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A Comparison of Mass Balance Between the Meikuang Glacier and the Xiao Dongkemadi Glacier, Tibetan Plateau

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ABSTRACT Continuous observations of glacial mass balance were conducted on the Meikuang Glacier in Xidatan near the Kunlun Pass, and on the Xiao Dongkemadi Glacier near the Tanggula Pass. Although mass balances on the two glaciers vary in the same phase, the accumulation and ablation are quite different because the climatic and environmental conditions for glacier development are different due to different geographical locations. The Meikuang Glacier is lower in altitude and higher in air temperature compared with the Xiao Dongkemadi Glacier. They have different water vapour origins. To the north of the Meikuang Glacier there is the dry Qaidam basin, while there is a relatively humid climate in the Xiao Dongkemadi Glacier due to the extensive distribution of lakes nearby. Therefore, the Meikuang Glacier is characterized by low mass balance, while the Xiao Dongkemadi Glacier by high mass balance. The most intensive ablation occurs in July—August on both glaciers. The highest ablation was 1 723 mm (1990 / 1991) on the Meikuang Glacier, much larger than that on the Xiao Dongkemadi Glacier, only 1 095.8 mm (1990 / 1991). The highest net annual accumulation on the Meikuang Glacier was 360 mm measured at 5 280 m in the firn basin, lower than 784.6 mm at 5 730 m in the firn basin on the Xiao Dongkemadi Glacier. Thus, the mass balance of the Meikuang Glacier is only half of that on the Xiao Dongkemadi Glacier.

KEYWORDS mass balance, Meikuang Glacier, Xiao Dongkemadi Glacier, Tibetan Plateau

1 INTRODUCTION

In the Tibetan Plateau, the third pole in the world, there are many glaciers, being the most in the low–mid latitude. The response of glaciers to global warming in different regions on the plateau is different due to different climatic conditions, especially the response of glacial mass balance. Simultaneous observation on mass balance on the Meikuang Glacier (Code CN5Y533B33, 94° 11′ E, 35° 40′ N), in the vicinity of the Kunlun Pass, north of the Tibetan Plateau, on the Xiao Dongkemadi Glacier (Code CN5K443D38, 92° 05′ E, 33° 04′ N), in the vicinity of the Tanggula Pass, and the middle of the plateau, has been conducted by Sino–Japanese Joint Expeditions since 1989. The mass balances on the two glaciers are compared in this paper to reveal the nature of glacial mass balance in the plateau.

2 MEASUREMENT AND CALCULATION

The mass balance year of a glacier is defined by a fixed date in this paper. Practically, it is defined from the previous end of September or beginning of October, a day at the end of the ablation period, to the same date of the next year. Of course, there would be a little time difference between the measured mass balance year and the real one, but this would not significantly affect the measurement and calculation.

Accumulation and ablation are the two components of mass balance. Measurement and calculation are the basic ways to acquire mass balance for a glacier. In the ablation area, snow surface variation is measured by means of snow scales. In addition, a snow pit is dug around a scale to measure the depth of a snow layer, a superimposed ice layer and dirt layer. In the accumulation area, snow pits are dug to determine the annual layers, assisted with scale measurement. Twelve scales were set up on the Meikuang Glacier in May 1989, and then increased to eighteen scales. Twenty five scales were set up on the Xiao Dongkemadi Glacier, and increased to 28 scales afterwards. Two times of regular measurement (at the beginning of autumn and at the end of spring) were conducted simultaneously on the two glaciers each year. An additional measurement was made on the Meikuang Glacier in July, 1993. Besides, a mass balance process was measured in detail on the Xiao Dongkemadi Glacier with a measurement interval of 10—15 days from May 23 to September 21, 1993.

Mass balance in each point can be calculated based on the measurements. Afterwards, the calculated point mass balances can be plotted on a large–scale map, then the isolines of accumulation and ablation can be drawn on the map. Thus the mass balance on a glacier can be calculated through isolines. In this paper we follow the methods suggested by Xie and Zhang (1988) and Pu and Yao (1993a).

3 BASIC STATE AND INTERANNUAL VARIATION OF MASS BALANCE

The calculation results of the two glaciers are listed in Table 1. It can be seen from Table 1 that the five–year mean mass balances of the two glaciers were positive. The balance (whether annual balance or mean) was always less on the Meikuang Glacier. The mass balance on the Meikuang Glacier was characterized by obvious decreasing from 1988 / 1989 to 1990 / 1991, with an annual decrease rate of 188 mm. Ablation was dominant, and the mass balance was negative in two of the three years, with a net mass balance of −105 mm in the three years. The range of mass balance variation in the three years was the largest. Towards the balance year of 1991 / 1992 and 1992 / 1993, the mass balance increased up to positive.

The decrease of mass balance on the Xiao Dongkemadi Glacier was more pronounced in the first three years. The average decrease was 239 mm each year, which was about 1.3 times higher than that on the Meikuang Glacier. In 1991 / 1992 and 1992 / 9192, the mass balance increased to a rather high positive balance. In the five years, accumulation was dominant except for 1990 / 1991. The ablation was less than that on the Meikuang Glacier, and the net mass balance was positive. The range of mass balance variation was also higher than that on the Meikuang Glacier. The net mass balance in the five years on the Xiao Dongkemadi Glacier is 8 times higher than that on the Meikuang Glacier.

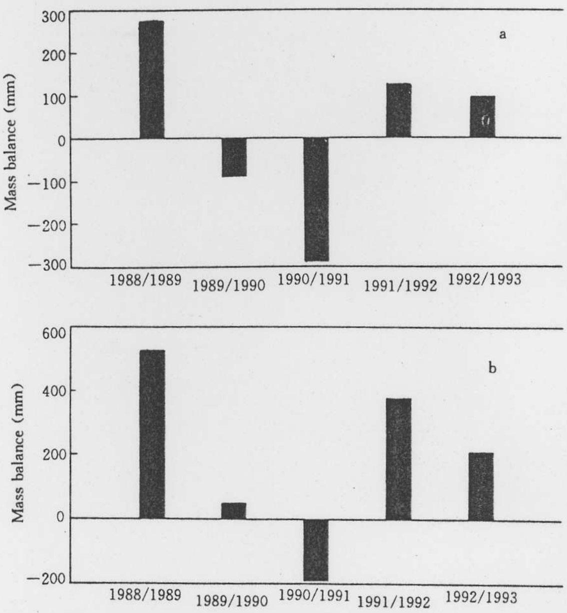

Fig.1 A comparison of mass balance on the Meikuang Glacier (a) and the Xiao Dongkemadi Glacier (b)

From the variation processes of mass balance on the two glaciers (Figure 1), we can find that the trend

Table 1 Mass balance on the Meikuang Glacier and the Xiao Dongkemadi Glacier

		1988 / 1989	1989 / 1990	1990 / 1991	1991 / 1992	1992 / 1993	Mean
Meikuang Gl.	Net ablation($\times 10^3$ m^3)	134.84	253.86	462.13	87.94	55.98	198.95
	Net accumulation($\times 10^3$ m^3)	436.40	155.28	143.83	222.42	161.30	223.85
	Net balance(mm)	274	−89.6	−289.3	122.3	95.7	23
Xiao Dongkemadi Gl.	Net ablation($\times 10^3$ m^3)	5.46	163.80	653.74	17.39	114.39	190.96
	Net accumulation($\times 10^3$ m^3)	933.46	251.09	316.43	681.44	487.89	534.06
	Net balance(mm)	525	49.4	−190.9	375.8	211.4	194

of the mass balance variation on the two glaciers was, to a great extent, in agreement with each other. A difference was the variation range, which in the Meikuang Glacier was smaller. This is because the locations of the two glaciers are under the effect of the plateau monsoon. Therefore, the climate variations at the two sites are similar to a great extent, and the difference exists only in the intensity of the effect. The accumulation and ablation is affected by the variation of climate, resulting in the mass balance variation as above mentioned. In addition, the local climate in the two glacierized regions also contributed a lot to the mass balance.

4 TEMPORAL AND ALTITUDINAL DISTRIBUTION OF MASS BALANCE ON THE GLACIERS

4.1 Altitudinal Variation of Mass Balance on the Glaciers

Mass balance is most sensitive to climate change. Altitude difference is large on a glacier, and the effect of climate on a glacier varies with altitude. Therefore, mass balance varies with altitude in the same period (e.g., one balance year). The equilibrium line altitude (*ELA*) on the Meikuang Glacier varies between 5 020—5 280 m, with an ablation gradient increasing from 4.3 mm / m near the *ELA* to 5.4 mm / m at the end of the glacier. The *ELA* on the Xiao Dongkemadi Glacier varies between 5 450—5 690 m.

It can be seen from the altitudinal distribution of mass balance that the mass balance gradient is always larger on the Xiao Dongkemadi Glacier whether in the accumulation area, the ablation area or in the *ELA* fluctuation zone. According to our study, the temperature gradient with altitude imposes a significant impact on glacial mass balance. The temperature gradient is 0.56 K / 100 m in the Meikuang Glacier region (from Germud to Wudaoliang), and 0.80 K / 100 m in the Xiao Dongkemadi region (from Wenquan to the glacier). The difference is remarkable between the two regions. The higher the temperature gradient, the larger the consequent discrepancy in snow melting. Therefore, for the Meikuang Glacier, a low temperature gradient results in a lower mass balance gradient.

4.2 Interannual Variation of Glacial Mass Balance

It can be seen from Figures 2 and 3 that the interannual variations of mass balance with altitude show a parallel trend for the two glaciers. However, the variation ranges are somewhat small in the accumulation zones and somewhat large at the terminuses, which means that the climatic and environmental influences decrease relatively with rising altitude. The influences become larger at the low altitude.

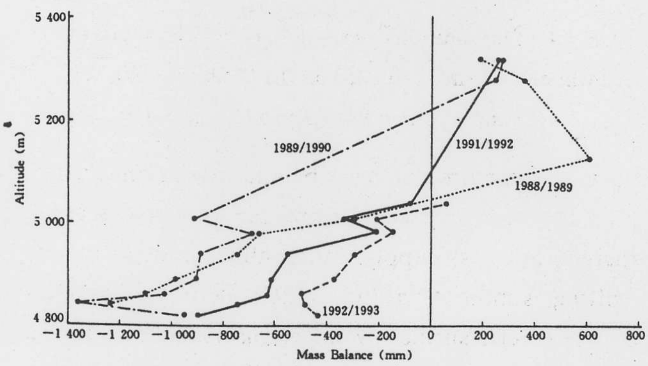

Fig.2 Distribution of mass balance with altitude on the Meikuang Glacier

4.3 Seasonal Variation of Glacial Mass Balance

Under monsoon conditions, precipitation mainly occurs in the warm season on the Tibetan Plateau. From October to April almost no precipitation

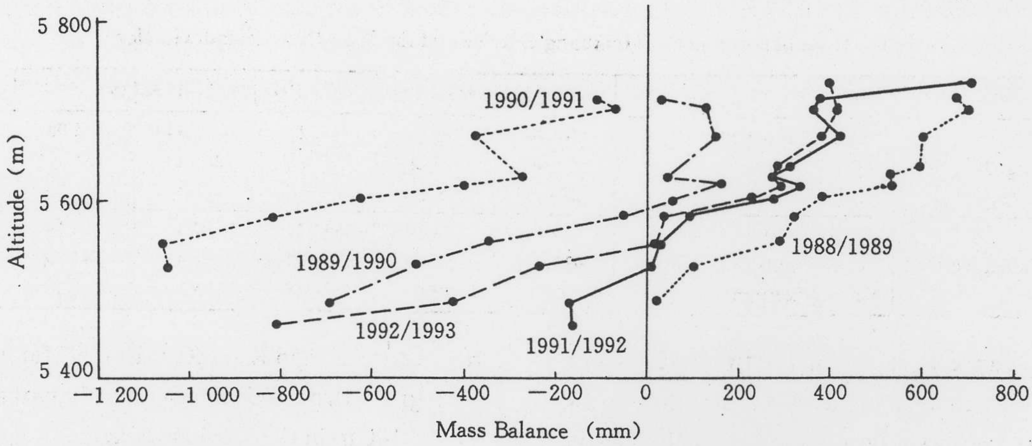

Fig.3 Distribution of mass balance with altitude on the Xiao Dongkemadi Glacier

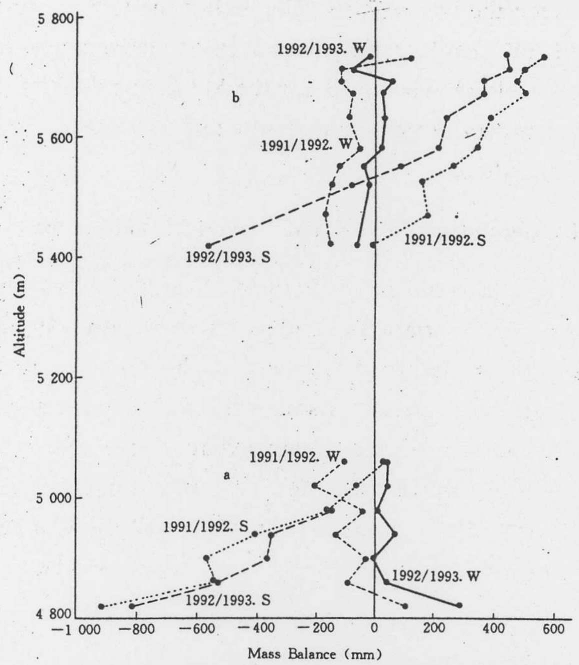

Fig.4 Distribution of mass balance with altitude at winter (W) and spring (S) on the Meikuang Glacier (a) and the Xiao Dongkemadi Glacier (b)

occurs. Therefore, the mass balance variation is mainly in the warm season. During the long cold season, there is no mass supply, but is ablation due to snow drifting, sublimation and a little melting sometimes on the glacier surface. Winter ablation was observed in the two glaciers in 1991 / 1992 (Figure 4).

Because of retreat in the past, the terminus of the Meikuang Glacier shows a concave shape surrounded by a few terminal moraine ridges. Strong winds in the cold season causes a large amount of snow to drift onto the terminus surface and this results in an abrupt increase in mass balance in the terminus. In some heavy accumulation years, the snow at the terminus can be maintained to the end of the ablation season. Whereas on the high and dome-shaped surface, the snow drifting causes a relatively high negative balance in the cold season. Influenced by both climate and topography, the distribution of winter mass balance varies irregularly. For instance, 208 mm of extraordinary negative mass balance was observed at Scale 1(5 010 m) in the winter of 1991 / 1992. Although little negative mass balance appeared on the Xiao Dongkemadi Glacier in the cold season, the increasing trend with altitude still can be seen (Figure 4).

The summer mass balance distribution has a better regularity. From the *ELA*, the mass balance increases with increasing altitude. Because the mass balance processes mainly occur in the warm season, the distribution of mass balance with altitude in summer is, therefore, similar to the annual distribution, which can be found in the two glaciers (Figures 2, 3 and 4).

5 FACTORS CONTROLLING THE GLACIAL MASS BALANCE

The mass balance of the Meikuang Glacier is less than that of the Xiao Dongkemadi Glacier, because of ablation in the former stronger than that in the latter. Based on observation, the annual precipitation around the *ELA* of the Meikuang Glacier and of the Xiao Dongkemadi Glacier was 345 mm and 302 mm respectively. But there was a large difference of air temperature between them. Extrapolated from the annual air temperature measured at Wudaoliang Meteorological Station, the mean annual temperature around the *ELA* of the Meikuang Glacier is −8.7℃, the mean monthly temperature is 2.3℃ and 1.9℃ in July and August respectively, and only −0.5℃ in June. The observed annual air temperature around the *ELA* of the Xiao Dongkemadi Glacier was −9.8℃, the mean monthly temperature was −2.2℃, −0.8℃, 0.3℃ and −1.9℃ in June, July, August and September, respectively. All the mean monthly temperatures in the Xiao Dongkemadi Glacier were lower than that in the Meikuang Glacier respectively. It can be deduced that under similar precipitation conditions, the air temperature and the surrounding environment are the dominant factors controlling mass balance. The dry Qaidam basin to the north of the Meikuang Glacier, together with the relatively higher air temperature, have a significant influence to glacial mass balance. As a result, the Meikuang Glacier is characterized by a strong ablation and a low mass balance. However, many lakes and rivers are distributed in the Xiao Dongkemadi Glacier region, and the air temperature is relatively low, so the Xiao Dongkemadi Glacier is characterized by a weak ablation and a high mass balance. Among the five mass balance years from 1988/1989 to 1992/1993, the highest net ablation was 1 723 mm (1990/1991, 4 980 m) in the Meikuang Glacier, while it was only 1 098 mm in the Xiao Dongkemadi Glacier (Pu *et al.*, 1994). Except for the abnormal high value of 600—1 113 mm measured in an ice–cascade area at 5 060—5 130 m nourished by avalanches and icefalls, the highest net annual accumulation on the Meikuang Glacier was 360 mm, lower than that in the Xiao Dongkemadi Glacier, 784.6 mm (Pu and Yao, 1993a, 1993b). Because of the great difference of accumulation and ablation between the two glaciers, the mass balance on the Meikuang Glacier is only half of that on the Xiao Dongkemadi Glacier. The calculated value of the five year mass balance level (Xie, 1980) is 600 mm for the Meikuang Glacier and 500 mm for the Xiao Dongkemadi Glacier, respectively. The difference reflects the difference in the hydrological cycle between the two glaciers. Ablation is more intensive in the Meikuang Glacier than in the Xiao Dongkemadi Glacier, and so is the meltwater to the river. Therefore, the hydrological cycle is more active in the Meikuang Glacier than in the Xiao Dongkemadi Glacier. It can be seen from the above discussion that the Xiao Dongkemadi Glacier is characterized by a higher continentality. The ice temperature of the Meikuang Glacier is a little higher than that of the Xiao Dongkemadi Glacier (Shao, 1993), which also identifies this explanation.

6 CONCLUSIONS

The hydro–thermal conditions for glacier development are slightly different between the Meikuang Glacier and the Xiao Dongkemadi Glacier due to geographical condition differences. Therefore, the variations of mass balance on the two glaciers are characterized by both agreement and obvious regional discrepancy.

(1) The two glaciers are influenced by the Tibetan Plateau monsoon, and the annual variations of mass balance of them show pronounced simultaneity.

(2) The two glaciers were characterized by positive mass balance during the five observed years, but the mass balance on the Meikuang Glacier was smaller than that on the Xiao Dongkemadi Glacier.

(3) The Meikuang Glacier is lower in altitude and higher in air temperature compared with the Xiao Dongkemadi Glacier. Therefore, the Meikuang Glacier is characterized by low mass balance, while the Xiao Dongkemadi Glacier is characterized by high mass balance.

(4) Based on the analysis, the continentality in the Meikuang Glacier region is lower than that in the Xiao Dongkemadi Glacier region.

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