

Characteristics of Monsoonal Precipitation around Peaks and Ridges in Shorong and Khumbu Himal*

Tetsuzo Yasunari** and Jiro Inoue***

Abstract

Through the monsoon period of 1976, precipitation phenomena were observed at temporary stations around peaks and ridges of high altitude (5000-5500 m) in Shorong and Khumbu Himal, in addition to the observations made at Lhajung station (4420 m) in the Khumbu region. Through these observations, it was found that the amounts of precipitation at these two stations is 4 or 5 times larger than that at Lhajung. While day to day convective precipitation contributes the major part of the total amount at Shorong and Glacier EB 050 (E9) stations, a few rainy days of large amount of precipitation account for most of the contribution at Lhajung station. It was also found that the statistical features of precipitation as a function of time of day are systematically different among these three stations. Along the slope to Glacier EB 050 (E9) in Khumbu Himal, the amount of precipitation gradually increases with increase of altitude. However, along the slope to Glacier AX 030 in Shorong Himal, the amount is almost uniformly distributed from 4000 m up to the terminus of the glacier (5200 m).

1. Introduction

Meteorological observations for about three and a half years at Lhajung station (4420 m) in the Khumbu region have revealed that the amount of annual precipitation appears at most 500 mm. This result suggests that though the precipitation is mainly due to the effect of the monsoon, a semi-arid climate is dominant in this region (Inoue, 1976; Yasunari, 1976b). During the monsoon period in 1974, a temporary meteorological station was established at Hidden Valley (5055 m) in west Nepal, to study and compare the climatic conditions of east and west Nepal. However, a great difference of the climate was not observed so far as the monsoon season is concerned (Shrestha *et al.*, 1976). On the other hand, through short period observations made on Glacier EB 050 and observations of precipitation by simple rain gauges at 50 points at altitudes of 4500 through 5500 m

in the Khumbu region, it has been shown that the amounts of precipitation around peaks and ridges of relatively high altitude (5000-6000 m) are much higher than at Lhajung (Ageta, 1976). It could be as high as 4 or 5 times more than that of Lhajung. The precipitation at these higher altitudes has been concentrated mainly during the daytime, while that at Lhajung has been mainly during the nighttime (Ageta, 1976). The same author also suggested that the precipitation phenomena around these peaks and ridges are probably due to local cumulus convection.

During the monsoon period in 1976, in addition to the meteorological observations at Lhajung, similar observations were taken at a temporary station (4900 m) near some glaciers in Shorong Himal, which is nearly 20 km to the south of Lhajung station. At the same time around Glacier EB 050 of Khumbu region, observations were also taken from June to September. In the present paper, on the basis of these data, including those at Lhajung, the characteristics of monsoonal precipitation around peaks and ridges of higher elevation (5000-5500 m) in Shorong and Khumbu Himal have been discussed. In this discussion, the data obtained at Shorong and Khumbu Himal have been compared to each other. Also, Lhajung has been used as a representative reference point in the valley (about 4500 m) of the semi-arid region.

* *Glaciological Expedition of Nepal, Contribution No. 47*

** *Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 616 (present address: the Center for Southeast Asian Studies, Kyoto University, Kyoto 606)*

*** *Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 616*

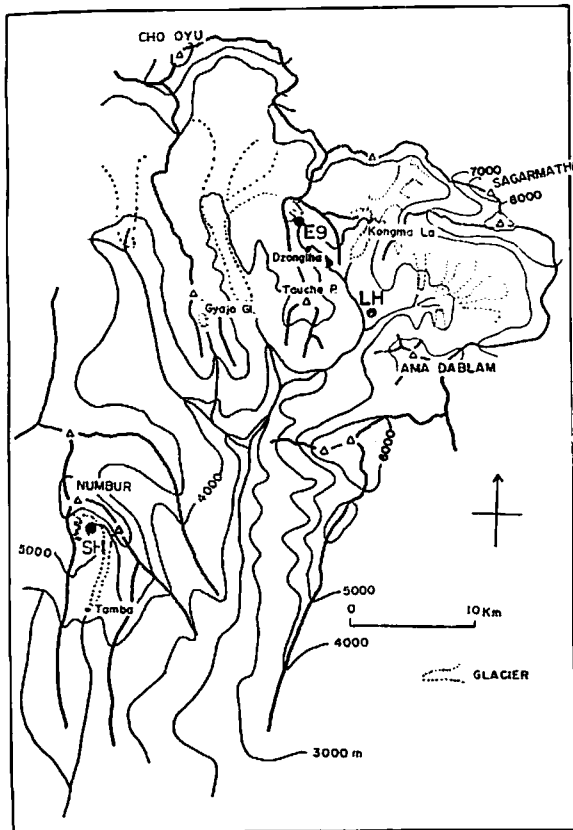


Fig. 1. Geographical locations of the three meteorological stations Glacier EB 050 (E9) Lhajung, Shorong) in Khumbu and Shorong Himal.

The geographical locations of these three stations are shown in Fig. 1.

2. Characteristics of monsoonal precipitation around peaks and ridges in Shorong and Khumbu Himal, and at Lhajung

2.1. Daily precipitation

Daily precipitation at Shorong station (4900 m), Glacier EB 050 station (5160 m) and Lhajung station (4420 m) during the period from June through September is shown in Fig. 2. These three time series show roughly in-phase variations, but the daily amounts of precipitation are far greater at Shorong and Glacier EB 050 station than Lhajung. Periodicities of about two weeks are prominent through these time series, which

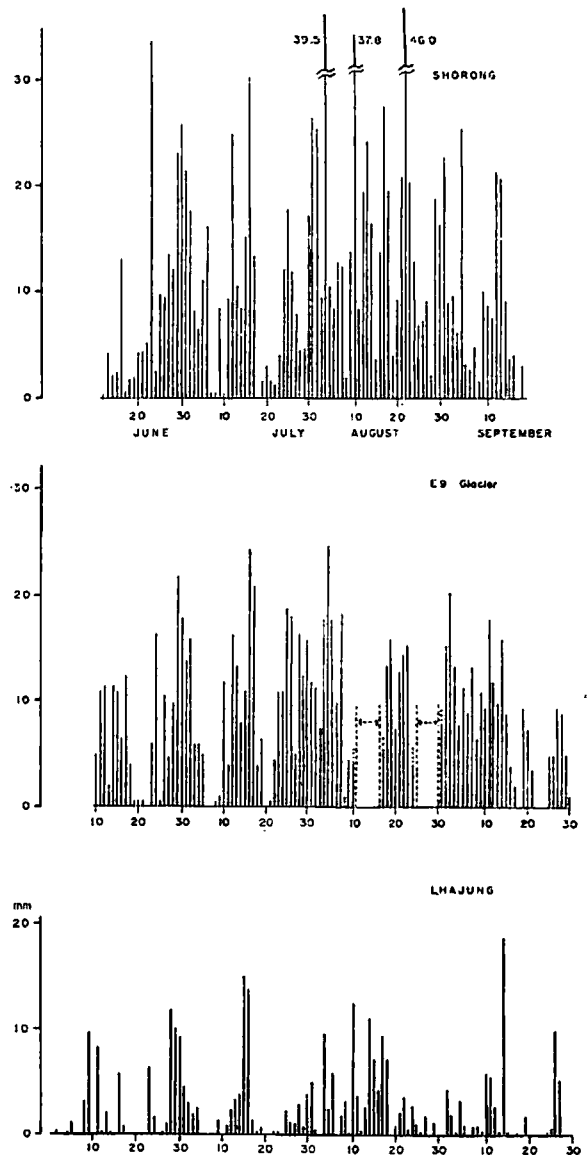


Fig. 2. Daily precipitations at Shorong, Glacier EB 050 (E9), and Lhajung station during the period from June to September. (Actually, the data are available from June to September 18 at Shorong station and from June 10 to September 30 at Glacier EB 050 (E9) station.)

may be closely related to the fluctuation of the large scale monsoon circulation (Yasunari, 1976a). The values of the averaged daily precipitation at these stations are shown in Table 1. The ratios

Table 1. Averaged daily precipitation at the three stations.

Station name	Observation period	Number of days	averaged precipitation (mm/day)
Shorong	June 12-September 18	99	11.3
Glacier EB 050 (5)	June 10-September 30	113	12.5
Lhajung	June 1-September 30	122	2.6

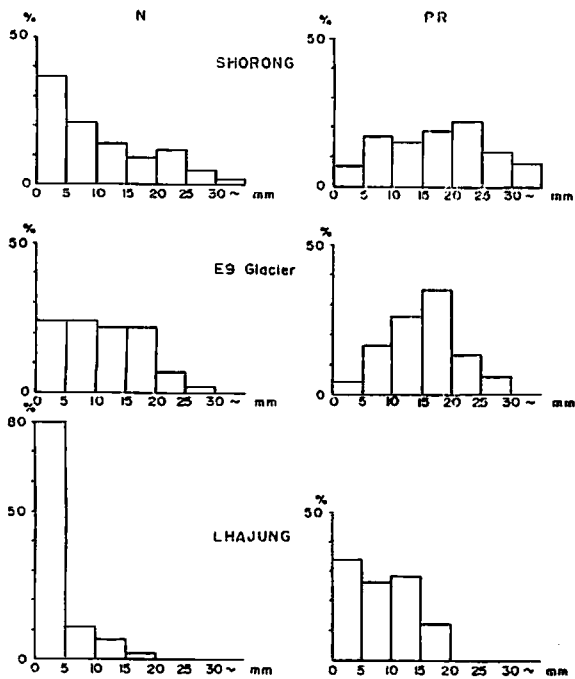


Fig. 3. Histograms of daily precipitation in each 5 mm range (N) and cumulative amounts of precipitation in each range (PR) for the three stations.

of the total precipitation during this period at Shorong station and Glacier EB 050 station to that at Lhajung are 4.2 and 4.8 respectively.

The histograms of daily precipitation in each 5 mm range and of the cumulative amounts of precipitation in each range are compared as shown in Fig. 3. Available data have been used from June 12 to September 18 (99 days) at Shorong and Lhajung stations, and from June 24 to August 23 (61 days) at Glacier EB 050 station. These two histograms indicate differences in the features of precipitation types between those stations around peaks and ridges like Shorong or Glacier EB 050, and a valley station such as Lhajung. At Lhajung most of the daily precipitation is drizzle type, represented by days of less than 5 mm. The drizzle falls mainly from thin cumulus or strato-cumulus flowing up along Imja Valley. But at the other two stations the daily precipitation values are more widely distributed. The percentage of the number of days of more than 5 mm to the total is 63% at Shorong station, 75% at Glacier EB 050 station, but only 20% at Lhajung. However, in the case of the observations in 1974, the total amount of precipitation at Lhajung was contributed mainly by a few rainy days with precipitation of over 5 mm per day, as has been previously

pointed out (Yasunari, 1976a). In the case of the observations in 1976 also, the contribution of rainy days of less than 5 mm to the total amount of rainfall reached nearly 70%, though the percentage of the number of rainy days of less than 5 mm to the total number was only 20% as mentioned above. At Shorong station days of less than 5 mm occupies the largest frequency, but the daily precipitation amounts are more widely distributed among other ranges. In contrast, at Glacier EB 050 station the days are mainly distributed in the range from 5 mm to 20 mm, and the contribution of these ranges to the total amount is also large (nearly 80%). Through these results mentioned above, it is suggested that the moist monsoonal air current from the Indian Plain becomes drier in providing precipitation along its course up to the inner and higher places of the Himalayan ranges. Therefore, the difference of the total amounts between Shorong and Lhajung station may be at least partly be due to the difference of the amount of water vapor and liquid supply at these two stations. However, the difference between Glacier EB 050 and Lhajung station may be due to the difference of activity of convection, since the water vapor content in the atmosphere around Glacier EB 050 station (about 5100 m) is probably less than that around Lhajung (about 4400 m) because of the relatively high altitude.

2.2. Characteristics of time sequences of precipitation during one day

In 1976, precipitation intensity was measured at Shorong and Lhajung stations by increasing the sensitivity of the rain gauge. The diameter of the receiving cylinder of a usual rain gauge is 20 cm. For the present purpose, the diameter of the cylinder has been increased to about 10 times that of a normal rain gauge. Thus, the tipping bucket tips at every 0.05 mm of rainfall. Of course, some problems may arise because of this modification. For example, the collection efficiency of rain drops may possibly decrease in the presence of a strong wind. However, the amount of rainfall measured through this procedure coincide well with the results of a normal rain gauge. By this procedure, we could obtain improved records of rainy spells. Detailed descriptions of the precipitation were obtained by using this method on the days August 3-4, 5, 7, 17, and 18. The durations of each continuous precipitation period are summarized in Fig. 4. At Lhajung the cases which have the greatest number (more than



Fig. 4. Histograms of durations of each continuous precipitation (rainy spell) for the three stations.

50%) are occupied by rainfall spells of less than 30 minutes and those of 1-2 hours follow. On the other hand at Shorong station, though the maximum cases are occupied also by less than 30 minutes' precipitation, the number of cases more than this are larger than at Lhajung. The maximum amount was associated with spells of rainfall continuing for over 4 hours. At Glacier EB 050 station, the precipitation intensity was not measured by the rain gauge mentioned above. However, during the meteorological observations on the Glacier EB 050, the durations of each continuous precipitation period was observed for several days. This result at Glacier EB 050 camp shows a similarity with that at Shorong station, as is shown in Fig. 4. The rainfall spells, whose time scales are less than 30 minutes and 1-2 hours, seem to be dominant through these three areas. Histograms of the frequency and the cumulative amount of precipitation at the three stations during 3-hour periods are shown in Fig. 5. In this procedure, to avoid time-delayed recording of precipitation, the recording of the melting of snow on the funnel of the rain gauge have been omitted from the data set.

At Shorong station, though the data is only available for 16 days, both the frequency and the amount of the precipitation are concentrated during the daytime, especially from 0900 to 1500. At Glacier EB 050 station (47 days), they are also concentrated during daytime, but a little later in

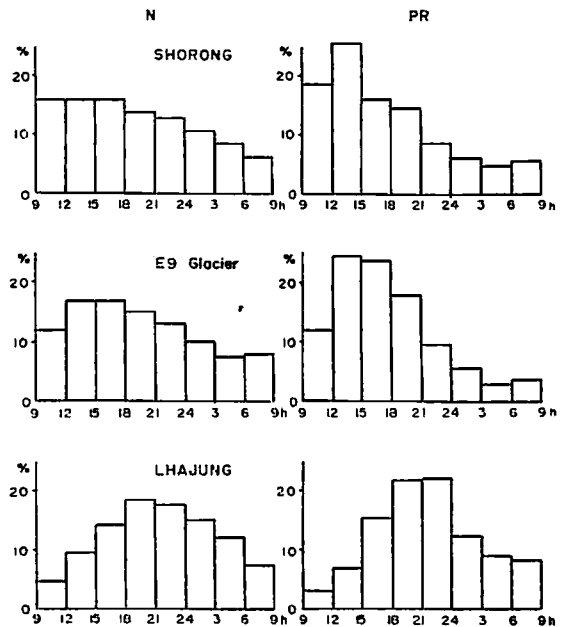


Fig. 5. Histograms of frequency (N) and cumulative amounts of 3-hourly precipitation (PR) for the three stations.

the day (from 1200 to 1800) as compared to those at Shorong station. At Lhajung station, on the other hand, they are concentrated during the evening through mid-night (from 1800 to 2400). Fig. 5 also suggests statistically the systematic delay of precipitation time from Shorong to Glacier EB 050, and from Glacier EB 050 to Lhajung station. The results at Shorong and Glacier EB 050 stations suggest that cumulus convection during daytime provide most of the precipitation. However, the difference of the time of maximum precipitation may be closely related to the differences of the two main factors governing the process of precipitation in these two areas; namely, one is the time when the daily moist current from the Indian Plain reaches each area, and the other is the type of convection in each area, as will be discussed in Chapter 3.

It was shown in a previous study (Ageta, 1976) that most of the precipitation at Lhajung falls during the nighttime (1740-0540). However, the present analysis has shown that the precipitation during the nighttime is concentrated from the evening until midnight (1800-2400). In this period, the valley wind coming up along the Imja valley still remains, though the wind speed becomes fairly weak (Inoue, 1976). Henceforth, the simplified model of the nocturnal precipitation in the valley by the convergence of mountain wind as presented

by Ageta (1976) should be at least partly revised, by considering the effect of a weak valley wind.

2.3. The distributions of the amount of precipitation along the slopes leading up to the glaciers in Khumbu and Shorong Himal

The amounts of precipitation along the slopes leading up to Glacier EB 050 were measured through the whole monsoon period. (from June to September) by six simple rain gauges in the area higher than the temporary summer village named Dzonghla (4830 m). In Shorong Himal also, those along the slope to one small glacier (Glacier AX 030) were measured by the same method in the area higher than the temporary village in the monsoon season named Tamba (about 4000 m). The distributions of the daily mean precipitation during the observed period of these two slope lines are shown in Fig. 6. The cross sections along the slope lines are also illustrated in this figure. In Shorong Himal, the slope lower than about 4500 m is coincident with the side moraine ridge along the lower part

of Dudh Kund glacier (Glacier AX 050).

Along the slope to Glacier EB 050, the precipitation gradually increases as the altitude increases and reaches its maximum near the terminus of Glacier EB 050 (point E9-5 in Fig. 6), where the daily mean precipitation is 11.6 mm and the ratio of the total precipitation to Lhajung is 4.8. The tipping bucket rain gauge was set up at this same point.

The results obtained through the shorter period observations along this slope in 1974 (Ageta, 1976) are in good agreement with that of the present analysis. It is noteworthy that at point 2 of Glacier EB 050 where the valley wind is supposed to have a weak downward component after crossing the small moraine hills the amount of precipitation becomes slightly decreased. Referring to the data at point (just beside Glacier EB 050) and the data of shorter period at Glacier EB 050 camp, as shown in Fig. 6, the decreasing rate of precipitation from point E9-5 toward higher altitudes seems to be

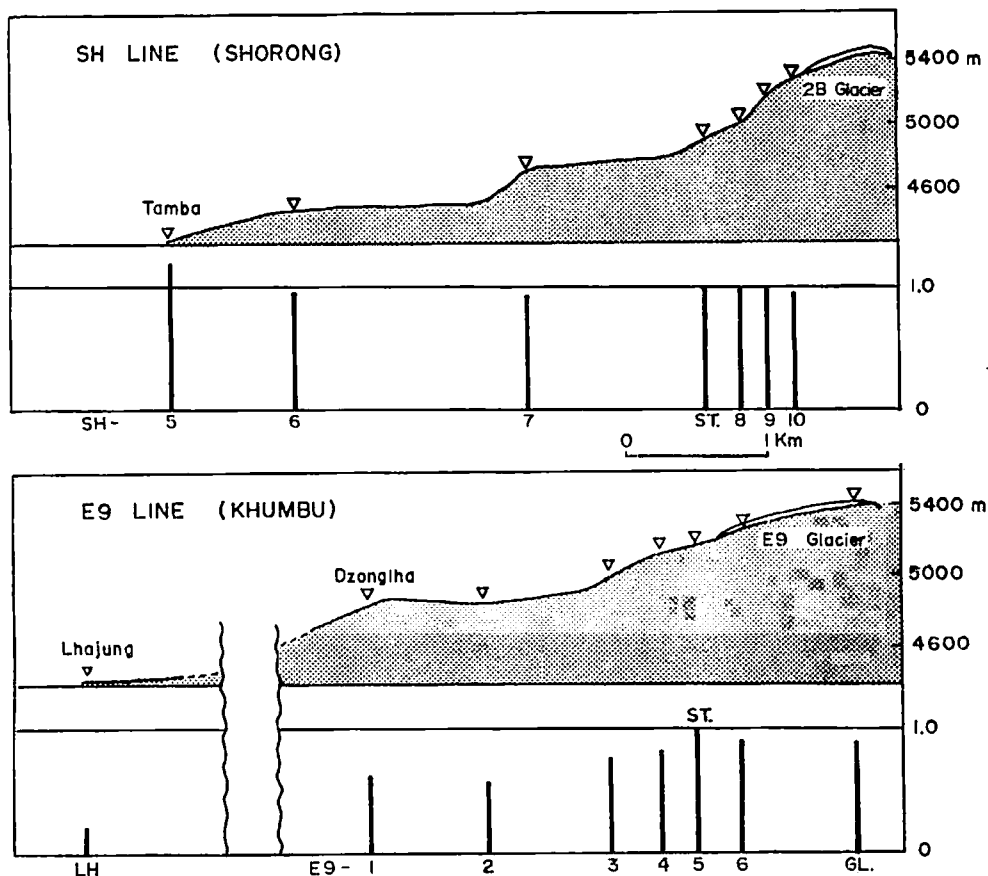


Fig. 6. Cross sections of topography along SH (Shorong) and Glacier EB 050 (E9) (Khumbu) lines and daily mean precipitation during the observed period along the two slope lines. Observation points are indicated by inverted triangles and ST. and GL. mean our temporary meteorological station at Shorong Himal and on Glacier EB 050 (E9), respectively.

small.

Along the slope leading up to the Glacier AX 030 in Shorong Himal, on the contrary, the daily mean precipitation at each point is almost uniformly distributed from point SH-5 (4310 m) to point SH-10 (5210 m) at the terminus of the glacier (the value is nearly 12.5 mm per day), and no significant features corresponding to the altitudes have been observed.

The distinctly different features of the areal distribution of precipitation between Khumbu and Shorong Himal may be summarized as follows: the precipitation around Glacier EB 050 is normally provided by cumulus convections with the orographical effect of the peaks and ridges of 5000-6000 m. In Shorong Himal also, the precipitation is provided by cumulus convection, but of a larger scale. This convection may be induced by the orography of larger scale such as the mountain ranges of Numbur (6954 m) and Karyolung (6681 m) including the long slope up to these barrier-like mountains.

3. Summary and Discussions

From observations of the precipitation phenomena during the monsoon period of 1976 at and around the three stations in Shorong and Khumbu Himal, the following conclusions have been obtained:

1. Daily precipitation shows roughly in-phase variations between these three areas, but the total amounts of precipitation are 4 or 5 times larger at Shorong and Glacier EB 050 stations than Lhajung station.
2. Around the two glacier regions (near Shorong and Glacier EB 050 stations), the contributions of precipitation by daily cumulus convection to the total precipitation are great, while at Lhajung the contribution by the few rainy days affected by large scale disturbances is relatively great.
3. Precipitation spells of less than 30 minutes and 1-2 hours seem to be representative through the three stations. However, the frequencies of spells of 1-2 hours are relatively larger at Shorong and Glacier EB 050 stations as compared to those at Lhajung.
4. At Shorong and Glacier EB 050 stations, the precipitation is concentrated during the daytime, while at Lhajung station it is concentrated during the evening through midnight. A systematic delay of precipitation time from Shorong to Glacier EB 050, and from Glacier EB 050 to Lhajung has also been observed.

5. Along the slope up to Glacier EB 050, the precipitation gradually increases as the altitude increases and reaches its maximum near the terminus of Glacier EB 050. Along the slope up to Glacier AX 030 in Shorong Himal, on the contrary, it is almost uniformly distributed from about 4000 m to the terminus of the glacier (5200 m).

Thus, orographically and thermally induced cumulus convection has a great effect on the precipitation around the glacier regions of high altitude (5000-5500 m) in the Nepal Himalayas. However, the difference of the features of precipitation between Shorong and Khumbu Himal is also found. In Shorong Himal, the role of the orography of the Numbur-Karyolung range as a barrier may be great. It is well known that over northern India moist static instability exists below about the 600 mb level throughout the monsoon period (for example, see Krishnamurti and Bhalme, 1976 or Murakami, 1976). Thus, precipitation of a broader scale in Shorong Himal may be caused by the convective instability released by forced uplifting of the conditionally unstable air of the lower troposphere from the Indian Plain along the southern slope of this mountain range. On account of this "barrier effect" of Shorong Himal and also Hinku Himal on the moisture supply, a semi-arid climate may appear in the Khumbu region, which is located on the lee side of Shorong and Hinku Himal. However, around the rocky peaks and ridges of 5000-6000 m in the Khumbu region, the relatively large amount of precipitation may be provided by the cumulus convection induced by the heating of the rocky ground by strong solar radiation. These features have been confirmed not only around Glacier EB 050 but also around Kongma Glacier (Glacier ED 020), Tauche peak and Gyajo Glacier (Glacier CB' 480) in this region (Ageta, 1976; Ageta, 1977). The distribution of the amount of precipitation and principal areas of precipitation along the Himalayan slope around Shorong and Khumbu Himal is schematically illustrated in Fig. 7. In this figure, the three areas of maximum precipitation are shown over Mahabharat Lekh, at the large frontal area of Shorong and Hinku Himal, and around minor peaks and ridges (5000-6000 m) in the Khumbu region.

Thus, it has been suggested that orographically and thermally induced cumulus convection has a great effect on precipitation in the Himalayas. However, the data we obtained are mostly on the precipitation phenomena as a result of cumulus

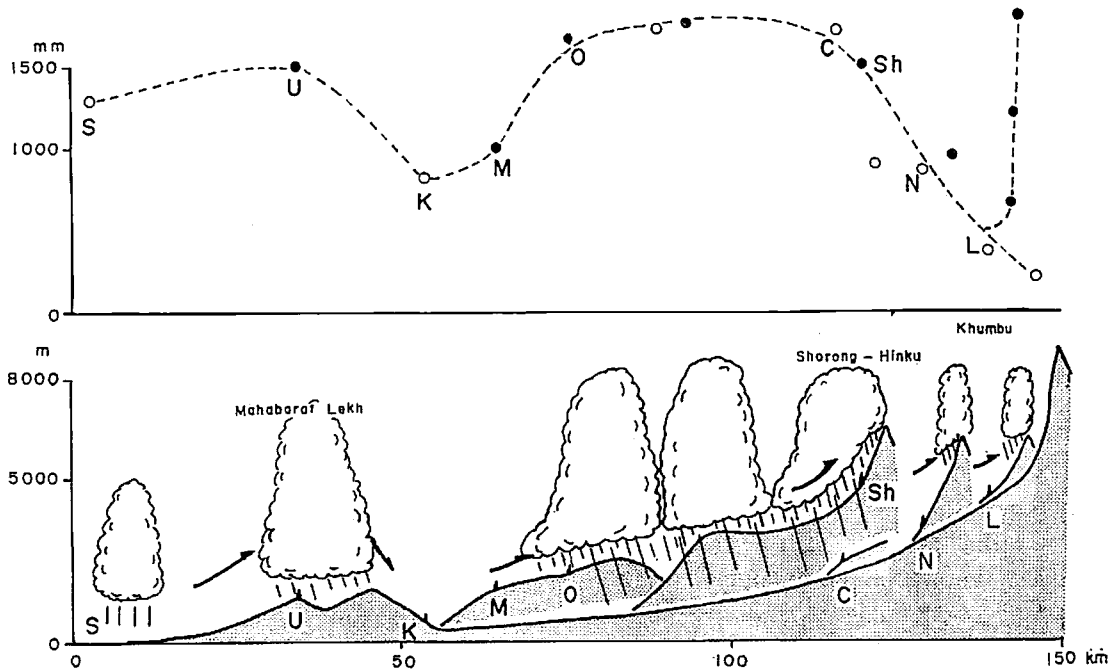


Fig. 7. Distribution of amount of precipitation (upper figure) and schema of principal areas of precipitation (lower figure) along the Himalayan slope around Shorong and Khumbu Himal. Black dots in the upper figure shows the observation points around peaks, ridges, and plateaus and white dots are those around bottoms of valleys.

convection. Therefore, as a next step, such problems as the time and spatial scales of each convective cell, its distribution over the Himalayas and also the relationship between the distribution of cumulus coluds and that of precipitation should be investigated.

Acknowledgements

The authors would like to express their hearty gratitude to Mr. Lhakpa Gyalub Sherpa (Khunde village) for taking the invaluable data at E9 and Lhajung stations by his own efforts through 2 months of the monsoon period, in spite of the troublesome work.

They are also indebted to Mr. Pemba Tsering Sherpa (Khunde village) for assisting them at Shorong station under the difficult conditions.

References

Ageta, Y. (1976): Characteristics of the precipitation

during monsoon season in Khumbu Himal. *Seppyo*, 38, Special Issue, 84-88.
 Ageta, Y. (1977): Personal communication.
 Inoue, J. (1976): Climate of Khumbu Himal, *Seppyo*, 38, Special Issue, 66-73.
 Krishnamurti, T.N. and Bhalme, H.N. (1976): Oscillations of Monsoon System. Part I. Observational Aspects. *J. of Atmos. Sci.*, 33, 1937-1954.
 Murakami, M. (1976): Analysis of Summer Monsoon Fluctuations over India. *J. Meteor. Soc. Japan*, 54, 15-31.
 Shrestha, M.L., Fujii, Y., and Nakawo, M. (1976): Climate of Hidden Valley, Mukut Himal during the Monsoon in 1974. *Seppyo*, 38, Special Issue, 105-108.
 Yasunari, T. (1976a): Spectral Analysis of Monsoonal Precipitation in the Nepal Himalayas, *ibid.*, 59-65.
 Yasunari, T. (1976b): Seasonal Weather Variations in Khumbu Himal, *ibid.*, 74-83.