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Characteristics of precipitation distribution in Tanggula, Monsoon, 1993

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Abstract

Intensive precipitation observation was conducted in Tanggula basin from May to September, 1993, together with aerological observations, to provide basic data for a basin scale water budget and to investigate the characteristics of spatial and temporal variation of precipitation distribution associated with unique monsoonal precipitation disturbances. The precipitation gauges were manually calibrated at Base Camp (BC), and the calibration data were used to correct data from the remote areas. Monthly precipitation in July was about 150 mm in the basin, decreasing 10–20% in the central basin and increasing 35% around the Dongkemadi Glacier (GC). Precipitation events lasting several hours were simultaneous throughout the basin, but correlation of 12h-precipitation amount was not observed between latitudinally scattered stations, except between BC and GC, due to the small amount of daily precipitation, only 3 to 5 mm. Diurnal variation of precipitation is not obvious except at D100 station situated at the northern edge of the Tanggula Mountain Range.

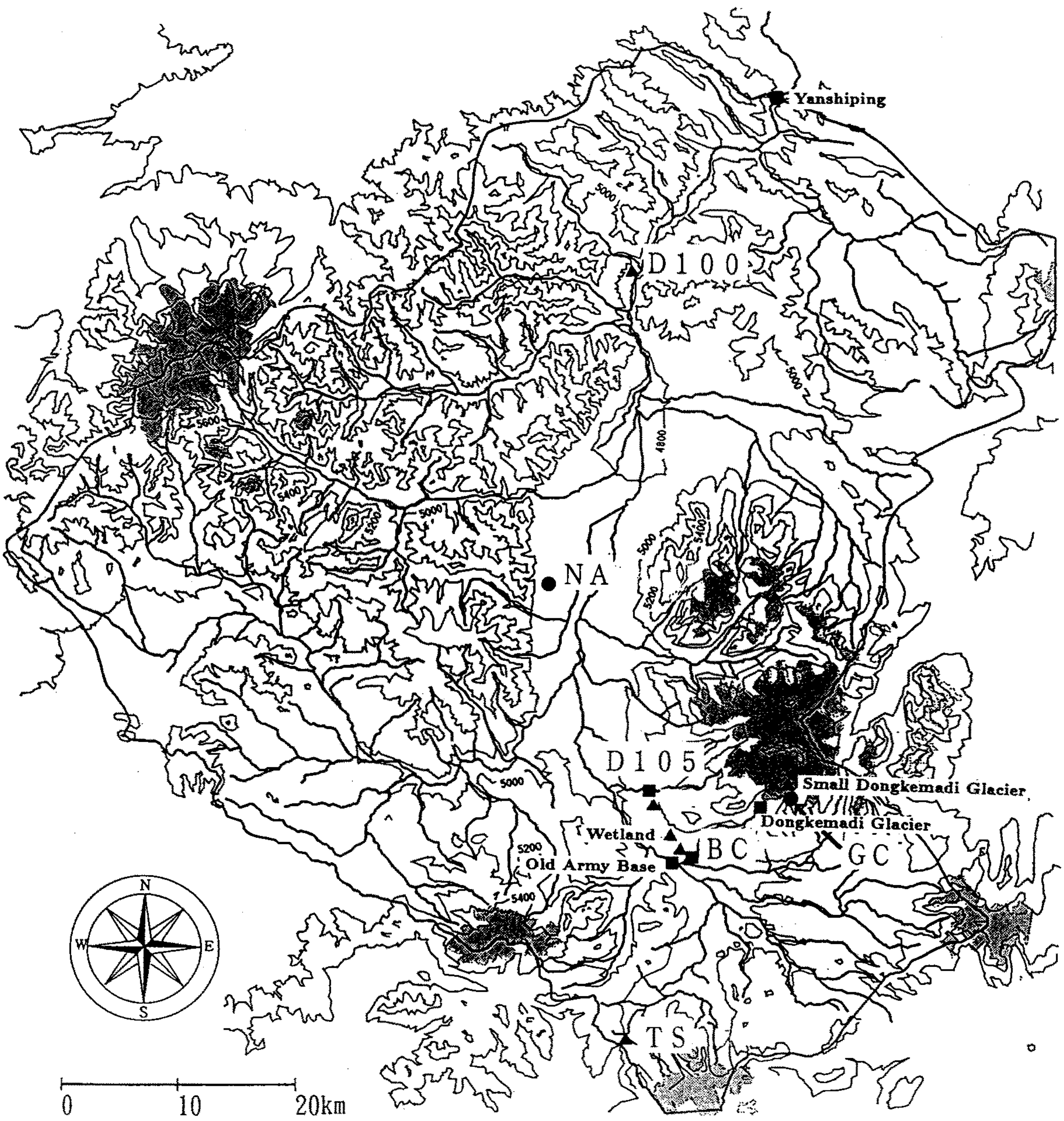
Relationships between the percentage of solid precipitation and surface air temperature were observed using automatic 2-minute interval intensive temperature recording and eye observation of precipitation types at BC. The probability curve is characterized as high altitude inland type, and the probability of solid precipitation markedly increases during hail as temperature increases.

1. Introduction

Most of the annual precipitation on the Tibetan Plateau takes place in the monsoon season. However, it is still unclear how local atmosphere-land interactions affect the large scale monsoon activity around the Plateau, in this season. Precipitation distribution, with its temporal and spatial variations, is one of the most basic elements for the water budget, and also provides the important information about the cloud system and related atmospheric disturbances. Intensive observation of precipitation was carried out from May to September in 1993 at 5 stations in the Tanggula basin with data calibration at Base Camp (BC, 5060 m a.s.l.). Temporal observation of the phase of precipitation was conducted together with automatic temperature recording at BC. The observation network, methods of data calibration, characteristics of precipitation distribution and probability of solid precipitation are discussed in this paper.

2. Observation network

Tanggula basin is located in nearly the center of the Tibetan Plateau (33°N, 92°E), with an area of 4538 km², and is mostly above 5000 m a.s.l. Figure 1 shows the topography in the basin. A Tretyakov storage type rain gauge with wind shield which is the WMO standard, and a Chinese storage type rain gauge without wind shield were set together at BC for data



▲:Hydro-meteorological Station, ●:Precipitation Gauging Station
■:Water-level Gauging Station

Fig. 1. Map of observation area. Stippled areas indicate glaciers.

calibration, where the precipitation was manually measured twice a day, at 0GMT and 12GMT. Tipping type rain gauges were set at BC, D105, D100, Tanggula Pass (TS), and Glacier Camp (GC). One pulse equals 0.5 mm (0.2 mm in D100), and the data were automatically recorded every 10 minutes. This type of rain gauge is useful because of its simple structure and independence of electric power, but also causes underestimates of the amount as shown later. Surface meteorological stations were set together with these rain gauges at all stations (Ohata *et al.*, 1994). Also intensive aerological observation was conducted using omega sondes to observe the diurnal and intra-seasonal variation of planetary boundary layer and synoptic situation for the precipitation disturbance at BC (Endo *et al.*, 1994). Another simple storage type of rain gauge were set at GC and New Army station (NA), where data was temporarily collected during the glaciological observation periods.

Phases of the precipitation, such as rain, snow, hail, and sleet, were observed randomly and recorded manually with time, at BC, a total of 232 times. Surface temperature with aspiration at 0.8 m height was recorded automatically at 2 minutes intervals through the period. The six-minute running mean of temperature was taken, and the percentage of solid precipitation was calculated for each 0.5°C interval. Sleet is treated as both liquid and solid precipitation.

3. Calibration of precipitation

When we observe precipitation on a high elevated plateau with dry and windy weather conditions, observational errors due to evaporation and wind effects are expected in different types of rain gauges. Therefore, first, precipitation over half-day intervals measured by the Tretyakov and Chinese storage type rain gauge and tipping bucket type rain gauge were calibrated against each other at BC. Daytime evaporation from the storage type rain gauge was observed to be 0.15 mmh^{-1} and 0.09 mmh^{-1} on fair and cloudy days, respectively. These observed values are two to four times larger than those observed by Lapin and Samaj (1989). The values were added to the daytime data measured by Tretyakov referred with fair and cloudy weather manually recorded over 3-hour intervals at BC. Nighttime evaporation is assumed to be 0 mmh^{-1}. The accumulated evaporation loss was 7 mm, 1.6% of the total precipitation through the monsoon season. The small amount of total estimated evaporation resulted from the small number of fair days due to the continuous rain through the monsoon season in 1993, as shown later. The corrected precipitation amount for the Tretyakov is treated as the standard precipitation amount at BC in this report.

Second, the aerodynamic effect (wind effect) was evaluated by comparison between this standard precipitation and the precipitation observed by Chinese type (without wind shield) rain gauge. At first, we tried to formulate a correction coefficient as a function of wind velocity during precipitation periods, but no significant correlation was found between them. The reason for lack of correlation between the wind speed and precipitation correction coefficient is believed to be that precipitation was measured over half day intervals, not hours or minutes, and most of the precipitation was rain with weak intensity. Therefore, the precipitation measured by the Tretyakov and Chinese types was directly compared, and the following experimental relation obtained,

$$Y = 1.0616X + 0.0406 \ (F = 133,\ R = 0.99), \qquad (1)$$

where X and Y indicate the half day amount of precipitation observed by the Chinese type and standard precipitation by Tretyakov, and F and R indicate the number of samples and correlation coefficient, respectively. The coefficient 1.0616 is nearly the same in case of rain as 1.05, reported by Rostad (1925) in case of rain and sleet, and is one order smaller than that for snow, 1.2−1.4, reported by Lapin (1989).

Corrected tipping bucket type precipitation (T) from the formula (1), and standard amount of Tretyakov (Y) were compared, and the following equation was obtained:

$$Y = 0.829T + 0.578 \ (F = 104,\ R = 0.9), \qquad (2)$$

which indicates that large discrepancy (underestimation) of Y on the order of 0.5−1.0 mm per 12 hour is caused if T is small. This order is not negligible compared with the mean daily precipitation in Tanggula of 5.1 mm per day and daily evaporation rate observed by Ohata *et al.* (1991). The reason may be evaporation from the 0.5 mm tipping bucket and bouncing of hail out from the gauge catchment which is frequently observed at the beginning of precipitation. These mechanical effects cause about 5% to 10% underestimate of total precipitation in the monsoon season. In order to solve these problems, several improvements for the precipitation observations are proposed such as : 1) use a smaller tipping bucket for weaker intensity of precipitation, 2) install a wind fence at a windy plain or summit station, 3) design the shape of gauge catchment to prevent the bouncing of hail.

All the accumulated 12h precipitation amount measured by tipping bucket type rain gauge were corrected by using the combination of equations (1) and (2). In case of no record for 12 hours by tipping bucket type rain gauge, the equations were applied only when a precipitation event was observed at BC. Experimental equations (1) and (2) are applicable to observations using a tipping bucket type rain gauge only during the continuous rainy season during monsoon with its intensity of 3–5 mm per day in the Plateau.

4. Results

4.1. *Temporal and spatial variations*

Time sequences of 12h precipitation amount at five stations and temperature at BC with diurnal variation from May 18 to Sept. 21 are shown in Fig. 2. Precipitation at BC is the standard amount observed by Tretyakov gauge, and data at D105, D100 and TS are corrected tipping bucket type measurements. At GC, the amount by simple bucket type gauge is shown because it is more reliable for snowfall than the automated tipping bucket type. Precipitation at BC was 441 mm through the period, the monthly amount in July was 143 mm, about 1.5 times larger than that from the Chinese climatological map of precipitation distribution (Yeh and Gao, 1979). A continuous precipitation period lasted from June 16 until August 24. Averaged daily precipitation was 5.1 mm, and precipitation was observed on 91% of the days in this period. This continuous precipitation was initiated with a sudden jump of the tropopause from 13 km to 17 km (Endo *et al.*, 1994). Therefore, the start of this continuous precipitation is defined as the onset of the monsoon in Tanggula. Increase of temperature trend is restrained by this onset, and minimum and daily mean temperatures varied little through the monsoon period.

Several fair days interrupted the monsoon activity at all stations, such as June 13–15, 22–24, July 7–9, 22–23, and August 29-Sep. 4 (black triangles in Fig. 2). These periods were initiated by cool temperature events in the lower troposphere with decrease of precipitation, followed by several fair days with

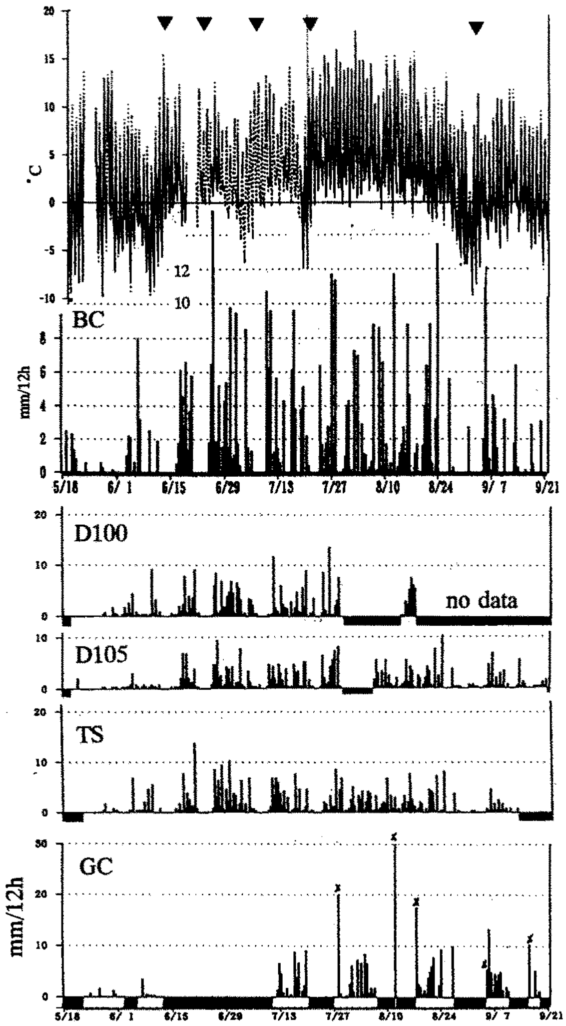


Fig. 2. Temperature variation with 30 minutes interval (upper) and the 12-hours precipitation variation (lower) at BC, D100, D105, TS and GC.

increasing surface temperature and northerly wind in the middle troposphere (see Endo *et al.*, 1994). In June and July, these cooling events also induce significant decrease of discharge (Ohta *et al.*, 1994) due to the suppression of melting glaciers and several no precipitation days. This unique and systematic behavior of the atmosphere and surface water relationships may be associated with intra-seasonal variation of the large scale monsoon circulation around the Tibetan Plateau.

Accumulated precipitation (percentage relative to

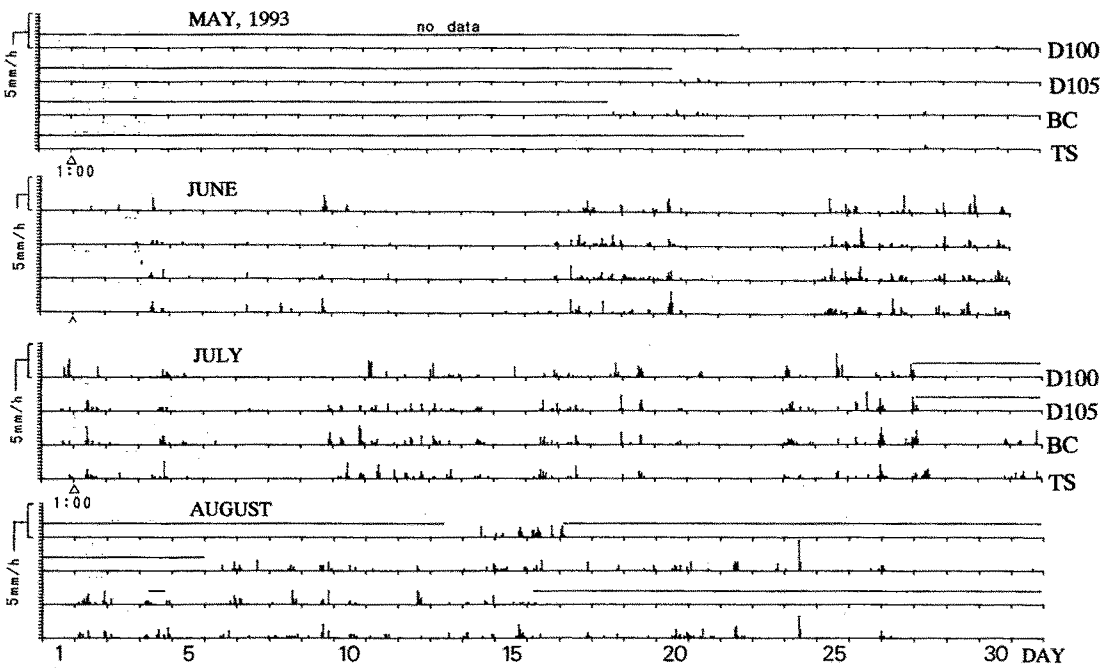


Fig. 3. Time sequences of hourly precipitation at four stations in Tanggula basin, from May to August, 1993.

BC) from May 23 to July 28 was 244.1 mm (100%) at BC, 238.5 mm (97%) at D100, 223.7 mm(91%) at TS and 185.5 mm (75%) at D105. All the stations except D105 were located in the hilly areas surrounding the basin, where differences of precipitation were within 10%. On the other hand, D105, located in a plain area of the central basin, recorded a smaller amount of precipitation. Accumulated precipitation manually observed during the same period at NA, located in the same plain area as D105 (see Fig. 1), also recorded 193.1 mm (79%) nearly the same as at D105. On the other hand, obvious strong wind speed was not observed at D105 compared with other stations (Ohata *et al.*, 1994). Therefore, the precipitation amount in the central plain is expected to be 20−30% smaller than that of the surrounding hilly areas.

Hourly precipitation change is compared simultaneously at four stations in Fig. 3. The continuous precipitation period shown in Fig. 2 actually consists of several precipitation periods of several hours each. It is obvious that most of these precipitation periods occurred simultaneously at all stations although the stations are separated by up to 70 km. In particular, time sequences of precipitation are similar between BC and D105, only 10 km apart. Meanwhile, at D100, independent pulses with larger intensity were observed, such as on July 1, 11, and 25. The results indicate that systematic mesoscale disturbance or rain bands associated with synoptic disturbances were basin-wide in extent.

Half day precipitation is compared between BC and other stations as shown in Fig. 4. Significant positive correlation is only observed between BC and GC, as follows:

$$Y = 0.95X + 1.22 \ (F = 54,\ R = 0.80), \qquad (3)$$

where X and Y indicate the 12h precipitation amount observed at BC and GC. Total precipitation over 54 days was 150.4 mm (100%) at BC and 215.1 mm(135%) at GC. Thus, the climatological precipitation at GC is 1.35 times larger than that at BC, and the amount at GC can be estimated from the data at BC. Especially, the second term constant (1.22) in equation (3) is the important factor, indicating that precipitation (Y) can be provided even no precipitation is observed at BC (X) due to the orographic development of clouds.

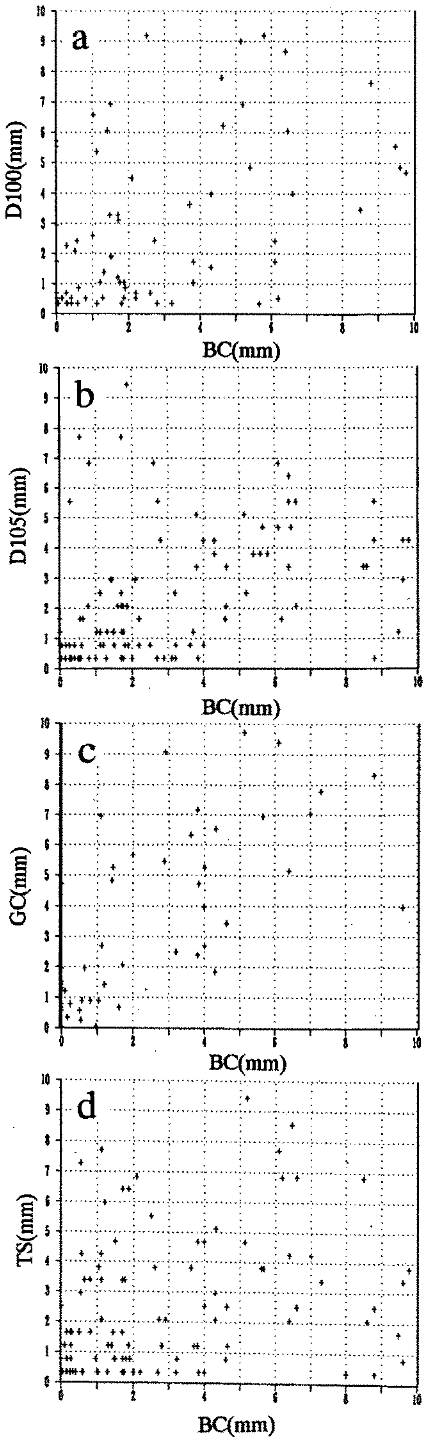


Fig. 4. Relationships of the 12-hour precipitation between a) BC and D100, b) BC and D105, c) BC and GC, and d) BC and TS, in cases of precipitation intensity below 10 mm/12h.

Except for GC, there are no obvious relations of 12h precipitation between BC and other stations, even for the nearest station, D105, only about 10 km from BC (Fig. 1). This result is the same when the analysis is performed using daytime and nighttime data, separately. The result seems to be contradictory to the fact that precipitation is provided by the same group of precipitation events in the basin, as shown in Fig. 3. It is speculated that precipitation events are provided by the meso-scale or synoptic scale disturbance simultaneously over the Tanggula Basin, but the amount in each station is strongly affected by development and trace of cumulus convection embedded in this disturbance with less than 10 km scale. At BC, the cloud system moved from west to east, and GC was 10 km ENE of BC. The significant relation in precipitation amount between BC and GC may result from this frequent eastward passing of the cloud systems. The results show the difficulty of experimental extrapolation from point precipitation values on a half-day time scale around Tanggula due to the small intensity of precipitation with sporadic convective activities.

4.2. *Diurnal variation*

Figures 5 show diurnal variation of the amount, frequency and intensity of precipitation observed by the tipping bucket type rain gauges at four stations through the same period. In this figure, the values were calculated from original data of the tipping bucket type rain gauge. Increase of amount and frequency are shown at 10 o'clock Beijing Standard Time (8 o'clock local time and 2 o'clock GMT). This is probably induced by the melting of snow or ice in the rain gauge by the sunrise. The same feature has been reported in the Nepal Himalaya (Ueno *et al.*, 1993). Increase of precipitation amount and frequency is observed in the evening only at D100, located at the terminus of Tanggula basin with the lowest altitude and out of the mountain range. Particularly, it is obvious in the frequency. The averaged intensity of precipitation is around 1 ± 0.5 mmh^{-1} without obvious diurnal variation. The results show that significant diurnal variation in the precipitation distribution is not observed in the Tanggula Mountain Range.

4.3. *Probability of occurrence of solid precipitation*

The probability of occurrence of solid precipitation is observed to estimate the variation of the precipitation phase, which determines the distribution of snowfall area and influences the accumulation of

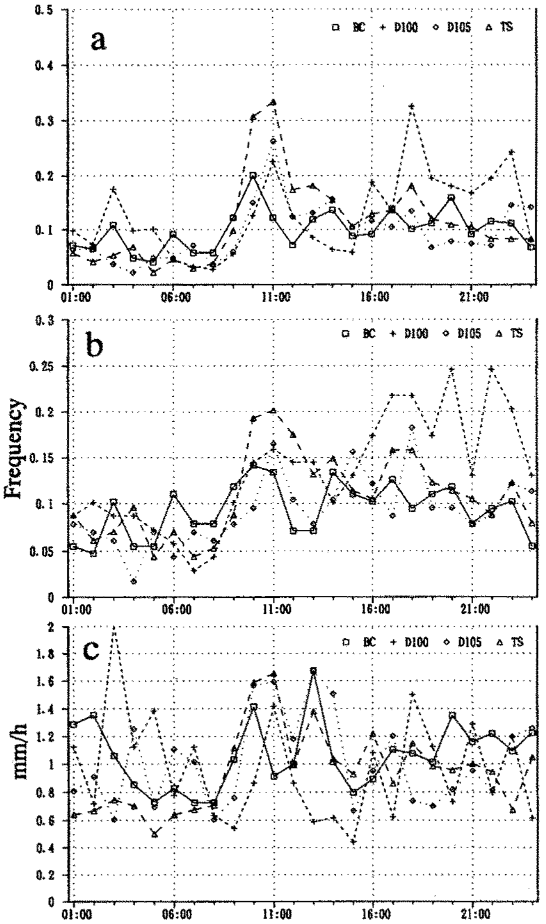


Fig. 5. Diurnal variation of averaged hourly precipitation (a), averaged frequency per hour (b), and averaged precipitation intensity (c). Beijing Standard Time is used.

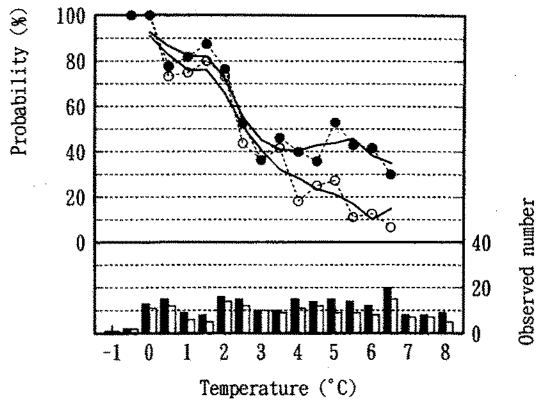


Fig. 6. Relation between the probability of occurrence of solid precipitation and the surface temperature (upper), and observation number (lower) in 0.5°C intervals. Dashed curves with black (white) marks indicate that hail is included (excluded) as solid precipitation. Solid curves indicate three-point running means. Black and white bars indicate the frequency in cases in which hail is included and excluded, respectively.

glaciers (Higuchi, 1977 ; Ageta *et al.*, 1980). There are some experimental results on the relations between the phase of precipitation and surface air temperature (Ito, 1944 ; Glazyrin, 1970 ; Ageta *et al.*, 1980 ; Hasemi, 1991), but few observations have been conducted on the Tibetan Plateau. Precipitation types also vary depending on humidity (Matsuo and Sasyo, 1981 ; Matsuo *et al.*, 1981). The present study only considers temperature for convenience in observation and systematic comparisons with previous results in the Himalaya and Japan.

Figure 6 shows the probability of solid precipitation for two cases, including and excluding hail, respectively. Temperature ranges above 6.5°C are excluded because of inconsistent increase in percentage related to the small sample numbers. When hail is excluded (white circles), the percentage decreases from 100% at 0°C to 6.6% at 6.5°C. The probability trend shows a slightly concave curve as the temperature increases. The highest temperature during snowfall was 8°C, and the lowest during rainfall was 0.5°C. The relation between the temperature and percentage is given by the following linear equation ;

$$P = -14.2T + 91.8 \ (0 \leqq T \leqq 6.5), \quad (4)$$

where T and P are the 0.8 m temperature with aspiration and the percentage of occurrence of solid precipitation, respectively. Higher probability of solid precipitation in warmer condition was observed in comparison with the observations in the Nepal Himalaya by Ageta *et al.* (1980) and in Japan by Ito (1944) and Hasemi (1991). The probability curve in this study is similar to the result observed at a higher altitude station in the inland are of Eurasia by Glazyrin (1970). When hail is included (black circles in Fig. 6), percentages of solid precipitation remain higher around 40%, above 4°C. This results from the falling of hail into low-level warm atmosphere caused by strong convective clouds. In fact, precipitation initiated by strong hail shower was often observed in BC. Unfortunately, enough samples of the phase observation of precipitation were not conducted above 6.5°C, and the trend of the probability curve including hail is not clear in Fig. 6. But the results indicate that frequent hail may significantly affect the probability of percentage of solid precipitation at warmer temperature on the central Tibetan Plateau. Observation of altitudinal variation of the probability of hail is proposed for the future.

5. Summary

Intensive precipitation observation was carried out at 6 points in Tanngula basin in the monsoon season, 1993. Results are summarized as follows.

1) Precipitation amount was calibrated by the standard amount observed by Tretyakov rain gauge at BC. Tipping bucket type rain gauge underestimated precipitation by 5 to 10% due to the mechanical problems under the low precipitation.

2) A continuous precipitation period was observed from June 16 to August 24. The total precipitation was 143 mm in July at BC in the Tanggula basin.

3) Several fair periods alternated with monsoon precipitation at all stations in the Tanggula basin, and were accompanied by cool events in the surface temperature.

4) Total precipitation amount in the plain area of the central basin was lower by about 25% than that in hilly areas surrounding the plain.

5) Isolated precipitation periods of several hours occurred simultaneously at D100, D105, BC and TS. But no obvious correlation in 12h precipitation amount was found among them.

6) Significant correlation was found between GC and BC in 12h precipitation ; the total precipitation at GC was 1.35 times larger than that at BC.

7) Diurnal variation in amount and frequency of the precipitation was only clearly observed at D100.

8) Probability of solid precipitation was obtained as a function of air temperature at BC (5060 m a.s.l.). The percentage of solid precipitation in warmer temperature was higher than that in the Nepal Himalaya and in Japan, principally due to the hail.

Results provide important information about the precipitation system in Tanngula basin. Precipitation events are basically associated with mesoscale disturbances covering the basin and therefore occurs simultaneously, but the amount is sporadically distributed in the basin due to the activity of convective clouds and their modification by the surrounding hills or mountains. Accurate estimation of the spatial distribution of precipitation by remote sensing observations, such as radar observation and GMS images, is necessary on the plateau. Observation of the physical structure of precipitation disturbances is proposed for the future.

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