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Changes in glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994

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ABSTRACT. Glaciological investigations were carried out in 1994 on the glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, in order to make a comparison with observations made in 1974. Most of the glaciers were found to have
in terminus elevation
longest glacier in the valley, has retreated by about 200 m. The areal average amount of surface lowering and the volume loss of the glacier was estimated to be 12.6 m ice equivalent and 13% of the total mass, respectively. The annual mass balance of $-0.55\ \mathrm{m\ a^{-1}}$ water equivalent was obtained as an average for 20 years, which is one of the largest negative values amongst small glaciers of the world.

INTRODUCTION

The shrinkage of small glaciers and ice caps has significantly contributed to sea-level rise over
association with the recent warming. Meier (1984) estimated the average mass balance of glaciers in the Pamir–Karakoram–Himalayan region to be $-0.31\ \mathrm{m\ a^{-1}}$ water equivalent
was based on a relationship between mass balance and annual mass-balance amplitude. The amplitude for this region, however, was derived by reference only to two particular glaciers. Also, most of the glaciers in the Himalayas are of a summer-accumulation type: the major accumulation and ablation take place simultaneously during the summer. Their mass-balance regimes could therefore be different from those for winter-accumulation-type glaciers which are abundant in most regions throughout the world (Ageta and Higuchi, 1984).

Although several
termini in the Himalayas have been made (e.g. Mayewski and Jeschke, 1979; Fushimi and Ohata, 1980; Higuchi and others, 1980; Yamada and others, 1992; Kadota and others, 1993), long-term (a few decades) mass-balance data are limited. However,
in the region, it should be possible to estimate their average mass balances and examine their recent behaviour in the Himalayas.

Glaciological research work began on the glaciers in Hidden Valley, Mukut Himal, in 1974. During that work, mass balance, glacier flow and terminus elevations were observed (Fujii and others, 1976; Nakawo and others, 1976). In order to assess the changes in the glaciers over
20 years since 1974, we carried out fieldwork in October 1994 (Fujii and others, 1996) as part of the Cryosphere Research Expedition in the Himalayas (CREH).

In this paper, the average mass balance during the past 20 years has been estimated using CREH data and compared with several decadal scale mass-balance averages of glaciers throughout the world.

FIELDWORK IN 1974

Hidden Valley is located in the northern part of the central Nepal Himalayas (28°50′ N, 83°30′ E). The climatic conditions around the valley are very
1976; Nepal, Ministry of Water Resources, 1988). There are 11 glaciers in the valley and their locations are shown in Figure 1. With the exception of glacier G2, which is highly debris-covered in its ablation zone, the glacier surfaces are relatively smooth and debris-free.

The elevations of the termini of glaciers G2, G3, G4, G5, G7, G8, G9 and G10 were measured using an altimeter. Rikha Samba Glacier (G5), the longest glacier in the valley, was closely observed. Nakawo and others (1976) measured the transverse surface profile of the glacier along line A (near the terminus), along line C (around the equilibrium-line altitude (ELA)) and along lines D and E (in the accumulation zone) (Fig. 2). In addition, they made a detailed map of the terminus area by plane-table survey.

FIELDWORK IN 1994 AND RESULTS

In 1994, the termini of glaciers G2, G4, G5, G8, G9 and G10 were remeasured using a Thommen altimeter. The terminus altitudes obtained in 1974 and 1994 are compared in Table 1, where a retreating trend can be seen for glaciers G5, G8, G9 and G10. In contrast, glaciers G2 and G4 appear to have advanced. However, it is unlikely that the terminus of glacier G2 has moved lower, because no movement
ice was detected in 1974 (Nakawo and others, 1976). This condition is also implied by the presence of a thick debris cover. The terminus of glacier G4 is in contact with the terminus of glacier G5, with a medial moraine between them. Therefore, it is considered that the nominal advance

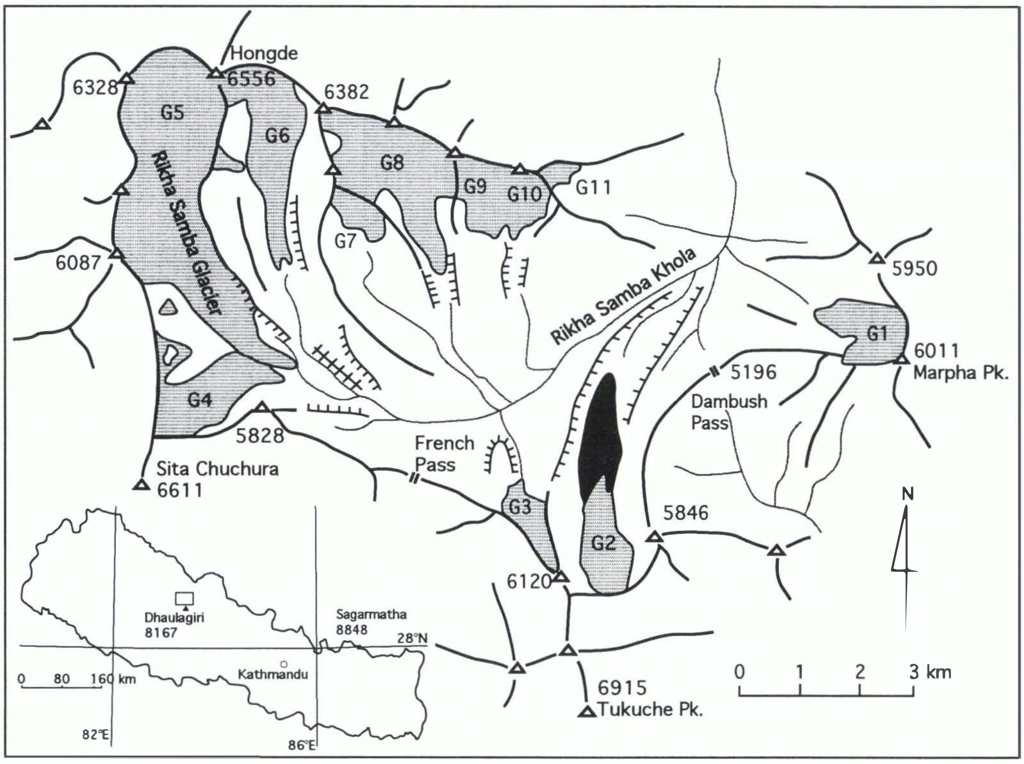

Fig. 1. Location of the glaciers in Hidden Valley, Mukut Himal. The shaded area denotes glaciers in Hidden Valley. The dark part of glacier G2 denotes the debris-covered area.

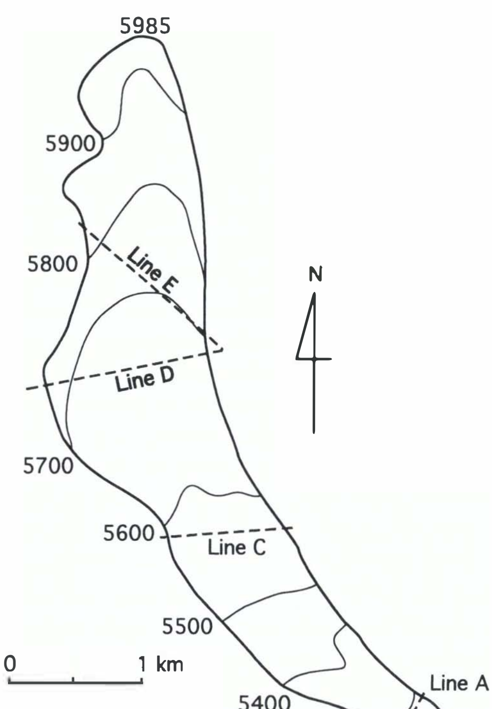

Fig. 2. Rikha Samba Glacier in 1974 showing the locations of the survey lines.

G4 could be due to shrinkage of glacier G5. Although the measurement was by altimeter, which uses air pressure and is not so reliable, the termini of the glaciers have apparently retreated and the bedrock has reappeared during the last 20 years as shown, for example, in Figure 3.

The terminus of Rikha Samba Glacier (G5) was resurveyed using a laser range-finder and theodolite (Wild T1600). Figure 4 shows maps of the terminus in 1974 (a) and in 1994 (b). The distance between benchmarks BM-A and BM-A0 were slightly different between the two sets of observations. The difference could be due to inaccuracy of the 1974 map, which was made by plane-table surveying. Nonetheless, Figure 4 shows clearly that the ice mass of the glacier near the terminus has disappeared in the 20 years between the surveys. Figure 5 shows the change in the surface profile along the longitudinal transect labeled X in Figure 4. It is clear that surface lowering of about 40 m and terminus retreat of about 200 m have taken place during 1974–94.

Table 1. Altitudes of glacier termini in 1974 and 1994 measured using an altimeter

Glacier	*1974* m a.s.l.	*1994* m a.s.l.	*Difference* m
G2	5043	5017	−27
G4	5350	5300	−50
G5	5245	5275	30
G8	5327	5362	35
G9	5499	5559	60
G10	5421	5480	59

The surface profiles along lines C (around the ELA), D and E (in the accumulation zone) were remeasured using the same survey instrument (Wild T1600), and the ice thickness was also measured using a 5 MHz radio-echo sounder. In the accumulation zone (lines D and E), the surface has lowered by 15–20 m during the past 20 years but no appreciable surface lowering was detected around the ELA (line C), as shown in Figure 6.

Figure 7 shows the change in surface elevation from 1974 to 1994 along the central flowline; the ice thickness obtained in 1994 and the areal distribution of the glacier in 1974 were digitized from Figure 2. The surface lowering above

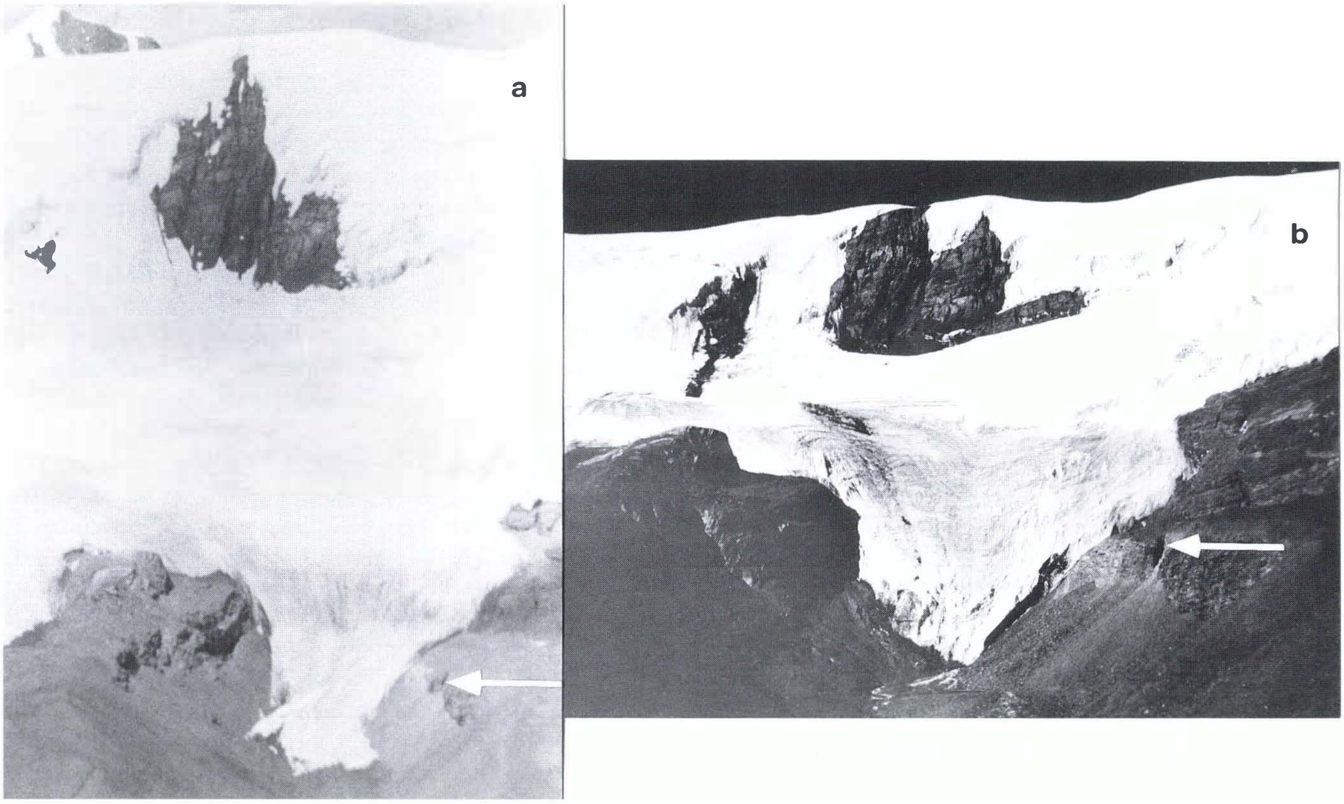

Fig. 3. *Photographs of glacier G10 in 1974 (a) and 1994 (b). In both photographs the arrows denote the same rock outcrop, although the places from which the photographs were taken are different.*

5700 m a.s.l. was assumed to average 10 m, because the thickness change could be reduced to zero at the uppermost point of the glacier from 20 m at line E. The average surface lowering for the whole glacier area is calculated to be 12.6 m

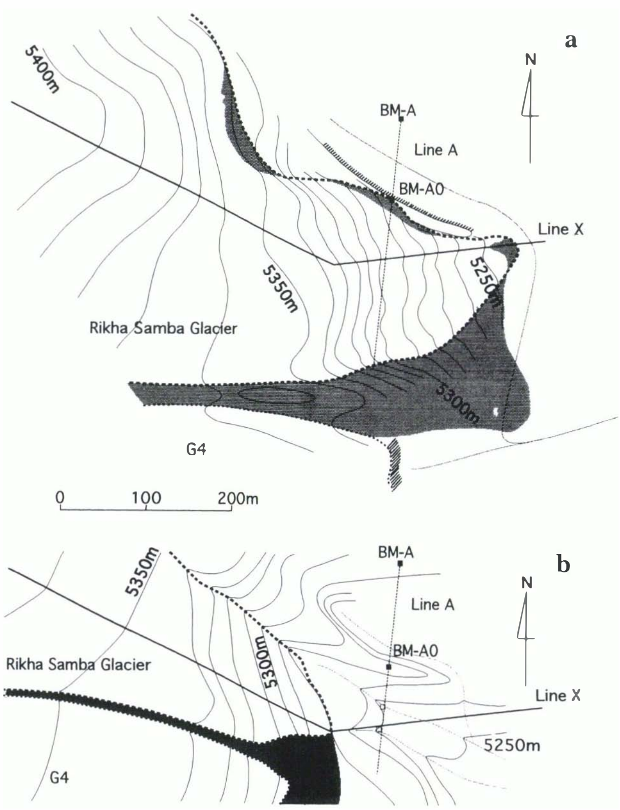

Fig. 4. Map of the terminus of Rikha Samba Glacier: (a) 1974, after Nakawo and others (1976), and (b) 1994, the present survey. Broken line, shaded area and solid squares represent the boundary of the glacier, debris-covered part and benchmarks, respectively, in each figure.

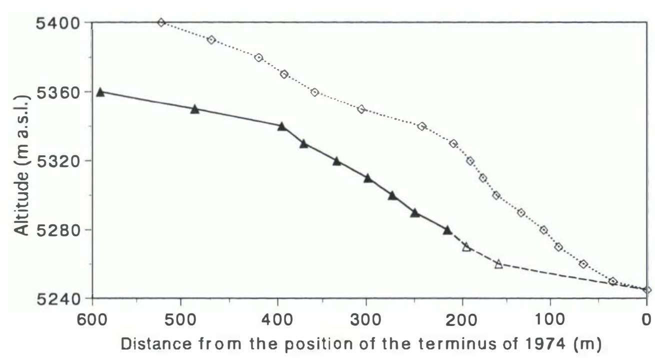

Fig. 5. Surface profile for 1974 (open squares), 1994 (solid triangles) and bedrock (open triangles) along line X near the terminus of Rikha Samba Glacier.

ice equivalent during the last 20 years. By assuming the ice depth, based on limited observational data, the total volume of the glacier is $46.2 \times 10^7\,m^3$ and the volume loss during 20 years is $6.0 \times 10^7\,m^3$ or 13% of the total volume.

The surface profiles measured in 1994 were very accurate (roughly ± 0.05 m) using a laser range-finder. For the 1974 observations, however, the error was estimated to be ± 0.45 m. Accordingly, the volume
be $(6.0 \pm 1.0) \times 10^7\,m^3$. However, the percentage volume loss would be associated with a larger error, because the still-undetermined ice thickness in the accumulation area as shown in Figure 7 would lead to greater uncertainty about the total ice mass of the glacier.

DISCUSSION

Figure 8 shows the average mass balance (m w.e. a^{-1}) of glaciers selected from IAHS (ICSI)–UNEP–Unesco (Müller, 1977; Haeberli, 1985; Haeberli and Müller, 1988; Haeberli

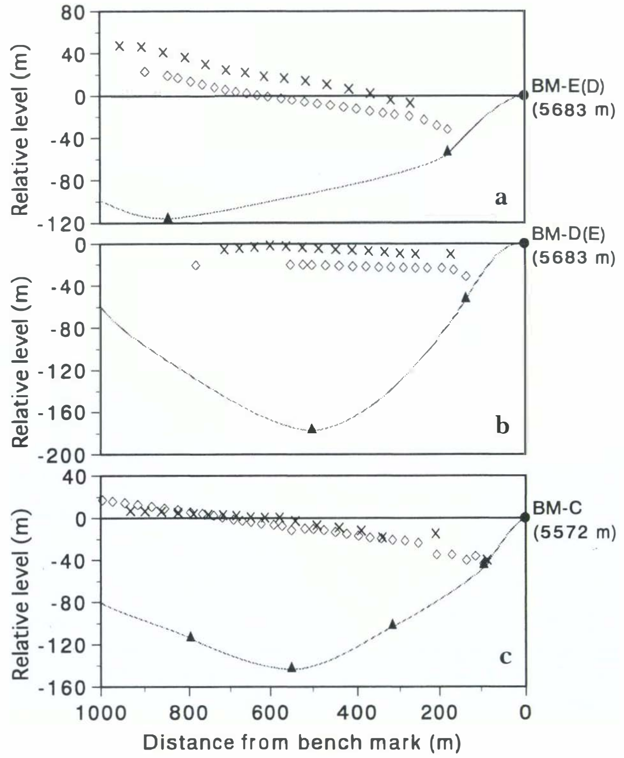

Fig. 6. Surface profiles for
and bedrock (triangles) along lines E (a) and D (b) in the accumulation zone and line C around the ELA (c) of Rikha Samba Glacier looking upstream. The solid circle denotes the

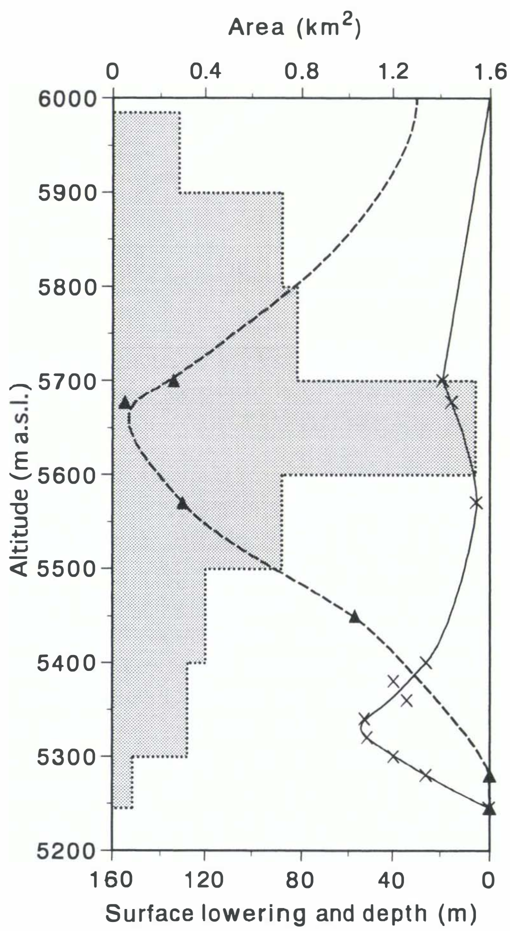

Fig. 7. Altitudinal distribution of the surface lowering (crosses) during 1974–94 and the ice depth (triangles) in 1994 along the central flowline and areal distribution in 1974 (shaded).

and Hoelzle, 1993), Glacier AX010 in Shorong Himal, east Nepal (Kadota and others, 1993), and Rikha Samba Glacier. All the mass-balance data are for the past 10–20 years, including the 1970s. Mass-balance data are not available for 26 glaciers including Rikha Samba Glacier. For those glaciers, the average annual mass balance was calculated from the difference in their volume during a certain period using an ice density of 870 kg m^{-3}.

This figure shows that the mass balance of Rikha Samba Glacier (-0.55 m w.e. a^{-1}) is one of the largest negative values amongst small glaciers in the world. The average mass balance of -0.55 m w.e. a^{-1} we obtained is also more negative than that estimated by Meier (1984; -0.31 m w.e. a^{-1}) for the Pamir–Karakoram–Himalayan region. It could indicate either that Meier's estimate was too small for this region or that the shrinkage of the glaciers in this region has accelerated during recent decades, since his estimate is for the past 100 years, whereas ours is for the past 20 years. Kadota and others (1993) have pointed out that glacier AX010 in Shorong Himal, east Nepal, had retreated drastically between 1989 and 1991 at a rate faster than in 1978–89. It is possible that shrinkage of Rikha Samba Glacier has recently accelerated.

Meier (1984) has discussed the mass-balance variation during the past 100 years by using a relationship between the annual mass-balance amplitude (a_m)and the long-term mass balance (b_l). He defined a_m and assumed a relationship between a_m and b_l as:

$$a_m = (b_w - b_s)/2 \tag{1}$$

$$b_l/a_m = -0.23 \tag{2}$$

where b_w is the winter balance and b_s (normally negative) is the summer balance. Winter and summer balances are respectively used instead of annual accumulation and ablation. In the Himalayan region, however, it is of little use to define winter and summer balances, because major accumulation and ablation occur simultaneously in the summer monsoon season (Ageta, 1983). It is therefore better to use the annual accumulation and ablation for b_w and b_s in Equation (1) in order to represent the mass gradient, an expression of climatic sensitivity of glaciers: (a) glaciers with a larger mass-balance gradient, which should have a larger a_m, are more sensitive to a change in ELA than smaller ones; (b) continental-type glaciers with a small a_m often have cold accumulation zones in which atmospheric warming does not lead to an increase in mass loss but to firn warming.

The relationship between a_m and b_l is examined using 51 selected glaciers from IAHS (ICSI)–UNEP–Unesco (Müller, 1977; Haeberli, 1985; Haeberli and Müller, 1988; Haeberli and Hoelzle, 1993) and AX010 from Kadota and others (1993) (Fig. 9). The time period considered for these data is more than 5 years, including the 1970s. The a_m for glacier AX010 and that for Rikha Samba Glacier were estimated from Ageta (1983) and Fujii and others (1976), respectively. Both glacier AX010 and Rikha Samba Glacier in the Himalayas showed very negative mass balances for corresponding annual mass-balance amplitudes (a_m).

It can be seen in Figure 9a that glaciers with a large a_m also show a large positive b_l, although those glaciers with a positive b_l are few. When b_l is negative, the negative correlation can be seen between b_l and a_m (Fig. 9b). The average values for the fraction b_l/a_m and the correlation coefficient for negative b_l are -0.28 and -0.55, respectively. The value

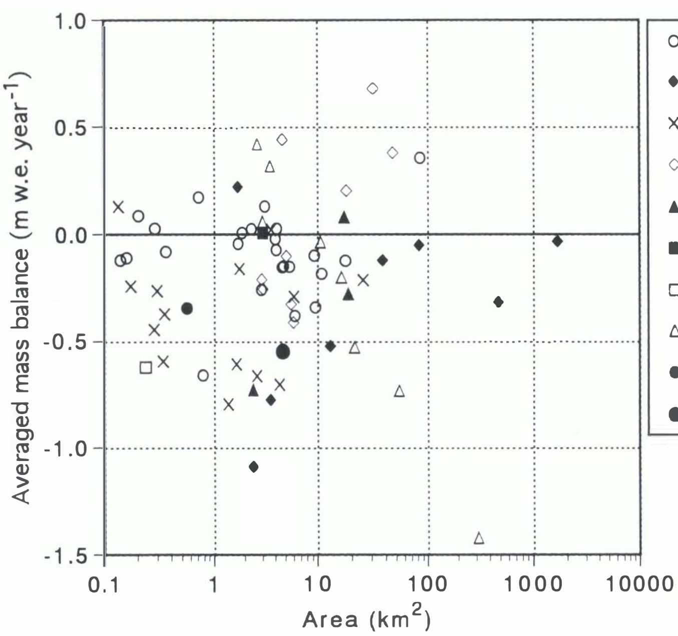

Fig. 8. The averaged mass balance for the last 10–20 years of 72 glaciers throughout the world.

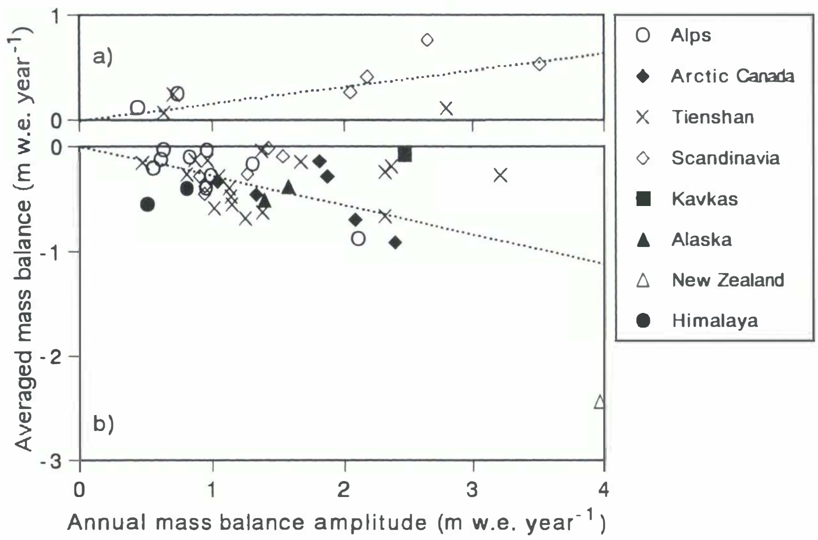

Fig. 9. The relationship between the annual mass-balance amplitude (a_m) and the average mass balance (b_l) during the recent few decades for 53 glaciers throughout the world. Each regression line is shown (a) for positive b_l (b_l/a_m is 0.16; R is 0.63) and for (b) negative b_l (b_l/a_m is −0.28; R is −0.55).

of −0.28 differs somewhat from but is similar to that of Meier (1984; −0.23) for the long-term trend. It would indicate that glaciers with a large a_m have
the recent warming.

Rikha Samba Glacier is a continental-type glacier having cold temperatures in the accumulation zone (−4.9°C at 23.25 m depth; 5740 m a.s.l.; Fujii and others, 1996) and its mass-balance amplitude is relatively small (a_m is 0.5 m w.e. a^{-1}; Fujii and others, 1976). The estimated 20 years mass balance, however, shows a large negative value (−0.55 m w.e. a^{-1}). Surface snow thickness of Rikha Samba Glacier was a few tens of centimeters, even in the accumulation zone (5740 m a.s.l.). Such a thin snow layer in the upper accumulation zone has also been observed in the central Tibetan Plateau (Fujita and others, 1996). Fujita and others (1996) suggested that such a thin snow layer is favorable to making ice cold in winter but has a disadvantage for accumulation; after complete melting of the thin surface-snow layer, surface ice with a lower albedo would start to melt drastically with strong solar radiation at a low latitude even at the upper accumulation zone. These glaciers would therefore have
though they belong to the continental type.

The b_l for Rikha Samba Glacier is one of the largest negative values in the world, although it has a relatively small a_m. Ageta (1983) has pointed out that the accumulation of the summer-accumulation-type glaciers would decrease drastically with an increase in summer temperature: the accumulation becomes small even
precipitation is very large, because the precipitation becomes rain with warmer conditions. So the mass balance would become largely negative
mulation as well as an increase in ablation for a warm summer. It is therefore considered that summer-accumulation-type glaciers would have a strongly negative mass balance even if accumulation and ablation (annual mass-balance amplitude) were to be small. The strongly negative mass balance found for Rikha Samba Glacier, in spite of the small annual mass-balance amplitude, could be attributed to the special characteristics of summer-accumulation-type

glaciers, although the average mass balance for a somewhat short time period may not be an expression of global climate change but of regional climate variability. The contribution of the Himalayan glaciers to sea-level rise could therefore be much larger than the previous estimate associated with recent global warming, because most of the glaciers in the Himalayas belong to the summer-accumulation type.

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