SURFACE MASS BALANCE AND ITS VARIATION ON THE MIZUHO PLATEAU, ANTARCTICA IN 1987-1988*

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Abstract From the surface mass accumulation data in year of 1987 / 88, the distribution and variation of annual mass balance on Mizuho Plateau are discussed. The authors also analyze the effects of short-term climatic and topographical variations on the mass balance. It is found that there are some differences in spatial distribution and annual average state in the year of 1987 / 88 and other years. In the area at elevation lower than 550 m near the coast, the mass balance appears to be negative. The annual mass balance over 80 km distance from S_{16} to inland is 0.84m snow depth. A low mass balance zone from 80 km site to Mizuho Station, is considered to be only 0.14 m snow depth. It is found from the comparison of mass balances that the mass-balance level on the glaciers in West China is 9 times higher than that on Mizuho Plateau, where the massbalance level appears to be low accumulative and low expensive, but inverse in middle and low latitude regions, such as on glaciers in West China. The effects of short-term climatic and topographical variations or the mass balance are more significant in this year than mean state in many years. In the high accumulation zone the effect of the short-term climatic variation is larger than that of topographical one, while in the low value zone the topographical effect is larger than the climatic variation.

Key words Mizuho plaleau, mass balance

1. Introduction

The prevailing katabatic wind resulted in continuous drifting of snow on the surface of Mizuho Plateau, East Antarctica. This caused not only difficulty in direct measuring precipitation, but also *in* understanding some regularities of temporal and spatial distribution of the mass balance. Meanwhile, the various surface landforms (e.g., sastrugi, dunes, etc.) formed from the drifting snow and their short-term change make the inconvenience and deviation in measuring the mass balance.

Rubin and Giovinetto (1962) discussed the snow accumulation in the central part of West Antarctica, considering meteorological factors and topographical effect. Whillans (1978), from the many-year data obtained by means of surveying stakes, analyzed the mass accumulation on the surface of the plateau. Then he made a discussion of the regional variation of mass balance on the surface near Byrd Station, based on the overall effects of the drifting snow and topographical and climatic variations. In the last years, Kazuhide Satow (1984, 1985) made successive studies of the many-year mass accumulation and the mass balance variation on the Mizuho Plateau, East Antarctica.

One of the authors of this paper, sent by the State Antarctic Committee as a Chinese visiting scholar, took part in the Japanese Antarctic Research Expedition (JARE) 29 th summer party. His main work is to measure the mass accumulation from spot S_{16} on the

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border of the plateau to inland Mizuho Station (70°41′53″S, 44°19′54″E, 2230 m); meanwhile, measurement of the ice supply and mass balance on snow pit and by poles was carried out from S_{16} (69°01′55″S, 40°02′56″E, 554 m) to Tottsuki Point near the coast. Here, from the obtained data during the observation and those got by JARE 28 (Nishio *et al.*, 1989) in relative time interval in 1987, we analyse and discuss the spatial distribution and temporal process of the 1987–88 mass balance on the Mizuho Plateau and its variation caused by the shortterm climatic and topographical changes and its regularities.

2. Surveying Method and Data Processing

Japanese Antarctic Surveying Groups have set up and maintained 130 stake surveying spots for measuring mass balance from S_{16} to Mizuho Station. Horizontal distance between two spots is approximately 2 km, and total distance is about 270 m (Fig. 1). Meanwhile, a mass balance surveying field of 36 stakes was set up and maintained at a certain distance. The square matrix of such fields is composed of 6 rows of stakes. The distance between the
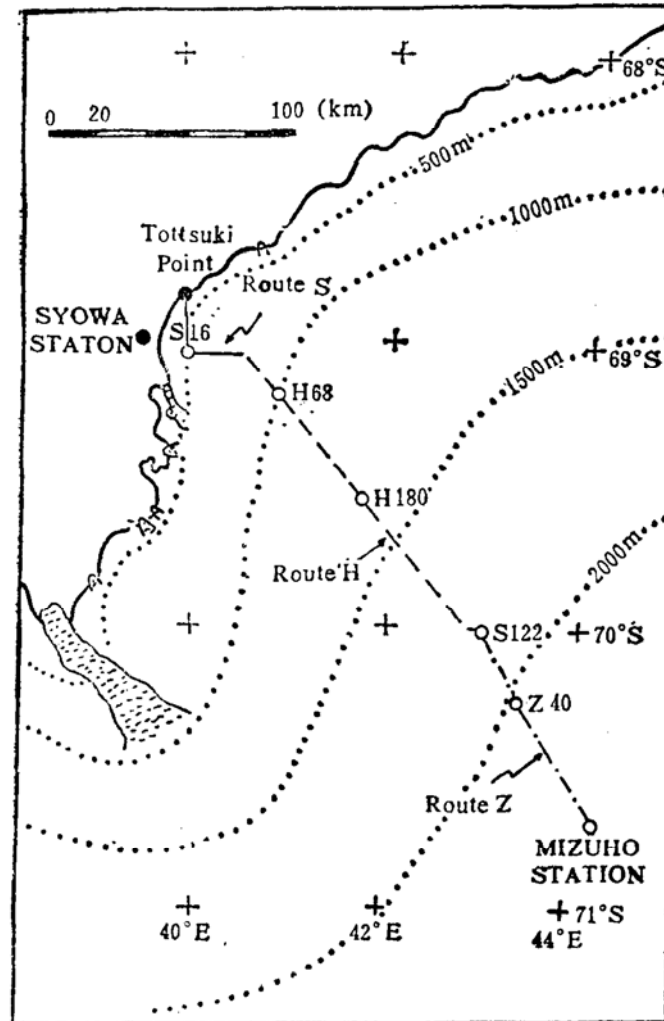

Fig. 1. Map of Mizuho Plateau showing the study area along traverse routes S,H and Z, leading to Mizuho Station. Circles denote the positions of 36-stake fields.

neighbouring two stakes is 20 m. The direction of the matrix is perpendicular to that of the katabatic wind. This matrix has an area of 100×100 square meters. In addition, 10 accumulation-melting stakes were set up between S_{16} and Tottsuki on the bank with a distance about 1.5 to 2.25 km between two neighbouring spots. In the year of 1987–88 the measurement on 130 stakes between S_{16} and Mizuho Station was carried out four times. The first time was from January 10 to 20, 1987; the second was from August 24 to September 4, 1987; the third time started on October 29, 1987 and ended on November 2 of the same year (which were carried out by JARE 28). The fourth measuring work from January 7 to 19,1988 was made by Mizuho Inland Surveying Detachment in which the authors of this paper both took part. The measurements on the fields S_{16}, H_{180}, S_{122} and Z_{40} were carried out two times. The first measurement was undertaken by JARE 28 from January 12 to 19, 1987, and the second was completed by our Mizuho Inland Detachment. Besides, the measuring of the accumulation-melting at the spots between S_{16} and Tottsuki was done on January 20, June 10, July 13 and October 29, 1987 respectively. The observation and surveying from October 29, 1987 to January 1988 failed because of the fall and loss of many stakes and other causes.

The seasonal fluctuation of the ice-covered surface shown by the stakes reflect the accumulation or expense of surface mass; while the yearly fluctuation may be defined as an annual net mass balance. Many field surveys (Endo & Fujiwara, 1973; Yamada & Watanabe, 1978; Nishio, 1978a) and spot observation by one of the authors repeatedly show that the density of the surface layer mass in this area is about 380 kg / m³ and the variation is not significant. Therefore, for convenience sake, the thickness (m) of snow is used as an indicator for the seasonal accumulation and expense and the annual net mass balance. All data of snow depth and the corresponding geographical locations (the distance from the coast or the elevation) are put into IBM computer using a relevant procedure, and the desired data and diagrams are typed out according to certain requirements.

3. Distribution of the Surface Mass Balance

Whether the morphological features of the surface or the distribution of ice-forming zones, the Mizuho Plateau can be divided at least into 3 zones: the blue ice zone or the superimposed ice zone less than 400m above the sea level; the damp snow zone between the firn line (400–500m) and the dry snow line (700–19000 m); and the dry snow zone at elevation above 1000 m.

1. Mass balance in the year of 1987–88 in the zone less than 500 m above the sea level

The main mass expense of the Antarctic ice cover takes place on the icebergs. The formation of icebergs is related with thickness and motion velocity of the ice cover tips. The blue ice zone near the coast is mostly the superimposed ice supply area. The profiles across snow pits show that most of the zone lower than 500 m above sea level on the Mizuho Plateau belongs to the many-year superimposed ice supply area (Fig. 2-a). The seriously polluted dynamic metamorphic ice of the glacier can be easily seen only along a narrow section of the seaside (Fig. 2–b). The main accumulation period is the autumn and winter seasons from February to September (Yamada et al., 1978). But the observation from January 20 to October 29 indicates that of 1987 this section is also in a state of negative balance, even in winter.
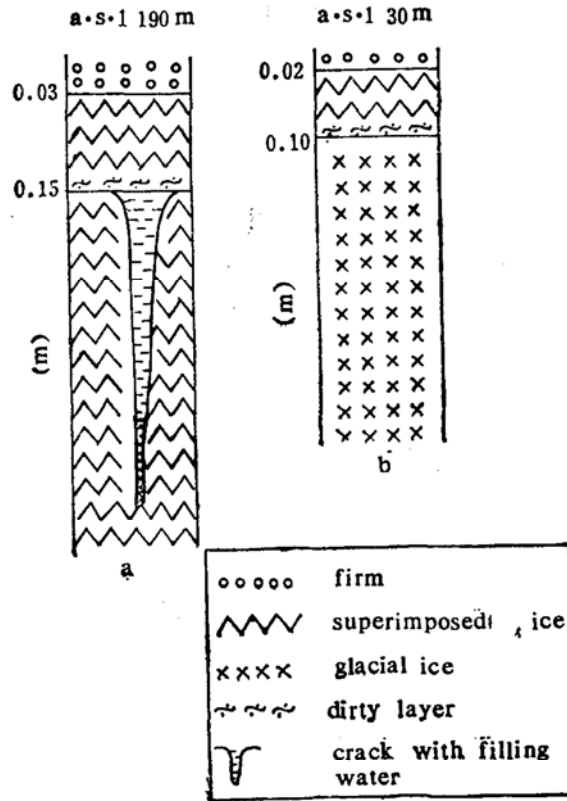
a·s·1 190 m   a·s·1 30 m

Fig. 2. Profile of the blue ice zone on the Mizuho Plateau.

Thus the negative balance in the whole year of 1987–88 is undoubted. The ice (snow) surface from stake No. 45 at elevation of 530m to stake No. 1 (30 m a.s.l.) in the vicinity of tottsuki spot is unexceptionally in a subsident state with an average value of 0.26m (Fig.3).
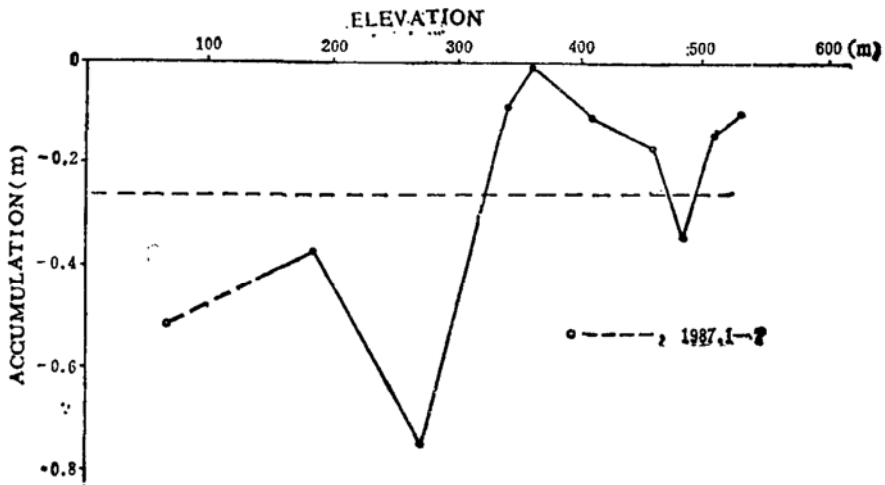
Fig. 3. Elevation-dependent mass balance variation of stakes at elevation lower than 550 m (a.s.l.) on the Mizuho Plateau from Jan. to Oct., 1987.

2. Distribution of mass balance in the area at elevation more than 550 m

Satow (1985), using the data obtained during 1968 and 1972–1983, discussed the spatial distribution of the many-year mass balance on the Mizuho Plateau (Fig. 4–a). The area at elevation of 600–1300 m was regarded as high accumulation area with its annual average accumulation of 0.52 m in depth; the area at elevation of 1300–1900 m (a.s.l.) has an annual average accumulation depth of 0.30 m; and the area at elevation of 1900–2230 m was considered to be a low accumulation area, with its annual average depth of only 0.13 m of the accumulated snow. From the observations made in the year of 1987–88, the thickness of the accumulated snow reaches 0.86 m at elevation of 600 and 1300m, 0.16m at elevation of 1300 and 1900 m, and only 0.12m at elevation of 1900 and 2230 m (Fig. 4–b). The calculated data show that the many-year average depth of the accumulated snow in the area from S_{16} to
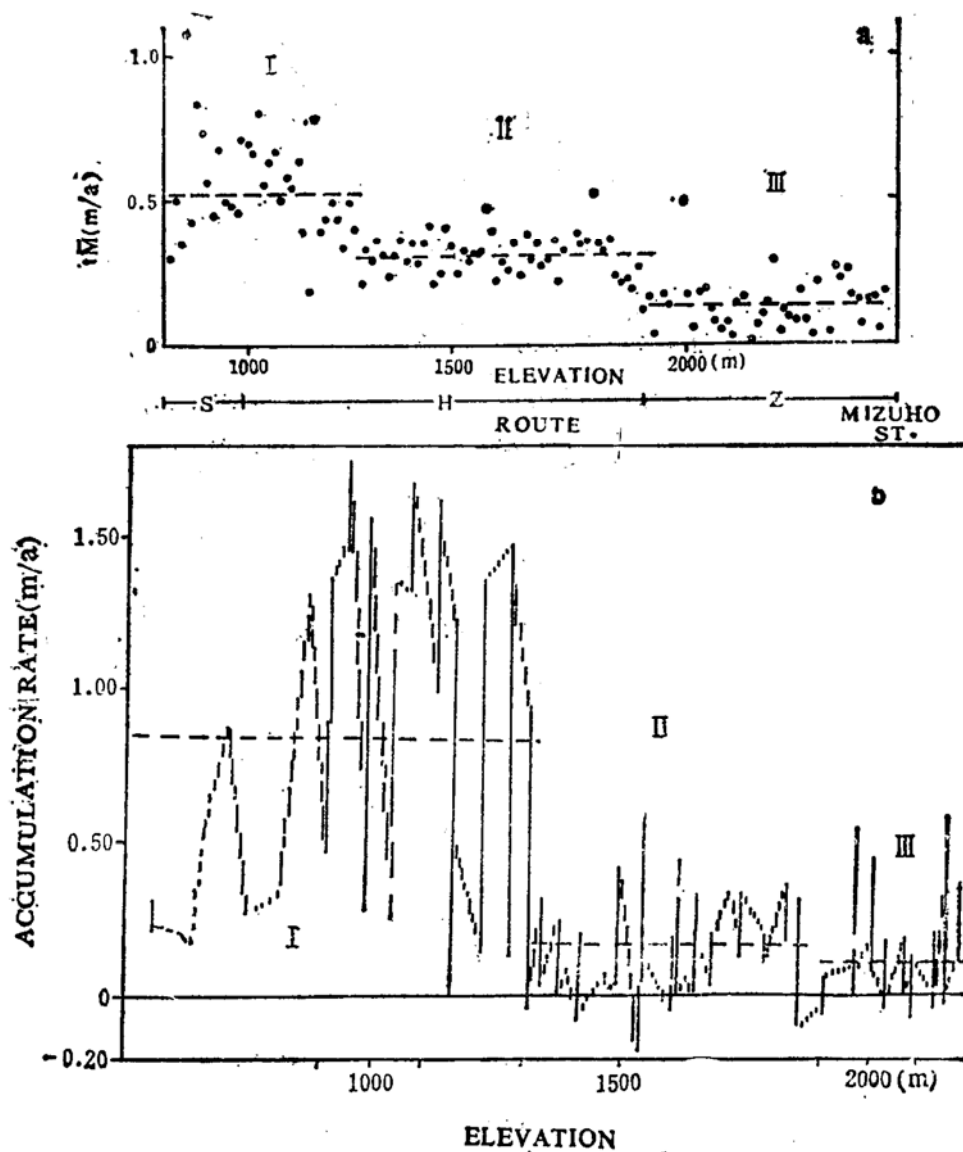

Fig. 4. Comparison between the spatial distribution of many -year average mass balance values (a) on the Mizuho Plateau and the values in the year 1987–88 (b).

Misuho Station is 0.30 m, but 0.31 m in the year of 1987–88, slightly increased.

Due to the gentle slope of the ice cover surface, the average gradient is only 8‰, and the elevation of many measuring spots at different distances from the coast is not greatly different or even completely the same, it is perhaps more practicable to use the distance from the coast rather than the elevation in discussing the spatial distribution of the snow accumulation at various spots (Fig. 5).
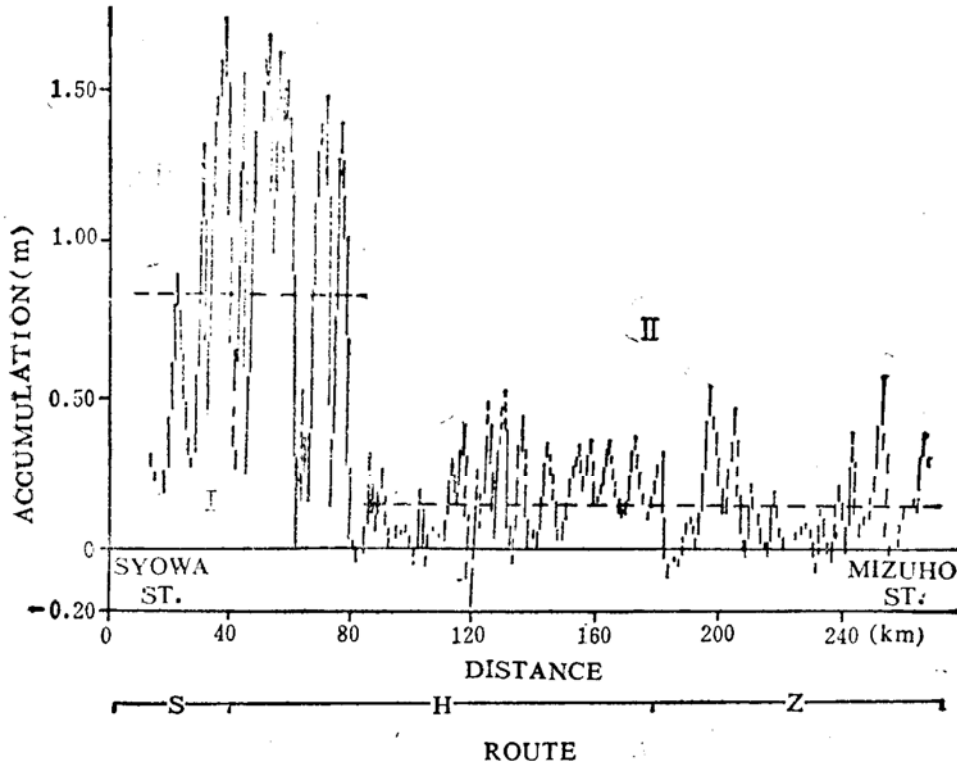
Fig. 5. Variation in distribution of the distance-dependent mass balance in the year of 1987–88 on the Mizuho Plateau.

We may know in Fig. 5 that the average depth of snow accumulation in the year 1987–88 is 0.84 m at the site 80 from the coastline, while the accumulation reduces abruptly from the 80 km point inland to the Mizuho Station at a range of about 190km, but doesn't vary greatly, and the annual average depth is only 0.14 m. That is to say, the mass balance in the year 1987–88 obviously appears in two different zones: one is the high mass accumulation zone (I) within 80 km from the coast, the other is the low value accumulation zone (II) from the 80 km point to Mizuho Station.

3. Seasonal distribution of the mass accumulation expense in a year

The observed values of mass accumulation at every spot between S_{16} and Mizuho Station in 1987–88 are plotted in Figure 6. Figure 6–a shows a process of the time-dependent spatial variation of the accumulation value at each spot from January to August, 1987. It may be seen that the variation amplitude is not significant: the average accumulation in depth is 0.29m in the area at 80km distance,and 0.13m in the area from the 80 km point to Mizuho Station. Fig. 6–b is the time-dependent spatial variation of the mass accumulation at each spot

from August to October, 1987.　It shows that the mass accumulation in the area at 80 km
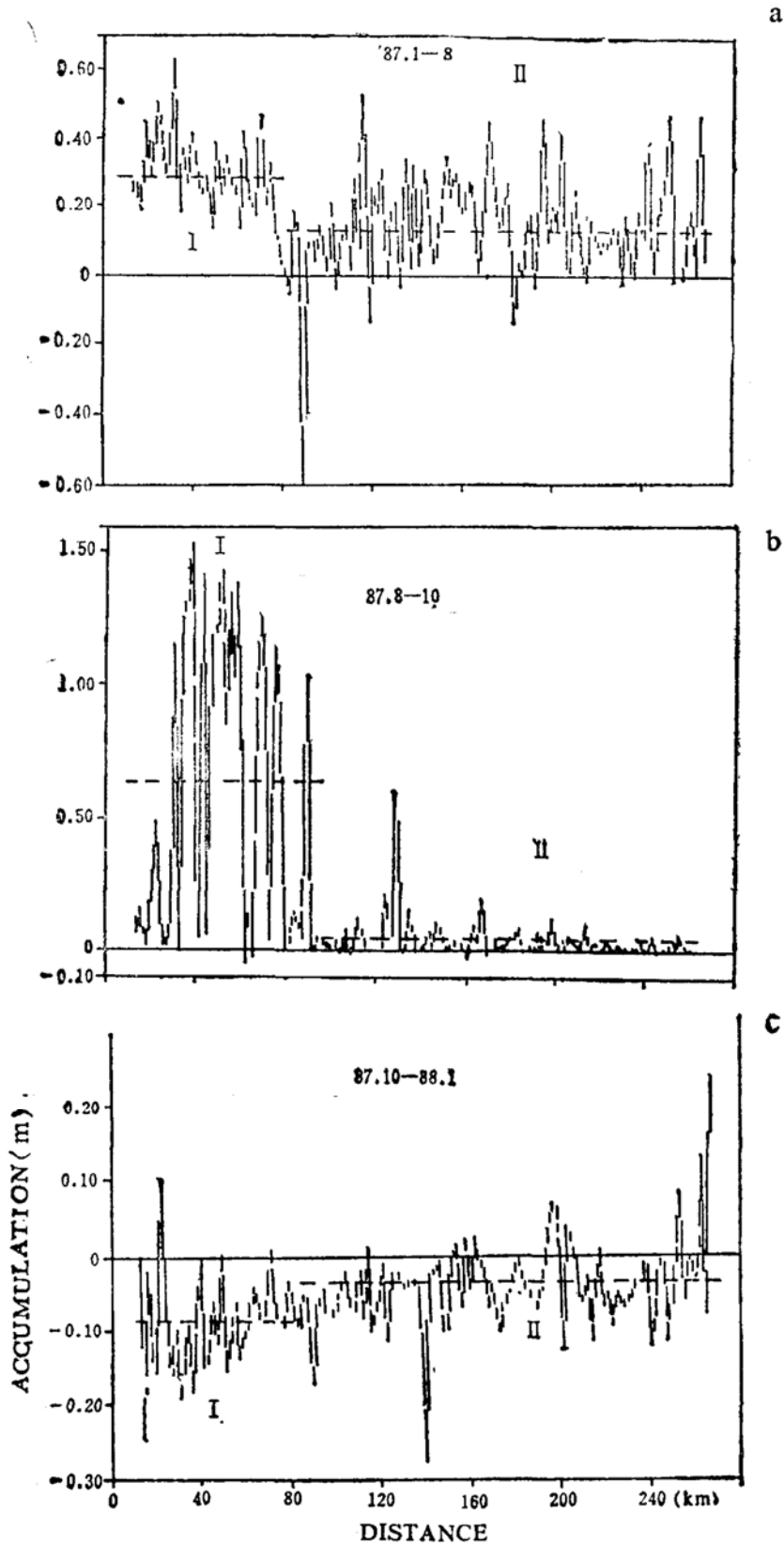

Fig. 6.　Seasonal variation of the mass accumulation / expense in 1987–88 on the Mizuho Plateau.
　　a. Jan. to Aug. 1987; b. Aug. to Oct. 1987; c. Oct. 1987 to Jan. 1988.

mainly occurs in this period; but the accumulation in area from the 80 km spot to Mizuho Station tends towards zero in the same period. We can see in Figure 6–c that the period from October 1987 to January 1988 is a season of mass expense within this area. Also in this period, the mass expense (−0.09 m) in zone I with higher annual accumulation is twice more than that (−0.038 m) in zone II with lower annual accumulation. And 104 out of the 130 mass accumulation observation spots give negative values, 7 spots show zero, and the spots with positive values only accounts for 14.6% of the total number of the observation spots. We can clearly see in Figures 5 and 6 that the mass accumulation in the low value zone II mainly takes place in winter, while in the high value zone I it mainly occurs between August and October, or from the end of winter to the beginning of spring.

4. Comparison between mass balances on Mizuho Plateau and in China

For comparison between mass balances in Mizuho Plateau and China, it is necessary to introduce the term 'level of mass-balance' (Xie, 1980). that is

$$m = \frac{c+a}{2}$$

Where, m: level of mass balance (mm); c: total accumulation (mm); a: total ablation (mm).

In the recent climatic condition, the Antarctic ice sheet (including Mizuho Plateau) is essentially stable. Thus, the level of mass balance (m) is equal to the total accumulation (c) actually (Xie, 1980). Mean annual snow depth is calculated to be 0.30 m and only 0.31m in the year of 1987/88, which can be reduced to 117 mm in water depth.

Because the types of glaciers are so more complex that the levels of mass balance are more different in West China. For example, the level of mass balance is above 2500 mm on Southeast Tibet, 700 mm on northern slope of Qomolangma, eastern Tianshan and western Qilian Mts., and 1500 mm on western Tianshan and even 400 mm on West Kunlun Mts., which are called monsoon maritime glacier, continental glacier and extra-continental glacier respectively (Xie, 1980; Zhang, 1989). It is clear to see that the level of mass balance on the extracontinental glacier in China is 3 times more than that on Mizuho Plateau. And the level of monsoon maritime glaciers in Tibet is 20 times more than later. For increasing the comparability between them we should average the values of level of mass balance in some main glacial areas of China. The mean value is about 1100 mm, being 9 times more than that on Mizuho Plateau. Therefore under the recent climate, the level of mass-balance in Mizuho Plateau appears to be mainly low accumulation and low expense, but inverse in middle and low latitude regions, such as on glaciers in West China.

4. Analysis of the Factors Affecting on the Surface Mass Balance

1. Analysis of standard deviation and deviation coefficient of average mass value

Due to the resisting and rising of the air flow by the mountains along the border, the distribution regularity of the alpine glacial mass balance as in middle and low latitude regions of West China, the surface mass value generally increases with the rising of the mountains.

However, on the Mizuho Plateau, when the cyclone moves from the coastal region toward the polar inland, it forms atmospheric precipitation. Since the ice-cover slope in the coastal region is great (12–19‰), the air flow is raised and obstructed in its motion, and the intensity of precipitation is greater. When the air flow moves inland to the plateau, as the ice-cover slope becomes more and more gentle (Hiromu shimizu *et al.*, 1978), the moisture in the air flow is relatively reduced, and the intensity of atmospheric precipitation obviously decreases because it relies mainly on heat power for its action. On the other hand, the existence of an inversion layer (kabayashi, 1978) with heights of 250 m (January, April and November) to 600 m over the Mizuho Plateau (August) gives rise to a prevailing katabatic wind all the year a round. The katabatic winds on the Mizuho Plateau may be called "inversion winds" (*schwerdtfeger*, 1970), because they are essentially controlled by the thermal wind due to the existence of a declined inversion layer. The drifting snow caused by the katabatic wind results in the redistribution of ice and snow mass, so that the mass balance regularity in this area becomes more complicated. But the general feature is that the value in the near area coast is higher than that in the area far from coast. Therefore, the mass balance value at each spot is determined not only by the quantity of atmospheric precipitation, but also by the intensity of mass redistribution caused by the drifting snow and its variation between years, and also by the positive-negative variation (e.g., sastrugi, dunes, etc.) and its scale of ice cover surface topography. That is:

$$M = t\overline{M} + M_c + M_r \qquad (1)$$

where $t\overline{M}$ is a many-year mean value of mass balance, M_c is a mass balance variable caused by many-year climatic variations, M_r is a variable caused by the change of many-year topographical conditions. But in a particular year, the factors affecting on the mass balance may be a short-term climatic variation, i. e., weather process variation, especially the weather process and the short-term topographical condition variation during the period of observation. Then equation (1) may be written as

$$M = \overline{M} + M_{sc} + M_{sr}$$

where $\overline{M}$ is a mean value of mass balance either in the high value zone I or in the low value zone II in the year, M_{sc} represents the variation of the shortterm weather process, and M_{sr} — the short-term topographical variation. Then $M_{sc} + M_{sr}$ may be indicated by

$$\triangle M = M - \overline{M}$$

The standard deviation S_M of the mass balance may be calculated from following equation:

$$S_M = \sqrt{\frac{1}{N}\varepsilon(\triangle M)^2} \qquad (2)$$

where N is a number of observation spots. By equation (2) we can find that the standard deviation of the mass balance in zone I is 0.57m, the deviation coefficient ($S_M / \overline{M}$) is 0.68, and these values in zone II are 0.15 m and 1.10 respectively. Such tendency of variation in deviation existed uniformly for many years, that is , the higher mean value of many-year mass balance in the area, the smaller the deviation coefficient in that area and vice versa (Sato, 1985).

2. Effects of the short-term climate and topographical variation on mass balance

In the previous section we have discussed the standard deviation and its coefficient of

the mass balance, and also conducted the effects of the short term climatic and topographical variations on the mass balance. In this section, we shall try to make a quantitative discussion of the relationship between the short–term climatic or topographical variations and the mass balance respectively.

The Mizuho Plateau is one of the regions on the Antarctic Continent with less precipitation. From the observations and estimates in many ways, the precipitation around Mizuho Station is approximately 100—300mm (*Takahashi*, 1985). Therefore, in the process of observation on the mass ac cumulation, both the short–term climatic process and ice–cover topographical variation can cause a considerable deviation of the observations. In general it is difficult to make a relatively accurate quantitative evaluation of the effects of the short–term climatic process and topographical variation on the mass balance. Yet, according to the variation of the short–term climatic process in the period of mass accumulation observation, the mass balance aM at a spot may be expressed as

$$aM = a\overline{M} + aM_c \qquad (3)$$

where $a\overline{M}$ is an average of mass balance at 15 successive spots. The centre of these spots is located near the surveying field of 36 stakes, with each two successive stakes 2 km apart. According to equation (3), the short–term climatic variation aM_c in a certain range may be written as

$$aM_c = aM - a\overline{M}$$

and the standard deviation Sc caused by the variation may be expressed as

$$S_c = \sqrt{\frac{1}{N}\Sigma(aM_c)^2} \qquad (4)$$

where N is 15, the number of observation spots.

Meanwhile, according to the topographical variation of the surveying fields, the mass balance M_f at each spot may be expressed as

$$M_f = \overline{M}_f + M_{fr} \quad \text{and} \quad M_{fr} = M_f - \overline{M}_f$$

where $\overline{M}_f$ is a mean value of mass balance on the surveying field of 36 stakes; M_{fr} is a variable caused by topographic variation at each spot of surveying field. And the standard deviation caused by the topographical variation in the surveying field is shown to be

$$S_r = \sqrt{\frac{1}{N}\Sigma(M_{fr})^2} \qquad (5)$$

Table 1 lists S_c and S_r values calculated from equations (4) and (5). It may be found in Table 1 that the effect of the shortterm climatic variation on the mass balance in zone I is larger than that of the topographical conditions while the effect of the topograhical variation in zone II is larger than that of climate.

Table 1. Effects of short-term climatic and topographical variations on the mass balance on the Mizuho Plateau in 1987–1988.

	Region	$a\overline{M}(\times 10^{-2}m)$	$S_c(\times 10^{-2}m)$	$S_r(\times 10^{-2}m)$
I	S_{16}	68.0	51.9	6.8
	H_{180}	12.7	17.1	22.7
II	S_{122}	14.1	16.5	19.5
	Z_{40}	5.1	7.6	11.1

5. Conclusions

Analysis of in mass accumulation data in the year of 1987—88 on the Mizuho Plateau enables us to clarify the following zcenario:

1. In the areas at elevation less than 550m, mass accumulation values at all spots are negative, even in winter from January to October of 1987.   It shows that the ice surface in this area was in a state of negative mass balance.   In the areas at elevation more than 550m, the mass balance in that year may be distinguished into two zones with two different orders of magnitude, one of which situated from S_{16} inland to the 80 km point belongs to the high value zone, and the other from the 80 km point to Mizuho Station to the low value zone.

2. The mass accumulation in the high value zone is mainly from August to October, and that in the low value zone from January to August.   The expense of the mass balance either in the high value zone or in the low value zone mainly occurs between October and January.

3. The deviation coefficient of the mass balance in the year is high , and the coefficient in "low value zone" is higher than that in "high value zone".

4. The effects of short–term climatic and topographical variations on the mass balance is significant. In the high value accumulation zone, the effect of short–term climatic variation is larger than that of topographical variation while in the low value zone, the effect topographical is larger than the climatic effect.

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References

Endo, Y. and Fujiwara, K. (1973): Characteristics of the snow cover in East Antarctica along the route of the JARE South Pole traverse and factors controlling such characteristics, *JARE Sci. Rep., Ser. C (Earth Sci.)*, 7, 1—27.

Nishio, F. (1978a): Density of surface snow along Routes S,H and Z, *JARE Data Rep.*, 44 (Glaciol. 5), 118—121.

Nishio, F. *et al.*, (1989): *JARE Data Report* (Glaciology 17).

Kobayashi, S., (1978): Vertical structure of katabatic winds in Mizuho Plateau, *Mem. Natl. Inst. Polar Res,. Spec. Issue*, 7, 72—79.

Rubin M.J. and Giovinetto, M.B. (1962): Snow accumulation in central West Antarctica as related to atmospheric and topographic factors, *J. Geophys. Res.*, 67, 5163—5170.

Satow, K. (1985): Variability of surface mass balance in the Mizuho Plateau, Antarctica, *Mem. Natl. Inst. Polar Res. Spec. Issue*, 39, 132—140.

Satow, K. (1984): On the scatter of snow accumulation measured at a given place on the Mizuho Plateau, *Mem. Natl. Inst. Polar Res. Spec. Issue*, 34, 132—136.

Schwerdtfeger, W. (1970): The climate of the Antarctic, Climate of the Polar Regions, ed. by Orvig. S. Elsevier, Amsterdam, 253—355 (World Survey of Climatology, 14).

Shimizu, H. *et al.* (1978): Morphological Feature of Ice Sheet in Mizuho Plateau, *Mem. Natl. Inst. Polar Res. Spec. Issue*, 7, 14—25.

Takahashi, S. (1985): Estimation of precipitation from drifting snow observations at Mizuho Station in 1982, *Nem. Natl. Inst. Polar Res. Spec. Issue*, 39, 123—131.

Watanabe, O. (1978): Distribution of surface features of snow cover in Mizuho Plateau, *Mem. Natl. Inst. Polar Res., Spec. Issue*, 7, 44—62.

Whillans, I.M. (1978): Surface mass-balance variability near "Byrd" Station, Antarctica, and its importance to ice core stratigraphy, *J. Glaciol.*, 20, 301—310.

Yamada, T. and Watanabe, O. (1978): Estimation of total mass of snow accumulation in Mizuho Plateau, *Mem. Natl. Inst. Polar Res., Spec. Issue*, 7, 182—197.

Xie Zichu (1980): Mass balance of glaciers and its relationship with characteristics of glaciers. *Journal of Glaciology and Geocryology*, Vol. 2, No. 4, p. 1—8.

Xie Zichu (1982): Primary researches on coefficient of stability of glaciers. Proceedings of the symposium on Glaciology and Geocryology Held by Geographical Society of China (Glaciology), P. 39—45.