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Characteristics of Winter Precipitation and its Effect on Glaciers in the Nepal Himalaya

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Abstract

The Nepal Himalaya is located under the summer monsoon climate, where summer precipitation exceeds winter precipitation. However, a large amount of winter precipitation occasionally occurs associated with inter-annual variability of storm tracks and the orographic effect. The variability of winter precipitation has a significant effect on the mass balance of glaciers in the Nepal Himalaya. Over a decade, however, glacier fluctuation follows the fluctuation of air temperature more than that of precipitation.

1. Introduction

The Asian highland region is the greatest mountainous region on earth and nourishes many glaciers. Glaciers in this area have a unique character. Snow on the gaciers in the Nepal Himalaya is usually accumulated mainly by summer precipitation caused by the Asian summer monsoon. In contrast, the Karakoram and Pamir ranges are under the Mediterranean climate region where winter precipitation affects the mass balance of glaciers considerably.

In the Nepal Himalaya, winter precipitation is usually a minor component of the mass balance of glaciers. However, winter precipitation in the Nepal Himalaya is highly variable from year to year.

The purpose of this paper is to investigate the characteristics of winter precipitation and its effect on glaciers in the Nepal Himalaya. First, we will describe a case study of a heavy winter precipitation event. Second, the effect of winter precipitation on the glacier mass balance will be discussed by using a simple model.

2. Data

Meteorological data in Langtang Valley from 1985 to 1986 were obtained by GEN-LP (Glaciological Expedition of Nepal, Langtang Project). Satellite images from INSAT were used in analyses of clouds and snow distribution. Climate data in Nepal are published by the Department of Irrigation, Hydrology and Meteorology, Nepal. Monthly climate data for the world edited by NOAA were used for making a climatic map.

3. General climatic feature

The ratio of winter precipitation (from October to March) to summer precipitation (from April to September) on the Eurasian continent is shown in Fig. 1. The region where winter precipitation exceeds summer precipitation extends from central Asia to the western periphery of the Tibetan Plateau. The so-called 'Mediterranean climate' is largely created by the frequent passage of cyclonic disturbances (storm track) in winter.

Winter precipitation dominates on the western periphery of the Tibetan Plateau (Karakoram and Pamir ranges), while the Nepal Himalaya and Tibetan Plateau are under the influence of the summer monsoon. However, the winter storm track is located close to the Nepal Himalaya, and shift of the storm track causes occasional winter precipitation on the range.

4. Case study of winter precipitation from 1985 to 1986

Monthly total precipitation from 1985 to 1986 recorded at Kyangchen in Langtang Valley, Nepal

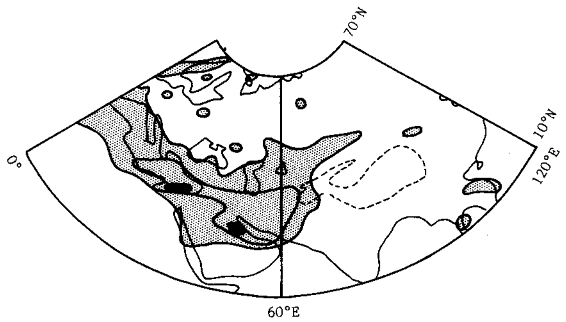

Fig. 1 Ratio of winter (October to March) precipitation to summer (April to September) precipitation in Eurasia. Contours denote the ratios of 1, 5 and 10. The region where the ratio is larger than 1 (10) is stippled (shaded).

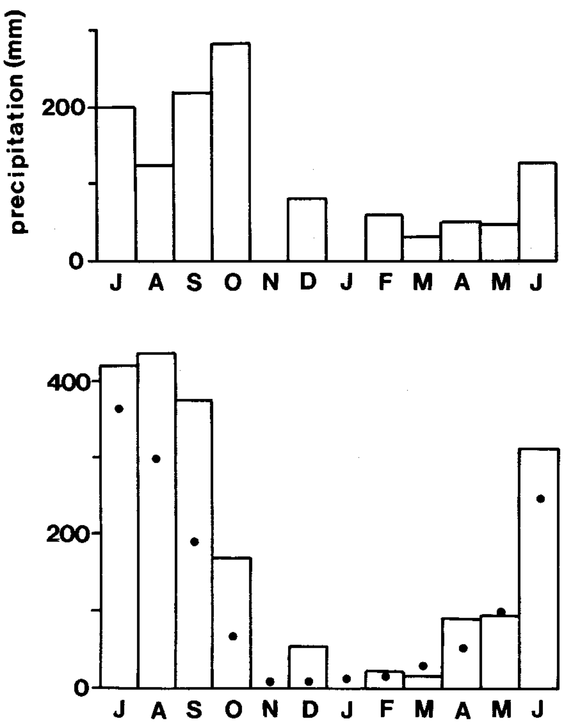

Fig. 2 Monthly precipitation at Kyangchen in Langtang Valley (3920 m a.s.l. ; above) and Kathmandu International Airport (1336 m a.s.l. ; below) from July, 1985 to June, 1986. Dots in the lower graph denote monthly mean values from 1968 to 1986.

Himalaya and Kathmandu I.A. (International Airport) are shown in Fig. 2. A large amount of snowfall occurred several times in this winter at Kyangchen (Takahashi *et al.*, 1987). Heavy precipitation occurred during the approach of cyclones in October and intermittent precipitation was caused by passages of western disturbances in December and February. Higher than normal precipitation was recorded in most observatories in Nepal from October 1985 to March 1986.

Fig. 3 shows satellite images during a precipitation event in February. Winter precipitation in Nepal was caused by intrusion of disturbances from the west onto the southern periphery of the Tibetan Plateau. The precipitation was so heavy that total precipitation reached 100mm within a few days. A disturbance which appeared in the Persian Gulf on 6th developed and influenced the Himalayan range on the 10th. The next disturbance, which appeared on the Arabian Peninsula on the 9th, followed a similar track. Deep troughs on the weather chart appeared in the west of the plateau during these events (Seko, 1987).

The Tanggula range on the central Tibetan Plateau was covered by snow which remained several months (Fig. 4). Disturbances which caused heavy precipitation on the Himalayan mountains partly influenced the Tibetan Plateau. However, the vortex pattern of clouds associated with the disturbances dissipated on the southern part of the Plateau. This can be due to the barrier effect of the Great Himalayan range which blocked moisture transport, and the decreasing vorticity of the air flow ascending the slope.

Table 1 shows the ratio of monthly precipitation at Kyangchen to that at Kathmandu I.A. (shown in Fig. 2). The contrast of the ratio from summer to winter is apparent and the value seems to be stable in each season. Hence, we calculated the amplification factor in the respective seasons as shown in Table 1. The ratio of winter to summer precipitation at Kyangchen is 0.66, compared to 0.14 at Kathmandu I.A. This contrast comes from the orographic effect on precipitation (Seko, 1987). The strong enhancement of winter precipitation is considered to be due to the ascending airflow along the slope of the great mountains. This results in a large amount of snowfall on a glacier in the valley (Iida *et al.* 1987).

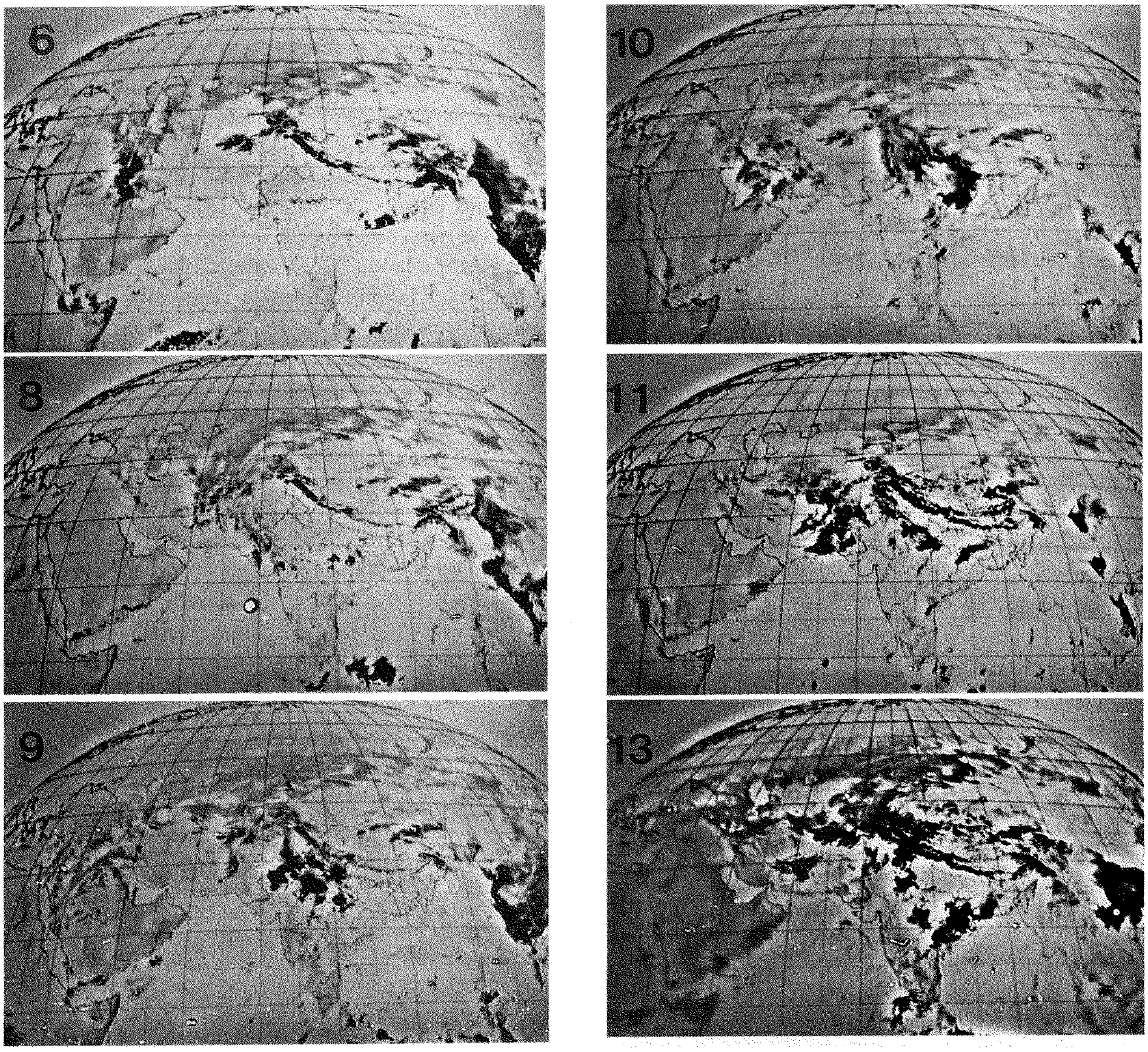

Fig. 3 Typical examples of satellite images during snowfall events at Kyangchen in February, 1986. Clouds and snow are expressed by reversed color (black). Dates are in the upper left corner.

Table 1 : Ratio of precipitation at Kyangchen to that at Kathmandu International Airport from 1985 to 1986 (%)

month	Jul.	Aug.	Sep.	Oct.	Nov	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
ratio(%)	48	29	58	169	×	149	×	261	194	54	49	40

summer average (Apr.－Sep.) : 46
winter average (Oct.－Mar.) : 193

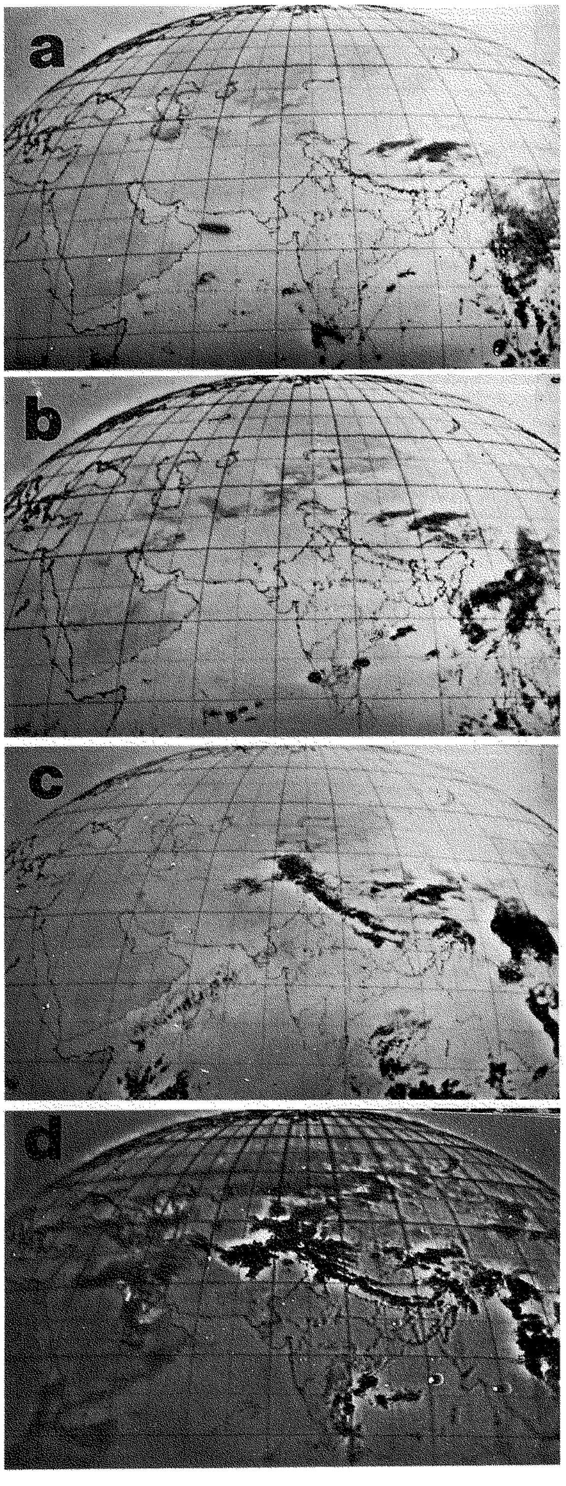

Fig. 4 Variation of snow covered areas on the Tibetan Plateau in winter from 1985 to 1986 by INSAT images on the following days. Oct. 20(a), Nov. 20(b), Jan. 2(c) and Feb. 18(d). Snow and clouds are expressed by reversed color (black).

5. Climatic characteristics of winter precipitation, and its effect on equilibrium line altitude of glaciers in the Nepal Himalaya.

Fig. 5 shows a time series of precipitation in winter and summer at Kyangchen estimated from data at Kathmandu. The seasonal amplification factor listed in Table 1 was used for the estimation. Glaciers develop at higher altitude than Kyangchen and the amplification of winter precipitation is expected to be larger (Seko, 1987). However, we use the value at Kyangchen, because whole-year data are unavailable on the glacier. Two different data sets are displayed separately in order to investigate as long a period as possible. Since the fluctuations reveal similar patterns during the period when both data are available, the trend appears to be continuous.

Winter precipitation exceeds summer precipitation in 10 years, including 1985–1986, among 66 years' data. Inter-annual variability of winter precipitation is very large. Nine years' running mean data are also presented in Fig. 5. On the decadal time scale, the fluctuation of winter precipitation is reduced, and winter precipitation never exceeded summer precipitation during this period.

It is necessary to also compare the fluctuation of summer temperature, which is regarded as the most significant factor affecting the mass balance of glaciers in the Nepal Himalaya (Ageta, 1983). Fig. 6 shows the summer 4 months' (June to September) average of daily minimum temperature at two Kathmandu stations. We use minimum temperature because monthly mean temperature data are unavailable and maximum temperature is greatly affected by weather. There is an apparent decreasing trend from the 1940s to 1970s, and increasing trend into the 1980s.

To assess the effect of winter precipitation on the mass balance of glaciers, a simple mass balance model will be presented. We use Ageta's (1983) simple parametrization for the calculation of ablation, because it is the only existing case study in the Nepal Himalaya. Summer (June to September) ablation (a_s) is parametrized as

$$a_s = -(T_s + 3.2)^{3.2} \times 10 \text{ mm}, \qquad \cdots\cdots(1)$$

The summer temperature (June to September : referred to T_s hereafter) at the equilibrium line altitude (ELA) can be estimated as the precipitation by this formula, assuming that annual precipitation equals annual accumulation and ablation in winter is negligible. By inputting 1000 mm, which seems to be

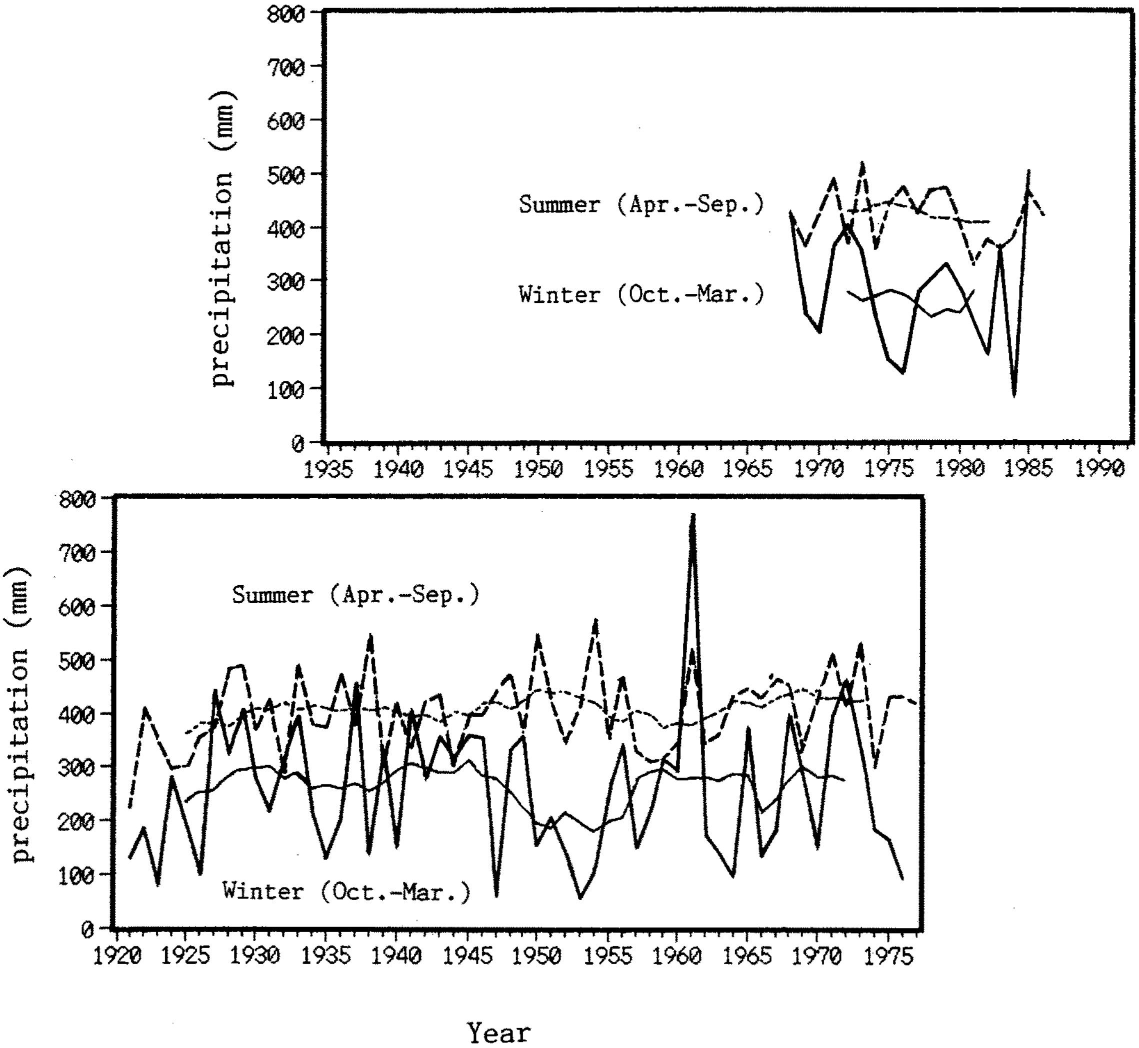

Fig. 5 Fluctuations of seasonal precipitation at Kyangchen estimated from the data at Kathmandu Indian Embassy (1921–1977 ; below) and Kathmandu International Airport (1968–1986 ; above). Yearly data and 9-year running mean data are expressed by thick and thin lines respectively.

a reasonable value for glaciers in Langtang valley as the annual precipitation, the T_s at ELA is estimated to be about 1 ℃.

By expanding (1) around this value, we obtain the sensitivity of ablation to climatic temperature change.

$$da_s/dT_s = 32\times(T_s+3.2)^{2.2}\ \mathrm{mm/^\circ C} \qquad \cdots\cdots(2)$$

The ablation can fluctuate.

$$\Delta a_s = da_s/dT_s \times \Delta T_s, \qquad \cdots\cdots(3)$$

We only compare the standard deviations of temperature and precipitation. Tables 2a and 2b show the standard deviations of the fluctuations of precipitation and T_s displayed in Figs. 5 and 6. Generally, The response of glaciers to climatic change occurs on a time scale longer than ten years. Hence, inter-decadal fluctuation of meteorological element is essential for the fluctuation of glaciers. We use the standard deviation of 9-year running mean data (0.15 ℃ *as* ΔT_s).

Δa_s in (1), da_s/dT_s in (2) and Δa_s in (3) are tabulated in Table 3 as a function of Ts at ELA. Δa_s is

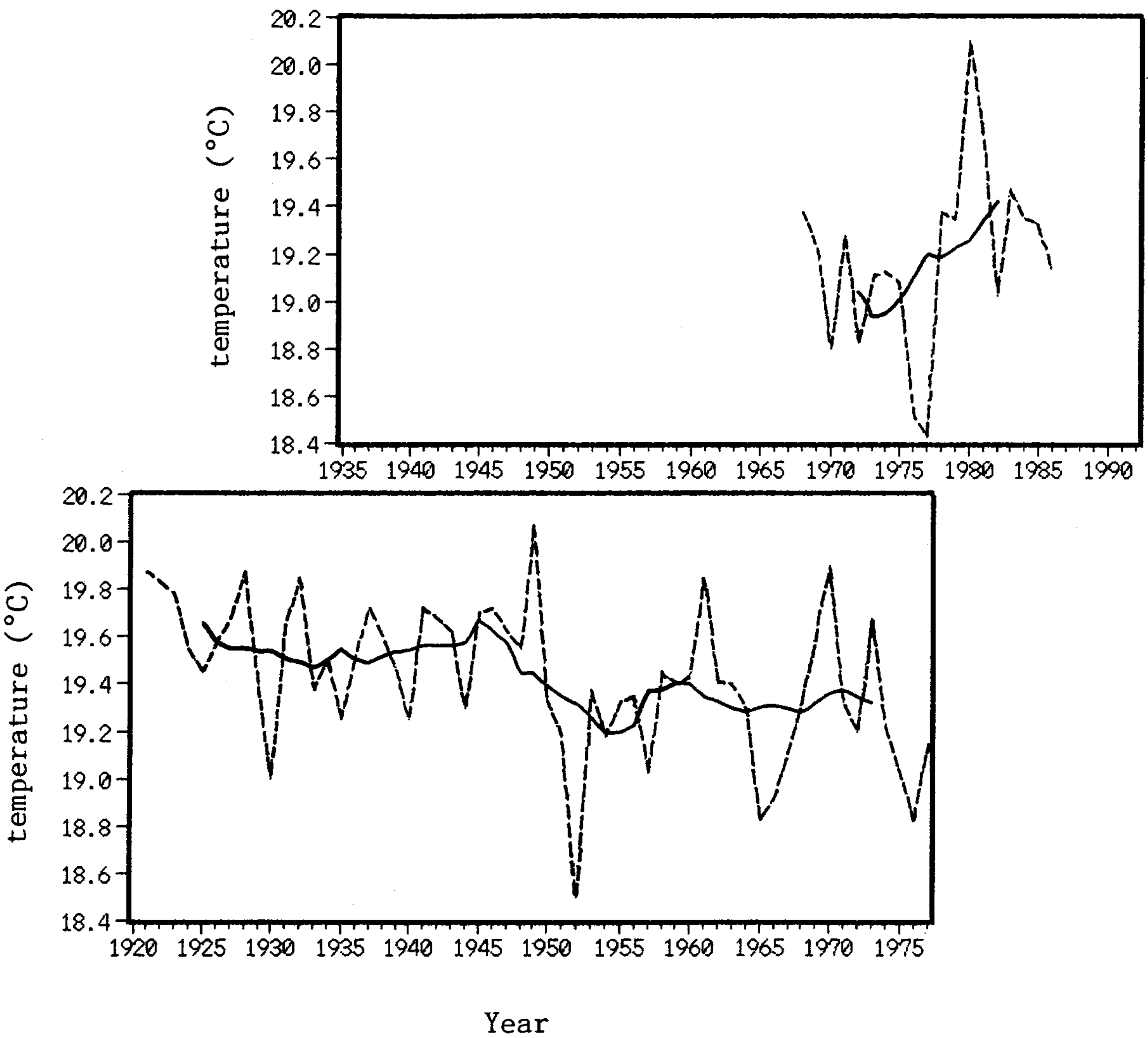

Fig. 6 Summer (Jun.-Sep.) temperature fluctuation at Kathmandu Indian Embassy (1921–1977 ; below) and Kathmandu International Airport (1968–1986 ; above). Data used are monthly average of daily minimum temperature. Yearly data and 9-year running mean data are expressed by broken and solid lines respectively.

Table 2a : Standard deviation of precipitation (mm) in winter (Oct.-Mar.) and summer (Apr.-Sep.). I.E. is an estimation from the data of Kathmandu Indian Embassy (1921–1977) and I.A. is from those of Kathmandu International Airport (1968–1986).

season	winter		summer	
location	I.E.	I.A.	I.E.	I.A.
yearly	110	132	53	75
9 years	27	39	16	28

Table 2b : Same as Table 2a except standard deviation of summer (Jun.-Sep.) temperature (°C).

location	I.E.	I.A.
yearly	0.38	0.31
9 years	0.15	0.15

113 mm, it is more than 4 times greater than the winter precipitation fluctuation (27 mm or 39 mm in Table 2b), if we assume the 9-year running mean values and T_s at ELA to be 1 ℃. As a result, the effect of precipitation fluctuation is less than that of T_s fluctuation on glacier fluctuation, while it disturbs the mass balance calculation in each year.

6. Discussions

a) On the parametrization.

The sensitivity of ELA to the change of winter precipitation and summer temperature is largely influenced by the increase of ablation rate with temperature. Table 3 shows the sensitivity of ablation at ELA to the T_s fluctuation in Ageta's parametrization. A T_s increase of 1 ℃ corresponds to winter precipitation increase of 752 mm at 1 ℃ of T_s at ELA. According to Ohmura *et al.* (1986), who analyzed glaciers with more accumulation in winter than in summer, this value is 450 mm/℃, which is similar to the value if T_s at ELA is 0 ℃ in Ageta's formula. The sensitivity calculated from Ageta's formula varies considerably with temperature.

Table 3 : as (mm), das/dT s and as in formula (1),(2) and (3), respectively. Ts is summer (Jun.-Sep.) mean temperature.

T_S	-3	-2	-1	0	1	2	3
a_S	0.06	18	125	414	987	1955	3433
$d\,a_S/dT_S$	0.93	48	181	414	752	1203	1772
$\triangle\, a_S$	0.14	7.2	27	62	113	180	266

Ageta's formula simply parametrizes the ablation as a function of temperature. However, actual snow ablation is caused by the sum of the energy, i.e. sensible heat, latent heat, long-wave radiation and short-wave radiation. Gentle wind and strong sunshine in the ablation season in the Nepal Himalaya cause the strong dependence of ELA on the radiative components. The nonlinear increase of ablation rate with T_s in Ageta's formula may be partly due to albedo decrease in the ablation area. Since we have little knowledge about the radiative component on the glaciers in the Nepal Himalaya, the albedo and long-wave change on glaciers should be studied for further understanding.

b) The relationship between climate and glaciers in the Asian highland region

The Asian highlands have several types of glaciers —from summer-accumulation type to winter-accumulation type, from very humid type to dry type. The response of glaciers to climatic change is different in each area.

The Nepal Himalaya is located under summer monsoon climate, while the Karakoram and Pamirs are under the influence of westerly disturbances in winter. The problem we treated here is essential for the interpretation of glacier fluctuation in the Asian highland region. Glaciers in the Karakoram and Pamirs might have more memory of the fluctuation of winter storm activities than Himalayan glaciers. Mayewsky *et al.* (1980) mentioned the opposite sense of glacier fluctuation between the two ranges. However, comprehensive analyses should be done on the basis of more scrutinized data.

Winter storm tracks do not seem to fluctuate so much on the decadal time scale in recent 60 years in the Nepal Himalaya. However, the temperature fluctuation seems to be significant. Recently, recession of glaciers has been reported in several regions in the Asian highland ; this is attributed to the warming trend. Kadota (1990) reported the recession of a glacier terminus from 1978 to 1989 in the Khumbu region, Nepal Himalaya. Shi and Ren (1990) mentioned the shrinkage of glaciers in the Tianshan Mountains and Pamirs in the 1980s.

It is necessary to know how extensively and how rapidly similar fluctuations are occurring. Analyses of remote sensing data (for example Shi et al., 1988) should be encouraged to learn the response of glaciers in the Asian highland region in cope with continuous mass balance monitoring.

Acknowledgments

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