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Glaciological observations of Yala Glacier in Langtang Valley, Nepal Himalayas, 1994 and 1996.

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Abstract

A glaciological survey was carried out to clarify the variation of Yala Glacier in Langtang Valley, Nepal Himalayas, 1994 and 1996. It was clarified that the glacier terminus retreated drastically in 1990s rather than 1980s. The surface profile of the glacier also showed the rapid lowering in recent two years (1994 - 1996). The flow velocities of the glacier surface have decreased since 1982. These results mean that the shrinkage tendency of the glacier has been accelerated in 1990s.

Areal averages of mass balance, accumulation and ablation for a central drainage area along flow lines during the monsoon season in 1996 were obtained as -357, 588 and -945 mm w.e., respectively. It was confirmed that an empirical relation between air temperature and ablation, which was derived from the observation at another glacier in east Nepal in the previous study, could not be applied directly to Yala Glacier.

1. Introduction

Evaluation of glacier mass balance in the Himalayas is one of the most important problems associated with not only regional water resources but also global sea-level change. Although several results on the fluctuations of glacier termini in the Himalayas have been appeared (*e.g.* Mayewski and Jeschke, 1979 ; Fushimi and Ohata, 1980 ; Yamada *et al.*, 1992), long-term (a few decades) mass balance data are limited. However, by examining the volume changes of glaciers, it should be possible to estimate their average mass balances and to examine their recent behavior in the Himalayas. The volume changes of glaciers in the Nepal Himalayas have been investigated only with two cases of Glacier AX010 in Shorong Himal, east Nepal (Kadota, 1997 ; Kadota *et al.*, 1993, 1997) and Rikha Samba Glacier in Hidden Valley, west Nepal (Fujita *et al.*, 1997a). More case studies are needed to evaluate the relation between long-term mass balance of glaciers and regional climate change in the Himalayas comprehensively.

Yala Glacier in Langtang Valley is one of the most investigated glaciers in the Nepal Himalayas. The highest and lowest altitudes, and the area of the glacier are 5749 m and 5094 m a.s.l., 2.5 km^2, respectively. The glacier has wide spread shape and gentle slope (22°) facing southwest as shown in Fig. 1. Many glaciological research works have been carried out on Yala Glacier since 1981 (*e.g.* Higuchi, 1984 ; Watanabe and Higuchi, 1987 ; Yamada, 1989 ; Steinegger *et al.*, 1993 ; Nakawo *et al.*, 1997). Volume change of the glacier, however, has not been observed in these previous studies though the survey works related to the evaluation of volume change was carried out in 1982 (Ageta *et al.*, 1984). In order to assess the changes in the glacier since 1982, we carried out field survey in 1994 and 1996 as part of the Cryosphere Research Expedition in the Himalayas (CREH). Study for mass balance and meteorology through a monsoon season, which will provide a basic information to understand long-term glacier variation, has not been carried out on Yala Glacier. We also carried out the mass balance observations during the monsoon season of 1996 to

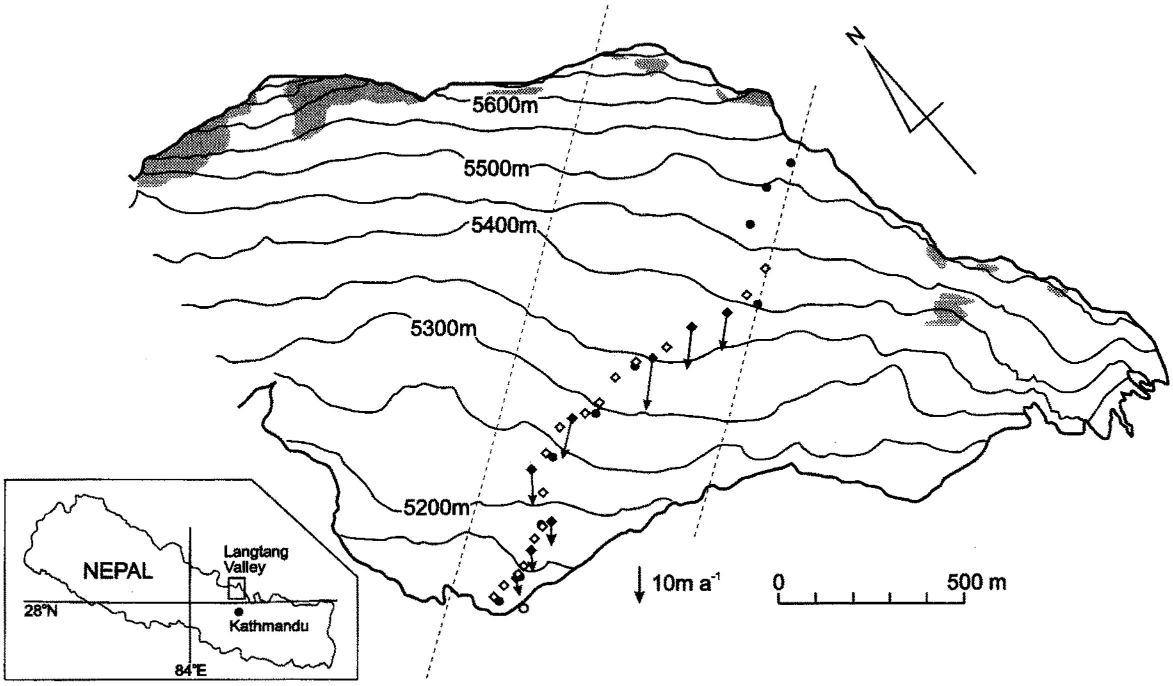

Fig. 1. Map of Yala Glacier surveyed in 1982 based on Yokoyama (1984). Shaded parts denote bared rock on the glacier. Open circle denotes the bench mark for the terminus change. Solid circles denote the stakes surveyed in 1982 (Ageta *et al.*, 1984). Open and solid squares denote the surveyed points for the comparison of surface profile and the stakes measured for mass balance and flow velocity in 1996, respectively. The arrows denote the surface flow velocities measured during the period from 22 May to 7 October, 1996. The areas between two broken lines are assumed as the representative areas for the calculation of surface lowering and mass balance.

obtain the basic data of mass balance. The preliminary results of the observations are presented in this report. The altitudes presented in the previous studies (Yokoyama, 1984 ; Fujita *et al.*, 1997b) are corrected by the traverse survey carried out in this study using the laser distance finder.

2. Observations and results

2.1. Variation of the glacier

2.1.1. Change in terminus

Surveys of the terminus were carried out in October, 1982 (Ageta *et al.*, 1984), September, 1994 and May and October, 1996. The change in the terminus periphery are shown in Fig. 2. The periphery observed in October, 1996 is shown as the result of 1996. Yamada *et al.* (1992) reported the variation of the terminus position from 1982 to 1989. The retreat rates

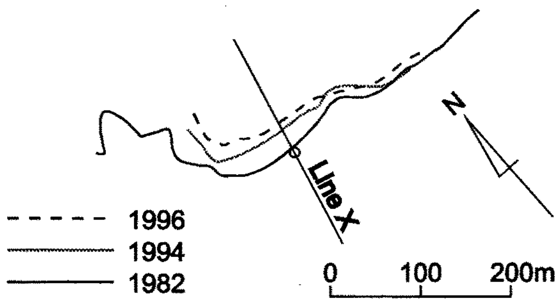

Fig. 2. The terminus peripheries of Yala Glacier in 1982 (solid line), 1994 (gray line) and 1996 (broken line). Open circle denotes the same bench mark shown in Fig. 1. Line X is assumed to be a representative axis for the terminus change through the bench mark, along which the retreat rates are summarized in Table 1.

of the terminus since 1982 along Line X are shown in Table 1. After 2.4 m advance during the first 5 years (1982 - 1987), the retreat rate of the terminus has increased gradually. Kappenberger *et al.* (1993) reported no significant changes in terminus position of Yala Glacier from 1980 to 1991 by the terrestrial photogrammetry. These results mean that the glacier terminus would have retreated rapidly in 1990s. Kadota (1997) also reported that the terminus positions of glaciers, which were measured in east Nepal, had retreated more rapidly in 1990s than in 1980s.

Table 1. Terminus retreat rates along Line X (Fig. 2) of Yala Glacier since 1982. Positive value denotes advance of the terminus position. Data from 1982 to 1989 are cited from Yamada *et al.* (1992).

Duration	Retreat rate (m a^{-1})
1982 - 1987 (5 years)	+0.5
1987 - 1989 (2 years)	−3.4
1989 - 1994 (5 years)	−3.9
1994 - 1996 (2 years)	−4.3

2.1.2. *Change in surface profile*

Figure 3 shows the change in surface profile since 1982 along the stake line shown in Fig. 1. The survey in 1994 was limited in the ablation zone. The figure shows that surface level around the terminus especially lowered. It is difficult to apply the lowering rates measured at the specific points toward edge of the wide spread glacier for the calculation of areal average. It was assumed, therefore, that the area at each altitude span and the glacier area were represented by the areas between the two broken lines shown in Fig. 1, which was a central drainage area along flow lines including the observed stakes. The averaged surface lowering rates are calculated as shown in Table 2 assuming the approximate linear relations shown in Fig. 3 and the areal ratio between the two broken lines in Fig. 1. The approximated surface level changes in 1994 and 1996 shown in Fig. 3 are assumed to be zero if they have positive value at higher altitude. Table 2 clearly shows the significant surface lowering of the glacier in a recent few years. Kadota (1997) clarified the surface lowering rates of Glacier AX010 in Shorong Himal, east Nepal as 0.71 m a^{-1} (1978 - 1991) and 1.14 m a^{-1} (1991 - 1996). The surface lowering rate of Rikha Samba Glacier in Hidden Valley, west Nepal was obtained as 0.63 m a^{-1} for the period from 1974 to 1994, though the detailed fluctuation is unknown (Fujita *et al.*, 1997a). These results

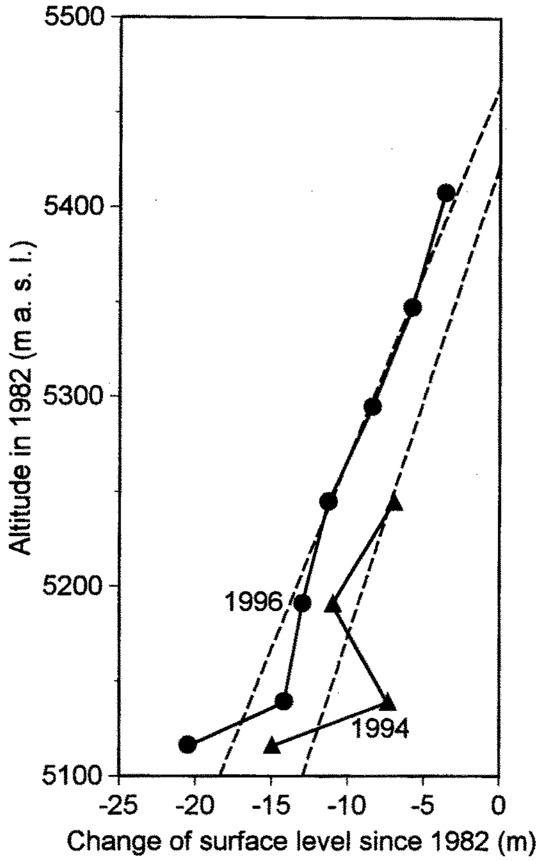

Fig. 3. Altitudinal distribution of the changes in surface profiles of Yala Glacier since 1982 along the stake line in Fig. 1. Triangles and circles denote the changes of 1994 and of 1996 since 1982, respectively. Negative value means that the glacier surface have lowered during a given period. Broken lines denote the approximated lines for each change. Averages of the surface lowering rates are summarized in Table 2.

Table 2. Averaged surface lowering rates of Yala Glacier since 1982.

Duration	Lowering rate (m a^{-1})
1982 - 1994 (12 years)	−0.31
1982 - 1996 (14 years)	−0.41
1994 - 1996 (2 years)	−1.05

show the recent rapid thinning of glaciers in the Nepal Himalayas, though examples are very limited.

2.1.3. *Change in flow velocity*

As results of stake surveys, flow velocity of the glacier surface was obtained for the period from 22 May to 7 October, 1996 (138 days). The horizontal velocity of each stake is shown in Fig. 1. Ageta *et al.* (1984) observed the surface velocity of the glacier for the period from 28 September to 27 October, 1982 (29 days). Although the season and the duration are different, the annual horizontal speeds are calculated assuming that the observed speeds were constant within an observed year in both observations (Fig. 4). Figure 4 suggests a significant decrease of the surface flow speed from 1982 to 1996. Kadota *et al.* (1997) also reported the significant decrease of the surface velocity on Glacier AX010 from 1978 to 1991. Seko *et al.* (1998) obtained that the flow speed of glacier surface in the debris-covered area of Khumbu Glacier has also decreased since 1950s. Although studies on temporal variation of glacier flow speed are few in the Nepal Himalayas, these three studies show the significant decrease of flow speed in recent few decades.

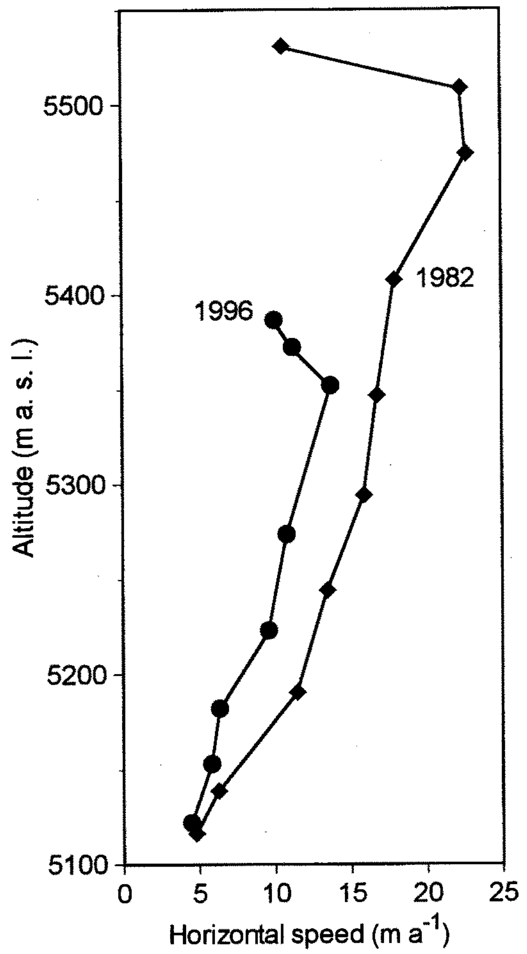

Fig. 4. Altitudinal distribution of the surface flow speeds surveyed in 1982 (solid square ; Ageta *et al.*, 1984) and in 1996 (solid circle ; this study).

2.2. Mass balance in the monsoon season, 1996

2.2.1. Surface level

Eight stakes were installed and maintained at different altitudes to obtain the mass balance of the glacier during the monsoon season, 1996. Figure 5 shows changes of the surface level at five different altitudes, the amount of observed/estimated daily precipitation at Glacier Camp (GC, 5110 m a.s.l.), which is located at the terminus of the glacier, and daily air temperature at 5350 m a.s.l. The estimation of precipitation is mentioned later. The surface levels except at 5390 m a.s.l. lowered until the early August because precipitation did not contribute as mass inputs under high air temperature. The surface levels above 5350 m a.s.l. rose from August due to snowfall, whereas the surface levels below 5350 m a.s.l. kept lowering until the early October since surface melting exceeded snow accumulation. Surface levels rose at all altitudes in the early October, since precipitation was accumulated onto the whole glacier as snow.

2.2.2. Accumulation on the glacier

Precipitation on Yala Glacier should be evaluated to estimate accumulation on the glacier. Fujita *et al.* (1997b) observed the meteorological parameters at GC and Kyangjin Base House (BH, 3880 m a.s.l.) during the period from May to October, 1996. They obtained the amount ratio of the total precipitation amount at GC to BH as 1.46 times in the observation period. Using this ratio, the amount of precipitation at GC was estimated from that at BH (Fig. 5b), since the amount of precipitation was not recorded continuously at GC. No altitudinal gradient of precipitation amount was assumed on the glacier since the altitude range of the glacier is small and no altitudinal gradient has been observed on Glacier AX010 in Shorong Himal, east Nepal (Ageta *et al.*, 1980).

The average of air temperature and the amount of precipitation for daytime (6 - 18 h) and nighttime (18 - 6 h) were calculated for the observation period to evaluate the solid precipitation, which is equivalent to accumulation. Ageta *et al.* (1980) derived a relation between the probability of solid precipitation and air temperature from an observation at Glacier AX010 in east Nepal as :

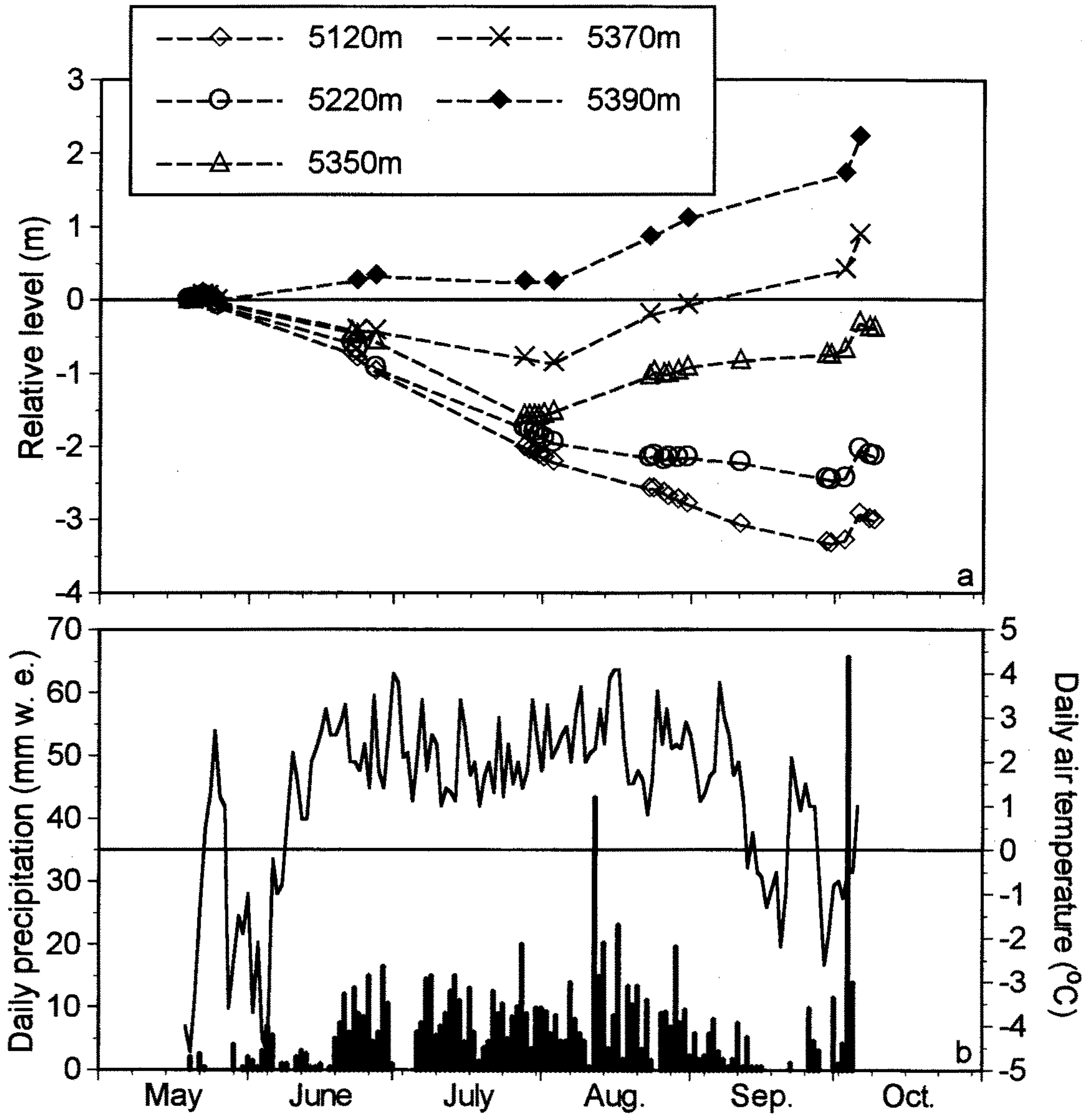

Fig. 5. Change of the relative surface levels at different altitudes obtained by the stake measurement (a), daily amount of precipitation at Glacier Camp (b) and daily mean air temperature at 5350 m a.s.l. (b) for the period from 19 May to 6 October, 1996.

daytime : $S = -34T_a + 118\ (0.5 < T_a < 3.5)$, (1)

nighttime : $S = -38T_a + 106\ (0.2 < T_a < 2.8)$, (2)

here, S is the probability of solid precipitation (per cent), T_a is air temperature (°C). The accumulation at each site was calculated for each half day. Lapse rate of air temperature was obtained to be 0.0055 °C m^{-1} between BH and the observation sites on the glacier (5220 m and 5350 m a.s.l.) for the observation period (Fujita *et al.*, 1997b).

2.2.3. Altitudinal distribution of mass balance

Specific mass balance (mm water equivalent, w.e.) at each site was calculated using density profiles obtained at each site by pit observations on 19 May and 6 October, 1996. The density of ice, which is used for the ablation zone, was assumed to be 870 kg m^{-3}. For each site, the amount of ablation (a) was calculated from the observed mass balance (b) and the estimated accumulation (c) using a relation as :

$$b = a + c. \qquad (3)$$

Figure 6 shows the altitudinal distribution of the observed mass balance, the estimated accumulation and the calculated ablation for the period from 19 May to 16 October, 1996. The amount of accumulation increases with altitude as air temperature decreases. The gradients of mass balance and ablation change largely at altitude between 5270 m and 5350 m a.s.l. Bare ice was exposed below 5300 m a.s.l. during the monsoon season from June to September, whereas the firn was observed above 5300 m a.s.l. The surface condition such as ice or firn would affect the surface albedo and the ablation largely even under a similar air temperature condition : the difference of air temperature was only 0.44 °C between 5270 m and 5350 m

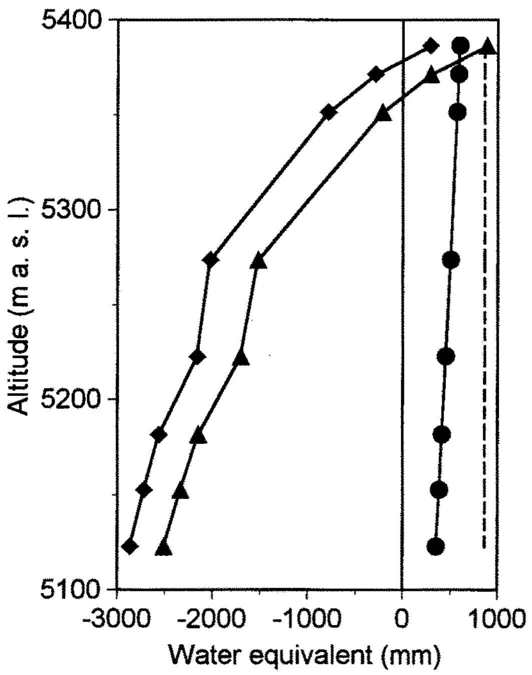

Fig. 6. Altitudinal distribution of the accumulation (circles), mass balance (triangles) and the ablation (squares) on Yala Glacier for the period from 19 May to 6 October, 1996. Broken line denotes the amount of precipitation during the observed period, which is assumed no altitudinal gradient on the glacier.

a.s.l. The areal averages of mass balance, accumulation and ablation are calculated as -357, 588 and -945 mm w.e. respectively assuming the areal ratio between the two broken lines shown in Fig. 1. Specific mass balance was assumed to be the same as accumulation at higher altitude, where no observation was made.

2.2.4. Ablation and air temperature

Ageta *et al.* (1980) derived a relation between air temperature and ablation of Glacier AX010 in east Nepal based on an observation in 1978 as :

$$a_d = 0.01(T_h + 3.0)^{3.2} \quad (T_h \geq -3.0), \qquad (4)$$

here, a_d and T_h are daily amount of ablation (mm w.e.) and daily mean air temperature (℃), respectively. The ablations on Yala Glacier, which are calculated from Equation 4 and from the difference between the mass balance and the accumulation (Fig. 6) at each stake site for the period from 19 May to 6 October, 1996, are compared with the average of daily mean air temperature for the same period as shown in Fig. 7. The estimated ablation for Yala Glacier is about 1.5 times larger than the observed one in the ablation zone where bare ice was exposed, though the ablation for Glacier AX010, which was estimated from Equation 4 during the monsoon season in 1995, was plausible

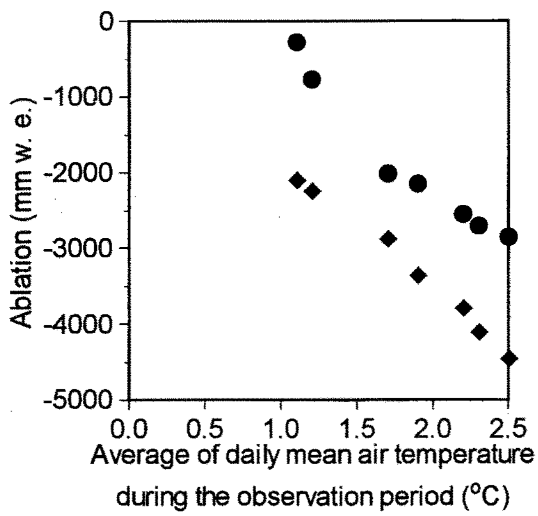

Fig. 7. The ablations obtained from the difference between mass balance and accumulation (circles) and from the Equation 4 in the text (squares) versus average of daily mean air temperatures at different stake sites for the period from 19 May to 6 October, 1996.

(Takeuchi *et al.*, 1998). Equation 4 derived by Ageta *et al.* (1980) was used in a few studies to estimate ablation of glaciers in Langtang Valley (*e.g.* Fukushima *et al.*, 1991 ; Rana *et al.*, 1997). However, Fig. 7 means that an empirical relation obtained at Glacier AX010 can not be applied simply to other glaciers in Langtang Valley. Regional difference of relations between air temperature and accumulation (Equations 1 and 2) should be also discussed in order to evaluate the accuracy of the 'observed' ablation, which was obtained as the difference between mass balance and accumulation.

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