier surface mass balance based on observations from 1991 to 1993.

2. Observation of Kangwure Glacier

Kangwure Glacier (28°27'07" N and 85°45' E) is situated on the north side of Mt. Xixiabangma, which is in the middle part of the Himalayas. In this paper the glacier is divided into the north and south parts, since no ice flows from south to north and no measurements have ever been done on the south part. We will only discuss some characteristics of mass balance observed on the north part which is 4.3 km in length and 3.454 km^2 in area (and thereafter referred to as Kangwure Glacier). The glacier terminus reaches to an altitude of 5680 m a.s.l. with an altitudinal difference of 476 m to the summit and the glacier exposes to the north in the upper area, then north-east. Apart from stakes installed in 1991 and 1992, an extra 14 stakes were also set up on the glacier surface, i.e., totally 27 stakes on the glacier in the summer 1993 (Fig. 1). Because of high elevation, only 4 stakes were positioned in the area above 6000 m a.s.l., and no stakes on the area above 6100 m with an area of 0.189 km^2.

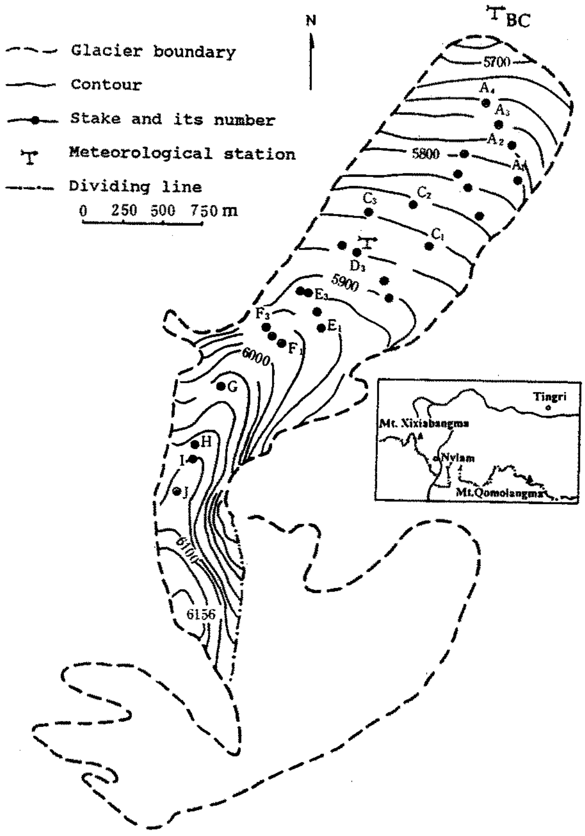

Fig. 1. Sketch map showing stake network on Kangwure (flat-top) Glacier.

Mass balance measurement was performed by the stake method in which snow and ice surface change was observed (Meier, 1962). Surface mass balance were measured at 5−10 day interval except the 4 higher stakes. Daily measurements were done at stake No. D3(5918 m a.s.l.) nearly everyday during the whole period, usually between 13 : 00 and 16 : 00 Beijing Standard Time(BST).

3. Climatic condition

During the field season from Jul. 10 to Sep. 15, 1993, some meteorological elements were observed at a temporary station, 5680m a.s.l., about 100m away from the glacier terminus (Table 1). An average air temperature of 0.6°C and a total precipitation of 126.9 mm without considering the capturing capacity of the precipitation gauge were observed for this period (Yang *et al.*, 1989). As for the cause of precipitation in this area, the summer monsoon with rich moisture prevailling in this region may transport tremendous amount of the moisture. Twenty-one days average air temperature in July (11−31) was up to 1.9°C, the average in August was 1.1°C and then decreased from the end of August and continued its decrease in September.

Table 1. Daily mean (TAVE), maximum (TMAX), minimum (TMIN) air temperature (°C) and precipitation (PSUM : sum of the period, PMAX : maximum daily (mm)) during the field season 1993 at the Base Camp (5680m a.s.l.).

		Temperature°C			Precipitation mm	
		TAVE	TMAX	TMIN	PSUM	PMAX
Jul. 11-31	Highest	4.1	10.5	0.4		
	Lowest	0.9	4.9	-3.5	32.4	11.8
	Mean	1.9	7.3	-1.8		
Aug.	Highest	2.9	8.9	-3.8		
	Lowest	-1.4	2.5	0.0	68.3	11.0
	Mean	1.1	6.1	-2.0		
Sep.1-15	Highest	-1.2	5.5	-4.4		
	Lowest	-2.8	1.0	-6.4	26.2	9.2
	Mean	-2.2	2.9	-5.2		
Mean for field season		0.6	5.8	-2.6	126.9	

In order to understand the climatic characteristics in the surveyed area, it is necessary to get a view of climatic elements recorded at meteorological stations around this region. Unfortunately, meteorological stations established nearby are few with the nearest ones (Nylam (3810 m a.s.l.) and Tingri(4300 m a.s.l.) stations) 50 km south and 130 km east of the region (Fig. 1). The long term records of air temperature are 3.4 and 2.3°C in average at Nylam and Tingri while annual precipitation at Nylam (668.6 mm) is almost 2.5 times of that at Tingri. The obstruction to humid air masses due to existence of the high Himalayas are very distinct from this rough statistic data. Actually the climatic features are different for regions on the south of Mt. Xixiabangma and on the plateau as demonstrated with precipitation distribution in a year at two stations. For example, precipitation in summer three months take the percentage of 85% of the annual at Tingri while the corresponding one is only 35% at Nylam. Though how the two stations show the climatic similarity with the surveyed glacier area can not be determined, long term climatic variations around the glacier may to some extent be relevant to that observed at the two stations. The climatic records (especially precipitation) at Nylam will be used for present discussion.

4. Mass balance

Measurement of glacier mass balance is one of the terms in monitoring global climatic and environmental changes. Different constitutional patterns of water and heat may result in different amplitude of glacierization and fluctuations of glaciers. It is of great interest in the study of glacial characteristics impacted by the southwest monsoon.

4.1. Daily mass balance

As the stakes set up on the glacier surface were taken both as survey points of surface movement and for mass balance observation, the stake network doesn't evenly cover the glacier surface. However a routine measurement of surface mass balance was performed at each stake within 5−10 days interval with one stake (D3) observed nearly everyday. The inter-diurnal variation of balance at stake D3 is shown in Fig. 2 together with daily mean air temperature at BC in the same period from Jul. 18 to Sep. 15, 1993. Negative daily balance occurred during more than half of the observation period, although snowfall was observed nearly in the whole period apart from 23 days without snowfall or just trace precipitation. A negative daily mass balance value was totalled as −377 mm water, about −7 mm/day (exclusive of Jul. 26−28 and Aug. 26−27 without daily measurements). From Fig. 2, a negative correlation between daily balance and air temperature can be derived that large negative balance occurred along with higher daily temperature, indicating that the surface ice was intensively melted out during the day with higher positive temperature, but sometimes both show a contrary trends, i.e. when temperature is high the negative mass balance is not so large as it should be. This means the temperature series do not correspond to mass balance series with each other, because surface mass balance on a glacier is controlled by water and thermal conditions. A single paremeter can not sufficiently describe mass balance processes and its characteristics. And there may exist measurement errors for some data especially after Aug. 28 when much snow fell on the glacier surface.

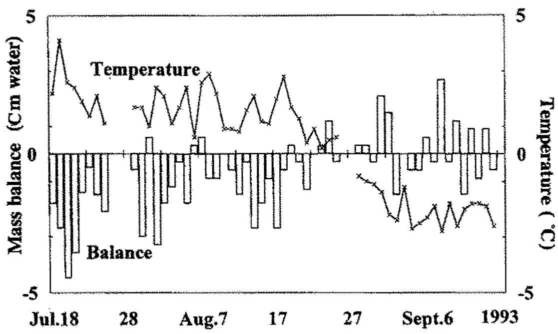

Fig. 2. Mass balance variation measured at stake D3 together with daily mean air temperature at the Base Camp.

Decided by its geographical position and the role of summer monsoon, this glacier may belongs to summer-accumulation type which has been checked out in the context above mentioned, the warm summer season is not only the ablation season but an accumulation period because of the monsoonal effect in the summer time. It is difficult to determine the ablation and accumulation elements separately while measuring the mass balance (Shi and Xie, 1964 ; Ageta, 1983). Therefore it is somewhat reluctant when we try to get a view of ablation dependence on the air temperature as many others have suggested the air temperature is a good index of the heat supply for ablation on glacier surface (Ambach, 1989 ; Chen and Funk, 1990). However it may be reasonable to refer to a short period without or with negligible precipitation as an ablation period. In the period from Jul. 18 to Sep. 15 except Jul. 26−28 and Aug. 26−27, there are discontinuous 5 days definitely without precipitation and 23 days with trace precipitation. If we assume these days as purely ablation days then the observed daily mass balance values are treated as daily ablation. A general tendency is found between daily ablation and daily mean air temperature at stake D3 extrapolated from the BC using a lapse rate of 0.68°C/100 m (Fig. 3). Compared with that on Glacier AX 010 in the Nepal Himalaya and the Chongce Ice Cap in the west Kunlun Mts. by Ageta *et al.* (1980) and Ageta *et al.* (1989), the ablation rate is much higher than those on the two glaciers when the temperature is at the same level and many

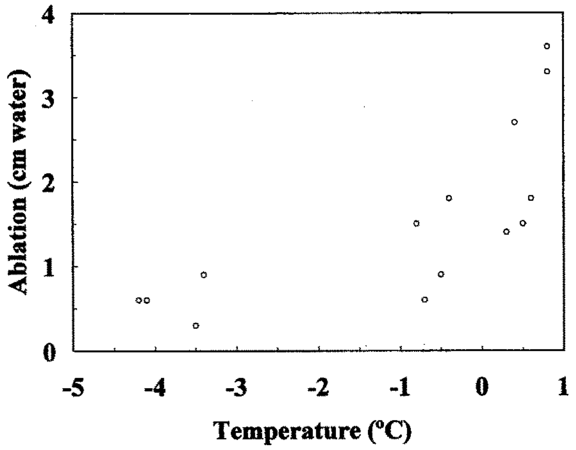

Fig. 3. Relationship between daily ablation at D3 and daily mean air temperature extrapolated from the data at Base Camp.

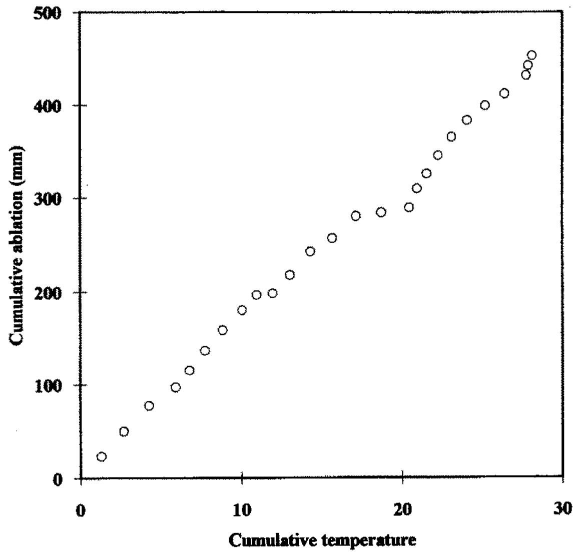

Fig. 4. Relationship between cumulative ablation at the four stakes of the first row and cumulative daily mean air temperature at each same site extrapolated from the base camp.

points in our case are concentrated at air temperature range from −1 to 1°C while on the Chongce Ice Cap all points are fallen at a temperature range between −2 and −6°C. These could be attributed to different climatic patterns of the three glaciers : their surface property (albedo), heat supply, precipitation type and amount, and so on. Temperature dependence on ablation does not show synchronism for different glaciers.

For the derivation of the degree-day factor for ice ablation on this glacier, balance observations of four stakes at the first row with 5−6 days interval during Jul. 20 and Aug. 25, 1993 are evaluated. Because of the lower altitude (5740−5794 m a.s.l.) frequent snow-fall on the glacier surface was melted away very soon so that ice albation was the main process. Therefore the observed balance can be considered as ice ablation. With this viewpoint the daily ablation rate and relevant mean air temperature extrapolated from base camp using a lapse rate of 0.68°C/100 m are calculated for each period at each stake. The relation between cumulative ablation (ΣA, mm water, absolute value) and cumulative air temperature (ΣT, °C) at the four stakes is founded (Fig. 4). The regressional formula reads :

$$\Sigma A = 15.8 \Sigma T$$

The correlation coefficient R is 0.99 with confidential level of 95%. The coefficient of ΣT is 15.8 (mm/°C·day), the so-called degree-day factor, nearly two times of that (9mm/°C·day) found on Glacier AX 010 (Ageta and Kadota, 1992) in the Nepal Himalaya, southeast side of Mt. Xixiabangma. It is also larger than the one obtained on Glacier No. 1 at the Urumqi river head in the Tianshan Mountains (Liu, 1995).

4.2. Summer (Jul. 20-Sep. 15, 1993) and annual mass balance

Although the stake network does not cover the upmost part of the glacier, it is only a small area on the upmost, further surface mass balance in the summer can be extrapolated by using altitudinal gradient derived from stake network measurement then calculated summer surface balance on the whole glacier.

Mass balance gradient is calculated by following method. Firstly the mean balance value of a row of stakes at the similar altitude is got from averaging balance results measured at stakes of this row and the mean altitude of the stake row is also by averaging altitudes of this stake row, both values of mean balance and altitude are put as a representative of the stake row. Other values can be calculated in the same way for other stake rows, then we get 10 sets of such data (with the upper 4 stakes standing for four sets) ; mass balance at each altitude can be evaluated for observational periods (Oct. 18, 1992 to Jul. 10, 25, 31, Aug. 5, 10 and 15, 1993). Then the glacier is divided into zones with a 20 m altitudinal interval. Using the vertical gradients of mass balance derived above, the area-mean balance for a 40 m altitudinal interval is obtained by area average of the total sum of balance in volume of the two neighbouring zones within 40 m altitudinal interval. For the summit area without stake measurements, surface mass balance is extrapolated in the same way by the same gradient on the upper part (Fig. 5). In the whole observation period, the glacier was in a great negative mass balance state except the upmost area where a small positive balance was observed. The total mass balance in volume from Jul. 20 to Sep. 15, 1993 was up to $-1.66\times10^6 m^3$ water corresponding to an area mean of -480 mm water.

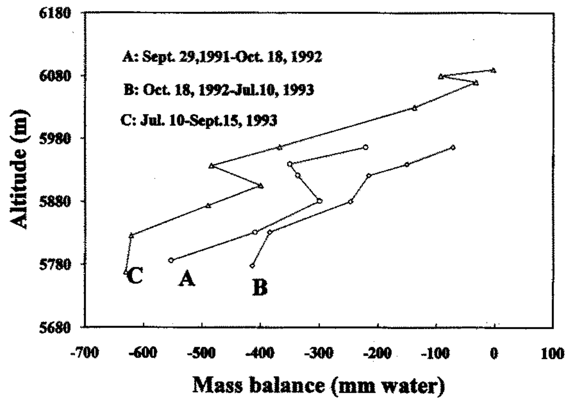

Fig. 5. Relation between mass balance and altitude on Kangwure Glacier.

As 12 stakes have been observed on Sep. 29, 1991 and Oct. 18, 1992, and re-observed during Jul. 10-Sep. 15, 1993, mass balance in the period from Oct. 18, 1992 to Jul. 10, 1993 can be calculated to be -160 mm water, -0.553×10^6 m^3 in volume, *i.e.*, a total mass balance was up to -640mm water during the period from Oct. 18, 1992 to Sep. 15, 1993, the glacier has lost a sum of mass of 2.21×10^6 m^3 water. During Sep. 29, 1991-Oct. 18, 1992 the glacier was also in a negative mass balance state which was about -250 mm water, equal to 0.864×10^6 m^3 water loss.

5. Discussion

This glacier has experienced great mass loss in the two balance years with a total amount of 890 mm water in area average. The result makes us think how the negative balance is formed during the two years. It is widely accepted that high precipitation and low temperature are favourable for a positive mass balance formation of a glacier and vice versa. Because of the shortage of long term observations or even a whole year climatic elements at the glacier base camp, climatic records at Nylam can serve the present discussion. This is also due to the incomplete data set at Tingri compared with that at Nylam.

The reason of mass losing trend in 1991/92 and 1992/93 can be inspected through analysis of air temperature and precipitation in both balance years at Nylam station. Accordingly long-term variations of precipitation and air temperature at Nylam station are examined. Variations of winter (Nov.-Apr.) and summer (May-Oct.) half year precipitation are shown in Fig. 6 with their 5-year moving averages. From 1967—1992, winter half year precipitation tends to increase annually though the summer one closely scattered around the long-term average. However the winter and summer precipitation in both 1991 and 1992 nearly reached to the lowest in the whole instrumental history, while air temperatures were close to the average in both years. This reveals that lower precipitation in 1991 and 1992 played an important role in the negative mass balance formation in 1992 and 1993, because of lower accumulation in winter and no enough remnant mass deposited on the glacier after the former balance year so that bare ice may be exposed too earlier in the coming summer, i.e., surface albedo decrease makes the ablation accelerated.

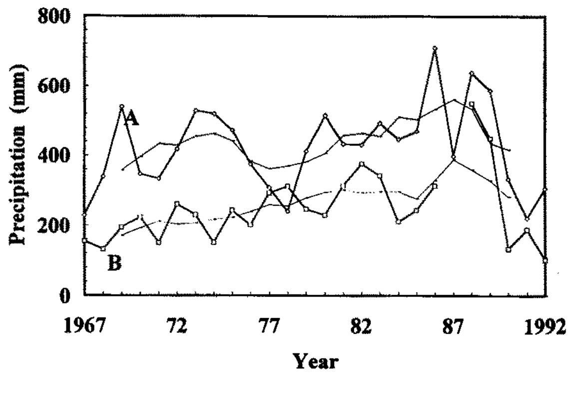

Fig. 6. Summer(A) and winter (B) half year precipitation and their 5-year moving averages at Nylam Station.

To get a view of mass balance characteristics, area means of mass balance on each 40 m interval are calculated for the periods from Oct. 18, 1992 to Jul. 10, 25, 31, Aug. 5, 10, 15, 1993. Area mean mass balance (B_t mm water) of the glacier is also estimated for these six periods. By drawing a figure of mass balance virsus altitude (Fig. 7), the corresponding transient equilibrium line altitude (ELA_t m) can be determined for individual time interval, denoted by t. So far mean mass balance $-ELA_t$ relationship (Fig. 8) is

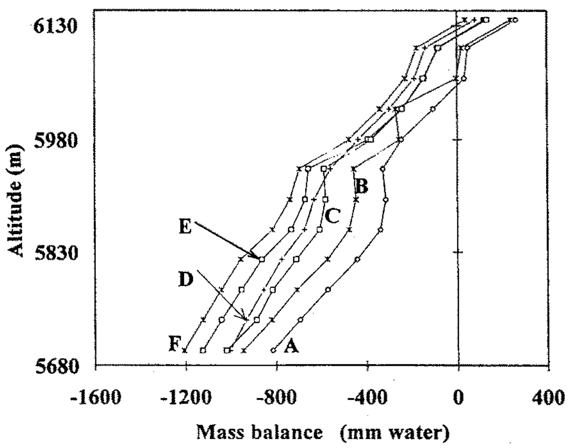

Fig. 7. Altitudinal distribution of mass balance for the period from Oct. 18, 1992 to Jul. 10 (A), 25 (B), 31 (C), Aug. 5 (D), 10 (E), and 15 (F), 1993.

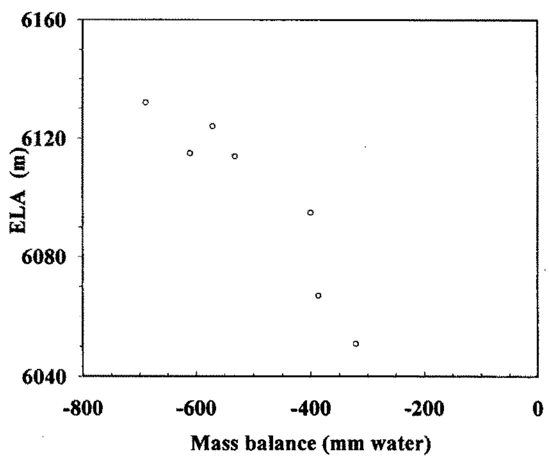

Fig. 8. Relationship between mean mass balance for various periods mentioned in Fig. 7 and their corresponding transient equilibrium line altitudes on Kangwure Glacier.

statistically derived as :

$$B_t = 5 \times (5994 - ELA_t).$$

Because all the ELA_t and B_t were measured in a single year (1992/93 balance year), and no positive balance and lowered ELA were observed, the above equation may not be used to indicate year to year mass balance-ELA variations. However the constant of 5 could be taken into account as the vertical gradient of the glacier in that balance year which corresponding to the level of glaciers in the Alps and central Asia (5.6 for glaciers in the Alps and 5.2 in central Asia, Table 1 in Braithwaite(1984)). If the constant 5994 is treated as the balanced ELA in the balance year 1992/93, it shows that the ELA is about 90 m higher than the median altitude. A low value of the accumulation area ratio less than 0.5 demonstrates the glacier condition of intensive mass losing. As demonstrated from the terminus fluctuations of the glacier, the glacier terminus has retreated 12.7 m in average during Aug., 1991-Aug., 1993.

According to observational results on the glacier and the discussion mentioned above, precipitation in the field season is not as high as expected, which forces us to make a further speculation about the characteristics of glaciers. Xie(1982) has estimated the annual precipitation about 500 mm at ELAs of Kangwure Glacier and Yebukangjiale Glacier —— originated directly from Mt. Xixiabangma. So we try to get a view of precipitation based on measurement in summer, 1993. Taking precipitation at Tingri Station as a reference and assuming the BC sharing the same annual precipitation distribution with Tingri, that is, long term average precipitation in August takes the same percentage as about 40% of the annual one at Tingri, annual precipitation at the glacier BC can be calculated to be only 179 mm. However precipitation in August 1993 at Tingri was 56% lower than the long term average. Then precipitation at BC is corrected as 304 mm. In the similar way the August precipitation and its percentage of the annual one at Nylam Station is taken as a reference, the calculated one at BC is 551 mm. So for a common year the BC area should obtain a sum of precipitation within a range of 304−551 mm, 428 mm in average. For a deep insight of fluctuations of mean mass balance and ELAs of the glacier we need to know their variation in those years with higher precipitation or close to the average at least. Nevertheless, a preliminary conclusion can be drawn that precipitation on glaciers on the north flank of Mt. Xixiabangma plays an much important role in the mass balance formation and ELA's shifting.

Acknowledgments

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