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Seasonal variation of altitudinal dependence of precipitation in Langtang Valley, Napal Himalayas

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Abstract

Precipitation in Langtang Valley was analysed mainly focusing on orographic effects on the altitudinal distribution of precipitation. A remarkable seasonal difference of the altitudinal dependence of precipitation existed. Precipitation in the summer monsoon period was caused mainly by convective clouds. The altitudinal dependence was strongly controlled by the characteristics of cumulus clouds and mountain-valley circulation. In the latter part of the monsoon period, some strong precipitation and altitudinal increase of the amount were found with passage of westerly troughs and vigorous disturbances from the Indian monsoon region. In winter, precipitation was produced by the occasional passage of westerly troughs and the amount increased with altitude. It is suggested that the orographic effect on precipitation played a crucial role on the accumulation of glaciers at high altitude throughout the year. To consider the accumulation on glaciers in Nepal, it is important to determine the behavior of the thermal circulation in mountain-valley scale in the summer monsoon season and the behavior of westerly troghs in the cold season. Especially, inter-annual variability of the latter is more important for the accumulation of glaciers than was expected.

1. Introduction

The altitudinal dependence of precipitation in mountainous regions is very important for not only mass-balance of glaciers but also hydrological problems. However, it is very difficult to discuss this problem comprehensibly, because of the large spatial and temporal variability of precipitation.

Climatically, altitudinal distribution of precipitation has been analysed according to the climatic region (Barry, 1981). In the Nepal Himalayas, which are located in the Monsoon climate region, apparent seasonal variation exists in meteorological fields. This means that the precipitation mechanism is different from season to season. Hence, it can be expected that the altitudinal dependence will vary seasonally as Flohn (1970) mentioned.

Precipitation in Langtang Valley was analysed mainly focusing on the seasonal variation of altitudinal dependence and its mechanism.

2. Data

Observation of precipitation was carried out continuously from July 1985 to June 1986 in Langtang Valley (Takahashi *et al.* 1987). Locations of tipping-bucket rain gauges are shown in Fig. 1. Hourly precipitation data were obtained in Kyangchen base house (3920 m a. s. l., referred as BH hereafter) for a whole

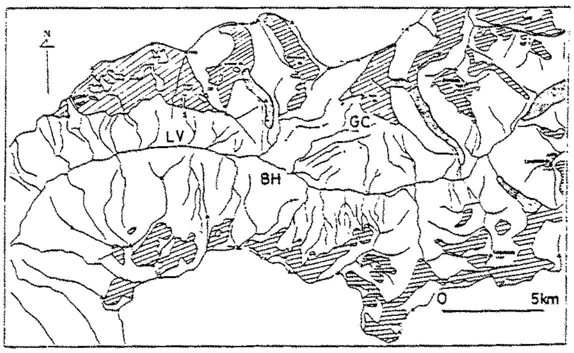

Fig. 1. Location of observation sites of precipitation in Langtang Valley. Hatched area denotes glacier.

year. 6-hourly precipitation measurements were obtained in Langtang village (3500 m a. s. l., LV) and Glacier camp (5090 m a. s. l., GC, data at GC are restricted from August to December 1985). Daily water equivalent depth was calculated from measurements of snow depth and density when solid precipitation occurred.

Daily precipitation at Kathmandu, 60km southwest of the Langtang region, was supplied by Department of Irrigation, Hydrology and Meteorology of Nepal. Satellite INSAT imagery was supplied by Indian Meteorological Department.

3. Seasonal variation of precipitation

In Table 1, total precipitation, maximum daily precipitation and the number of days of more than 0.5 mm precipitation at BH are shown for each month. Characteristic features are summarized as follows;

In the middle part of monsoon period (July to August), total precipitation was large and precipitation occurred almost every day. However, the daily amount did not exceed usually 20 mm.

In the latter part of the monsoon period (September to October) the maximum daily amount was considerably greater, while the number of rainy days decreased gradually from previous months. This means that intermittent strong precipitation occurred several times.

In winter, precipitation occurred on only a few days. However the maximum daily precipitation was rather large.

In the pre-monsoon season (April to May), the maximum daily amount became small, while the number of days increased month by month.

Fig. 2 shows the variation of altitudinal dependence of precipitation. The seasonal variation is as follows;

From July to September, the precipitation decreased with altitude from Kathmandu to BH. This is probably due to the decrease of water vapour with altitude. The amount of precipitable water at BH is about 1/3 times that at Kathmandu, if the atmosphere is assumed to be saturated with the temperature lapse rate of 6 ℃/1000m. Another noticeable feature in this season is that the amount at GC was 1.3 times that at BH. This tendency is due to convective precipitation associated with meso-scale thermal circulation in the valley.

In winter (December to March), the precipitation increased with height. The amount at BH was about 2 times that at BH. Generally, winter precipitation in Nebal is produced by synoptic disturbances, which has

Table 1. Seasonal variation of precipitation at BH

Month	7	8	9	10	11	12	1	2	3	4	5	6
Total	200	125	218	283	0	82	0	60	31	50	48	127
Max. daily amount	21	14	55	112	0	47	0	41	11	17	14	29
Number of days	30	29	22	10	0	3	0	2	8	11	12	14

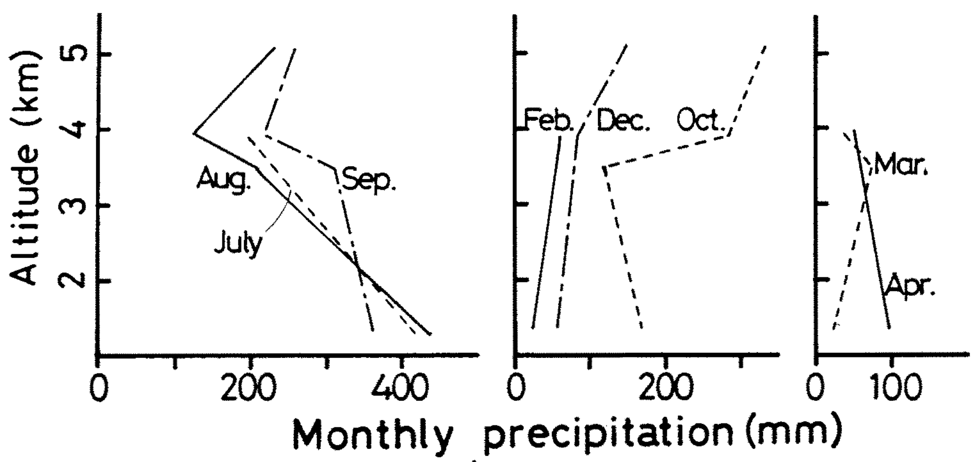

Fig. 2. Altitudinal dependence of precipitation in each month.

been called 'western disturbances' (Ramage, 1971). The disturbance is accompanied by southerly moist air flow in the middle troposphere. In such a situation, probably, orographically forced ascending flow amplifies precipitation at high altitude.

It is noteworthy that precipitation at BH was greater than that at Kathmandu in October, and the the September profile seems to be between that of August and October. These months are classified as 'monsoon period' conventionally. However, the altitudinal distribution was similar to that of winter. The difference of synoptic environment between August and later months can be found clearly in Fig. 3 which shows INSAT images on typical days from August to October. In August, a large cloud band on Indian subcontinent was separated from the Himalayan range, while cumulus convection occurred every day on mountain ranges of Nepal and Tibet. In contrasts, from September to October synoptic disturbances which originated in the Bay of Bengal or Arabian Sea influenced the Nepal Himalayas region several times. Persistent precipitation occurred associated with these disturbances. The disturbances in October produced snowfall in Central Tibet. Kunlun Shan and

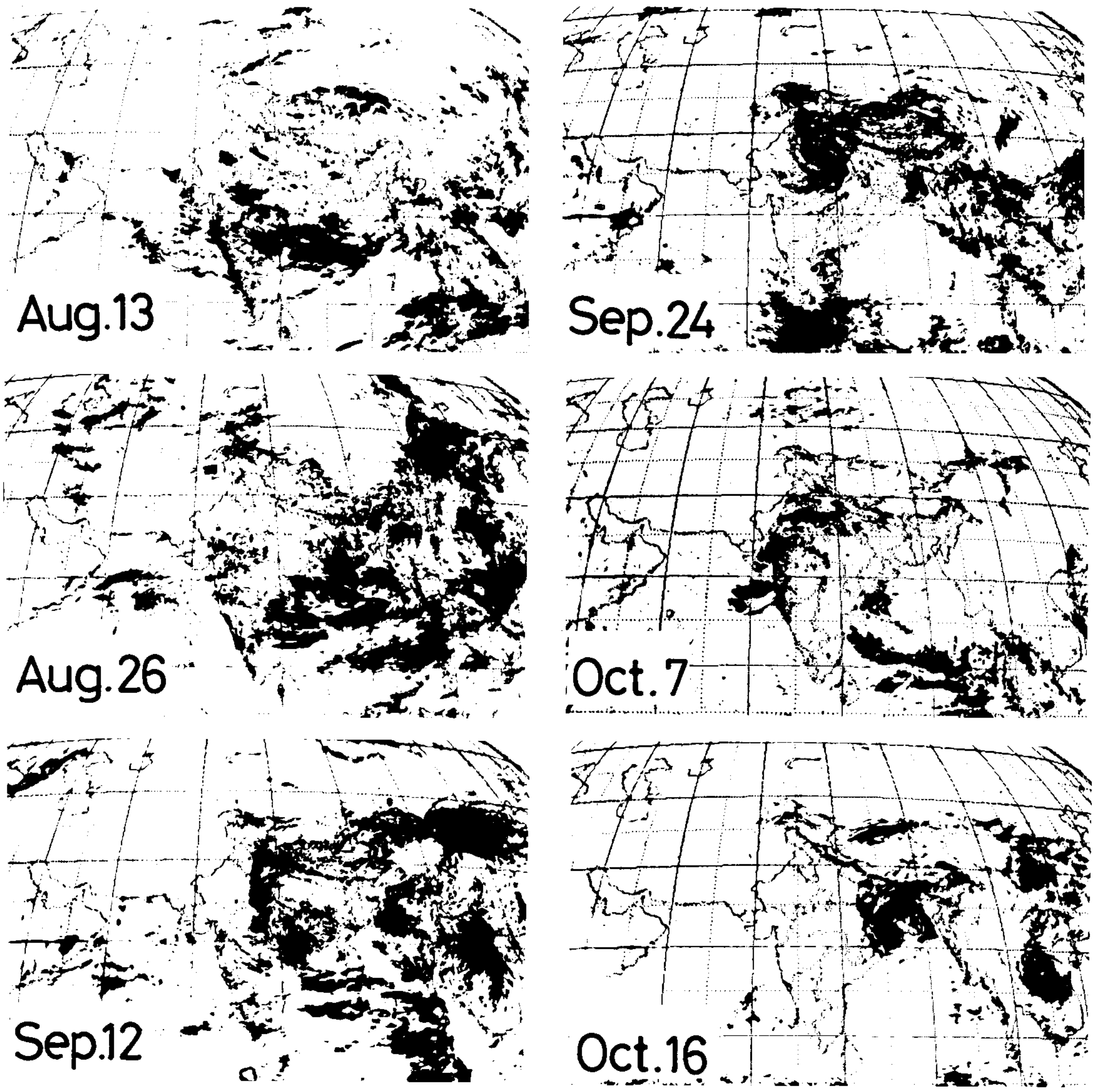

Fig. 3. INSAT imageries on typical days from August to October 1985. Visual imageries at 6.00 G.M.T. are shown in reversed color.

Nyenchen Tangla mountain range were covered by snow after the passage of disturbances on Oct. 7 and Oct. 16 respectively.

It can be suggested from these observations that the altitudinal dependence of precipitation can be classified into two types. One occurs in precipitation associated with cumulus convection without synoptic disturbances and another in persistent precipitation associated with disturbances. They will be discussed in the following sections separately.

4. Precipitation caused by local circulation

Fig. 4a shows the diurnal variation of precipitation from July to September at BH and August at GC. BH and GC are located at the bottom of the valley and on a slope near a ridge respectively.

In August, typical diurnal variation of precipitation can be found at both stations. During the daytime, showery precipitation at GC was produced by cumulus clouds developing on the ridge. Convective clouds on ridge were formed in early morning and sustained at least throughout the daytime. In accordance with the development of convective clouds, an up-valley wind prevailed in daytime. It can be said that the wind along valley supplies moisture to clouds developing on both side slopes of the valley. At BH, on the other hand, there was cloud-free space above the valley floor and little precipitation occurred during the daytime.

At night, on the other hand, precipitation occurred at both sites. Nocturnal precipitation was the dominant component of total precipitation at BH. It is noteworthy that the precipitation amount at GC exceeded that at BH even at night. This suggests that clouds developed up to more than 1000 m from the bottom of the valley even at night. Actually, weak up-valley wind continued to flow even at night during precipitation. Nocturnal precipitation and prolonged up-valley wind have been observed in Khumbu Himal (Higuchi *et al.*, 1982, Ohata *et al.*, 1981) and stations around the Tibetan Plateau (Ye and Gao, 1979). If radiative cooling near the ground is considered, descending flow prevails and precipitation is suppressed at night. However, observation shows that BH was mostly covered by stratus in evening and it continued until a few hours before sunrise. In such a situation, the stratus prevents the ground temperature from decreasing and up-valley wind may be sustained until midnight. Nocturnal precipitation has significant meaning as a major source of valley soil moisture. Future research is necessary to investigate the mechanism.

The pattern of diurnal variation changed with the month. The typical diurnal variation disappeared in September. Precipitation in October had similar character, while quantitative 6-hourly data are not avail-

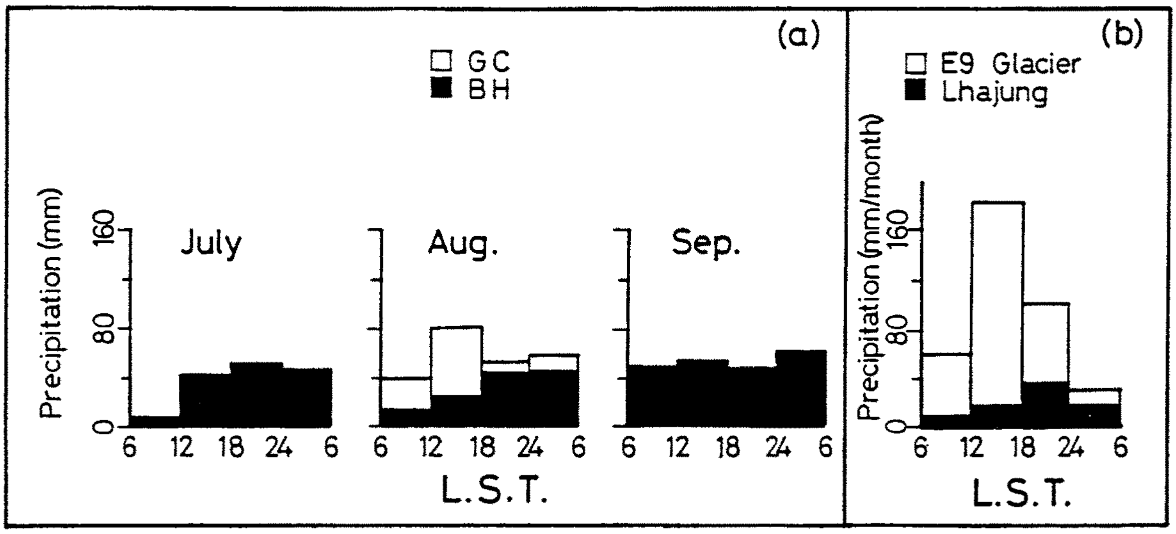

Fig. 4. (a) Diurnal variation of precipitation at BH and GC in Langtang Valley in each month.
(b) Diurnal variation of precipitation at Lhajung (4420m a.s.l.) and Glacier E9 (5160m a.s.l.) in Khumbu Himal. Period of data is from June 1—September 30. 1976 at Lhajung and June 10—September 30. 1976 at Glacier E9.

able due to solid precipitation. This suggests that thermal circulation with cumulus convection became weak and persistent precipitation occurred frequently in these months.

Fig. 4b shows the diurnal variation of precipitation in Khumbu Himal (Yasunari and Inoue, 1978) on the same scale as Fig. 4a. Precipitation at Glacier E9 exceeded that at Lhajung throughout the day. This is similar to the result from Langtang. However, the ratio of glacier to valley precipitation is considerably great in Khumbu. Furthermore, the amplitude of diurnal variation is large in Khumbu and nocturnal precipitation seems to cease earlier at Lhajung than that at BH. Total annual precipitation at Lhajung is about half that at BH, since Khumbu Himal has a drier climate than Langtang valley. Amplification of precipitation by cumulus convection might be large in a dry region. It might create spectacular scenery − glaciers hanging on a slope in a dry valley−. Future research to investigate the interaction between convective clouds and mountain-valley circulation, and effects of them on the distribution of precipitation should be encouraged.

5. Precipitation associated with synoptic scale disturbances

Large amounts of precipitation, more than 50 mm within a few days occurred at BH several times from September to February. They were caused by synoptic scale disturbances. Fig. 5 shows the weather charts at 500 mb around the Tibetan Plateau during the precipitation events.

In September and October, the origin of the disturbances can be traced back to depressions in the Bay of Bengal or Arabian Sea as shown in Fig. 3. On the other hand, the influence of mid-latitude westerly troughs became large in the latter part of the monsoon period. Ye and Gao (1979) investigated severe weather events on the Tibetan Plateau in September and October which are similar to the present case. Owing to the humid environment and intrusion of westerly troughs, a large amount of precipitation can be easily produced in September and October.

Precipitation in December and February was caused by westerly troughs. Troughs which developed on the west side of the Plateau moved eastward along the southern periphery of the Plateau and dissipated around the southeastern part of the Plateau. Associated with the intrusion of troughs into the Nepal Himalaya region, warm and moist southerly winds prevailed at 500 mb. This was a common feature not only in the winter months but also October, and may be one of the most important causes of altitudinal increase of precipitation in these seasons.

Precipitation from October 1985 to March 1986 was very large in Langtang Valley. Fig. 6 shows anomalies of precipitation and 500 mb height around Nepal. The excessive precipitation was recorded in NW-India and Nepal. The excessive precipitation corresponds to height field anomalies. This suggests more frequent arrival of western distubances to NW-India and the Nepal Himalaya than in a normal year.

Excessive winter precipitation was amplified at high altitude by the orographic effect. It caused considerable snowfall on Himalayan glaciers. Actually, snow depth measurenent on Yala Glacier shows considerable accumulation in October and December (Iida *et al.*, 1987). It appears that the inter-annual variability of westerly troughs affects the accumulation on glaciers in the Nepal Himalaya more than expected. According to climate data at Kathmandu, inter-annual variability of precipitation in winter including Octo-

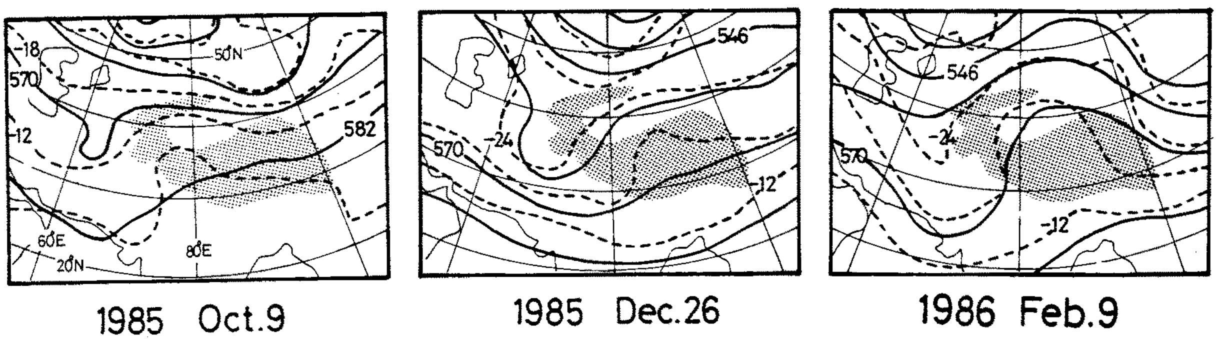

Fig. 5. Weather charts at 500 mb, 12 G.M.T on the day of strong precipitation in Langtang. Height (10m) and temperature(°C) are shown by solid and dotted line respectively.

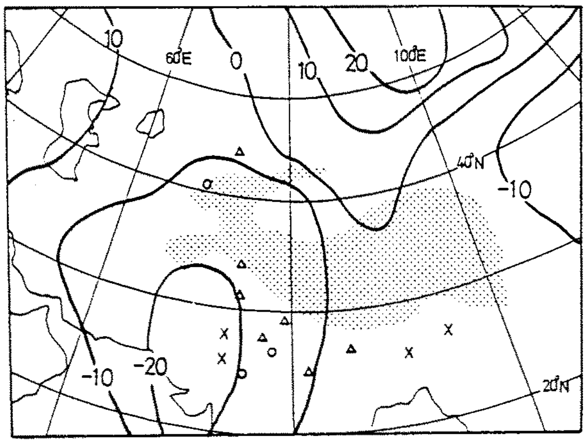

Fig. 6. Anomaries of precipitation and height at 500 mb from October 1985 to March 1986. Unit of height anomaly is m. Anomary of precipitation is expressed as follows:
○: more than 200% of mormal value.
△: from 150% to 200% of normal value.
×: less than normal value.
Averaged values from 1950 to 1980 are taken as normal values.

ber is very large. To discuss the variation of mass-balance of glaciers in the Nepal Himalaya, further investigation will be necessary.

Winter precipitation has a significant effect on the behavior of snowline (Morinaga *et al.,* 1987). It is noteworthy that Eurasian snow-cover extended over a large area at the end of 1985 (Ropelewski, 1986). It might be possible to say that anomalous precipitation from October 1985 to February 1986 was due to inter-annual variability of planetary waves and it was related to anomaly of Eurasian snow-cover area.

6. Concluding remarks

Precipitation in Langtang valley was observed from July 1985 to June 1986. Altitudinal dependence of precipitation in Lantang Valley revealed remarkable seasonal variation.

Precipitation during the summer monsoon period which is a major component from accumulation of glaciers in the Nepal Himalayas, was strongly influenced by the meso-scale mountain valley circulation. Remarkable diurnal variation was found in precipitation and had a crucial effect on the distribution of precipitation. This problem has been investigated from observations around the Tibetan Plateau including the Nepal Himalayas. However, the ratio of valley to slope precipitation shows remarkable differences from region to region. Future research to investigate the coupled system of cumulus convection with mountain-valley circulation and valley nocturnal precipitation mechanism are necessary.

Associated with intrusion of westerly troughs, strong precipitation occurred in the latter part of the monsoon period and winter. Altitudinal increase of precipitation was found in these events. Winter precipitation is considered a minor component in accumulation on glaciers in Nepal. However, if altitudinal dependence of precipitation is taken into account, the contribution is not negligible at high altitude.

Especially, from October 1985 to March 1986, the amount of precipitation was large and it was controlled by behavior of westerly troughs (western disturbances). Precipitation in the cold season is also associated with the problem of large scale snow cover. Future research should be encouraged to investigate the behavior of western disturbances as a problem of inter-annual variability of precipitation in the Himalayas-Tibet region.

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