Bulletin of Glacier Research 8 (1990) *93 – 101*

Diurnal Variation of Precipitation in Langtang Valley, Nepal Himalayas

Ken'ichi UENO[1] and Tomomi YAMADA[2]
1 Institute of Geoscience, University of Tsukuba, Ibaraki 305 Japan
2 Institute of Low Temperature Science, Hokkaido University, Sapporo 060 Japan

(Received December 26, 1989 ; Reviced manuscript received October 5, 1989)

Abstract

The characteristics of diurnal variation of the precipitation in the Langtang Valley, Nepal Himalayas, were investigated using 10-minutes precipitation data during the late monsoon season to the post-monsoon season (from the middle of August to the beginning of October) in 1987. Three types of precipitation are found within a diurnal variation of precipitation. The predominant type, which is a type of simultaneous precipitation all over the valley, shows the maximum precipitation from the early evening (16h-18h) until midnight (11h-02h). This type occupied the largest amount of daily precipitation to as much as about 50%. The other two types respectively represent the distribution from morning (7h-8h) to afternoon (14h-16h), and from the late night (0h-2h) to the early morning (5h-6h). The former mainly appears on the ridges or peaks of the mountains and the amount decreases with decreasing altitude. In contrast, the latter mostly appears in the bottom of the valley, which is characterized by a decrease in the amount with increasing altitude.

The lapse rate of the surface air temperature along the mountain slope was also measured. It tends to decrease after passing the trough in the mid-latitude westerlies.

1. Introduction

Precipitation in the Nepal Himalayas during a monsoon season is strongly affected by a orographically and thermally induced local circulation (Shrestha *et al.*, 1976, Yasunari and Inoue, 1978). Ageta(1976) represented a simplified pattern of diurnal variation of the cloud system, with a special attention to the differences of precipitation phenomena during daytime and nighttime. He concluded that precipitation is brought about by convective clouds in daytime and by the stratiform clouds in nighttime. The areal and the temporal fluctuations of precipitation along a mountain slope are very important for the mass balance of glaciers (Higuchi, 1977). They also give important information for understanding the development of cloud systems relating to local circulation. The detailed features of daily and diurnal variations of precipitation in the Himalayan mountain regions, however, still remain unknown.

Surface air temperature is also one of the important factors in detecting criteria for rainfall/snowfall and glacier melting. The distribution of surface air temperature is usually estimated from observed data at a known altitude using the lapse rate. Though Takahashi *et al.* (1987) showed the variation of daily lapse rate in Langtang Valley, further studies on the characteristics of its variation remain for the future study.

In this paper, discussions are made on the areal and temporal characteristics of precipitation, and the temporal variations in the lapse rate of surface air temperature.

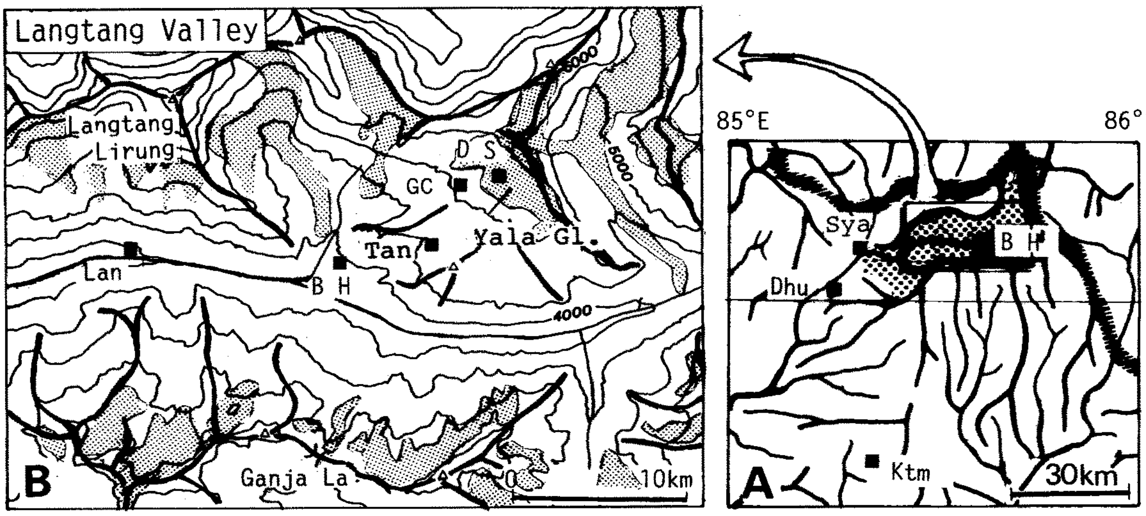

Fig. 1. Locations of the observational points around the Langtang Himal (A), and in the Langtang Valley (B) Langtang Valley is shown by a dotted area in the figure (A), and the location of the glacier is shown by shaded areas in the figure (B).

2. Observations

Observations of precipitation and air temperature were conducted in late monsoon season to post-monsoon season, from August to October, 1987. The location of observation points are shown in Fig. 1-A and B.

The daily amount of precipitation was measured at 6 : 00 NST (Nepal Standard Time) by a simple rain gauge of a store type at five observation points at Dhunche(Dhu, 1960m), Syabrubensi(Sya, 1463m), Base House(BH, 3920m), Glacier Camp(GC(R), 5090m) set up on the moraine in front of the Yala Glacier, and Drilling Site(DS, 5304m) in the accumulation area. The points Dhu and Sya were located outside of the Langtang Valley as shown in Fig. 1-A. In addition to the above data, daily precipitation data at Kathmandu(Ktm, 1336) was used, which was offered by the Department of Hydrology and Meteorology, Ministry of Water Resources.

The 10-minutes precipitation was intensively measured in a digital recorder (data logger system) using a tipping-bucket raingauge from the end of August to the end of September at Langtang Village (Lan, 3500m), BH, Tangdemo (Tan, 4600m) and GC(R). The air temperature was also measured in a digital recorder by using a thermistor sensor every ten minutes at Lan, BH, Tan, GC(I) (on the Yala Glacier terminus about 40m up from GC(R)), and DS. The wind direction was also recorded every ten minutes using a wind vane at BH. The air temperature measurement using a bimetal type thermometer in a screen box, was also made at GC(R) and BH for supporting the digital recorders. The manual observations on cloudiness, visibility and the altitude of the snow line on the southern-facing slope of the Langtang Valley, were visually made at BH, GC(R)and DS. Analysis of the 10-minutes precipitation was mainly made using the data from Aug. 26 to Sep. 12, when the data was simultaneously taken at above mentioned four points.

3. Characteristics of precipitation

3.1 Precipitation on a broad scale

The records of daily precipitation data had been taken over differing lengths of time from point to point due to logistical difficulty (cf. Fig. 3). To know the broad characteristics of altitudinal distribution, the data was cumulated in three periods for comparing with the precipitation at each points, and normalized by the precipitation rate at BH. Though the data are missing for one to three days in above three periods in some points, it does not affect the following discussions and results. The cumulated values at

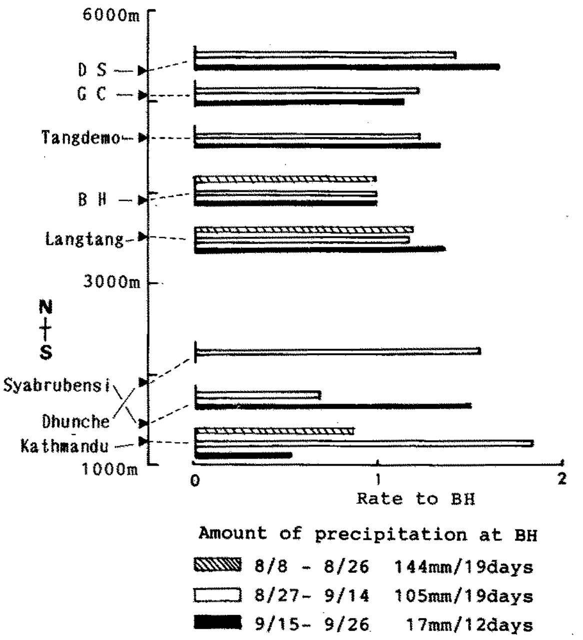

Fig. 2. Altitudinal distributions of the cumulative precipitation in given three periods presented as the rate to BH. Lower list in the figure shows the amount of cumulative precipitation at BH in each period.

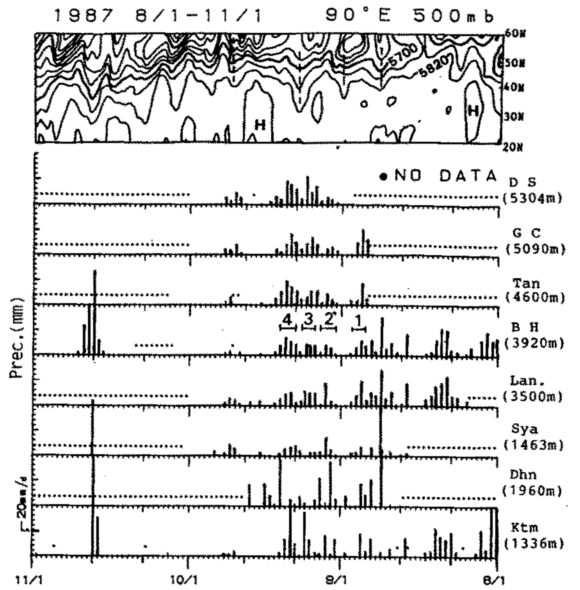

Fig. 3. Daily amount of precipitation and meridional time cross section of geopotential height at 500mb level along 90°E.

each of the points are shown in Fig. 2. At the points outside of the Langtang Valley (Dhu, Sya and Ktm), precipitation has no clear trend in the altitudinal distribution. It shows a marked variation from period to period. On the other hand, at the points along the mountain slope (BH-DS), precipitation tends to increase with the increasing altitude.

Figure 3 shows the time variation of daily precipitation for each point and the meridional time section of geopotential height at 500mb level along 90°E. In the geopotential fields, the migration of deep westerly troughs was seen during the latter monsoon season around Aug. 24, Aug. 31, Sep. 9 and Sep. 23 as indicated by dotted lines in the figure. It rained rather heavily just before or after these troughs. The troughs also bring cold air into the Himalayas providing proper conditions for snowfall over the wide area. Discussion on this aspect will be made in chapter 4. Five to ten day cycle can be seen in the precipitation fluctuation at all observation points (Fig. 3). These periodicities disappear after Sep. 27 when the monsoon season is over. While, at the points outside of the Langtang Valley, daily precipitation is widely spread in its fluctuation, daily precipitation fluctuate smoothly at the points in the Langtang Valley.

The precipitation rate around the peak is reported to be almost twice that at the bottom of the valley in Khumbu Himal region (Ageta, 1976), while the rate was less than twice in the Langtang region as shown in Fig. 2. The valley of Khumbu Himal is opened to the south and runs from the south to the north. On the other hand, the Langtang Valley runs from the west to the east. Since sufficient moisture is supplied from the south associated with the monsoonal circulation over the Nepal Himalayas, the up-valley wind may produce stronger moisture convergence in the Khumbu Valley than in the Langtang Valley.

The cyclic fluctuation of precipitation seen in Fig. 3 may correspond to the cyclic fluctuation of monsoon activity pointed out by Murakami(1976) and Yasunari(1976). Meanwhile, cumulonimbus were usually observed to the south and to the west of Langtang region. The cumulonimbus should generate a sporadic local heavy rainfall. It markedly causes the areal and temporal variations of cumulative precipitation (Fig. 2) and the large variation of daily precipitation (Fig. 3), at the points outside of the valley. On the other hand, in the Langtang Valley, the fluctuation of daily precipitation seems to correspond to the monsoon activity. This suggests that the daily preci-

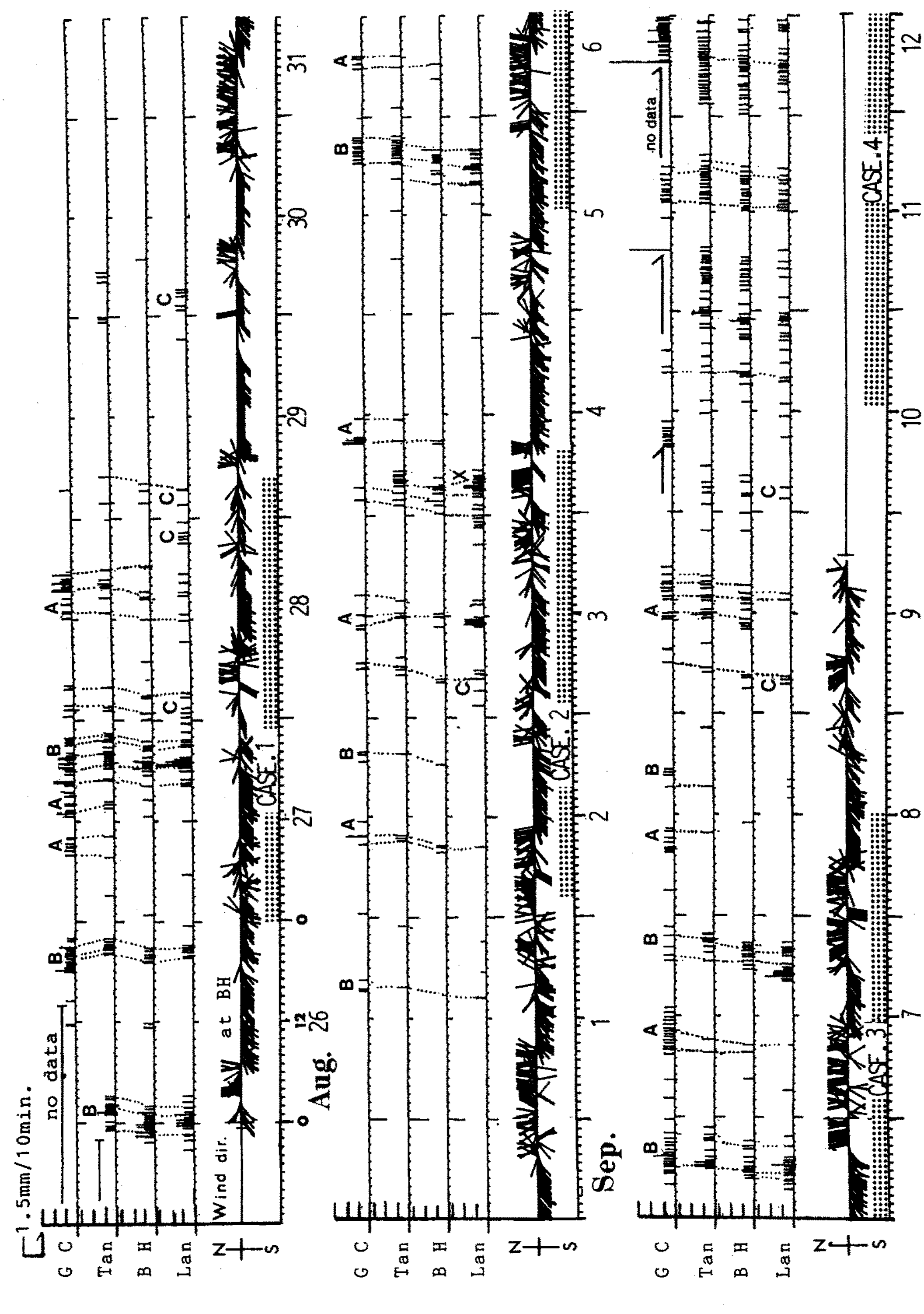

Fig. 4. Time sequences of the 10-minutes precipitation and wind direction at BH.

pitation is mainly induced by the local circulation in the valley, which is subjected to the monsoon activity in the degree of its development. The relations between the diurnal precipitation pattern and the synoptic field in four cyclic fluctuations of precipitation in the periods indicated as 1-4 in the middle part of Fig. 3, will be discussed in the next chapter.

3.2 Diurnal precipitation variation in Langtang Valley

The 10-minutes amount of precipitation data was obtained simultaneously at four points (Lan, BH, Tan and GC) along the bottom and the slope of the Langtang Valley from Aug. 26 to Sep. 12 as shown in Fig. 4. The arrows at GC after Sep. 10 indicate a lack of data, because the snowfall occurred at night in Sep. 10 and 12, and precipitation could not be measured. The data during the daytime was available due to the immediate melting of snow after deposition by strong sun radiation. The change of wind direction at BH is also shown in the figure.

We can see three types of systematized precipitation groups continuing several hours shown by dotted lines connecting point to point vertically in Fig. 4. These types show the characteristics of diurnal precipitation variations in the valley, and conventionally called type (A), (B) and (C). As shown in the figure, type (A) : precipitation tends to occur in the morning at upper points, GC and Tan ; type (B) : it simultaneously precipitates all over the valley in the evening ; type (C) : precipitation occurs after midnight at the bottom of the valley such as BH and Lan. These three groups of precipitation type are indicated by (A), (B) and (C) in Fig. 4. Especially type (B) is the major one in its amount and appearance during the observation period.

For understanding the statistical diurnal variation of precipitation at each points, hourly precipitation is cumulated at each point in the period from Aug. 26 to Sep. 9 and shown by histogram in Fig. 5. Three peaks can be seen clearly in the diurnal variation corresponding to the three precipitation types (A), (B) and (C). The contribution of these precipitation types to the total amount of precipitation was calculated as the percentage at each point, and shown by the horizontal histogram in Fig. 5. The three types of precipitation are characterized as follows :

Type (A): The contribution to the total precipitation increases with increasing altitude, and suddenly decreases in the lower area under Tan. This type appeared from the morning (7h-8h) to the afternoon (14h-16h).

Type (B) : The contribution is largest, more than 50%, at all points. The precipitation period is from early evening (16h-18h) until midnight (11h-02h). It tends to precipitate earlier at lower points than at upper points.

Type (C) : The contribution is larger at the lower points in the valley such as Lan and BH, and gradually decreases with increasing altitude to the points Tan and GC. The precipitation period is from midnight (0h-2h) to early morning (5h-6h), and it also tends to precipitae earlier at the lower points. It precipitates continuously with weak intensity. The daily appearance and association of these three types of precipitation may correspond to the synoptic scale activity of monsoon circulation. Four typical cases are examined, which are indicated by the horizontal dotted bar in Fig. 4, that coincide with cyclic fluctuation of synoptic scale precipitation periods 1 to 4 in Fig. 3. Representative 500mb weather chart in the four cases are shown in Fig. 6 with the position of Langtang region

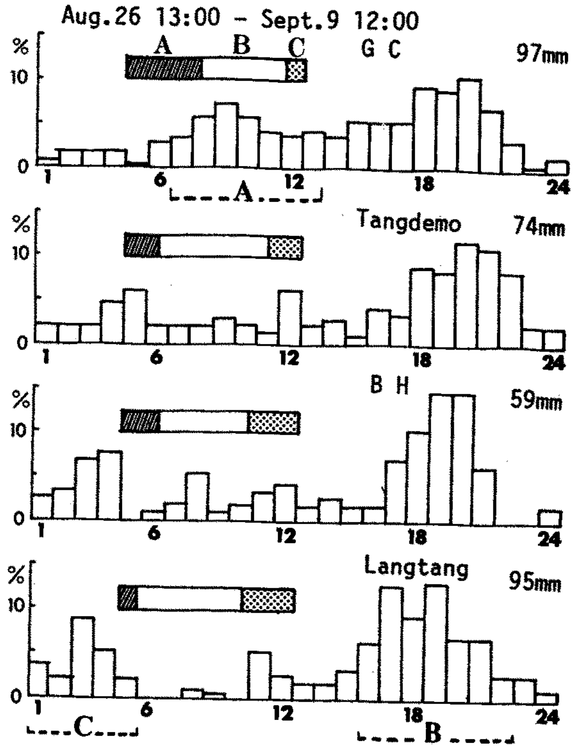

Fig. 5. Histograms of the cumulative amount of hourly precipitation from Aug. 26 to Sep. 9, and the contribution of three precipitation types (A,B and C) to the total amount shown in the right side

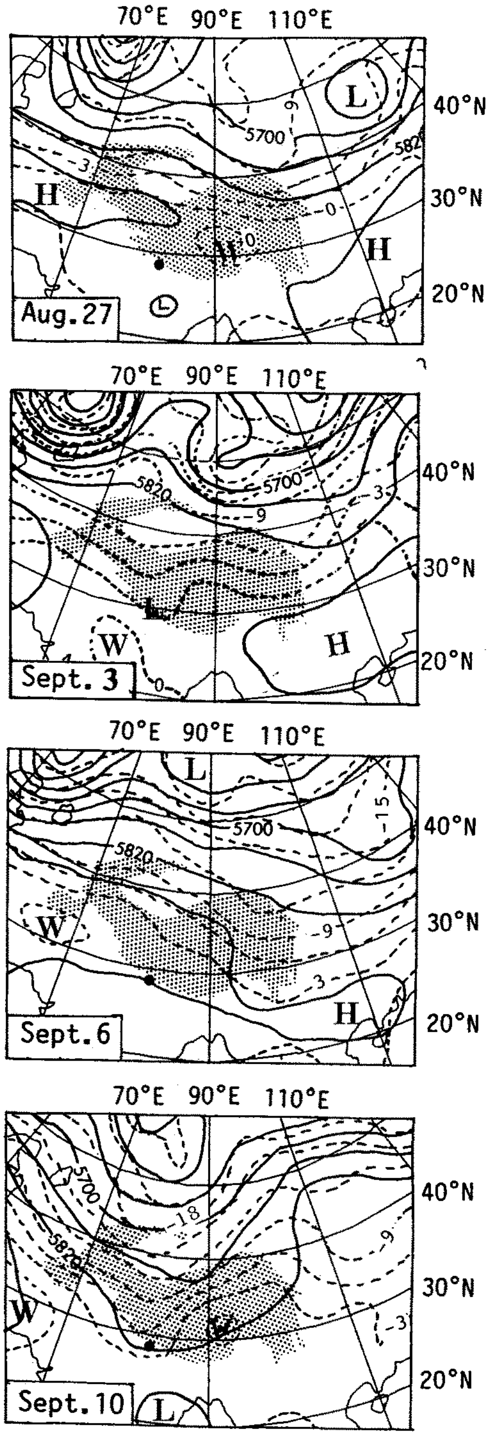

Fig. 6. Weather chart of 500mb at 1200 GMT for Case 1, Case 2, Case 3 and Case 4. The dotted ares indicate highland region above 5000m a.s.l., and the black circle indicates the position of Langtang Valley.

as the black circle.

Case 1 is from Aug. 27 to 28. The 500mb chart shows the trough at 70°E, and the warm area spread over the Himalayas, which indicated strong convection activity. The trough and Tibetan anticyclone spread widely from 40°E to 110°E can also be seen in the 100mb chart. This synoptic pattern indicates the active monsoon period in the Nepal Himalayas. As shown in the wind direction in Fig. 4, an up-valley wind with a south-west component prevailed through out the day except in the early morning from 5 AM to 7 AM on 27 and 28. A little disturbance of wind with a north-east component appeared around midnight with the precipitation of type (C) on 28. This disturbance would be the result of the convergence of down-slope wind and the weak up-valley wind. In this period, all three precipitation types were observed in the valley (Fig. 4).

Conversely, in Case 3 from Sep. 5 to 8, an anticyclone belt appeared with no trough near the Himalayas in the synoptic fields at 500mb. The up-valley wind clearly shifted to down-valley wind with the north component in the early evening every day, which suggests that the large scale monsoon circulation was weaker during this period. In this case, only types (A) and (B) appeared periodically.

The contrast between Cases 1 and 3 suggests that precipitation Type (C) is considered to be brought from stratiform clouds developed between the mountain ridges, which were generated by a moist air flow of up-valley wind and by the radiative cooling through the night during the active monsoon period.

In Case 2 from Sep. 2 to 4, 500mb isobaric surface showed no trough like Case 3, and the warm area extended from the south-east of the Nepal Himalayas. In Langtang Valley, precipitation types (A) and (B) appeared weakly. On the other hand, the heavy precipitation occurred from 2h to 5h in Sep. 4 as indicated X in Fig. 4. Also the intensive daily precipitation was observed in Dhu as seen in Fig. 3. These results suggest that this precipitation was caused by the small disturbance which passed in the south region of Langtang Valley, and it would not be cataloged as type (C).

In Case 4 from Sep. 10 to 12, the cold air associated with passing of a westerly trough inflew over Himalayas, which brought on the snowfall in the areas above some 4500m a.s.l. after Sep. 10. The precipitation types can not seen clearly and weak precipitation continues during the day. Since the snow cover suppresses the development of valley wind (Ohata *et al.*, 1981), the continuous and weak precipitation in Case 4 suggests that magnification of snow cover affected the systematic development of cloud system brought about precipitation types (A), (B) and (C).

The mechanism of the three precipitation types is assumed as follows :

Type (A) is conduced by the convective clouds which are induced by up-slope wind and generated near the ridges in the valley. Type (C) is conduced by the stratiform clouds generated by the moist air and radiative cooling in the night and fixed in the bottom of the valley. The cloud top is usually below the ridges surrounding the valley. It is supposed to appear strongly especially during the active monsoon period in the Nepal Himalaya such as Case 1. Types (A) and (C) might be caused by the peak-valley scale precipitation system as mentioned in Ageta's model. On the other hand, type (B) is brought by the precipitation system induced by the up valley wind, and developed at a larger scale than a valley scale during the daytime. Especially the type (B) predominantly appeared in three types and is quite important for the amount of daily precipitation in all the Himalayan mountain regions.

Table 1. Mean lapse rate (Γ) along the slope with its number of samples (F) and the standard deviation (δ) during the period of each precipitation types (A), (B) and (C).

	F	Γ_s (°C/100m)	δ
A	30	0.58	1.52
B	46	0.62	0.92
C	31	0.62	0.63

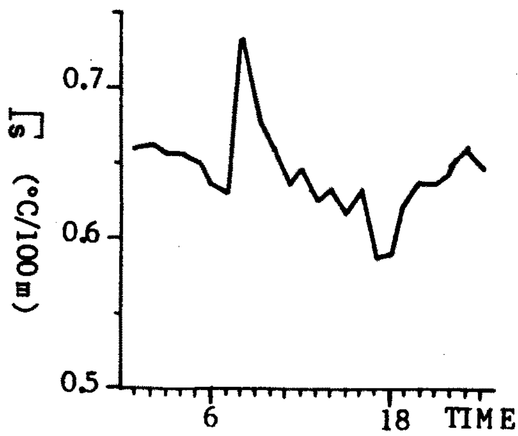

Fig. 7. Diurnal variation of mean lapse rate along the slope during Aug. 25 to Sep. 27.

4. Temporal variation of lapse rate

Lapse rate of surface air temperature (Γ) is calculated from the hourly temperature data of Lan to DS during Aug. 25 to Sep. 27. Mean value of Γ, relation of Γ along the slope to the precipitation type and its characteristics of the diurnal and daily variations are discussed in this chapter.

Mean values of Γ are 0.53°C/100m along the bottom of the valley (Lan-BH), 0.64°C/100m along the mountain slope (BH-GC(R)) and 0.75°C/100m along the Yala Glacier (GC(I)-DS).

The value of Γ(BH-GC(R)) is almost the same as the value of 0.6°C/100m (BH-GC(R)) measured by Takahashi *et al.* (1987) during the late monsoon season on 1986. Γ(Lan-BH) is lower in above three mean values, because the surface heating by the solar radiation in the daytime and the obstruction of radiative cooling by the stratiform clouds appearing at night may decrease the potential temperature gradient of the air mass along the bottom of the valley. On the other hand, along the glacier slope, the value of Γ is largest, since temperature at the observation points GC(I) was affected by the warm air advection from snow free moraine areas in the daytime (Takahara *et al.*, 1984).

The values of Γ along the mountain slope (Γs) are important to estimate the altitudinal temperature distribution. The Γs during each precipitation type are tabulated for comparison with its sample number (F) and standard deviation (δ) (see Table 1). The value of δ is larger during type (A) and smaller during types (B) and (C), while the mean values(Γs) are almost the same for each type. Large variation of Γs during type (A) suggests that the air temperature in the surface layer fluctuates greatly as the cumulative clouds develop along the mountain slope by the heating of strong solar radiation in the morning.

The diurnal variation of mean Γs is shown in Fig. 7. Γs tends to increase suddenly after 7 a.m., because the temperature at BH is increased by the warm air advection along the bottom of the valley by the up-valley wind. Fig. 8 shows the temporal fluctuation of Γs, with 7-days weighted running mean using the normal curve smoothing function, is compared with the 24-hour running mean of temperature and daily

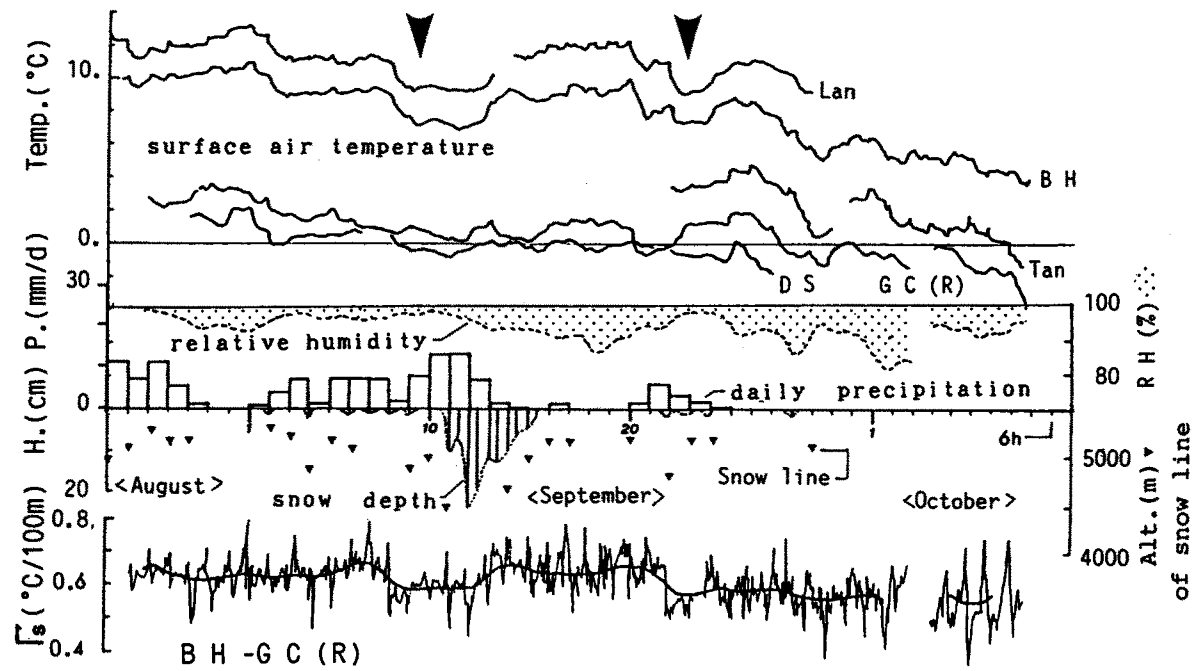

Fig. 8. Time sequences of the surface air temperature in 24 hour running mean, relative humidity and daily precipitation at BH, snow depth at GC(R), lowest altitude of the snow line on the southern-facing slope and the lapse rate of surface air temperature along the slope with 7 days weighted running mean.

snowcover condition. The time sequences of daily amount of precipitation and relative humidity at BH are also referred. After the passing of the westerly troughs at Sep. 9 and 23 as indicated by ▼, the peak of Γs in the morning shown in Fig. 7 did not appeared, and the mean value of Γs decreased to about 0.1°C/100m. At the same time, new snow covered areas spread down to about 4800m-4500m a.s.l.. Although there is not enough information to discuss about the effect of the westery troughs to the magnification of snowcover, the result suggests that the westery trough plays an important role for the weekly time scale fluctuations of altitudinal air temperature distribution through the change of local circulation system in the valley. And also, if the snow-rain boundary is estimated using critical temperature deduced from the mean value of Γs, the altitude of its boundary will be estimated lower than the actual boundary is.

5. Concluding remarks

The observations show the existence of three precipitation types and respective distribution characteristics. The mechanism of the developing cloud system for each precipitation type is strongly related to the local circulation, topography of the valley and the monsoon activity. It should be investigated in future with the three-dimensional meteorological observations, such as radiosonde and remote sensing observations. Also the study of snowcover effect to the precipitation type (B) remains for future study. Discussions are made in diurnal and daily variations of the lapse rate of surface air temperature along the mountain slope and its characteristics. The characteristics of the temperature profiles, in the deep valleys of the Nepal Himalayas, should also be observed more continuously under different synoptic situations, since it determines the snowfall conditions which in turn will finally affect the development of the precipitation system through the change of local circulation around the valley.

Acknowledgments

The authors would like to express their appreciation to the Department of Hydrology and Meteorology, Ministry of Water Resources, His Majesty's Government of Nepal, for offering the vital data. They also would like to express their gratitude to all members of GEN-LP '87 for their help in the meteorological observations and useful discussions during the expedition.

References

Ageta, Y. (1976) : Characteristics of precipitation during monsoon season in Khumbu Himal. Seppyo, Special Issue, **38**, 84–88.

Higuchi, K. (1977) : Effect of nocturnal precipitation on the mass balance of the Rikha Samba Glacier, Hidden Valley, Nepal. Seppyo, Special issue, **39**, 43–49.

Murakami, M. (1976) : Analysis of summer monsoon fluctuations over India. Jour. of Meteor. Soc. of Japan, **54**, 1, 15–31.

Ohata, K., Higuchi, K. and Ikegami, K. (1981) : Mountain-valley wind system in the Khumbu Himal, East Nepal. Jour. of Meteor. Soc. of Japan, **59**, **5**, 753–762.

Shrestha, M.L., Fujii, Y., Nakawo, M. (1976) : Climate of Hidden Valley, Mukut Himal during the monsoon in 1974. Seppyo, special Issue, **38**, 105–108.

Takahara, H., Higuchi, K., Mulmi, D.D. (1984) : Heat balance study on Yala Glacier in Langtang Himal. Glacial Study in Langtang Valley, Report of the Glacier Boring Project 1981–82 in the Nepal Himalaya, No. **2**, 49–60.

Takahashi, S., Motoyama H., Kawashima K., Morinaga Y., Seko K., Iida H., Kubota H., and Turadahr N.R. (1987) : Meteorological feature in Langtang Valley, Nepal Himalayas, 1985–1986. Bulletin of Glacier Research, **5**, 35–40.

Yasunari, T. (1976) : Spectral analysis of monsoon precipitation in the Nepal Himalaya. Seppyo, Special Issue, **38**, 59–65.

Yasunari, T and Inoue, J. (1978) : Characteristics of monsoonal precipitation around peaks and ridges in Shorong and Khumbu Himal. Seppyo, special Issue, **40**, 26–32.