ESTIMATION OF MASS INPUT IN THE SHIRASE AND THE SÔYA DRAINAGE BASINS IN MIZUHO PLATEAU

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Abstract: The amount of mass input was estimated for the Shirase and the Sôya drainage basins in Mizuho Plateau, East Antarctica, using the data of surface mass balance, obtained by means of the snow stake measurement and the stratigraphic analysis performed over seven years from 1968 to 1974 in consideration of the regional characteristics of the balance as a function of elevation, the influences of the topography of the ice sheet on the balance and the annual variations of the balance. The Shirase and the Sôya drainage basins are, respectively, 200×10^3 and 22×10^3 km^2 in area; 20.8 and 5.9 Gta^{-1} in estimated maximum mass input; 4.6 and 0.1 Gta^{-1} in estimated minimum mass input; 12.7 and 3.0 Gta^{-1} in hypothetic average of mass input, which correspond to 64 and 150 kgm^{-2} a^{-1} in balance.

1. Introduction

As reported by AGETA (1971a), studies have been made extensively of the mass budget of the Antarctic Continent by various investigators, but the data of surface mass balance used in their estimation have been obtained in very limited regions against a huge continental expanse of the ice sheet. Moreover, their measurements of balance have been made mainly in West Antarctica which has the different climatic condition from that of East Antarctica. An increase in the accuracy of mass budget for the entire Antarctica is made possibly by obtaining more reliable results on mass budget in individual drainage basins constituting the Antarctic Continent.

This paper was prepared to estimate the amount of mass input in the Shirase and the Sôya drainage basins in Mizuho Plateau, East Antarctica, using the data of balance in Mizuho Plateau.

2. Observation and Result

For the purpose of estimating the amount of mass input in the Shirase and the Sôya drainage basins, the thickness of snow deposited on the snow surface in one year was measured in the nearest centimeters by the snow stake method and snow stratigraphic analysis along the traverse route, as shown on the contour map of Mizuho Plateau, East Antarctica (Fig. 1). A density profile of surface snow layers was also observed for the conversion of the thickness of snow into the mass of water equivalent, namely, a balance.

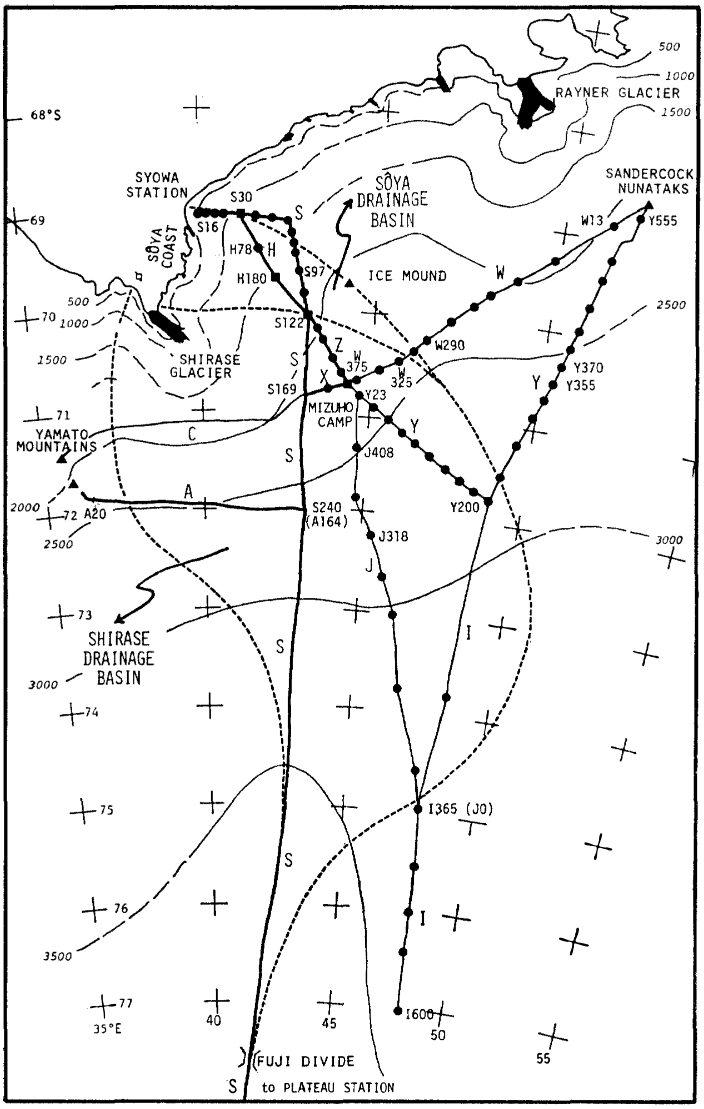
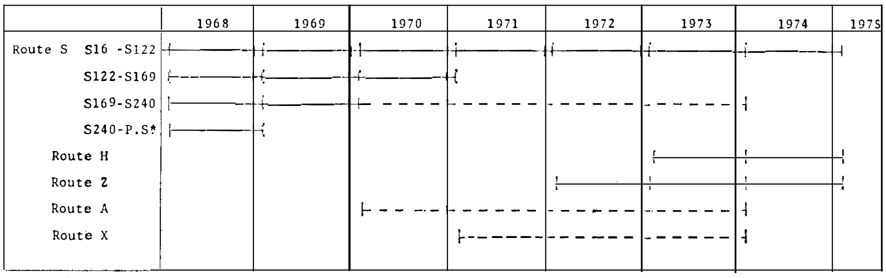


Fig. 1. Oversnow traverse routes and boundaries of the Shirase and the Sôya drainage basins in Mizuho Plateau, East Antrarctica.

2.1. *Snow stake measurement*

Measurements were carried out by the snow stake method along Routes S, H, Z, X and A (FUJIWARA and ENDO, 1971; AGETA and WATANABE, 1972; YAMADA *et al.*, 1975; YOKOYAMA, 1975; SATOW, 1977), as shown by thick solid lines in Fig. 1, for seven years from 1968 to 1975. The periods and the routes of the measurements are illustrated in Fig. 2; solid lines represent one-year measurements from January to next January, while dashed lines represent four-year measurements, 1970–1973, along Route S from S169 to S240 and along Route A, and a three-year measurement, 1971–1973, along Route X.

Table 1 represents the values of area-mean annual balance (kgm^{-2} a^{-1}) measured along the various routes in Mizuho Plateau. The values along Route S are shown in this table separately by the different ranges of elevation, because the mode of balance along this route varied with the increase of elevation whereby the annual balance decreased as a function of elevation, which has a positive correlation with continentality in Antarctica. The area-mean annual balance was



*: Plateau Station

Fig. 2. The periods and the routes of the stake measurement.

Table 1. Area-mean annual balance (kgm^{-2}a^{-1}) by stake measurements.

Route	S30-S100	Route H	S120-S169	Route Z	Route X	S170-S240	S241-S390	S391-Plateau Station
Elevation (m)	1000-1700	1000-1900	1700-2100	1900-2200	2100-2200	2100-2600	2600-3500	3500-3700
Number of stakes	71	74	50	45	20	71	150	272
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1968	181		53			59	69	46
1969	112	(67)	41	(32)	(53)	46		
1970	283	(170)	114	(80)	(134)	(101)		
1971	204							
1972	228			121		78		
1973	181	99		23	92			
1974	173	114		20				
Mean	195	(117)	(71)	(55)	(93)	(70)		

calculated for each area by the data obtained by the single stakes set up on the snow surface at intervals of 2 km along Routes S, H, Z and X. As for Route A, each of the single stakes was also used as a marker for the triangulation survey aimed at studying the movement and deformation of the ice sheet and so erected at intervals of 1 to 4 km near the top of the surface rise of the undulation of the ice sheet for securing the longest unobstructed view to neighbouring markers. Therefore, the area-mean annual balance along Route A was excluded from Table 1. Values in parentheses show the seven years' averages of area-mean annual balance and estimated values in 1969 and in 1970 which are calculated on the basis of the reason discussed in section 3.3.

2.2. Stratigraphic analysis

In order to see the characteristics of snow cover and to obtain an average value of annual balance at a given location, a great number of stratigraphic observations have been made since 1968 (FUJIWARA and ENDO, 1971; WATANABE, 1972; NARUSE, 1972; ENDO and FUJIWARA, 1973; YAMADA, 1975; WATANABE, 1977). Results reported in this paper are based on three methods of stratigraphic analysis, namely snow stratigraphy, oxygen isotope variation and gross β activity, which were used to identify annual snow layers (WATANABE, 1972; WATANABE, 1977; WATANABE, 1978b; KATO and WATANABE, 1977). The first method was applied *in situ* during the summer months in 1970–1971 and in 1974–1975, using 2-m pit walls at 16 locations, 1-m pit walls at 7 locations, 10-m cores obtained by drilling at 10 locations and 2-m cores at 44 locations along the routes, as indicated by solid circles in Fig. 1. The other two methods have been applied in the laboratory after taking the snow or core samples back to Japan, whereas the measurements of gross β activity have been completed for only two samples obtained at H128 and S97 (KATO and WATANABE, 1977; WATANABE, 1978b) and measurements of the remaining samples are being made with great efforts.

Table 2. Area-mean annual balance ($kgm^{-2}a^{-1}$) obtained by snow stratigraphic analysis.

Route and Elevation (m)	S (500–800)	S (1000–1700)	Z (1900–2200)	W (2000–2400) Y (2100–2600)	W (2200–2400) Y (2300–2900) Y (2600–2900) J (2500–2800)	I (3200–3400) J (2800–3300)
Number of locations	4	8	4	16	26	10
Mean	210	210	105	204*	103**	70

* Obtained in areas along Route W from W13 to W290 and along Route Y from Y370 to Y555.

** Obtained in areas along Route W from W325 to W375, along Route Y from Y23 to Y355 and along Route J from J318 to J408.

The identification of annual layers was conducted by using these methods separately or together.

The estimated area-mean annual balance obtained by the stratigraphic analysis is shown in Table 2 for each area along the routes. Areas are also separated in this table in the almost same way as Table 1 to allow a comparison with the values of area-mean annual balance obtained by the stake method. The values in this table are simple averages of the data at 4 to 26 locations indicated also therein. The mean value at a given location was calculated by the following process: Each of annual layers was identified; the product of the thickness of an annual layer and its density was obtained as the deposited mass; finally the deposited mass of each annual layer was averaged. The number of annual snow layers identified at a location was chiefly three, although it varies between two and eleven depending on locations. The detailed methods and results of the stratigraphic analysis are described in another paper (WATANABE, 1978b) in this volume.

2.3. Density of surface snow layers

The density profiles were measured every 5 to 20 cm in thickness from the surface to the depth of 1 to 2 m (NARUSE, 1975; WATANABE, 1975); Fig. 3 shows maximum, minimum and average densities (solid circles) from the surface to 1 m in depth at various elevations from 500 to 3000 m a.s.l. along the routes. The density profiles indicated no tendency of density increase with depth. As seen in Fig. 3, the average densities are fairly constant with elevation, namely, 0.43±0.05 Mgm^{-3}. According to ENDO and FUJIWARA's observation (1973), the average density in the inland plateau above 3000 m a.s.l. decreased to 0.35±0.03 Mgm^{-3}. Therefore, these values of density, 0.43 and 0.35 Mgm^{-3}, are respectively employed for the estimation of the water equivalent in the accumulation area between 1000–3000 m a.s.l. and in the inland plateau above 3000 m.

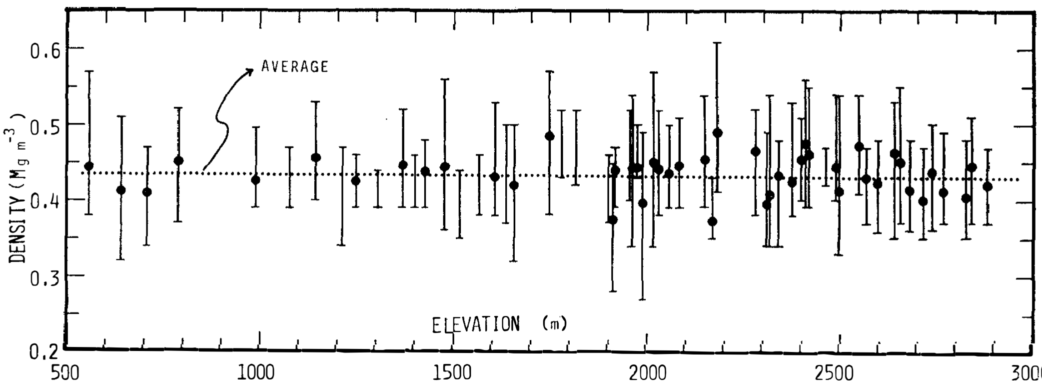


Fig. 3. Density ranges between maximums and minimums with averages (solid circles) in snow layers from the surface to 1 m in depth plotted against elevation.

3. Areal and Temporal Variability of Surface Mass Balance

Although it is prerequisite for estimating the mass input that the regional distribution of average balance at the surface of the ice sheet must be obtained in the Shirase and the Sôya drainage basins, the data obtained were limited to "lines" along the traverse routes and not simultaneous for all locations covered. For estimating the average annual balance from these data and then extending it to the whole areas of both the basins, the following discussions were thus devoted to the areal and the temporal variability of balance.

3.1. Regional characteristics of the surface mass balance

Since the balance in Antarctica is directly dependent on the net mass transport by the atmosphere across the boundary of the ice sheet, the amount of balance may essentially have an inverse correlation with elevation. In fact, such a correlation is recognizable from the results of stake measurements along the routes which recorded the maximum balance in the coastal area around 1300 m a.s.l. and the value gradually decreases with increasing elevation (YAMADA *et al.,* 1978). However, the amount of balance shows a great areal variability at locations along the routes, which results in the distinct regional characteristics of balance.

The terrain observed along the routes is divided into an ablation area below 400–500 m a.s.l. and an accumulation area above this elevation. The coastal area below 700–1000 m a.s.l. is characterized by the occurrence of summer melting. Consequently the firn line and the dry snow line, defined independently by BENSON (1962) and MÜLLER (1962), can be respectively drawn

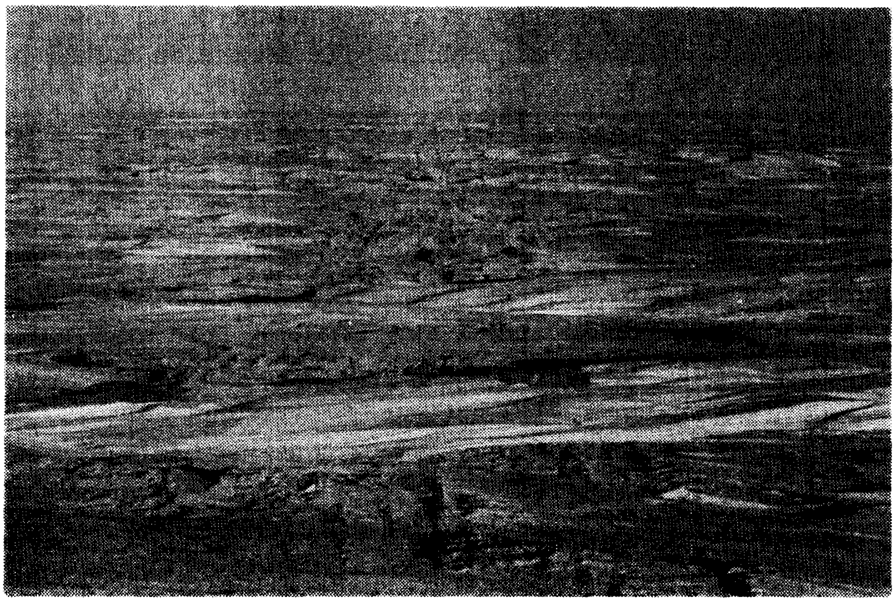


Fig. 4. Patch-like deposits of snow found near Z30 on the traces previously made by snow vehicles.

at 400–500 and 700–1000 m a.s.l. (YAMADA *et al.,* 1978). Glaciological and meteorological observations suggest two other lines, one of which can be drawn at 3000–3200 m a.s.l., which discriminates between the coastward region and the inland plateau region, where the meteorological circumstance concerning the balance may differ from each other (SHIMIZU *et al.,* 1978b), although the data are scanty for the inland plateau region.

In the coastward region below this elevation, strong katabatic winds prevail almost throughout the year with the remarkably stationary direction (AGETA, 1971b; WATANABE, 1978a; INOUE *et al.,* 1978) and disturb the uniform deposition of snow. Under the strong katabatic winds a unit layer of snow covers the snow surface in the patch-like shape with a horizontal scale of the order 10^0–10^2 m as shown in Fig. 4 (OKUHIRA and NARITA, 1978). A unit layer of snow is defined as the fairly homogeneous snow layer that is formed by snow continuously deposited in an unbroken period of a meteorological condition with no hiatus (WATANABE, 1978b). The annual layer that represents the annual balance is composed of the unit layers which were deposited onto the snow surface at various times during the year.

In the accumulation area between 400–500 and 1700–1900 m a.s.l. on the routes (accumulation area I), the annual layer covers almost all the snow surface without gaps, and one can find the formation of the continuous horizon of an annual layer in this area. On the other hand, as for the accumulation area between 1700–1900 and 3000–3200 m a.s.l. (accumulation area II), the unit layers cannot cover the entire surface of the area during one year or several years. Therefore, hiatuses are found in the formation of an annual layer for great parts of the snow surface of the area. The area-mean annual balance in accumulation areas I and II was respectively more and less than approximately 90 kgm^{-2} a^{-1}. The critical value of balance of 90 kgm^{-2} a^{-1} separates accumultaion area I from II (YAMADA *et al.,* 1978). From the foregoing the elevation of 1700–1900 m a.s.l. constitutes the final dividing line.

Accumulation areas I and II occupy approximately 90% of the total area each of the Shirase and Sôya drainage basins (Fig. 5b). Therefore, the value of balance in accumulation areas I and II may exert the most important influence on the assessment of the amount of mass input for both drainage basins, while the inland-plateau region above 3000–3200 m a.s.l. (accumulation area III), being relatively small in the annual balance, could be considered to contribute little to the amount of mass input.

3.2. *Influence of the topography or flows of the ice sheet on the surface mass balance*

The topography of the ice sheet exerts influence on the regional distribution of balance at the surface of the ice sheet, because the topography may govern the action of katabatic winds and the intrusion of cyclonic disturbances. As has been pointed out by many glaciologists, the shape of the ice sheet is determined by the balance on the ice sheet and the flow of the ice sheet. The change in its shape caused by an emergence and a submergence flow should be compensated by an areal variability of balance. That is, an interaction between winds and the topography may cause mass to be removed from the surface in the area where an emergence flow takes place and to be added to the surface in the area where a submergence flow takes place in areas where strong katabatic winds flow stationarily. The surface mass balance is considered to occur in such a way in which a change in the shape of the ice sheet due to a flow could be modified.

In the vicinity of the Yamato Mountains bare ice is exposed on the surface of the ice sheet, where the emergence flow of 6 to 8 cma^{-1} and the negative surface mass balance of approximately -60 $kgm^{-2}a^{-1}$ were found (YOKOYAMA, 1975; NARUSE, 1978). Bare ice is also exposed near the Sundercock Nunataks. High density snow with the density of more than 0.7 Mgm^{-3} can be found on the surface of the Ice Mound located about 100 km coastward from Mizuho Camp (Fig. 1), caused by the rise of the bedrock (ABE *et al.*, 1978). As the snow cover cannot be found in these areas, an emergence flow and a negative balance may occur. On the contrary, a relatively large positive balance was observed in the area between A19 and A164 (identical with S240) where the submergence flow was surveyed (NARUSE, 1978). A relatively large positive balance was obtained in the trough of the Rayner Glacier, which is a surface depression of a large scale. That is, snow stakes of approximately 160 cm in height from the snow surface set up in 1971 along Route W running across the trough of the Rayner Glacier around 1900–2000 m a.s.l. were completely buried with snow deposited during four years by the time of the remeasurement made in 1975. The balance was estimated at 170 kgm^{-2} a^{-1}, which is 1.7 times larger than the balance of 100 kgm^{-2} a^{-1} obtained in the area of the same elevation (1900–2000 m) along Routes S and Z. The same trend can be found along Route C established across the trough of the Shirase Glacier (NARUSE, personal communication). The elevation of the boundary between accumulation areas I and II may be considered to rise to about 2200 m a.s.l. in the trough of the Shirase Glacier, while it is situated at 1700–1900 m on the observed routes.

The balance on the windward slope of the obvious ridge of the ice sheet was markedly larger than that on the leeward slope, as disclosed by a comparison of the balances in the areas along Route H and S (YAMADA *et al.,* 1978).

According to photographs of the Sôya Coast transmitted by Satellite ERTS on 21 January 1974, the maximum elevation of the firn line in the Sôya Coast to the south of Route S was estimated to be about 700 m a.s.l., while the firn line in the observed area along the routes was situated at the elevation estimated at 400–500 m a.s.l.

The boundary lines of the ablation area, accumulation areas I, II and III found out on the observed routes shift upward or downward by 100 to 500 m in elevation for the different areas of the basins from our observed areas due to the influence of the topography of the ice sheet. The upper and the lower limit lines of these boundaries are drawn by fine vertical solid lines in Fig. 5a.

The relatively small or negative value of balance and the relatively large value of balance could be interpreted to take place in the area of the emergence and the subemergence flow, respectively.

3.3. *Annual variation of surface mass balance*

3.3.1. In the accumulation area

The data were not simultaneous for all locations because they were obtained for various periods of time in the range of seven years from 1968 to 1975, as shown in Fig. 2. The data for more than two years are available only in the coastward area below the elevation of S240 (2639 m a.s.l.). There are unfortunately no data that can be used in discussing the annual variation of balance in the inland above this elevation.

The range of the annual variation of balance is about ±45% of the mean value of 195 $\mathrm{kgm^{-2}\,a^{-1}}$ during the seven years in the accumulation area between 1000 and 1700 m a.s.l., as shown in the second column in Table 1. The maximum value of 283 $\mathrm{kgm^{-2}\,a^{-1}}$ was observed in 1970, approximately 2.5 times larger than the minimum of 112 $\mathrm{kgm^{-2}\,a^{-1}}$ in 1969. As seen in the table, it seems that the annual variations in accumulation areas I and II respectively below and above 1700–1900 m a.s.l. indicate approximately a positive correlation between them, although a relatively large annual variation is found in the area along Route Z. Therefore, it may be allowed to consider that the value of annual balance averaged over all the widely spreading areas of accumulation area II may vary within the same range as that of the annual variation in accumulation area I. Taking the foregoing into consideration, values in parentheses in the third to the seventh column in the table were calculated to give seven years' mean values (in the bottom line) and values in 1969 and 1970 which correspond to the years of the minimum and maximum respectively during the observed seven years.

The degree of annual variation of balance is comparable to that of annual precipitation in Hokkaido, the northernmost island of Japan, although the annual precipitation itself in the latter is far larger than the annual balance of the former. It should be noted here that since the average annual precipitation for the latter is based on observations for several decades at this location in the medium latitude, measurements will be necessary for the same duration of years for accurate estimation of the average annual balance in Mizuho Plateau.

3.3.2. In the ablation area

According to the stake measurement (YAMADA *et al.,* 1978), the annual balance in the ablation area below the firn line (400–500 m a.s.l.) is estimated to be -340 kgm^{-2} in January 1970–January 1971 and -220 kgm^{-2} in January 1971–January 1972. It was observed that violent melting occurred in the summer of 1973–1974. The annual variation of balance may be considered to vary in the range from -200 to -400 kgm^{-2} a^{-1}. In the coastal area of Wilkes Land, the location of the firn line widely changes in elevation from year to year and sometimes disappears depending on the meteorological condition of an individual year (BLACK and BUDD, 1964). The ablation area in the Sôya Coast, however, has never vanished since Syowa Station was established in 1957.

4. The Annual Mass Input in the Shirase and the Sôya Drainage Basins

A comparison of the mean values in Tables 1 and 2 indicates a coincidence between the mean values obtained by the stake method and the stratigraphic analysis in the area between 1000 and 1700 m a.s.l. where the continuous horizon of the annual layer is formed, whereas it indicates that in accumulation area II between 1700 and 3000 m a.s.l. the latter are to be overestimated 1.5 to 2 times larger than the former, because of the hiatuses in accumulation. This fact leads to the ratio of a missing year or years to be 30 to 50%; *i.e.*, three to five annual layers are not formed for ten years in accumulation area II. Since it is difficult to estimate the number of missing years in the snow strata, only the data by the stake method are available for the estimation of the mass input. In the area where strong katabatic winds blow stationarily and the annual balance is less than 90 kgm^{-2} a^{-1}, it is evident that the methods by snow stratigraphy and oxygen isotope variation are unfortunately useless to determine the balance.

For estimating the accurate mass input in the Shirase and the Sôya drainage basins, the regional distribution of balance must be obtained from the observed data, in consideration of the influence of the topography or the flow of the ice sheet on the balance. Since the influence has been understood not quantitatively but qualitatively, an arbitary factor could not be avoided in the estimation of the regional distribution of balance. Consequently in the Shirase and the Sôya drainage basins the calculations were made of the maximum and the minimum mass inputs, which are considered to represent the upper and the lower limits of the mass input respectively. The real value of mass input should be found in the range between the two limits, namely, the maximum and the minimum values.

First of all, the maximum and the minimum annual balances are estimated as a function of elevation by the following procedure: The values of area-mean annual balance in 1970 and in 1969 which are tabulated in Table 1 are indicated

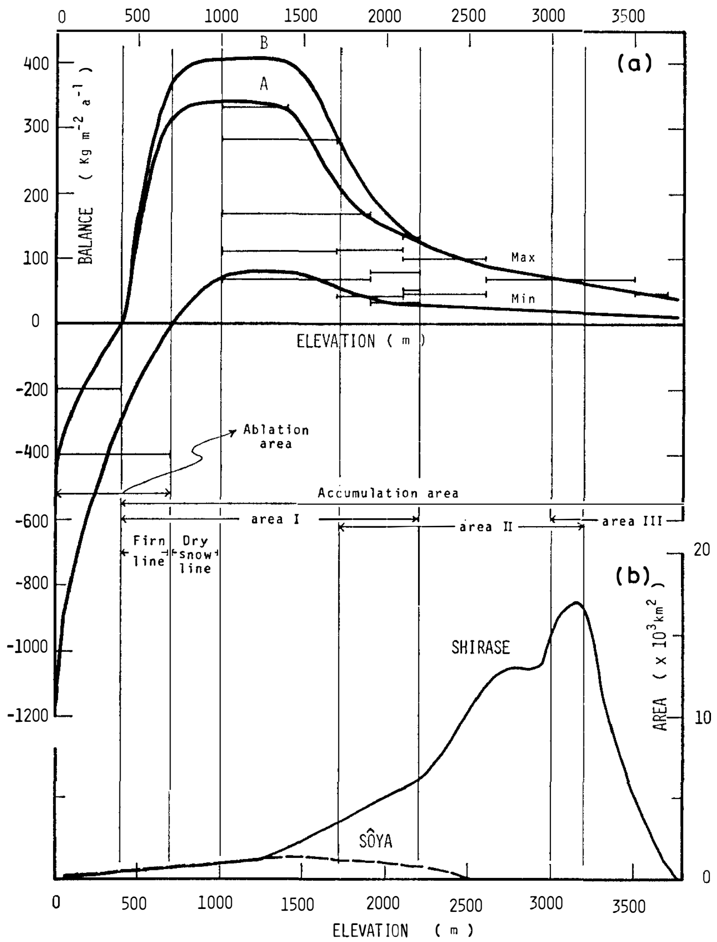


Fig. 5a. Maximum and minimum annual balance against elevation. Lines A and B respectively correspond to maximum for the Shirase and that for the Sôya drainage basin.

Fig. 5b. The area (km²) of sections bounded by 100 m contour lines against elevation in the Shirase and the Sôya drainage basins.

by fine horizontal solid lines in Fig. 5a. The values obtained in 1970 and 1969 respectively correspond to the maximum and the minimum annual balances for the area between 1000 and 2600 m a.s.l. In accumulation area I, the mound-like distribution of annual balance is noticed along Route S, having the flat peak in the area between 1000 and 1400 m a.s.l. (YAMADA *et al.*, 1978). The peak value obtained in 1970 (331 kgm^{-2} a^{-1}) was the maximum annual balance in the observed area along the routes, and is shown also in Fig. 5a. As for the area above 2600 m a.s.l., only the values obtained in 1968 were available and are shown by fine horizontal solid lines in Fig. 5a. According to many previous measurements, the annual balance in the inland plateau region above 3000 m a.s.l. is 30 to 50 kgm^{-2} a^{-1} (BULL, 1971), which is smaller than the values obtained in 1968 along Route S. Then the data in 1968 may be temporarily regarded as the maximum value in this area. Since the mass input over Antarctica is directly dependent on the amount of moisture transported from the sea to the continent, the amount of balance may be considered to have an inverse correlation to elevation. Consequently, each of the maximum and the minimum annual balance can be delineated as a function of elevation by a smooth curve. As for the ablation area below the firn line, each of the maximum and the minimum annual balance can also be drawn in a smooth curve in such a way that the mean value becomes -200 and $-400\,kgm^{-2}\,a^{-1}$ (see section 3.3.), respectively, because the amount

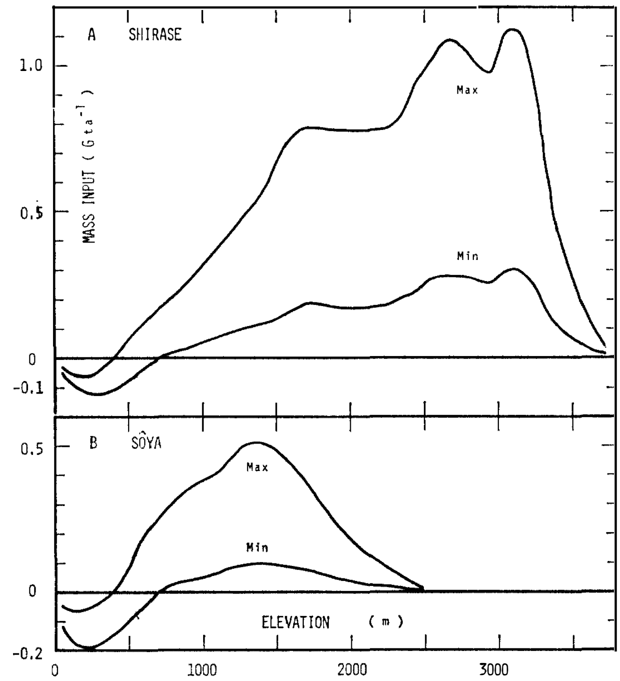


Fig. 6. Amount of maximum and minimum mass inputs in sections bounded by 100 m contour lines against elevation in the Shirase (A) and the Sôya (B) drainage basins.

Table 3. Calculated values of mass input (Gta^{-1}) in the Shirase and the Sôya drainage basins.

		Shirase	Sôya
Accumulation area	Maximum	20.9	6.1
	Minimum	5.1	1.0
	Mean	13.0	3.6
Ablation area	Maximum	−0.1	−0.2
	Minimum	−0.6	−0.9
	Mean	−0.3	−0.6
Mass input	Maximum	20.8	5.9
	Minimum	4.6	0.1
	Mean	12.7	3.0

of meltwater decreases sharply but smoothly with increasing elevation (YAMADA *et al.,* 1978). Meanwhile as for the minimum curve in the area above 2600 m a.s.l., it is drawn with a smooth curve in such a way that the mean value becomes 30 $kgm^{-2}a^{-1}$ in the area above 3000 m a.s.l. The maximum and the minimum curves are thus obtained for all the elevations as illustrated in Fig. 5a, where the maximum curve is designated as curve A.

The balance may be larger in the trough of the Shirase Glacier than in the area along the routes at the same elevations as discussed in section 3.2. Although this difference is difficult to estimate quantitatively, if the difference is *a priori* assumed, for instance 20% in the trough of the Shirase basin between 500 m and 2200 m a.s.l., maximum curve A may shift upward by 20%, which is designated as curve B in Fig. 5a. The maximum and the minimum mass inputs are respectively calculated on the basis of maximum curve B and the minimum curve in the Shirase drainage basin and maximum curve A and the minimum curve in the Sôya drainage basin, respectively.

The Shirase and the Sôya drainage basins have the areas of 200 and 22×10^3 km^2, respectively (SHIMIZU *et al.,* 1978a). The boundaries of the two basins are shown by dashed lines in Fig. 1. From the contour map of Mizuho Plateau, the area (km^2) of the sections bounded by the 100 m contour lines is calculated in both the basins and represented as a function of elevation by smooth curves in Fig. 5b.

The amount of mass input in every section is then calculated as the product of the balance and the area (km^2) in the corresponding section and is shown in relation with elevation for the Shirase and the Sôya drainage basins in Fig. 6-A and -B, respectively. By integrating the values of the maximum and the minimum mass inputs in every section against elevation the maximum and the minimum mass inputs in both the accumulation and the ablation areas are respectively calculated. The results are shown in Table 3. The calculated maximum and the minimum mass inputs are 20.8 and 4.6 Gta^{-1} for the Shirase drainage basin and 5.9 and 0.1 Gta^{-1} for the Sôya drainage basin, respectively.

As the first approximation, if the mean values of the maximum and the minimum mass inputs are employed as the hypothetic average of mass inputs, these are 12.7 and 3.0 Gta^{-1}, corresponding to the annual balance of 64 and 150 $kgm^{-2}a^{-1}$ over the Shirase and the Sôya drainage basins, respectively.

5. Discussion

For making clear the areal variability of balance in a narrow area at a given location where strong katabatic winds blow, a statistical treatment was given to the results of measurements made by the use of 36- and 200-stake networks installed each in the limited area, 100×100 m, at locations between S30

Table 4. Area-mean annual balance, standard deviation, maximum and minimum ($kgm^{-2}a^{-1}$) obtained by 36-and 200-stake networks each in the narrow area of 100×100 m at locations of S30, H180, S122 and Mizuho Camp for years from 1972 to 1974.

Location	S30	H180	S122			Mizuho Camp				
Elevation (m)	988	1540	1910			2230				
Year	1972	1972	1972	1973	1974	1972	1973		1974	
Number of stakes	36	36	36	200	200	36	36	200	36	200
Mean	381	131	85	53	30	43	18	48	0	7
Standard deviation	62	55	72	58	56	54	41	47	33	38
Maximum	520	241	267	159	172	176	112	133	95	138
Minimum	275	0	−26	−60	−56	−26	−34	−52	−34	−52

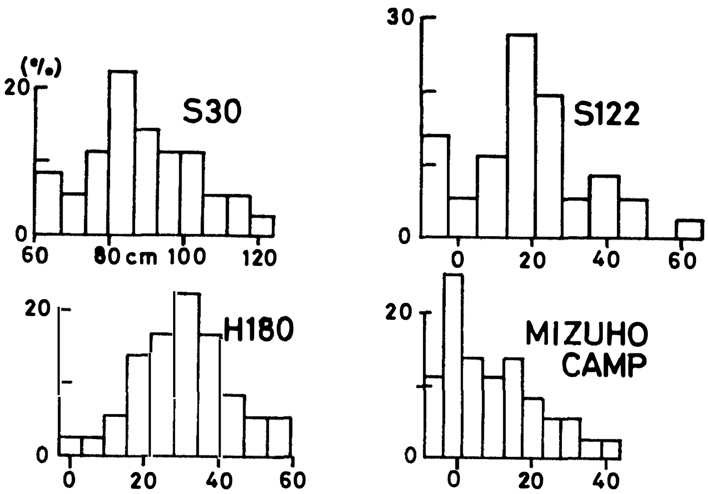


Fig. 7. Histograms of annual balance of snow in cm measured by 36-stake networks in the narrow area of 100×100 m at locations S30, H180, S122 and Mizuho Camp.

(988 m a.s.l.) and Mizuho Camp (2230 a.s.l.), as indicated by solid square marks in Fig. 1 (Yamada *et al.*, 1975; Yokoyama, 1975; Satow, 1977). The locations are situated in accumulation areas I and II, which are characterized by strong katabatic winds. Table 4 shows the area-mean annual balance, standard deviation, maximum and minimum of balance. Fig. 7 illustrates the histogram of frequency distribution of depth of snow during the year 1972 obtained by stakes in the given network. From the data in Table 4 it may be recognized that the values of standard deviation differ little despite that the values of area-mean annual balance decrease with increasing elevation. Moreover, in spite of the occurrence of a large annual variation of balance at a given location, a significant annual

variation could not be found in standard deviation there. These observations indicate that the degree of fluctuation of a surface level due to the areal variability of balance is almost constant regardless of the amount of annual balance in the whole area characterized by strong katabatic winds around the Antarctic Continent. The area-mean annual balance calculated by the data of single stakes is considered to show a reasonable mean value of balance in the corresponding area.

The calculated average balance of 64 $kgm^{-2} a^{-1}$ over the Shirase basin is smaller than 150 $kgm^{-2} a^{-1}$ over the Sôya basin, because the area of the Sôya basin does not include the inland plateau above 2600 m a.s.l., where the balance is considerably lower than in the coastward area. According to up-to-date estimation by BULL, the balance over the whole Antarctic Continent was obtained as 155 ± 20 $kgm^{-2} a^{-1}$ (BULL, 1971), which is larger than that over the two basins studied. GIOVINETTO's estimation of balance over the drainage system, which includes the Shirase and the Sôya drainage basins, was 127 ± 33 $kgm^{-2} a^{-1}$ (GIOVINETTO, 1964). From these facts, the annual balance in East Antarctica is considered to be much smaller than that in West Antarctica.

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References

ABE, Y., YOSHIMURA, A. and NARUSE, R. (1978): Gravity anomalies and bedrock relief in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 37–43.

AGETA, Y. (1971a): Nankyoku no shitsuryô shûshi to kongo no kadai (Mass budget in Antarctica and its future problem). Seppyo (J. Jap. Soc. Snow Ice), **33**, 205–214.

AGETA, Y. (1971b): Higashi Nankyoku Mizuho Kôgen fukin no kishô jôtai ni tsuite (Some aspects of weather conditions in the vicinity of Mizuho Plateau, East Antarctica). Nankyoku Shiryo (Antarct. Rec.), **41**, 42–61.

AGETA, Y. and WATANABE, O. (1972): Net accumulation of snow by stake measurements in Mizuho Plateau, East Antarctica, 1968–71. JARE Data Rep., **17** (Glaciol.), 38–47.

BENSON, C. S. (1962): Stratigraphic studies in the snow and firn of the Greenland ice sheet. SIPRE Res. Rep., **70**, 1–93.

BLACK, H. P. and BUDD, W. (1964): Accumulation in the region of Wilkes, Wilkes Land, Antarctica. J. Glaciol., **5**, 3–15.

BULL, C. (1971): Snow accumulation in Antarctica. Research in the Antarctic. Washington, D.C., Am. Assoc. Adv. Sci., 367–421.

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, **7**, 1–27.

FUJIWARA, K. and ENDO, Y. (1971): Preliminary report of glaciological studies. JARE Sci. Rep., Spec. Issue, **2**, 68–109.

GIOVINETTO, M. B. (1964): The drainage systems of Antarctica: Accumulation. Antarctic Snow and Ice Studies, Washington, D.C., Am. Geophys. Union, 127–155 (Antarct. Res. Ser., **2**).

INOUE, M., YAMADA, T. and KOBAYASHI, S. (1978): Effects of synoptic scale disturbance on seasonal variations of katabatic winds and moisture transport into Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 100–114.

KATO, K. and WATANABE, O. (1977): Oxygen isotope profiles in firn cores from Mizuho Plateau, Antarctica. Nankyoku Shiryo (Antarct. Rec.), **58**, 254–262.

MÜLLER, F. (1962): Zonation in the accumulation area of the glacier of Axel Heiberg Island, N.W.T. Canada. J. Glaciol., **4**, 302–318.

NARUSE, R. (1972): Stratigraphic observation of the surface snow cover in Mizuho Plateau, East Antarctica, 1969–1970. JARE Data Rep., **17** (Glaciol.), 77–87.

NARUSE, R. (1975): Density and hardness of snow in Mizuho Plateau in 1969–1970. JARE Data Rep., **27** (Glaciol.), 180–186.

NARUSE, R. (1978): Surface flow and strain of the ice sheet measured by a triangulation chain in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 198–226.

OKUHIRA, F. and NARITA, H. (1978): A study of formation of a surface snow layer. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 140–153.

SATOW, K. (1977): Net accumulation of snow in measured (in 1974–1975) by stake method. JARE Data Rep., **36** (Glaciol.), 36–58.

SHIMIZU, H., YOSHIMURA, A., NARUSE, R. and YOKOYAMA, K. (1978a): Morphological feature of the ice sheet in Mizuho Plateau. Mem. Natl. Inst. Polar Res., Spec. Issue, **7**, 14–25.

SHIMIZU, H., WATANABE, O., KOBAYASHI, S., YAMADA, T., NARUSE, R. and AGETA, Y. (1978b): Glaciological aspects and mass budget of the ice sheet in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 264–274.

WATANABE, O. (1972): Stratigraphic observation of the surface snow cover in West Enderby Land, East Antarctica, 1970–1971. JARE Data Rep., **17** (Glaciol.), 88–110.

WATANABE, O. (1975): Density and hardness of snow in Mizuho Plateau-West Enderby Land in 1970–1971. JARE Data Rep., **27** (Glaciol.), 187–235.

WATANABE, O. (1977): Stratigraphic observations of surface snow cover. JARE Data Rep., **36** (Glaciol.), 61–125.

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

WATANABE, O. (1978b): Stratigraphic studies of the snow cover in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 154–181.

YAMADA, T. (1975): Stratigraphy of snow cover in Mizuho Plateau in 1971–1972. JARE Data Rep., **27** (Glaciol.), 68–83.

YAMADA, T., NARITA, H., OKUHIRA, F., FUKUTANI, H., FUJISAWA, I. and SHIRATSUCHI, T. (1975): Net accumulation of snow by stake measurement in Sôya Coast-Mizuho Plateau in 1971–1973. JARE Data Rep., **27** (Glaciol.), 10–67.

YAMADA, T., OKUHIRA, F., YOKOYAMA, K. and WATANABE, O. (1978): Distribution of accumulation measured by the snow stake method in Mizuho Plateau. Mem. Natl Inst. Polar Res., Spec. Issue, **7**, 125–139.

YOKOYAMA, K. (1975): Net accumulation by stake measurements. JARE Data Rep., **28** (Glaciol.), 62–82.

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