Spectral Analysis of Monsoonal Precipitation in the Nepal Himalaya*

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Abstract

Spectral analysis was performed on records of the daily precipitation during the monsoon season of 1973 at stations in the Nepal Himalaya. Through power spectral analysis on the data at 12 stations and also on the areal averaged data (east, central and west Nepal), a predominant periodicity of around 10 days and secondary periodicity of about 5 days are found. Through crossspectral analysis between these data, the periodicity around 10 days is found to be correlated with large-scale disturbances causing precipitation simultaneously in all of Nepal, and the periodicity of about 5 days seems to be associated with monsoon lows moving westward along the monsoon trough in northern India. The periodicity of around 10 days also seems to be related to the oscillation of the Tibetan High and or level of activity of the monsoon regime over the Indo-Tibetan region.

1. Introduction

It has been found that most of the annual precipitation in the high altitudes of the Nepal Himalaya falls during the monsoon (from June to October). through observations for 2 years, namely, 1973 and 1974, at Lhajung (4420 m) in Khumbu Himal (see the Appendix.I). Accordingly, the amount of accumulation on the glaciers in this region, which is one of the main factors governing the glacier regime, depends on the variation of precipitation activity during the monsoon season.

It is well known that precipitation over the Hindustan Plain and along the southern periphery of the Himalayas is strongly influenced by the "monsoon trough" where disturbances such as monsoon lows and depressions travel westward through this region. Therefore, precipitation over the Nepal Himalayas is considered to be caused at least partly by these disturbances. On the other hand, it has been found that the southwest monsoon circulation over the Indian subcontinent through the Tibetan Plateau is closely related to the quasi-steady thermal anticyclone over Tibet called "Tibetan High". This anticyclone is considered to be produced and maintained by a strong sensible heat supply from the high level ground and latent heat released by active cumlus convection over the Tibetan Plateau and the Himalayas. In other words, monsoonal precipitation over the Nepal Himalayas may be related directly to the movement or variation of this

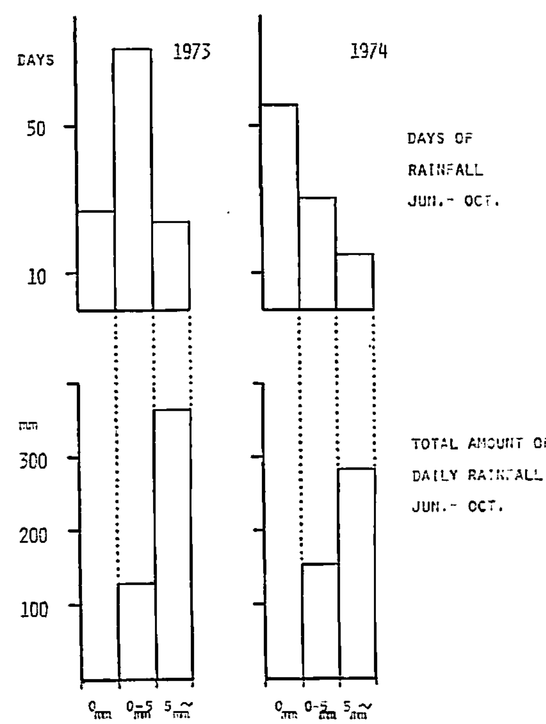

Fig. 1. Cumulative amount of precipitation in each range of daily precipitation during the monsoon season in 1973.

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** *Disaster Prevention Research Institute, Kyoto University, Uji-shi, Kyoto* 611 anticyclone. However, since the mechanism of the monsoon circutlation over the Indo-Tibet region combined with the Tibetan High still has many problems to be solved, precipitation phenomena in the Himalayas should be studied from the point of view of non-linear interaction between cumulus convection and the Tibetan High.

Monsoonal precipitation at Lhajung ocurred during the period from the beginning of June to the middle of October in both 1973 and 1974, though the duration varied slightly between 1973 and 1974. Precipitation occurred almost every day during this period, but moderaterly rainy days alternated with occasional days of no rainfall or heavy rainfall. Most of the rainly days are characterized by drizzle less than 5 mm of precipitation per day but the contribution to the total amount is made mainly by a few rainy days with precipitation of 5 mm per day (Fig. 1).

In this paper, as a preliminary study to clarify the characteristics of the disturbances causing a large amount of preciptation and also the interrelationship between precipitation over the Himalayas and monsoon circutlation over the Indo-Tibetan region, an analysis of the periodicity appearing in monsoonal precipitation over the Nepal Himalayas was carried out.

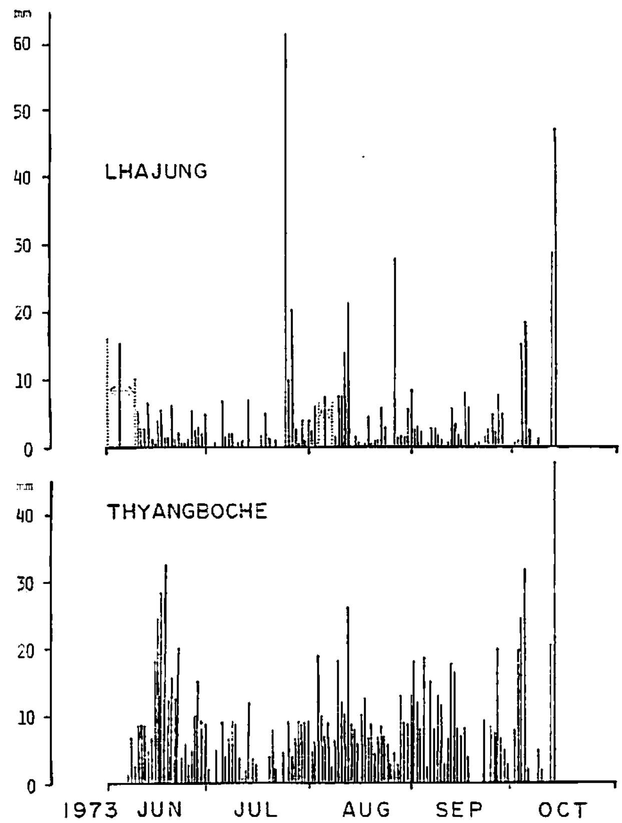

Fig. 2. Daily precipitation at Lhajung and Thyangboche for the period June 9 through October 15, 1973.

2. Data and Procedure

The daily precipitatipn data on 129 days during the monsoon season (June 9-October 15) in 1973 at 33 points in Nepal were used, including the data at Lhajung station. Most of the data were prepared by Mr. M.L. Shrestha and other staff members of the Meteorological Service, H.M.G. Nepal. The data at 2 points in India are also used from the daily weather report published by the Indian Meteorological Department.

To examine the periodicity of daily rainfall and the correlation between precipitation at the stations, power and cross-spectral analysis was applied to time series of rainfall data. To estimate power and cross-spectra, the lag correlation method discussed by Blackman and Tukey (1958) was used. The use of this method in meteorological problems, especially in the study of large-scale disturbances, is described in detail by Maruyama (1968, 1975). Through this method, we can discuss not only the predominant periodicity at one station, but also cross-correlation and similarity of the same periodical wave at other stations and the phase lag between different stations, by the use of cross-spectra (co-spectral estimates and quadrature spectral estimates, and coherence). In this method, the time interval of time series data and the maximum lag number determines the number and the frequency interval of spectral estimates. When the maximum lag-number is M and the time interval of the time series data is Δt, $M+1$ spectral estimetes are given at the frequency interval of $1/(2M\Delta t)$.

Since monsoonal precipitation in the Nepal Himalaya ocurres mainly by cumulus convection, the daily amount of precipitation at each stations has a strong random compoment even if the stations are located at a short distance from each other. For example, the distance between Lhajung and Thyangboche (3870 m) is only 9 km along the Imja valley, but the variations of the daily amounts are only weakly correlated (Fig. 2). Since the main purpose of the present study is to clarify the periodicity of the disturbances appearing in precipitation, the data were normalized by taking the cubic roots of the original values of the precipitation (mm), which also made it possible to make a certain degree of approxima-

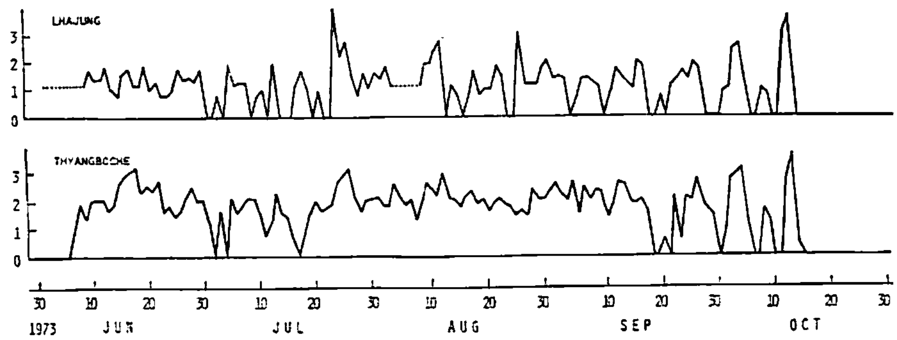

Fig. 3. Data of daily precipitation at Lhajung and Thyangboche normalized by taking the cubic root.

tion to the normal distribution of the the data for the analysis. The time series of normalized data at Lhajung and Thyangboche are shown in Fig. 3. Then, a spectral analysis was performed on the normalized data. In this computation, the time interval is $\Delta t = 1$ day and the maximum lag number is $M = 30$, which gives 31 spectral estimates at intervals of 1/60 cycle per day in the frequency range from 0 to 0.5 cycle/day.

3. Spectral analysis of precipitation

3-1 Precipitation in Khumbu Himal.

First, the quasi-periodicity of precipitation at the higher elevations in Nepal will be discussed. In Fig. 4, power spectra of precipitation at Lhajung and Thyangboche, and also co-spectral easimates and its coherene and phase difference Lhajung and Thyangboche, are shown. As seen in this figure, a spectral peak with a period of 8 to 12 days is predominant. From co-spectral estimates, the waves of this periodicity at these 2 points have a good correlation almost as a simultaneous phenomena (phase difference is almost zero and coherence is about 0.9). Another peak with a period of 4 to 5 days is also found

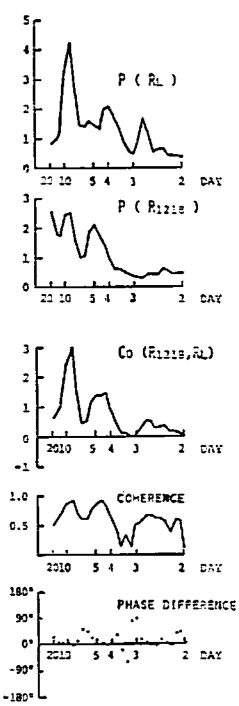

Fig. 4. Power spectra of normalized precipitation at Lhajung and Thyangboche, and cospectrum, coherence, and phase difference between the data from both station.

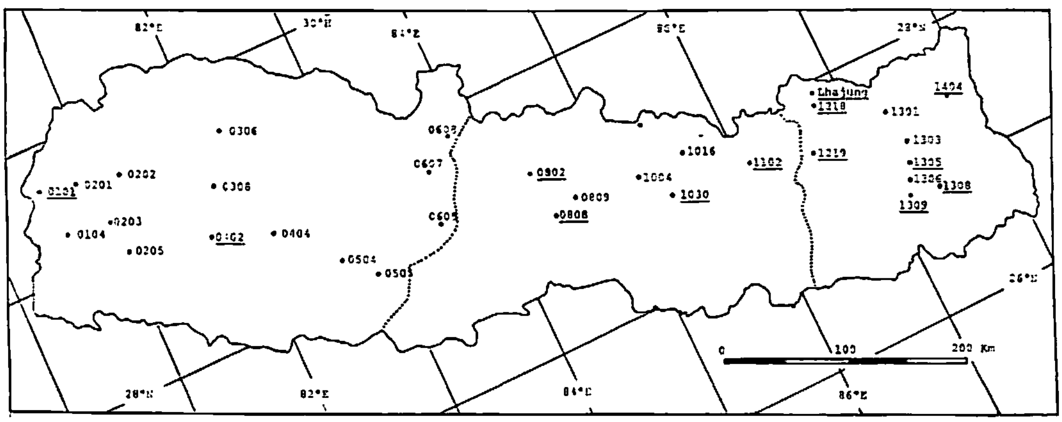

Fig. 5. Distribution of observation stations in Nepal used in the present study. The stations shown in Fig. 6 and Fig. 7 are indicated with the station number underlined.

and the correlation between 2 points appeared to be fairly good.

3-2 Precipitation at other stations in the Nepal Himalaya

To confirm the scale and the characteristics of propagation of the waves with predominant periods in the previous sub-section, precipitation at 12 stations in Nepal were analyzed with the same method, and cross-correlated with data from Lhajung by the use of cross-spectral analysis. The locations of these 12 stations are indicated in Fig. 5 with station number underlined. Five stations in east Nepal (Phaplu, Leguaghat, Mulghat, Tribeni, and Taplethok), 5 stations in central Nepal (Khudi Zazar, Bondipur, Timore, Kathmandu and Charikot), and 2 points in west Nepal (Kakar Pakha and Dailekh) were chosen to compare spectral feature zonally along the Himalayan range.

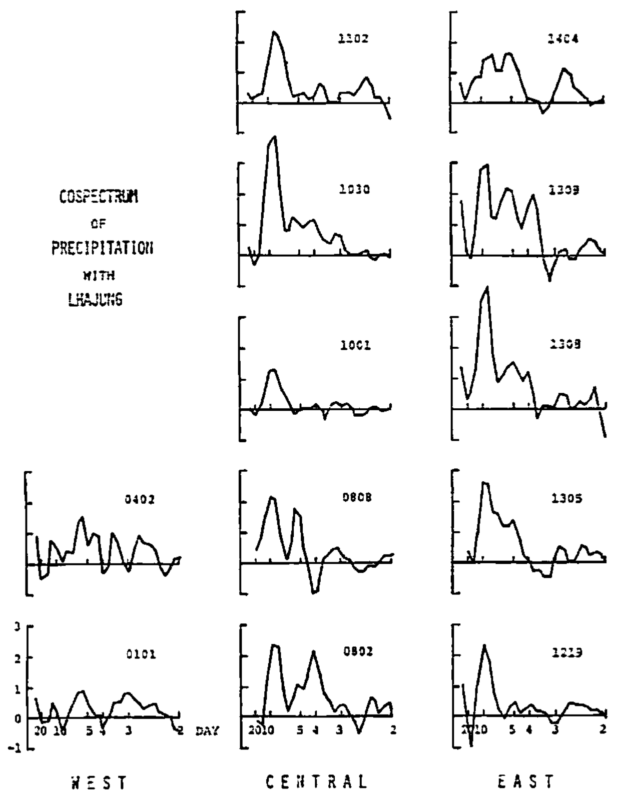

Fig. 7. Cospectra of normalized precipitation between Lhajung and each station in Fig. 6.

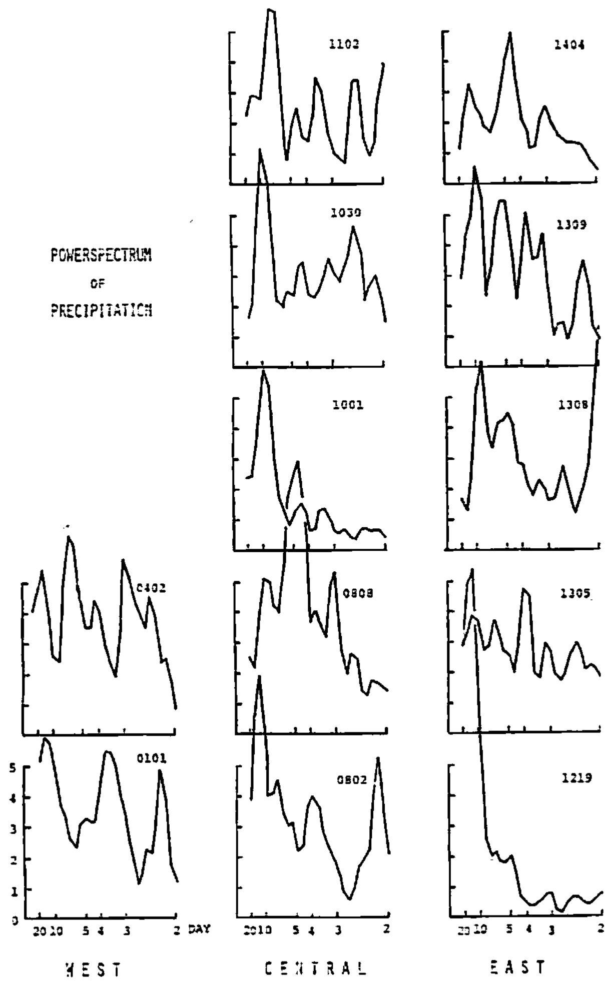

Fig. 6. Power spectra of normalized precipitation at 12 stations in Nepal. Five stations each from east and central Nepal and 2 stations from west Nepal are chosen for this analysis.

(i) Precipitation in east and central Nepal

Fig. 6 shows the power spectra at all stations and Fig. 7 shows co-spectral estimates between Lhajung and each of the other stations. Though the power-spectra at individual stations look different from each other, a prominent peak with a period of around 10 days, and seecondly, a peak with a period of 4 to 6 days can be seen. At some stations (1305, 1404) the strongest peaks are around 4 to 6 days. Cross-spectra also indicate a good correlation for these 2 period ranges (the coherence is 0.6-0.8 in most cases) with small phase differences (within a day). The smallness of phase difference indicates that the disturbances appearing in these periodicities have larger scale than this area.

(ii) Precipitation in west Nepal.

Two stations are located west of Kali Gandaki, where a relatively dry climate is dominant. Though the spectral analysis was performed on the data at only 2 stations at present, the power spectra appeared somewhat diffrent from those in east and central Nepal, as shown in Fig. 6 and Fig. 7. At both stations peaks of around 10 to 15 days exist, but significant peaks of around 5 days are not found; rather, peaks of around 6 days and 3 days are prominent at Dailekh (0402), and peaks of around 3 to 4 days and 2 days are prominent at Kakar Pakha (0101) in the western most part of the country. No significant features were found through cross-spectral analysis between these 2 stations and Lhajung.

Power and cross spectral analysis of normalized precipitation at 12 stations, suggests that significant periodicity of around 10 days (8 to 15 days range) exists in the whole of Nepal and also a periodicity of around 5 days exists, especially in east and central Nepal.

3-3 Areal averaged precipitation in Nepal.

As described in the previous sections, a predominant periodicity of around 10 days and secondary periodicity of about 5 days were found by the spectral analysis of normalized precipitation at the individual stations. However, on account of the fact that that actual precititation at each station is caused by small-scale convective cells, the spectral features appeared somewhat different at each station. Since the scales of disturbances appearing in these 2 spectral ranges appears to be greater than that of the eastern half of Nepal, the areal averaged precipitation is considered to represent the influence of disturbances more clearly. Averaged precipitation at the stations in three areas (east, central and west) and in the whole country (all of Nepal) are computed from the data at 33 stations. In Fig. 5, these stations are indicated by black points, and the boundaries between 3 areas are also indicated by the dotted lines. These boundaries are plotted nearly along Sun Kosi and Kali Gandaki. The stations in the Hindustan Plain (called "Terai" in Nepal) are excluded in this analysis. The daily averaged precipitation over the whole country is shown in Fig. 8, and power spectra for each area in Fig. 9. The data were also nolmalized by taking cubic roots before the spectral analysis. As seen in Fig. 9, significant peaks were found at around 10 days, and about 5 days, 3 to 4day and 2 to 3 days in all areas. Power spectra with the period range longer than 20 days are neglected in the present discussion. Through cross-spectral analysis amoung these three areas, the periodicities at around 10 days and about 5 days were found to have a good correlation (coherences are 0.5 through 0.8) with small phase differences among these areas. This

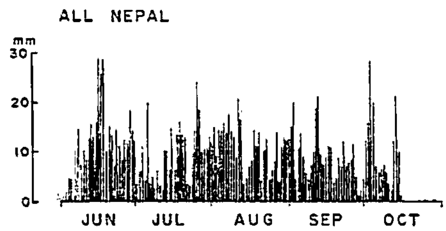

Fig. 8. Areal averaged daily precipitation for all of Nepal obtained from the data at the 33 stations shown in Fig. 5.

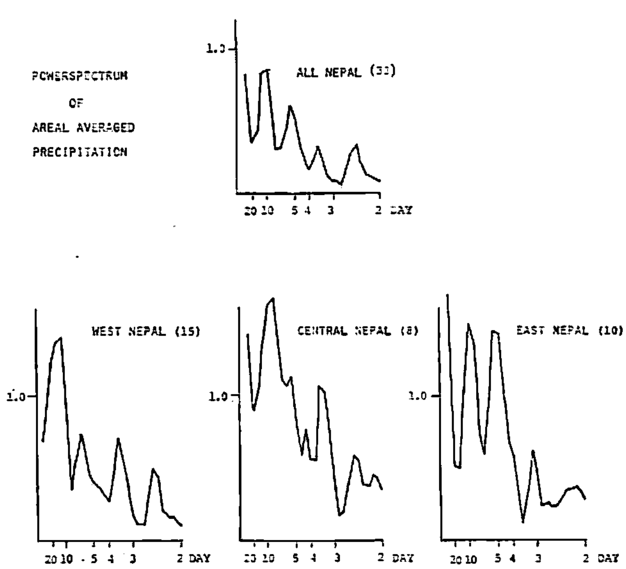

Fig. 9. Power spectra of normalized precipitation for east, central, west, and all of Nepal, using the data at 10, 8, 15, and 33 stations, respectively.

fact means that the periodicities of these two period ranges are due to large-scale disturbances with heavy precipitation occurring simultaneously or with a small time difference in the whole country.

To examine the differences between disturbances appearing in these two spectral ranges, the variance of each period range in the three areas is compared as shown in Fig. 10. In this figure, the average precipitation in each area is also illustrated. The zonal distribution of variance indicates that the periodicity of around 10 days (8.57 days through 15 days) dominates almost equally io the three areas. In contrast, the periodicity of about 5 days (4.0 through 6.0 days) is largest in east Nepal, rapidly decreasing from east to west, and the phase differences of this period range shows that the phase of east Nepal precedes that of west Nepal by about 1 day.

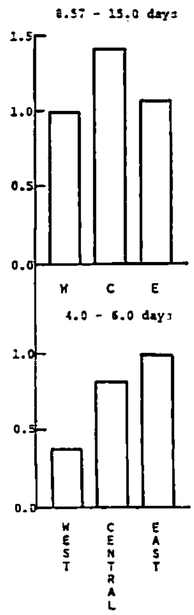

Fig. 10. Variances of normalized precipitation of the two spectral ranges (8.57-15.0 days, and 4.0-6.0 days) for three areas in Nepal.

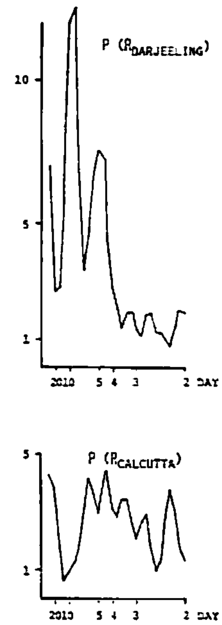

Fig. 11. Power spectra of normalized precipitation at Darjeeling and Calcutta in India.

Though the phase differences are examined in only 2 cases and the distance between east and west Nepal seems to be too small (5° longitudinal difference) to discuss the scale of the disturbance, it is suggested that disturbances appearing in this period range propagate westward with a phase speed of about 500 km/day and with a horizontal scale of about 30° in latitude.

4. Summary and Remarks

Through power spectral ananlysis of daily precipitation during monsoon season by the use of the data from 33 stations in Nepal, a predominant periodicity of around 10 days and a secondary periodicity of about 5 days are found. Through cross-spectral analysis with the same data, it is found that the periodicity of around 10 days appears almost simultaneously in all of Nepal and that of about 5 days reflects disturbances propagating westward with a phase speed of about 500 km/day.

The periodicity of about 5 days seems to reflect the influence of "monsoon lows" traveling westward through the monsoon trough over the Hindustan Plain, which has been found recently by Murakami (1976), and the horizontal scale assumed above mentioned is confirmed through his analysis. The westward decrease of variance of this period range is supposed to correspond to the decline of the monsoon low as it progresses westward. The similtaneous oscillation of precipitation around 10 days period in all of Nepal may be closely related to that of the same period range (10 to 15 days) associated with a cycle of the level of activity of monsoon circulation, which is also pointed out by Murakami (1976). His result is obtained through the analysis of the fluctuation of the zonal wind, temperature, specific humidity and surface pressure over India. However, this periodicity appearing in the precipitation seems to be more noticeable around the Himalayan range than over the Indian subcontinent, as seen in a comparison of the power spectra of rainfall at Darjeeling on the Himalayan slope, and rainfall at Calcutta in the Indian plain in Fig. 11. Though this problem should be analyzed by the use of the data over a broader area of the south-west monsoon region in Asia, it is suggested that there exists a close relationship between the cycle of the level of cumulus convective activity and the cycle of the level of the monsoon circulation. It was found by the present author (Yasunari 1976), that the daily strength of the Tibetan High at the 500 mb level has a period of around 10 to 15 days, which is also found through the spectral analysis of the stream function at the 200 mb level over Tibet (Krishnamurti et. al., 1973). Therefore, the interrelationship among cumulus convectivity around the Hiamalayas, monsoon circulation over India, and the Tibetan High should be clarified as a next step. This poblem will involve the fundamental problem on the mechanism of the southwest monsoon circulation over Asia.

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