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Relations Between Meteorological Conditions and Mass Balance of a Glacier on the North Slope of Mt. Bogda, Tian Shan

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Abstract

On glaciers in the eastern Tianshan Mountains, separate measurements of amounts of accumulation and abation are difficult, since accumulation and ablation occur simultaneously in the warm season. To estimate accumulation and ablation independently, meteorological observations around Glacier D 5 were made in summer. In comparison with air temperature on the ground, much lowering of that and smaller diurnal range were seen on the glacier. From the analysis of upper weather charts, the main cause of precipitation is attributed to the cold trough from the polar region. Since the relation between the probability of occurrence of solid precipitation (S: %) and surface air temperature (T: °C) is important for glacier accumulation, the relation of [$S = 25T - 108$] is obtained from the observational results. The relation between ablation (a: cm water) and the degree day index (ΣT: sum of daily mean air temperature, °C·day) is also obtained as [$a = 1.5\Sigma T$]. By the use of these relations, accumulation, ablation and balance on the glacier are estimated. The agreement between the calculated balance and observational results is fairly good except when the glacier is covered by new snow with high albedo. Meteorological conditions and mass balance are compared briefly with those in the Nepal Himalaya.

I . Introduction

Observations of the relation between the climatic elements and the amount of accumulation and ablation of glaciers are important for understanding the influence of climatic variation upon the glacier mass balance. Many glaciers in China and the Himalaya receive much of their annual accumulation in the summer season, hence are called 'type of accumulation in the warm season' by Xie (1980), while the glaciers in Europe and North America are called 'type of accumulation in the cold season'. Since accumulation and ablation occur in the warm season simultaneously on glaciers of the former type, the separate measurements of amounts of accumulation and ablation are difficult. In such a case, detailed discussion of the relation between climate and mass balance is difficult.

For a glacier in the Nepal Himalaya, Ageta et al (1980) could estimate accumulation and ablation separately from the data of observed mass balance (net value of accumulation and ablation) and meteorological elements. Glaciers in the eastern Tianshan Mountains are also the type of accumulation in the warm season. Zhang (1981) calculated annual accumulation and annual ablation by the use of climatic data for

Glacier No. 1 at the headwaters of the Urumqi River for 16 years.

In the summer of 1981, the meteorological conditions and mass balance of Bogda fan-shaped diffluence glacier (the inventory No. 5Y725 D-5) on the north slope of Mt. Bogda in the eastern Tianshan Mountains were observed by the China-Japan Cooperative Glaciological Expedition (Fig. 1). In this paper, meteorological conditions and relations between them and mass balance elements will be described, comparing with the conditions of the Himalayan glaciers. The observed glacier is called 'Glacier D-5' in this paper.

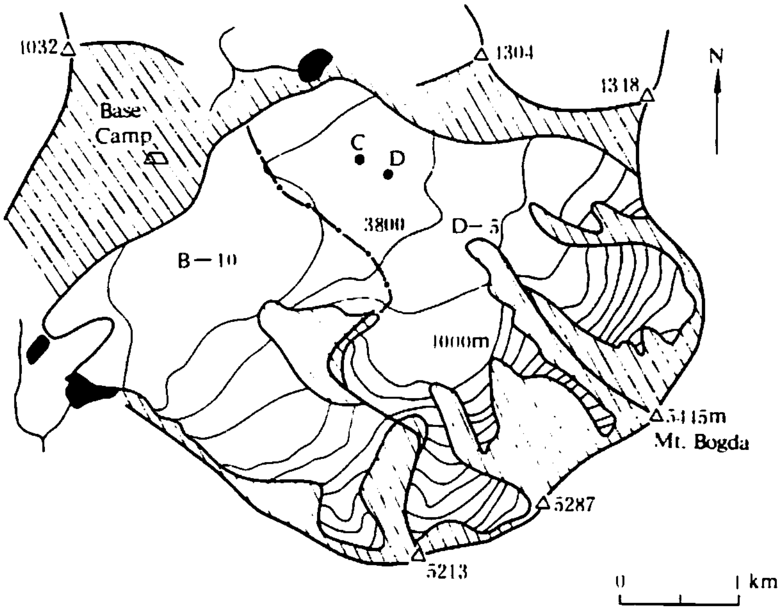

Fig. 1. Glacier D-5 and the stations for observations in the Mt. Bogda region. Glacier B 10 flows to the other river system.

Ⅱ. Meteorological conditions during the summer of the observations

Ⅱ-1. Meteorological observations

Meteorological observations were made mainly at the base camp (3640m a.s.l.) and station D (3749m a.s.l.) in the ablation area of Glacier D-5 during the period from 24 July to 15 August, 1981. Hygrothermographs were set in screens at the two stations, but simultaneous records were obtained only after 1 August due to trouble in an instrument on the glacier. Beijing Standard Time is used in this study. Summarized meteorological data at the base camp are shown in Table 1.

Ⅱ-2. Interdiurnal variation of meteorological conditions

Interdiurnal variations of air temperature, air pressure and precipitation during the observation period are shown in Fig. 2. Air pressure was measured with a Thommen pocket altimeter. A variation of 100m corresponds to about 8mb at the altitude of the base camp. Nearly parallel variations can be seen in Fig. 2 between air temperature at the base camp and at station D, and air pressure.

Precipitation was measured at station A (3652m a.s.l.), D and E (3802m a.s.l.) on

Table 1. Summary of meteorological data at the base camp (altitude 3640m) in the Mt. Bogda region.

Date		Weather			Air temperature (C)			Humidity (%)	Precipitation (mm)		
1981		8h	14h	20h	Maximum	Minimum	Daily mean	Daily mean	8-20h	20-8h	Total 8 next 8h
July	24	⦶	◎	⭘					0.2	5.4	5.6
	25	◗	◎	◎	5.3	1.1	3.2	76	0.3		0.3
	26	⦶	◎	◎	8.1	2.1	4.2	59	0	-	0
	27	○	◎	⭘	6.9	0.8	3.7	65	0	0	0
	28	◐	⦶	⦶	6.6	1.3	4.4	76	0	7.3	7.3
	29	⭘	◎	⦶	4.5	0.8	3.1	78	1.9	-	1.9
	30	⦶	◎	⭘	4.9	0.9	2.7	79	2.5	6.7	9.2
	31	⭘	✳	✳	1.3	-0.2	0.4	98	21.5	1.3	22.8
August	1	○	⦶	○	7.6	-1.2	2.9	74	-		-
	2	⦶	◎	◎	8.8	0.8	5.2	64	-	-	
	3	◎	⦶	⦶	8.5	4.2	6.1	75	-	-	-
	4	◎	≡	⧖	7.2	-0.4	3.7	82	6.5	12.9	19.4
	5	◎	⦶	○	5.8	-1.2	2.3	66	-	-	-
	6	○	⦶	◎	6.8	0.2	3.2	55	6.8	0.6	7.4
	7	⦶	⦶	⦶	6.9	0.7	3.3	60	-	0	0
	8	⧖	◎	○	4.6	-0.2	2.4	63	4.8	-	4.8
	9	⦶	⦶	○	5.9	0.8	3.0	43	-	-	-
	10	⦶	✳	○	6.5	0.5	3.4	57	0	-	0
	11	⦶	◎	◎	6.6	1.8	4.4	63	0	1.3	1.3
	12	◐	⧖	⦶	3.1	0.1	1.3	80	5.7	-	5.7
	13	◎	◎	⦶	2.0	-1.0	0.3	76	2.0	0.8	2.8
	14	⦶	⦶	○	4.1	-1.8	0.9	63	-	-	-
	15	○	✳	⦶	4.3	-1.4					
mean or total		cloud amount 6.1	7.5	6.5	5.7	0.4	3.1	69	52.2	36.3	88.5

○*clear*. ⦶*fine*. ◎*cloudy*. ⭘*rain*. ◗*drizzle*. ◐*rain & snow mixed*. ✳ *snow*. ⧖ *snow pellets*. ≡ *fog*.

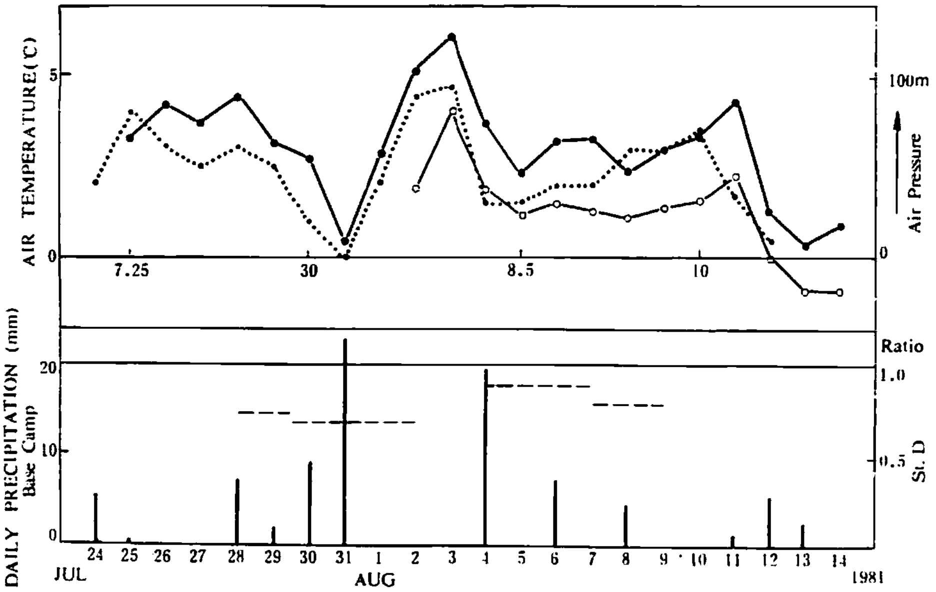

Fig. 2. Daily mean air temperature, air pressure and precipitation at the base camp (3640m) and station (3749m) on Glacier, D-5 in the Mt. Bogda region. Air pressure (dotted line) is shown as the variation of readings from an altimeter at the base camp (20h). Precipitation at station D (dashed line) is shown as the ratio to precipitation at the base camp, for lack of daily data.

Glacier D 5, and the terminus (3600m) and station No. 10 (4030m above the firn line) on Glacier D 4 (northern neighbour of Glacier D 5), for observations of the local distribution of precipitation. Precipitation at all of the above 5 stations on the glacier side was similar and the ratio to that at the base camp was about 0.8, as shown in the case of station D in Fig. 2.

Large precipitation on 31 July and 1 August was different from the results on the other days, as seen in Fig. 2. On 31 July, air temperature and air pressure showed sharp minimum. On the other hand, on 1 August, although air temperature and air pressure were much lower than on the previous day, they were not so low as the values on 31 July, and there was little variation on the following some days.

For discussion of the meteorological conditions affecting precipitation, two time sections of upper air temperature were prepared from weather charts at the surface (918m a.s.l.), 850mb (1480m approximate level in this period over Urumqi), 700mb (3100m same) and 500mb (5800m same). Cold troughs from the polar region can be seen both on 31 July and 1 August in Fig. 3, and the former trough is stronger than the latter one. Specially near the surface level, the case on 1 August did not become as cold as that on 31 July, probably due to high temperature on the preceding 2 and 3 August. At the base camp in the Mt. Bogda region, good weather continued during the

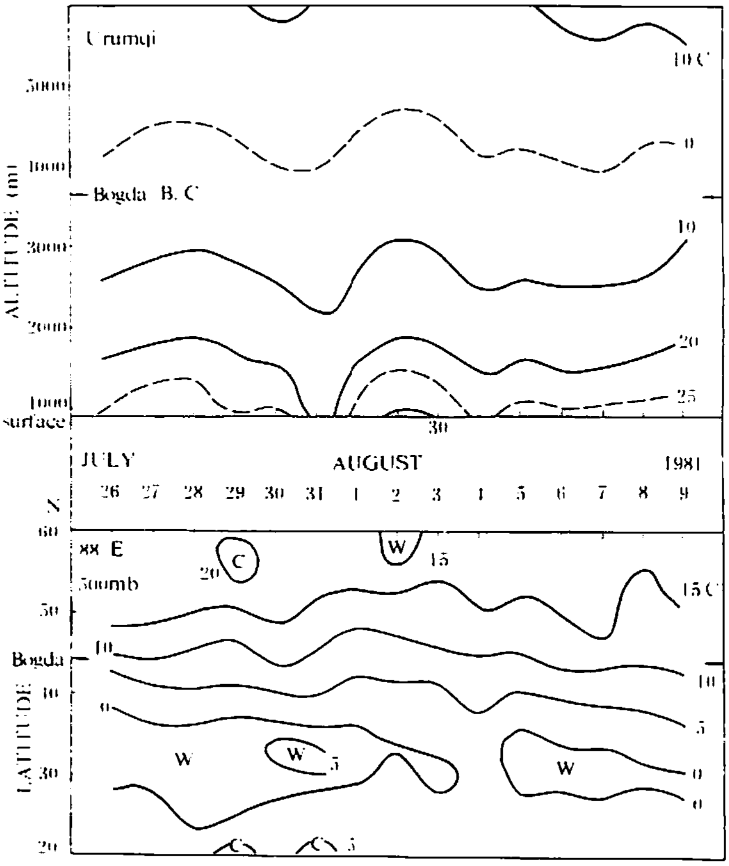

Fig. 3. Vertical time section of upper air temperature over Urumqi and latitudal time section of air temperature at the 500mb level along 88 E during the period from 26 July to 9 August at 20h (12GMT).

beginning 3 days of August and raised the air temperature, as seen in Fig. 2. Consequently, precipitation on 4 August was considered to be caused by a heat thunderstorm,caused by instability of the atmosphere due to intrusion of cold upper air over the heated surface. In this connection, thunder and ice pellets were observed on this day.

In conclusion of the above discussion, it can be said that precipitation was caused by a strong large scale cold trough on 31 July and by a cold trough associated with local effect on 4 August. The aerological weather type of these cold troughs is favourable for glacier accumulation in the Tian Shan and Qilian Shan, as analyzed statistically from 500mb charts by Kang and Ding (1981). It can be seen in Fig. 3 that such cold troughs from the polar region extend toward lower latitudes and can influence summer accumulation of snow on glaciers on the Qinghai-Xizang (Tibet) Plateau. Such precipitation under cold conditions contributes much to the accumulation in summer, because precipitation on glaciers in the warm season falls sometimes as rain as described in the next chapter.

II 3. Diurnal variation of meteorological elements on the glacier and the ground

Averaged diurnal variations of air temperature and humidity on the glacier (station D) are compared with those on the bare ground (the base camp) during the simultaneous observation period for 13 days in Fig. 4. Mean air temperature during this period was 1.3 C at station D and 3.0 C at the base camp. The difference of temperature between two stations was as large as 1.7 C, in spite of an altitude difference of only 110m. And the diurnal range of air temperature on the glacier was less than that on the ground as seen in Fig. 4. These differences of temperature condition are mainly attributed to lower temperature (0 C and below) and higher albedo at

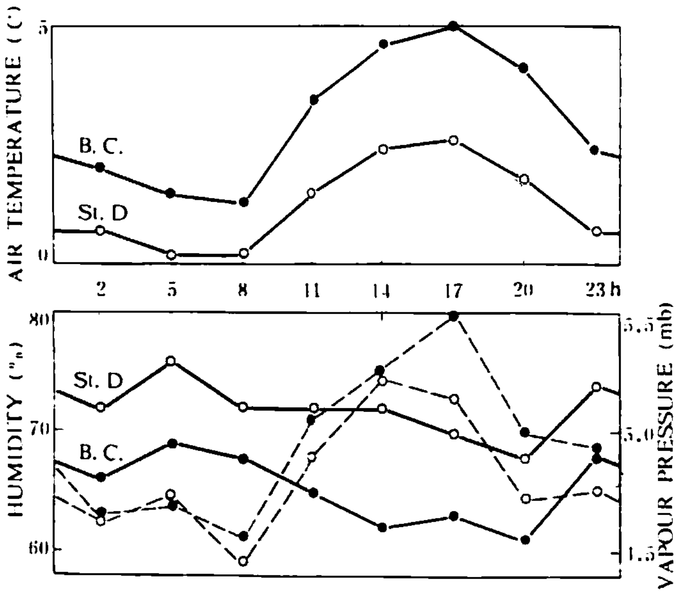

Fig. 4. Diurnal variations of air temperature, relative humidity and vapour pressure(dashed line) at the base camp and Station D. (Averages during the period from 2 to 14 August).

the glacier surface.

Average relative humidity and vapour pressure for 13 days at the base camp were 65% and 4.9mb, and those at station D were 72% and 4.8mb, respectively. Differences of both values between the two stations were not large. Since the diurnal variations of vapour pressure corresponded to those of air temperature at both stations, diurnal variations of relative humidity were small as seen in Fig. 4.

The mean diurnal range of air temperature at the base camp was 5.3℃ as seen in Table 1. This value is similar to the mean in July and August in the Shorong Himal. (5℃) and Khumbu Himal. (6℃) in east Nepal, while smaller than that in the Mukut Himal. (9℃) in west Nepal. The effect of diurnal variation of temperature is important for the melting-refreezing process in glaciers.

In case of the Nepal Himalaya, the diurnal cycle of weather, including wind, cloud and precipitation, is caused by the orographical circulation (Ageta, 1976). In the Mt. Bogda region, such a distinct cycle cannot be seen in weather, cloud amount or precipitation in Table 1. Precipitation is caused mainly by the general circulation as described in section Ⅱ.2.

Ⅲ. Relation between the phases of precipitation and air temperature

In a region where precipitation is high in summer, it is important for accumulation of snow on glaciers whether that precipitation is solid or liquid. Ageta et al (1980) estimated the summer accumulation on a glacier in the Nepal Himalaya, utilizing the observational results of the linear relations between the probability of occurrence of solid precipitation and surface air temperature. The similar method was taken to obtain such a relation in the Mt. Bogda region, as follows.

At first, the phases of precipitation and self-recorded surface air temperature at the precipitation time during the stay at the base camp were checked at intervals of 30 minutes. The number of occurrence of solid precipitation was counted in each 0.5℃ interval. Mixed precipitation of solid and liquid phases was regarded as a half occurrence (0.5). Then, the ratio of the occurrence of solid precipitation to all cases of precipitation was calculated in each temperature range. A total of 107 cases including 41 cases in the nighttime (20h-next 8h) were used for the calculation. The results are shown in Fig. 5. A linear relation between the surface air temperature and the probability of occurrence of solid precipitation can be seen in Fig. 5. The relation is given by the following formula.

$$S = 25T + 108 \qquad (0.3 < T \leqq 4.3) \qquad (1)$$

Here, S is the percentage of the occurrence of solid precipitation to all cases of precipitation, and T is the surface air temperature (℃) at the time of precipitation. In this case, S of 50% is given at T of 2.3℃.

This result is compared with the relation obtained by Ageta et al (1980) in the Shorong Himal. on the southern slope of the Nepal Himalaya in Fig. 5. The probability of solid precipitation in the Mt. Bogda region is higher at the same temperature than that in the Nepal Himalaya, and such difference increases in proportion to the increase of air temperature. Though such difference is caused by complex factors, it may be explained as follows.

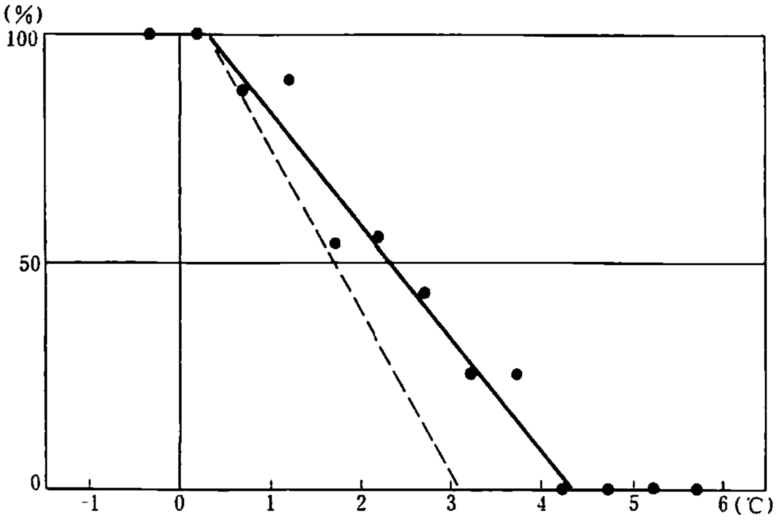

Fig. 5. Relation between the probability of occurrence of solid precipitation and surface air temperature at the base camp in the Mt. Bogda region. For comparison, the result in the Shorong Himal. in Nepal (Ageta et al. 1980) is shown with a dashed line.

The time of suspension of precipitation elements in air with the temperature above the melting point is longer in the case of the Shorong Himal. due to the effect of the strong valley wind in that area, while in case of Mt. Bogda, the precipitation elements are kept cold, since the elements lost much latent heat due to active sublimation from them under dry condition inland. Such a relation between the probability of solid precipitation and relative humidity was pointed out on the snowfall in Japan by Matsuo and Sasyo(1981). However, further studies should be done in the Tianshan Mountains, because the solid phase of precipitation (mainly snow pellets) was sometimes observed at the high air temperature of 6 7 C around glaciers in the Urumqi River headwaters.

IV. Relation between ablation and air temperature

It is very difficult to measure summer ablation of glaciers in the Nepal Himalaya, because accumulation occurs simultaneously almost every day. In the Mt. Bogda region, weather condition of no precipitation sometimes continues for several days. Therefore, the relation between ablation and the degree day index (ΣT: sum of daily mean air temperature) was obtained on Glacier D-5 by the following method.

Ablation measured by the stake method at stations D and C was used, since station C (3733m a.s.l.) was the nearest to meteorological station D with an altitude difference of only 16m (Fig. 1). Meteorological conditions at station C were considered to be the same as at station D. Ablation in water equivalent was calculated assuming a density of 0.85g/cm^3 for ice and 0.35g/cm^3 for surface wet snow fallen during the observation period. Periods with precipitation less than 10mm at the base camp were used for this analysis. Daily mean air temperature at station D for the period before the start of self-recording of air temperature was estimated by adding 1.7 C to that at the base camp. This 1.7 C is the mean difference between two stations as reported in section II.3. Because stake measurements were made in the daytime, half values of daily mean temperature were used for air temperature on the measurement days of the beginning and the end of each period.

Results are shown in Fig. 6. The following linear relation between ablation (a: cm water) and the degree day index (ΣT: C·day) can be obtained from Fig. 6.

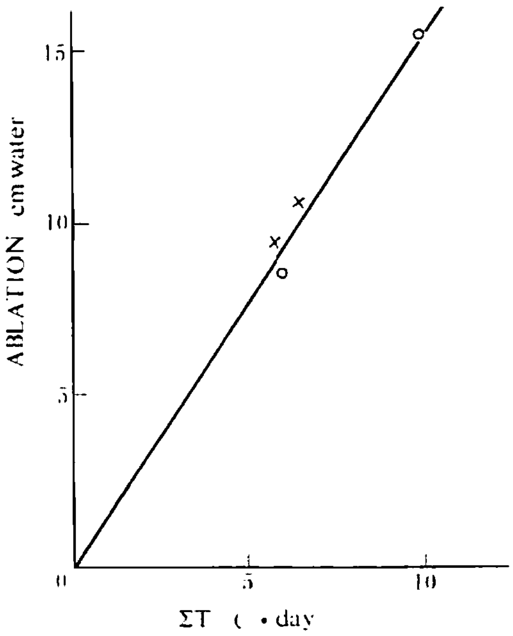

Fig. 6. Relation between ablation and the degree day index (ΣT: sum of daily mean air temperature) on Glacier D 5 on Mt. Bogda. (open circle: station D, cross: station C)

$$a = 1.54\,\Sigma T \tag{2}$$

Such linear relations were obtained in other places, but the coefficients are 0.9 for Glacier AX010 in the Shorong Himal, and 0.96 for the Yukikabe snow patch in Japan (Takahashi et al, 1981). The high value of the coefficient, in other words the high ablation under a given temperature condition, on Glacier D-5 can be attributed to high percentage of radiation among the sources of heat for ablation on glaciers in the interior of the continent. The approximate albedo at station D and C, which was measured on 4 August by a method using an exposure-meter in a camera (Ohata et al, 1980), was low, around 0.2, due to dirt on the ice surface. Therefore, the coefficient may be lower in case of higher albedo in the same region.

V. Estimation of mass balance elements from the meteorological data

Using the obtained relations between meteorological conditions and mass balance of the glacier, accumulation and ablation at station D from 25 July to 7 August are estimated separately.

The amount of solid precipitation can be estimated from the amount of precipitation in a certain period and the mean surface air temperature in the same period by the use of the relation between the phases of precipitation and surface air temperature, as described in Chapter Ⅲ. Since this relation was compiled from instantaneous observations and air temperature changes during precipitation, the amounts of solid precipitation should ideally be estimated in time intervals as short as possible. However, the time intervals of the observation on the amount of precipitation at station D were long, 2 or 3 days, while they were 3 to 12 hours at the base camp. Therefore, the following method was used to estimate the amount of solid precipitation at station D.

Precipitation at station D in the same time interval as the base camp was estimated from that at the base camp by the use of ratios of precipitation between two stations as shown in Fig. 2. Air temperature at station D for the period before the start of temperature recording was estimated from that at the base camp by the use of averaged diurnal variation of temperature difference between two stations as seen in Fig. 4. Then, the amount of solid precipitation, in other words accumulation, was calculated from the amount of precipitation in the minimum time interval, the mean air temperature in the same interval and the relation in formula (1). The total of solid precipitation during this period was 49mm, which was 93% of the total precipitation (53mm).

Ablation at station D was estimated from formula (2) by the use of the daily mean air temperature which was obtained in Chapter Ⅳ. Total ablation during this period was 33.3cm water. Then, balance can be calculated from the above estimated accumulation and ablation, as -28.4cm during this period. Results are shown in Fig. 7.

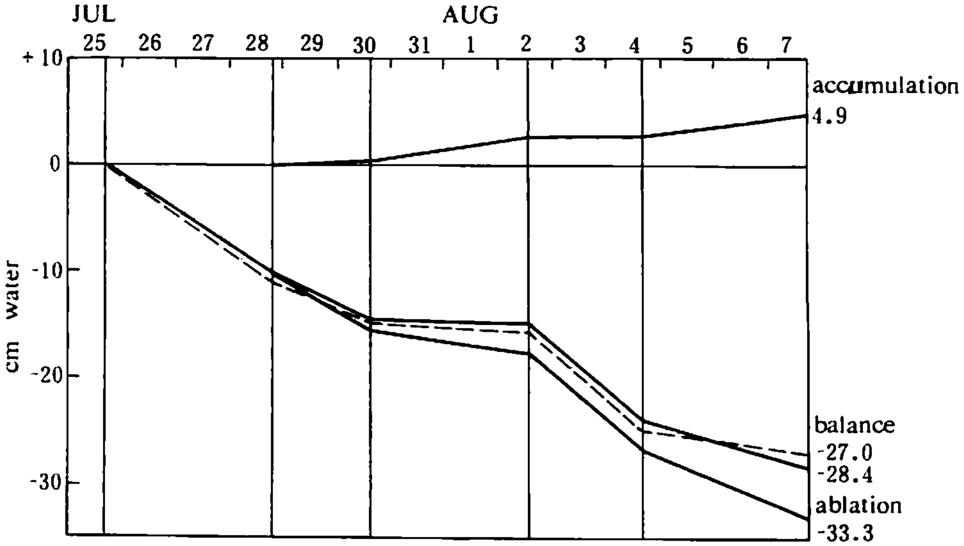

Fig. 7. Estimated mass balance elements (accumulation, ablation and balance: solid line) and balance measured by the stake method (dashed line) in averages at Stations D and C on Glacier D-5 on Mt. Bogda.

For comparison, measured values of the average balance at stations D and C by the stake method are also shown with dashed lines in Fig. 7. The same densities as mentioned in Chapter Ⅳ were used to obtain balance in water equivalent, as 27.0cm during this period.

It can be said from Fig. 7 that the estimated balance agrees well with the measured balance until 4 August, though the difference in change of balance during the period from 4 to 7 August is large. The cause of this difference is considered to be the effect of the high albedo of new snow which fell on 4 and 6 August. Although the amount of snowfall during the period from 30 July to 2 August was similar to the above case, the calculated ablation was small due to low temperature. The effect of high albedo due to new snow in the favourable season for ablation is important for the mass balance of glaciers which receive much precipitation in summer as pointed out for the Altai in the USSR by Tronov (1962) and for the Nepal Himalaya by Ageta et al (1980) and Ohata et al (1980). Consequently, further observations on ablation are necessary also in the Tianshan Mountains, where radiation is important, as mentioned in Chapter Ⅳ.

From the measured balance in Fig. 7, the mean daily balance is obtained as 2.1cm for this period which is thought to be the warmest of the year. On the basis of air temperature in Fig. 2, daily mean air temperature can be assumed to be below 0 C at an altitude of 200—300m higher than station D. Therefore, it can be said that ablation hardly occurs at any time of the year on ice falls and snow walls which face north, over an altitude of 4000m.

Ⅵ. Concluding remarks

Ablation of glaciers which face south in the Tianshan Mountains is considered to show different characteristics in comparison with glaciers which face north, such as Glacier D 5, because radiation is important for inland glaciers. For example, it is supposed that summer new snow with high albedo melts away sooner on south-facing than on north-facing glaciers. In this case, the effect to restrain ablation by new snow as mentioned in Chapter Ⅴ cannot continue long. Therefore, comparative studies on ablation are thought to be important to understand the distribution and the difference of variation of glaciers in the continent.

As seen in Chapter Ⅱ and Ⅲ, the climatological and meteorological process of summer precipitation on a large scale and local scale are both important for an understanding of glacier accumulation, because the conditions of accumulation have much difference in the large continent. Further comparative studies on the glaciers in a chain from the Tianshan to the Himalaya are needed.

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