Bulletin of Glacier Research 6 (1988) 55－63

Some remarks on the mass balance and the terminal-lateral fluctuations of San Rafael Glacier, the Northern Patagonia Icefield

Hiroshi KONDO[1] and Tomomi YAMADA[2]

1 Disaster Prevention Research Institute, Kyoto University, Uji 611 Japan. Present address : Japan Weather Agency, 3－16－11, Higashiimazato, Higashinari, Osaka 537 Japan
2 Institute of Low Temperature Science, Hokkaido University, Sapporo 060 Japan

(Received December 24, 1987 ; Revised manuscript received January 26, 1988)

Abstract

For the purpose of studying the mass balance of the glacier and its relations to meteorological elements, meteorological and glaciological observations were carried out in summer of 1985－86 on San Rafael Glacier, the Northern Patagonia Icefield. From the terminus to the icefield area of the glacier, the surface balance were measured by the stake method. For estimating the surface accumulation, empirical equations of relations between the probability of the occurrence of solid precipitation and surface air temperature are derived. Surface ablation is obtained as the residual value of the surface balance and accumulation. Little accumulation and heavy ablation occured in the lower part of the glacier in summer, while both accumulation and ablation occured on the icefield area of the glacier. As a part of estimating the amount of ablation due to calving of the glacier, flow velocities of the surface were measured near the terminus. Large velocities of 17－22 m/day was found out. The terminal and lateral fluctuations of the glacier near the terminus were obtained during the period from January, 1984 to February, 1986. The terminal position retreated in 190 m. The lateral positions lowered vertically in 20－30 m and rtreated transversely in 20－50 m.

1. Introduction

Glaciers in Patagonia are characterized by considerably large amount of accumulation and ablation due to heavy precipitation and warm climate. In this region, climate tends to vary greatly from year to year, and large amount of glacier fluctuations have been known (e.g. Lliboutry, 1956 ; Mercer, 1962). However, the response of glaciers to the local climatic change is still remained unknown, since routine meteorological station and meteorological and glaciological informations on glaciers are lacking in such a remote region.

Since November 1981, the Chilian Air Force has made year-round meteorological observations at the station 3 km far from the terminus of San Rafael Glacier which is an outlet glacier located in the northwestern side of the Northern Patagonia Icefield. The glacier on which routine meteorological data are available in its neighborhood, such as San Rafael Glacier, is only one in Northern Patagonia Icefield. For the purpose of studying the mass balance and its fluctuations due to the local climatic change, we made glaciological and meteorological observations on San Rafael Glacier in summer of 1985－86. Those were carried out as successive investigations after the ones conducted in summer of 1983－84 (Nakajima, 1985).

The glacier is approximately 45 km long and 25 km wide in maximum, as shown by the topographical map in Fig.1. The total glacier area is about 7.8×10^2 km^2. Altitudinal distribution of the area is shown also in Fig.1. Approximately 55 % of the total area is a

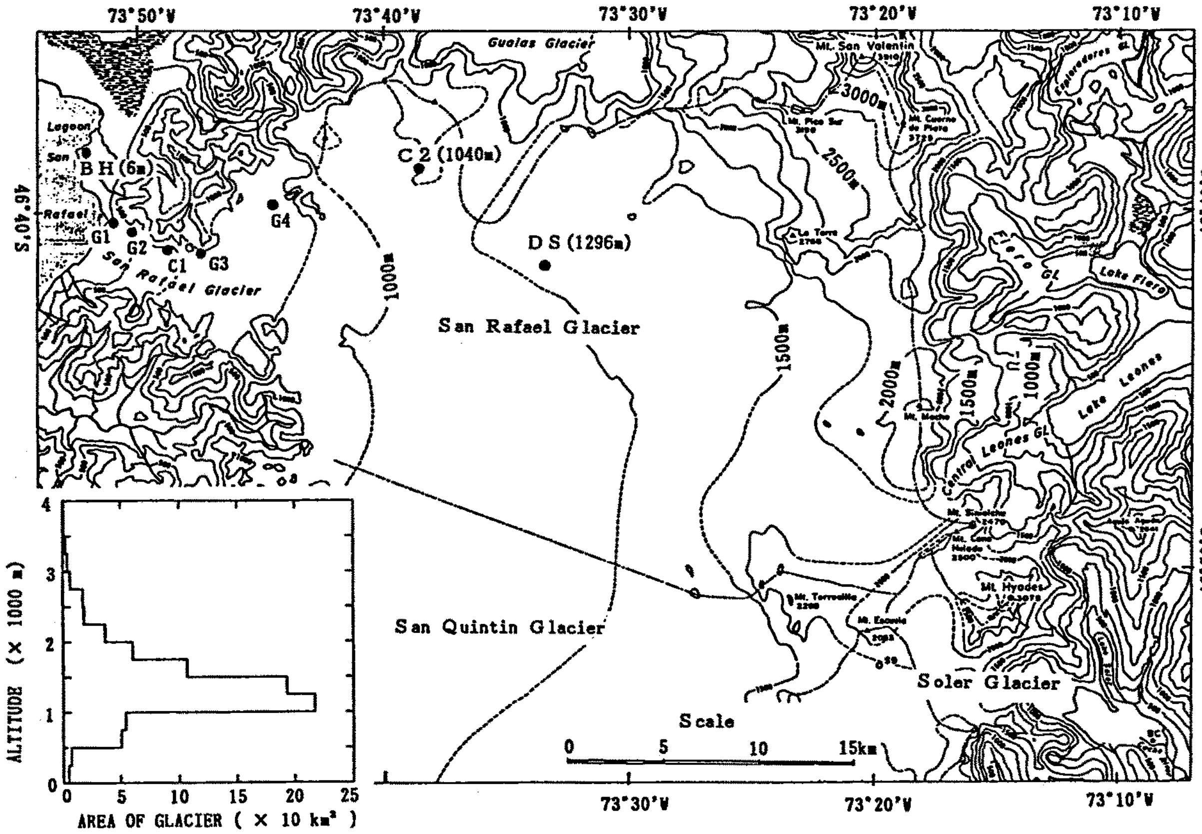

Fig. 1. Topographical map of San Rafael Glacier and the altitudinal distribution of the glacier area.

relatively flat and little inclined region between the altitude of 1000 m (a.s.l.) and 1500 m, which is called as the icefield. The area above 2000 m is a relatively steep mountainous region occupying about 10 % of the total area. The area below 500 m is a valley glacier region occupying only less than 2 % of the total area. The terminus of the glacier is calving into the sea. Due to the large portion of the icefield area to the whole glacier area, the total amount of surface accumulation and ablation in the area of the icefield must play an important role to the total amount of those in the whole glacier.

In the previous investigation, characteristics of the surface ablation in early summer were studied mainly in the valley area of San Rafael Glacier, and the ablation due to calving is supposed to occupy considerable part of the total ablation (Ohata et al., 1985a). However, observations of accumulation and ablation on the icefield were insufficient due to the logistic difficulties of getting to the area.

The present investigation aimed to get the surface mass balance data on the icefield during the heaviest ablation season. In this report, we describe the surface mass balance components observed on the glacier in summer. By analizing the relations of the observed surface accumulation to the observed meteorological elements, we derive the empirical equations with which the surface accumulation can be estimated. In order to get the basic data for estimating the amount of ablation due to calving, flow velocities of the glacier surface were measured near the terminus. The change in the terminal and lateral positions of the glacier is also reported from the results of two successive measurements in January, 1984 and in February, 1986.

2. Observations

Meteorological and glaciological observations were carried out from October 20, 1985 to February 6, 1986. The sites, their altitudes, durations and elements of the meteorological observations are tabulated in Table 1, as well as the mean values of each element in each duration. Locations of the sites are shown in Fig.1 by the symbols in Table 1. The details of the methods and results of the meteorological observations were reported by Inoue et al. (1987). The meteorological station of the Chilean Air Force is marked by BH in Fig.1.

Observations of the surface mass balance were made by the stake method at the sites from G1 to DS. The altitudes and surface albedos of each stake site are summarized in Table 2. Surface of the glacier was bare ice below G4 and covered with snow above C2 for almost all of the observation period. Locations of the stake sites are also shown in Fig.1 by the symbols in Table 2. Measurements of snow stakes were made every several days. Flow velocities of the glacier were measured near G1. Some meteorological data observed in December, 1983 (Ohata et al., 1985b) were also used for deducing the relations of the surface accumulation to meteorological elements.

3. Surface mass balance

3.1. Balance

Figure 2 shows the variations of the mean daily surface balance in water equivalent averaged over the each duration between two successive stake measurements at each site. For the calculation of the balance in water equivalent, we assumed the ice density as 0.85 Mg/m^3, and the snow density as 0.5 Mg/m^3 except for DS as 0.4 Mg/m^3. These values of snow density were measured in December and January at C2, and in November at DS.

The balance averaged over the each duration of the stake measurements was negative throughout the observation period at the sites below G4, and was occasionally positive at C2. The values of the balance decreased from early-summer to mid-summer ; i.e.

Table 2. The altitudes, albedos and the dominant surface conditions of the stake sites along San Rafael Glacier. The altitudes of the stake sites G1, C1 and C2 are not equal to those in Table 1, because the points of the stakes were not exactly same as the points of meteorological observations. *mean of 2 stakes, **mean of 10 stakes.

Stake site	G1	G2	C1*	G3	G4*	C2**	DS
Altitude(m)	79	214	426	580	680	1034	1296
Albedo	0.1	0.2	0.2	0.2	0.4	0.7	
Surface condition	ice	ice	ice	ice	ice	snow	snow

Table 1. The sites, their altitudes, durations, elements and averaged values of the meteorological observations along San Rafael Glacier from October 1985 to February 1986. Temperature lapse rate means the value between BH and each station. The large value between BH and G1 is due to the cold downward glacier wind dominated in the valley area. (R : automatic recording, M : meter reading or visual observation, I : integrating meter)
*year-round observatory operated by the Chilean Air Force.
**No record during the DS observation.

Sites Altitude(m)	BH* 6	G1 89	C1 422	C2 1040	DS 1296
Duration		Oct. 24 -Feb. 6	Oct. 20 -Feb. 6	Oct. 26 -Feb. 1	Nov. 16 -Dec. 2
Atmos. Pressure	R	—	—	R**	R
Air Temperature	R	R	R	R**	R
Relative Humidity	R	R	R	R	R
Wind	M	R	M	M	M
Precipitation	M	M	R	R	M
Global Radiation	I	I	I		
Weather	M	M	M	M	M
Atmos. Pressure(mb)	1015.2	—	—	895.1	
Air Temperature(℃)	10.4	8.5	7.8	4.9	
Temp. Lapse Rate(℃/100m)	—	2.3	0.63	0.53	
Relative Humidity(%)	83	79	85	84	
Specific Humidity(g/kg)	6.4	5.3	5.7	4.9	
Vapor Pressure(mb)	10.49	8.69	8.86	7.06	
Global Radiation(MJ/m^2)	14.8	15.1	15.4	—	

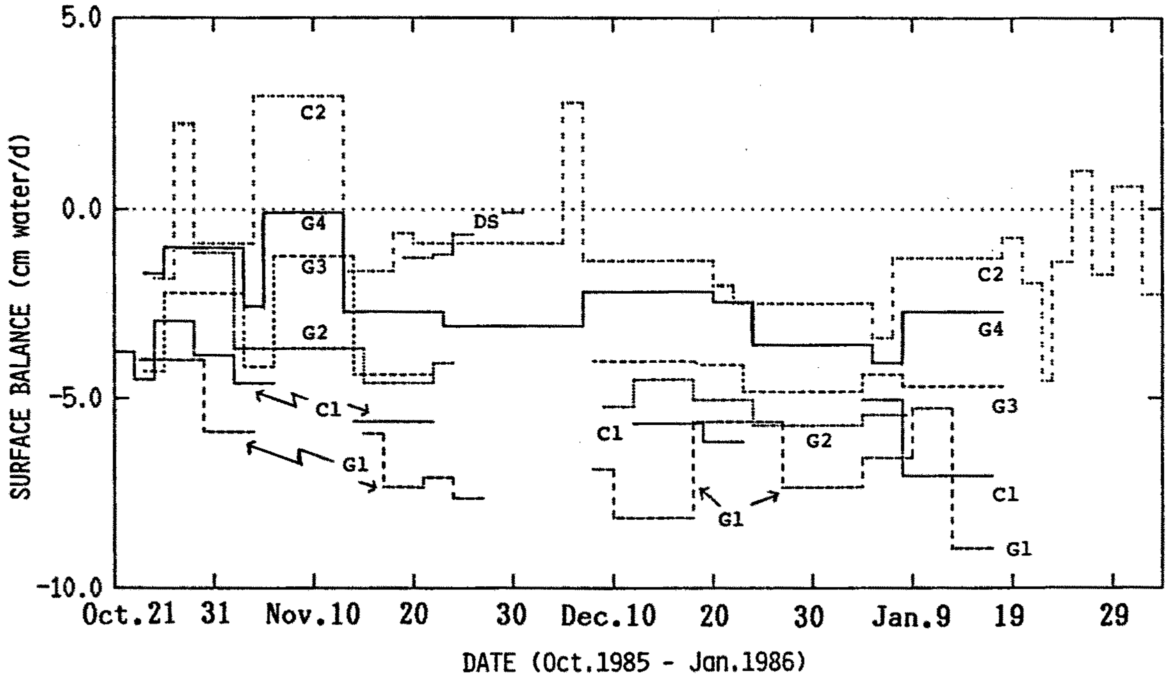

Fig. 2. Mean daily surface balance at the stake sites from G1 to DS in water equivalent.

from October to January. Such decreasing tendency with the time lapse in the observation period is larger at the sites above G3 than at the sites below G2. This is due to the facts that both the decrease of accumulation and the increase of ablation occurred with the time lapse at higher sites, whereas only ablation increased at lower sites, as to be described in the following sections.

3.2. Accumulation

In general, solid precipitation occurs even when the surface air temperature is above 0 °C. Mean surface air temperature at C2 during the whole observation period was 4.9 °C, as shown in Table 1. While both solid and liquid form precipitation occurred in summer over the icefield, the distinction of the amount of solid precipitation from total precipitation is difficult without continuous and visual observations.

In such a warm condition, the probability of the occurrence of solid precipitation above melting point should be known for estimating the amount of surface accumulation (Ageta and Higuchi, 1984). The probability is highly related to the air temperature near the surface, types of precipitation particles such as the shape and density (Higuchi, 1977), and humidity near the surface (Matsuo et al., 1981). Since the vertical profile of air temperature near the surface varies depending on the time whether in daytime or in night, the probability also depends on the time (Ageta et al., 1980). It is also found to be different from region to region (e.g. Ageta and Higuchi, 1984).

Surface relative humidity observed during the precipitation was almost always high such as 80–100 %. Therefore, we obtained relations of the probability to surface air temperature in daytime (9h–21h in local time) and in night (21h–9h) separately, from the data of precipitation form (solid or liquid) and surface air temperature obtained on the glacier in summer of 1983–84 and 1985–86. Total number of such observations were 268 in daytime and 186 in night. Each probability was obtained deviding the number of the occurrence of solid precipitation by the total number of the occurrence of both precipitation forms at a certain air temperature range. Since the total numbers of such data in a fixed temperature range are not equal each other, we divided the air temperature range to include the same total number of such data each other.

Figure 3 shows the relations between the probability of the occurrence of solid precipitation (S %)

and the surface air temperature (T ℃). The probability was slightly higher in daytime than in night at the same air temperature. Following empirical equations were obtained from Fig.3 ;

$$
\begin{aligned}
&\text{daytime: (9h-21h)} \quad S=55\ln(4.5-T)+23 \quad \text{for } 0.4<T\leqq 2.5\\
&\qquad S=195\exp(-0.4T)-11 \quad \text{for } 2.5<T<7.1\\
&\text{night: (21h-9h)} \quad S=67\ln(3.8-T)+22 \quad \text{for } 0.6<T\leqq 1.9\\
&\qquad S=190\exp(-0.5T)-9 \quad \text{for } 1.9<T<6.1
\end{aligned} \tag{1}
$$

The probability of the present result is about the same as the result obtained at the coastal region along the Sea of Japan (Ito, 1944), and is higher than the result obtained at the terminus of a glacier in Shorong Himal, Nepal (Ageta et al., 1980).

Amounts of hourly solid precipitation during the observation period were estimated by eqs.(1) at G1, C1 and C2 where hourly air temperature and hourly amount of precipitation were observed. The amount of solid precipitation was negligible at G1. It accounts for 10 % of the total precipitation amount at C1 and 45 % at C2 in October–November, but less than 5 % at C1 and 15 % at C2 in December-January. A considerable amount of accumulation occurred in early summer at C2 and it decreased with the time lapse in the period, while the accumulation at G1 was negligible for the whole period.

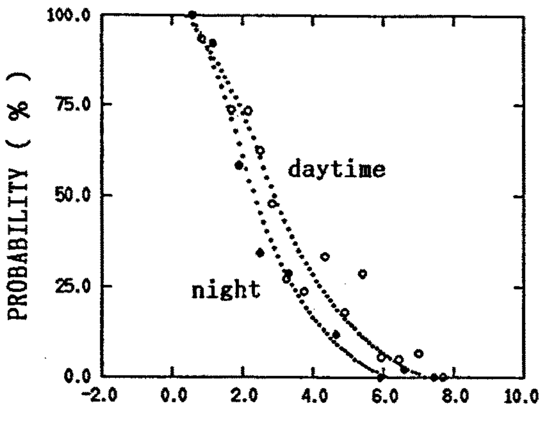

Fig. 3. Relations between the probability of the occurrence of solid precipitation and surface air temperature. Open circles are in daytime (9–21h in local time), solid circles in night (21–9h).

To estimate the surface accumulation for the whole year and in the whole glacier, we can utilize the meteorological data of Chilean Air Force at BH. Since they measure the precipitation amount at every 12 hours, from 9h to 21h and from 21h to 9h in next day, it is necessary to derive the relation between the percentage of the amount of solid precipitation against the total precipitation and the mean air temperature during every 12 hours. We derived the above relation using the hourly data at C1 and C2. The amounts of solid precipitation for every 12 hours were obtained by summing up the hourly amount of solid precipitation calculated by eqs.(1).

The results are shown in Fig. 4. According to the present analyses, they are formulated by the same equations as eqs.(1). This means that there seems to be no particular bias of the distribution of air temperature in time of precipitation to the mean air

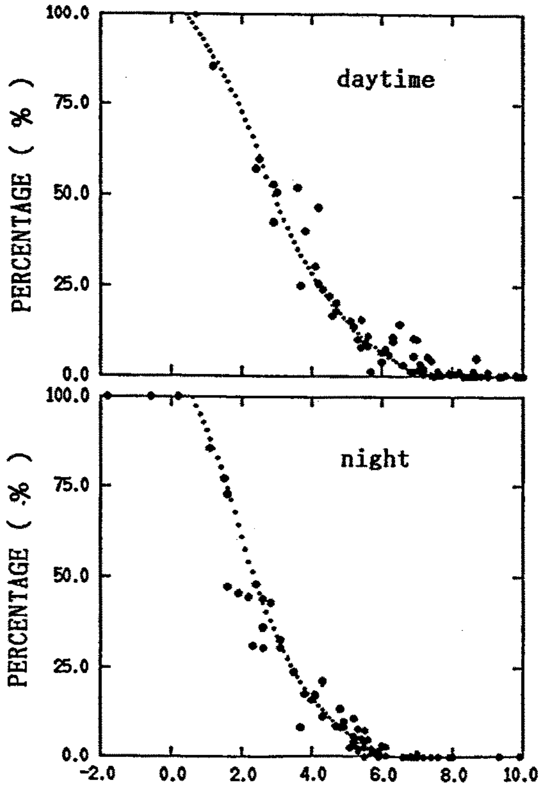

Fig. 4. Relations between the percentage of the amount of solid precipitation against the total precipitation and the mean air temperature during every 12 hours at C1 and C2. Upper is in daytime (9–21h in local time), lower is in night (21–9h).

temperature in each 12 hours' duration. In other words, the relations obtained from instant observations as shown in Fig.3 hold same for the 12 hours' mean conditions.

Now we could estimate the surface accumulation over the glacier using eqs.(1), if we could know the precipitation amount and surface air temperature on the glacier. Further studies of a relation of precipitation amount between BH and any place on the glacier, and a temperature lapse rate between the same places are necessary in whole year for the estimation of the annual surface accumulation. Seasonal change of the relations between the percentage of the amount of solid precipitation and surface air temperature should also be studied.

3.3. Ablation

Surface ablation was obtained as the residual value of the surface balance observed and the surface accumulation calculated at each site. Figure 5 shows the mean daily ablation in water equivalent averaged over the each duration of the stake measurements.

The figure shows that the area where ablation occurs in summer extended up to the high altitude on the icefield. Mean daily ablation was −5.9 cm at G1 and −4.7 cm at C1 in October-November, and −6.9 cm at G1, −6.2 cm at C1 and −2.6 cm at C2 in December-January. The amount of surface ablation in mid-summer is about three times larger near the terminus of the glacier, the site G1, than at the lowest altitude on the icefield, the site C2. Broken line in Fig. 5 represents the possible maximum daily ablation against the altitude averaged during several days. It suggests that the surface ablation could occur up to the area at the altitude of about 2000 m (a.s.l.) in summer.

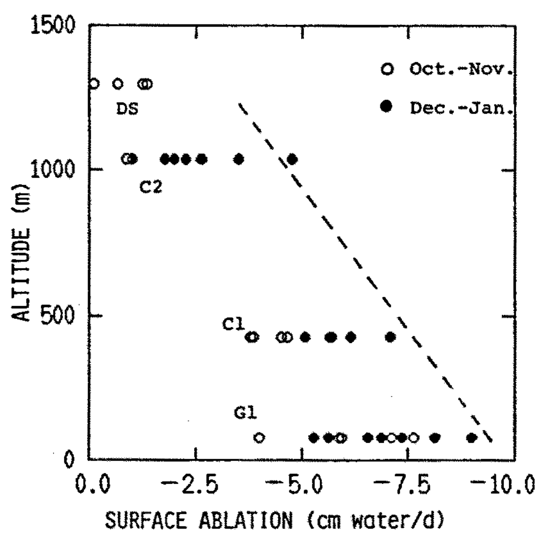

Fig. 5. Mean daily surface ablation at G1, C1, C2 and DS in water equivalent. Broken line represents the possible maximum daily ablation against the altitude averaged during two successive stake measurements of sevaral days' interval.

4. Flow velocity near the terminus

Calving of ice occurred many times a day from the glacier terminus during the observation period. The amount of calving is regarded as nearly equal to the ice flux through the transversal section near the terminus. We can estimate the amount of calving from the flow velocity, the transversal sectional area and the density of ice mass near the terminus of the glacier.

Surface flow velocities near the terminus of San Rafael Glacier were measured for three days in November, 1983 (Naruse, 1985) and for two weeks in December, 1983 (Ohata et al., 1985a). They observed the large values of flow velocities as 14−18 m/day, but the data were obtained from the measurements for short periods only. As a part of estimating the amount of calving, we measured the surface velocities near the terminus of the glacier from October, 1985 to January, 1986.

The method of the measurements was as follows ; We chose remarkable seracs as the markers on the glacier, since we could not approach to the center of the glacier surface near the terminus due to countless crevasses and seracs. Their positions were measured with a transit from two datum points near G1 with a base line of 254 m along the right bank. We set up an automatic 35 mm camera at one datum point in the fixed direction, and took pictures of the seracs two or four times a day continuously. This procedure was repeated for seven seracs. Assuming the flow direction as parallel to the banks, we obtained the surface flow velocities from the change in the positions of the seracs. Estimated error of the velocities was less than 2 m/day.

Table 3 shows the positions and the measured durations of seven seracs. Distances between the seracs and the right bank are one third or one fourth of the glacier width. Mean daily flow velocities of each serac during each duration are also shown in Table 3. Their values are 17−22 m/day, which are larger than the previous results of this glacier.

Figure 6 shows the daily and the mean daily flow velocities of the seven seracs. The flow velocities of S2 and S3 were smaller than those of S5, S6 and S7. The positions of the latter seracs were 200−300 m nearer to the terminus than the former seracs. The most probable cause is the difference of the longitudinal positions of the seracs, since the velocity of this glacier was found out to increase toward the terminus (Naruse, 1985).

However, the velocity of S4 was larger than that of S3 in spite of the longitudinal position of them being almost the same. Naruse (1987) deduced the contribution of the basal sliding to the glacial flow in Soler Glacier, an outlet glacier in the eastern side of the icefield. During the measurement of flow velocity of S4, surface ablation at G1 was the largest among the seven durations of the measurements, as can be seen in Fig.2. The increase of the velocity with the time lapse from S3 to S4, whose longitudinal positions were almost the same, seems to agree with the increase of the amount of surface ablation for each corresponding duration. A large amount of melting water may contribute to a basal sliding also in San Rafael Glacier.

The flow velocity near the terminus seems to depend on both longitudinal positions and the amount of melting water. The influence of the difference of transversal positions was not clear among the seven seracs.

Table 3. The positions, measured durations and the mean daily flow velocities of the seracs (S1-S7) used for markers of the measurements of flow velocities in San Rafael Glacier. A: transversal distance from the right bank, B: longitudinal distance from the terminus on the first day of each duration.

Serac	A (m)	B (m)	Duration	Flow velocity (m/day)
S1	788	253	Oct. 19-Oct. 26	22
S2	1004	460	Oct. 30-Nov. 8	17
S3	998	317	Nov. 14-Dec. 5	20
S4	841	323	Dec. 11-Dec. 21	22
S5	714	147	Dec. 24-Dec. 30	21
S6	880	161	Jan. 1-Jan. 7	22
S7	909	90	Jan. 10-Jan. 14	22

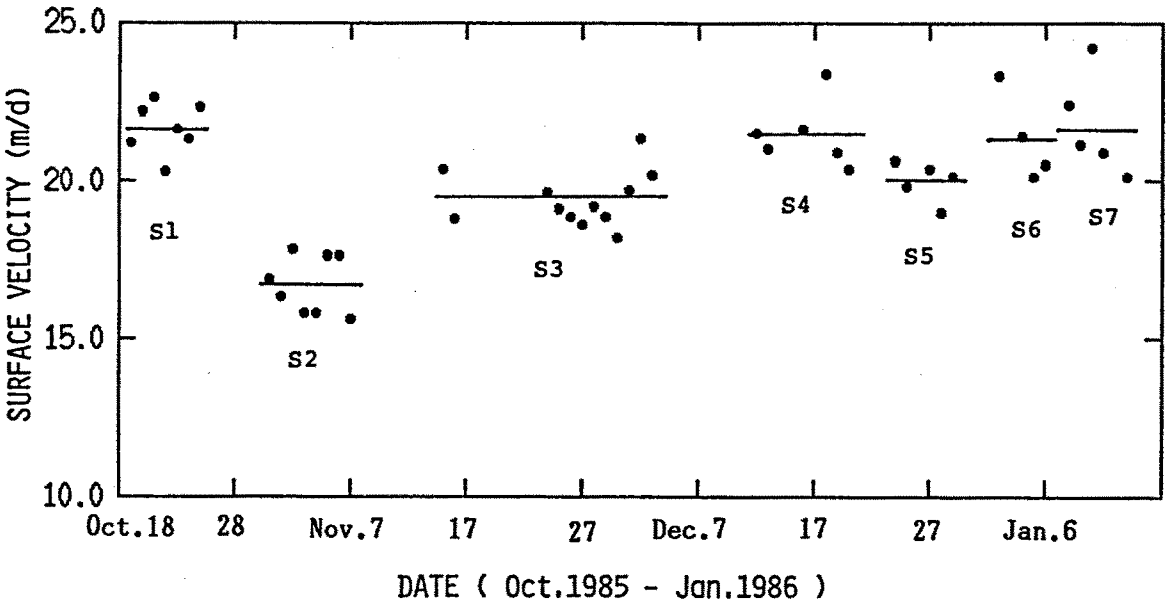

Fig. 6. Daily surface flow velocities near the terminus of San Rafael Glacier. Horizontal bar shows the mean value of each measurement of a serac (see text).

5. Glacier fluctuation near the terminus

We marked the terminal and lateral positions along the right margin of the glacier on the bedrock at eight points from the terminus up to 2 km distanse on January 4, 1984. The marks were remeasured on February 6, 1986. Table 4 shows the vertical lowering and horizontal (longitudinal or transversal) retreat of the marginal positions of the glacier at the measured points. The point M5 is near the site G1 and M8 is 2 km far from the terminus.

The marginal positions lowered and retreated at all measured points. The values of the vertical lowering were 20−30 m during only two years' period, and they decreased toward the terminus. The values are larger than the value of 40 m estimated by Aniya and Enomoto (1985) on this glacier for forty years from 1944 to 1984. The values of the transversal retreat were 20−50 m, and they increased toward the terminus conversely to the lowering. Although the marginal data cannot be extended directly to the whole ablation area, the glacier in the valley is evidently found out to be shrinked.

The value of the longitudinal retreat of the terminus was 190 m during the two years. This value is fairly larger than the fluctuations observed in other glacial regions (e.g. Aniya and Enomoto, 1985). Such large fluctuation of the terminus occurred frequently on this glacier in the past. Table 5 shows the fluctuations of the terminus of San Rafael Glacier for the last 200 years evaluated by various investigations (e.g. Liboutry, 1956). Large advance and retreat have been found out on this glacier. Mean annual retreat was accelerated from 1940 to 1984, however the acceleration is not seen in the last two years.

Table 4. Lowering and retreat at the right margin of San Rafael Glacier during two years from January 4, 1984 to February 6, 1986. M1 is the terminus in 1984, R5 near G1 and M8 2 km far from the terminus.

Measured point	Lowering (m) (vertical)	Retreat (m) (horizontal)
M1		191 (longitudinal)
M2		111 (〃)
M3	18	47 (transversal)
M4	20	41 (〃)
M5	27	42 (〃)
M6	30	27 (〃)
M7	33	24 (〃)
M8	20	20 (〃)

Table 5. Mean annual fluctuations of the terminus of San Rafael Glacier for the last 200 years. positive: advance, negative: retreat.

Duration	Fluctuation (m/year)	Literature
1766-1871	80	Brüggen cited by Vildosola (1981)
1871-1905	−30	〃
1905-1935	−200	Lliboutry (1956)
1935-1945	200	〃
1940-1958	little	Lawrence cited by Mercer (1962)
1944-1974	−20	Aniya and Enomoto (1986)
1974-1984	−200	〃
1984-1986	−100	present authors

6. Concluding remarks

Surface balance was observed by the stake method both in the valley and the icefield area of the glacier. The empirical equations were derived for estimating the surface accumulation in rather warm area where solid precipitation frequently occurs in the surface air temperarure above 0 ℃. The equations show relations between the probability of the occurrence of solid precipitation and the surface air temperature, and also between the 12 hours' amount of solid precipitation and 12 hours' mean air temperature. Surface ablation was obtained as the residual value of the balance observed and accumulation calculated. A considerable amount of surface accumulation occurred on the icefield even in summer, and surface ablation occurred simultaneously on the icefield. Large flow velocity of the glacier near the terminus (17−22 m/day) were measured for three months in summer. The fact indicates that the ablation due to calving could occupy a large part of the total ablation of the glacier. On the other hand, relatively large terminal (190 m) and lateral (20−30 m in vertical and 20−50 m in transversal) retreats of the glacier were observed in the last two years.

It has been known generally as the conspicuous features of glaciers in Patagonia that the heavy accumulation and ablation, large flow velocities and remarkable fluctuations. And many of the outlet glaciers from the icefield are calving into the sea or lakes. However no synthetic studies about those important phenomena have been made except for San Rafael Glacier. In this report we described the preliminary studies of the surface mass balance together with the flow velocity concerning the calving and the glacier fluctuation, based on the data observed on the glacier.

Fujiyoshi et al. (1987) derived the relation of the precipitation amount between BH and the observation sites on the glacier. Inoue et al. (1987) obtained the temperature lapse rate in this area. Kondo and Inoue (1988) measuerd the heat balance on the icefield to study the ablation processes of the glacier. However, those works are regrettably limited in the area below C2 and also limited only in summer. The thickness of the calving ice mass can be êstimated from the water depth of the sea measured near the terminus of the glacier (Nakajima et al., 1987), and the terminal height of the glacier above sea surface. However, for estimating the annual amount of calving, seasonal change of the flow velocity of the glacier should be necessary, as well as a reasonable evaluation of a transversal sectional area and an apparent density of the ice mass which is filled up with many crevasses and seracs.

For the estimation of the accurate annual mass balance of the glacier including the ablation due to claving, more extensive observations are desired not only in summer but in winter including the whole altitudinal range of the icefield. Accomplishing the reasonable estimation of the mass balance, the continuous meteorological data at BH, near the terminus of the glacier, and the data of the past and current glacier fluctuations will be of great value for the study of the mass balance and the fluctuation of glaciers related to the local climatic change.

Acknowledgments

We would like to express our gratitude to National Corporation of Forests at Lagoon San Rafael for their accommodations throughout the observation period. This study was supported by the Grant-in-aid for Overseas Scientific Survey of the Japanese Ministry of Education, Science and Culture. The project title is "Glaciological Research Project in Patagonia, 1985–86" (Project numbers : 60041035 and 61043031).

References

Ageta, Y., Ohata, T., Tanaka, Y., Ikegami, K. and Higuchi,K. (1980) : Mass balance of Glacier AX010 in Shorong Himal, East Nepal during the summer monsoon season. Seppyo, **41**, special issue, 34–41.

Ageta, Y. and Higuchi, K. (1984) : Estimation of mass balance components of a summer-accumulation type glacier in the Nepal Himalaya. Geografiska Annaler, **66A**, 249–255.

Aniya, M. and Enomoto, H. (1986) : Glacier variations and their causes in the Northern Patagonia Icefield, Chile, since 1944. Arctic and Alpine Research, **18**, 307–316.

Fujiyoshi, Y., Kondo, H., Inoue,J. and Yamada,T. (1987) : Characteristics of precipitation and vertical structure of air temperature in the northern Patagonia. Bulletin of Glacier Research, **4**, 15–24.

Higuchi, K. (1977) : Effect of nocturnal precipitation on the mass balance of Rikha Samba Glacier, Hidden Valley, Nepal. Seppyo, **39**, special issue, 43–49.

Inoue, J., Kondo, H., Fujiyoshi, Y., Yamada, T. and Fukami, H. (1987) : Summer climate of the Northern Patagonia Icefield. Bulletin of Glacier Research, **4**, 7–14.

Ito, H. (1944) : Snowfall and air temperature (in Japanese). Tenkiyoho-Shiryo Shuroku.

Kondo, H. and Inoue, J. (1988) : Heat balance on the icefield of San Rafael Glacier, the Northern Patagonia Icefield. Bulletin of Glacier Research, **6**, 1–8.

Lliboutry, L. (1956) : Snow and Ice of Chile (in Spanish). University of Chile, Santiago, 471p.

Matsuo, T., Sasho, Y. and Sato, Y. (1981) : Relationship between types of precipitation on the ground and surface meteorological elements. J. Meteor. Soc. Japan, **59**, 462–476.

Mercer, J. H. (1962) : Glacier variations in the Andes. Glaciological Notes, **12**, 9–31.

Nakajima, C. (1985) : Outline of the Glaciological Research Project in Patagonia, 1983–1984. Glaciological Studies in Patagonia Northern Icefield. Data Center for Glacier Research, Japanese Society of Snow and Ice, 1–6.

Nakajima, C., Inoue, j., Fujiyoshi, Y. and Nagao, I. (1987) : Water depth of Lagoon San Rafael, Patagonia. Bulletin of Glacier Research, **4**, 103–105.

Naruse, R. (1985) : Flow of Soler Glacier and San Rafael Glacier. Glaciological Studies in Patagonia Northern Icefield. Data Center for Glacier Research, Japanese Society of Snow and Ice, 64–69.

Naruse, R. (1987) : Characteristics of ice flow of Soler Glacier, Patagonia. Bulletin of Glacier Research, **4**, 79–86.

Ohata, T., Enomoto, H. and Kondo, H. (1985a) : Characteristic of ablation at San Rafael Glacier. Glaciological Studies in Patagonia Northern Icefield. Data Center for Glacier Research, Japanese Society of Snow and Ice, 37–45.

Ohata, T., Kondo, H. and Enomoto, H. (1985b) : Meteorological observation at San Rafael Glacier. *ibid.*, 22–31.

Vildosola, M. (1981) : Program of interpretation in development of National Park Lagoon San Rafael (in Spanish). Corporacion Nacional Forestral, Puerto Aysen, Chile. 112p.