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Characteristics of Monsoon Rainfall over Bangladesh in 1995

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Synopsis

Characteristics of rainfall over Bangladesh during the monsoon season of 1995 were investigated, using surface meteorological data, aerological data, raingauge data, GMS-4/5 infrared data and 700 hPa isobaric charts. The monsoon rainfall in 1995 was normal over Bangladesh. The monsoon season over Bangladesh can be divided into BAM (Bangladeshi Active Monsoon) phase, BBM (Bangladeshi Break Monsoon) phase and transient phase. With our definition, 4 periods of BAM phase and 3 periods of BBM phase were selected. By comparing the features of BAM and BBM phase, it is found that the positions of the monsoon trough and the vertical wind profiles were obviously different, but the vertical thermodynamic structures were not different between both phases. The temporal variation such as BAM and BBM phase can be interpreted, to some extent, in terms of the spatial structure of monsoon circulation relative to the monsoon trough. And it can be said that the variation of rainfall over Bangladesh depended on the movement of the deep convective area located to the south of the monsoon trough with strong southwesterly wind in its lower layer.

Keywords : *Bangladesh; Monsoon trough; Active or Break period*

1. Introduction

The seasons of a year in Bangladesh can be divided into pre-monsoon season (April to May), monsoon season (June to September), post-monsoon season (October to November) and dry season (December to March). During the monsoon season the warm and wet southerly wind prevails in the lower layer and brings much moisture from the Bay of Bengal. The world record of the maximum yearly rainfall was observed at Cherrapunji in India (26461mm/yr, 1860/61), which is located to the north of the Sylhet District in the northeastern part of Bangladesh. The area consisting of Myanmar, Bangladesh and the Assam District of India is one of the heaviest rainfall areas of the world.

In Bangladesh the yearly rainfall exceeds 4000mm/yr in the northeastern part along the southern periphery of the Chillong plateau and in the southeastern part along the coast line of the Bay of Bengal. The averaged yearly rainfall over the country is about 2500mm/yr. More than 70 percent of the yearly rainfall is concentrated in the monsoon season from June to September. It is not rare to have heavy rainfall in excess of a few hundred millimeters a day in this area during this season. Such a heavy rainfall often causes a flood dis-

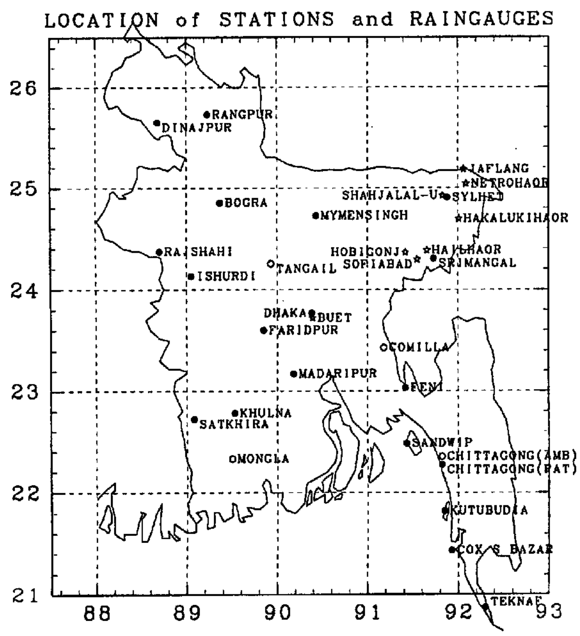

Fig. 1 Distribution of stations and raingauges. circles and Asterisks indicate meteorological stations and raingauges, respectively. Especially filled circles indicate the stations used for the mean daily rainfall over Bangladesh (Fig.4).

aster, together with much inflow of the river water (Ganges R., Brahmaputra R., Megna R.) from the outside of the country. Recently, severe floods occurred in 1987 and 1988 and the associated rainfall situations were reported by Matsumoto et al.(1996).

This study is conducted as a part of the Japan-Bangladesh Joint Research Project for prevention of flood disasters. The characteristics of rainfall during the monsoon season in 1995 were analyzed as a first step of the investigation of the general characteristics of the monsoon rainfall and the mechanisms of heavy rainfall causing flood disasters in Bangladesh.

2. Data

The main data used in this study are 3-hourly surface data of 23 meteorological stations in Bangladesh (Fig.1), 8 raingauge data in the Sylhet District specially set up for this study, infrared satellite data from GMS-4/5, daily aerological data at Dhaka, and daily 700 hPa isobaric charts. The normal values of monthly rainfall averaged in recent 30 years

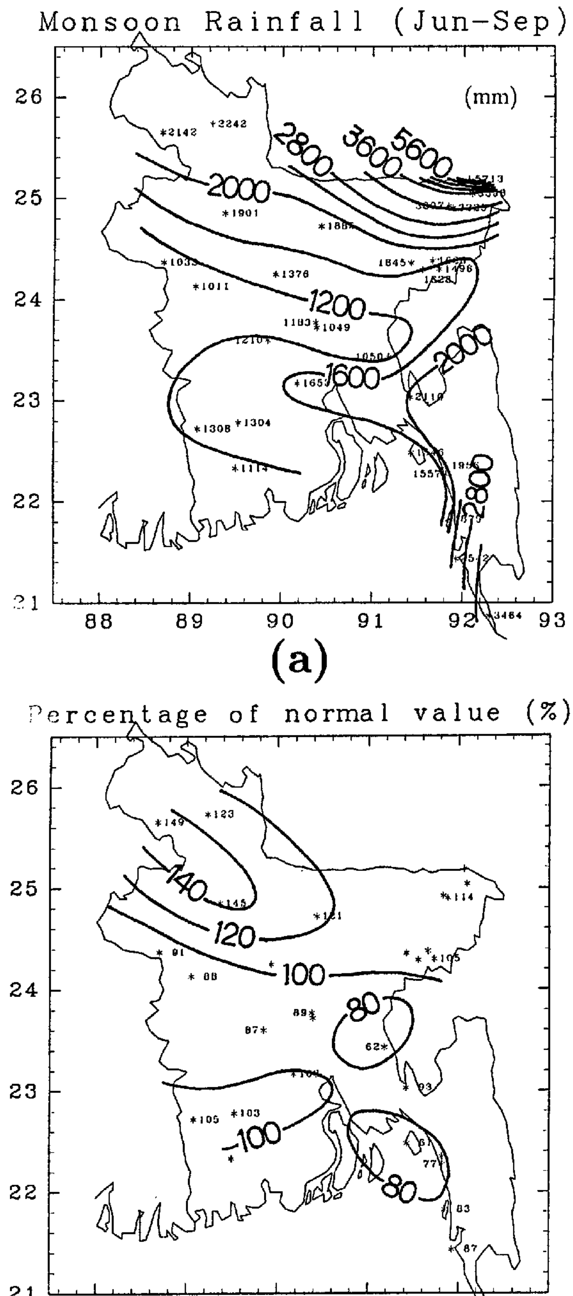

Fig. 2 (a) Monsoon rainfall (mm) from June to September of 1995. (b) Percentage of normal value averaged in 30-years (1966 to 1995).

at 19 meteorological stations (shown in Fig.1) were also used. The surface and aerological data and the 700hPa isobaric charts from June 1 through September 30 of 1995 were provided by Bangladesh Meteorological Department (BMD). The 8 raingauges recorded the

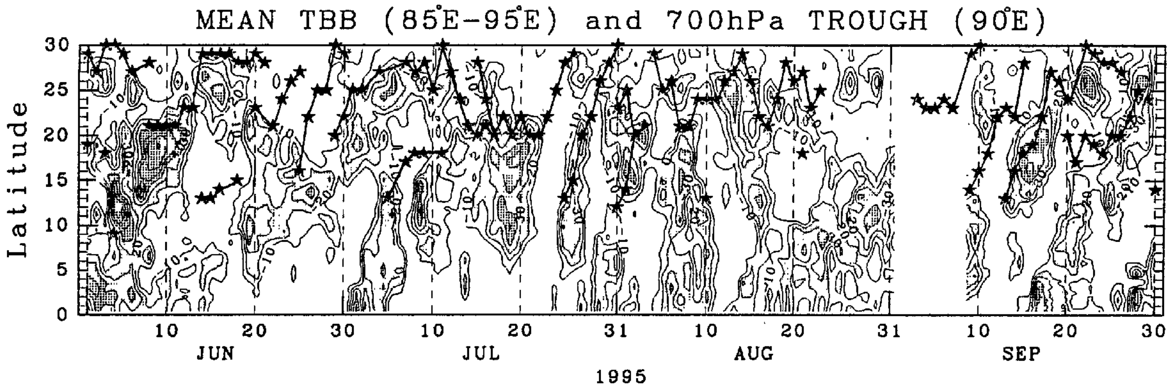

Fig. 3 Time-latitude cross section of TBB averaged between 85°E and 95°E. Asterisk indicates the position of the 700 hPa trough, which is defined as the position of the minimum pressure at 90 °E on the daily 700 hPa isobaric charts.

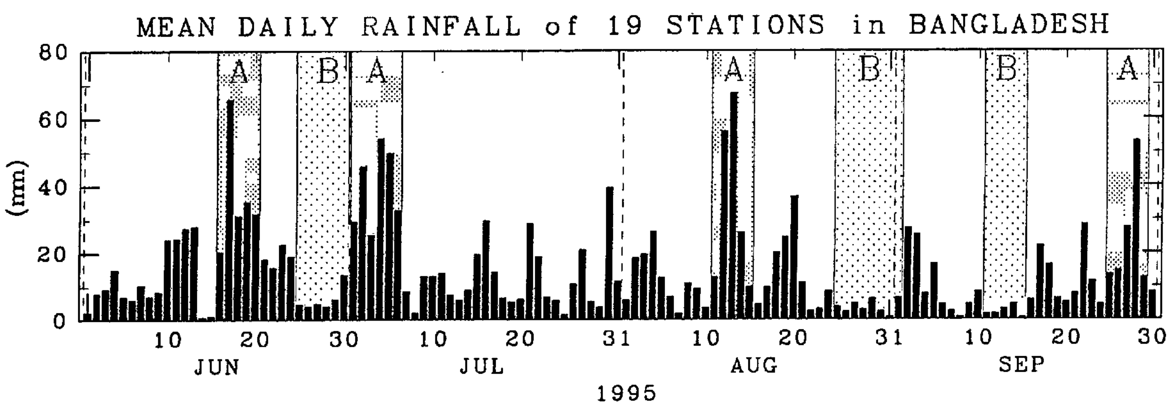

Fig. 4 Intraseasonal variation of the mean rainfall (mm) of 19 stations over Bangladesh. Letters A and B indicate BAM phase and BBM phase, respectively.

time of the pulse for each 0.5mm rainfall, and the data were converted into 3-hourly rainfall to be comparable with the rainfall data from BMD. The GMS-4/5 data are received every hour in the severe storm research section. The IR1 channel (10.5μm-11.5μm) data were converted to mesh data with 0.2° resolution over South Asian area (80°E-100°, 0°N-30°N) from June 1 through September 30, with missing data from September 1 to September 8.

3. Monsoon Season in 1995

The total monsoon rainfall from June to September is shown in Fig.2 (a). The value exceeded 2000mm in the Sylhet District in the northeastern part and in the southeastern coastal region of the Bay of Bengal. This large rainfall may be affected by the orography, for example, the Shillong plateau and the hills along the coast line of the Bay of Bengal. Especially, at Jaflang at the south foot of the Shillong plateau, the rainfall of 5713mm was observed, that was about twice of rainfall at Netro-Haor only 20km to the south of this point. Fig.2 (a) shows a zone of small rainfall below 1200mm extending over the flat area from the western part to the central part of the country.

Fig.2 (b) shows the ratio of the rainfall in 1995 to the normal value. The rainfall exceeded the normal value in the northern part and, especially, the ratio was more than 140 percent around Dinajipur. On the other hand, the rainfall was less than the normal value at many stations in the southern part. But it is concluded that, as a whole, the monsoon rainfall of 1995 can be regarded as normal, because the mean rainfall at all stations was 103 percent of the normal value.

In the South Asia, it is known that rainfall oscillates with 40 to 50 days periodicity corresponding to the Madden-Julian Oscillation (MJO) during the monsoon season (Hartmann and Michelsen, 1989). The oscillation with active/break cycle in this region is thought to be associated with the northward movement of the MCZ (Maximum Cloud Zone) (Sikka and Gadgil, 1980) or the phase of cloudiness (Yasunari,1980), which are related to MJO. In order to see the time history during the monsoon season of 1995, the time-latitude cross section of the mean TBB (85°E-95°E) from GMS-4/5 infrared data and the mean daily rainfall at 19 stations over Bangladesh are shown in Fig.3, Fig.4, respectively. The deep convective area moved northward from the equatorial region to 27°N around the Himalayas several times. The speed of northward movement was about 1°-1.5° a day. This deep convective area was often accompanied by the 700 hPa trough, referred to as the monsoon trough, as shown in Fig.3. The trough was approximately several degrees to the north of the convective area.

The periods of large rainfall were seen with the periodicity of several ten days, as shown in Fig.4. When the deep convective area came northward over Bangladesh (21°-26°N) in Fig.3, the rainfall increased extremely over Bangladesh. However, in the case of middle August, the significant rainfall seems to be associated with the southward movement of the deep convective area. It is not clear whether this phenomenon is a general one or an unusual one observed only in this year, since such a deep convective area moving southward has not been reported in the past studies. In any case, the variation of the mean daily rainfall over Bangladesh was closely related to the position of the deep convective area moving with the periodicity of several ten days which is associated with the MJO.

4. Active or Break Monsoon Phase

4.1 Definition of BAM and BBM phase

In the previous section, it is shown that there was the evident intraseasonal variation of the rainfall over Bangladesh. The periods when the rainfall is especially large during a monsoon season are, in general, referred to as 'Active', the ones when the rainfall is especially small are referred to as 'Break'. In this study the periods in 'Active' and 'Break' phase were selected with the definition based on the daily rainfall data at 19 stations. Therefore, hereafter, we refer to 'Active' phase as BAM (Bangladeshi Active Monsoon) phase, and to 'Break' phase as BBM (Bangladeshi Break monsoon) phase. The periods between them are called transient phase. The definitions are as follows.

- **BAM phase**
  1. *The duration of a period is at least 5 days.*
  2. *During the period daily rainfall above normal is observed at more than 6 stations.*
- **BBM phase**
  1. *The duration of a period is at least 5 days.*
  2. *During the period daily rainfall above normal is observed at less than 3 stations.*

Because the daily normal value at each station was not available, we used the value of the monthly normal value (30-year mean) divided by the number of days of the month as the daily normal value in this definition. With this definition, 4 periods including 21 days were selected as BAM phase and 3 periods including 19 days were selected as BBM phase. The selected periods were as follows.

- **BAM phase**
  - June 16 to June 20
  - July 1 to July 6
  - August 11 to August 15
  - September 25 to September 29
- **BBM phase**
  - June 25 to June 30
  - August 25 to September 1
  - September 11 to September 15

These periods are shown in Fig.4, as well.

4.2 Comparison of BAM and BBM phase

In Fig.3 and Fig.4, it is easy to recognize the difference of positions of the deep convective area and the 700 hPa trough between BAM and BBM phase. This difference

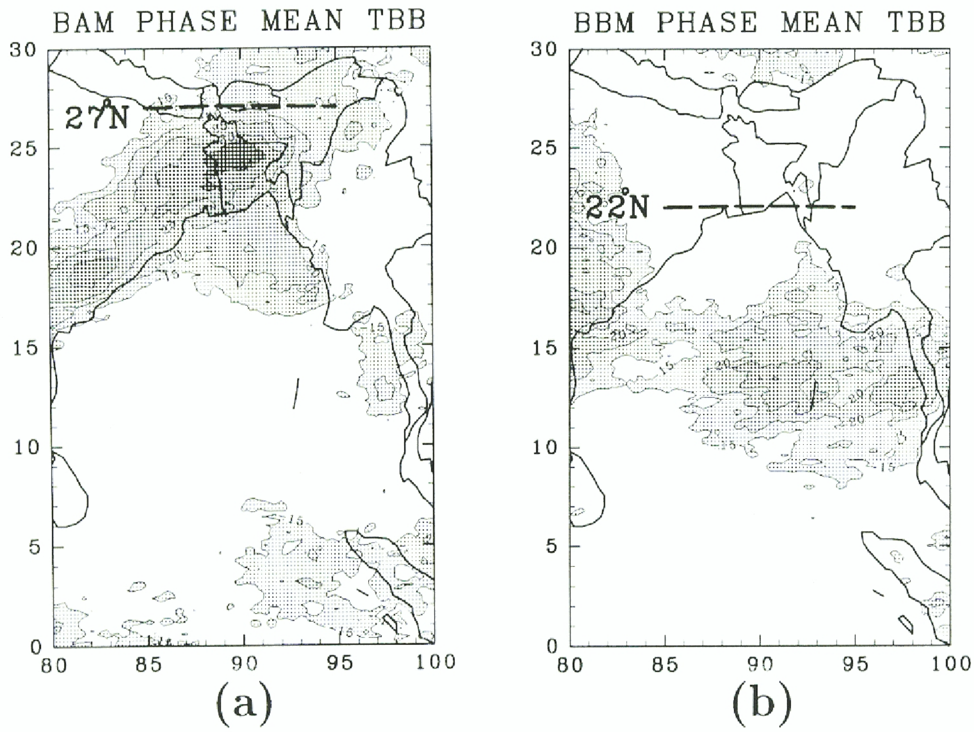

Fig. 5 Mean TBB distribution in **(a)** BAM phase, **(b)** BBM phase. Dashed line indicates the mean position of 700 hPa trough (monsoon trough), based on the 700 hPa isobaric chart.

is clear in Fig.5, which shows the mean TBB distribution in each phase. The deep convective area extended approximately from 17°N to 27°N in BAM phase and from 10°N to 17°N in BBM phase. The position of the deep convective area in BAM phase was about 10 degrees to the north of the one in BBM phase. The dashed line in Fig.5 shows the 700 hPa trough along 90°E, which located at 27°N in BAM phase and at 22°N in BBM phase. The positional difference between the deep convective area and the 700 hPa trough was about 5° for BAM phase and 10° for BBM phase, respectively.

The difference is also clear in Fig.6, which shows TBB distribution and 700hPa isobaric charts on June 17 and June 26, which are the typical days in BAM and BBM phase, respectively. On June 17, the 700 hPa trough was located near the Himalayas (27°N) at 90°E, and Bangladesh was covered with deep convective clouds, while on June 26 the 700 hPa trough crossed Bangladesh and the deep convective clouds were far south of it. On both days, the deep convective clouds located to the south of the 700 hPa trough. The difference of the meteorological conditions between BAM and BBM phase was not only in the position of the 700 hPa trough, but also in the depth of the trough, which was deeper on June 17 than on June 26. The deep 700 hPa trough near the Himalayas were always found in BAM phase.

It is shown in Fig.7, which shows the hodograph at Dhaka, that rather strong southwesterly wind (e.g.9m/s at 850 hPa) was seen in BAM phase, while weak (about 3m/s) southeasterly wind is seen in the lower to the middle layers in BBM phase. It is also noticed that vertical wind shear was larger in BAM phase than in BBM phase, and the shear between 850 hPa and 200 hPa exceeded 12m/s in the southwestern direction in BAM phase. The wind direction turned clockwise from surface up to 500 hPa and anticlockwise above this level in BAM phase, while in BBM phase the wind was almost constant below 500hPa. The easterly wind in the upper layer was stronger in BBM phase than in BAM phase.

These features mentioned above make it reasonable to interpret the monsoon trough as a large horizontal shear zone formed between the southwesterly wind to the south and the southeasterly wind to the north of its axis.

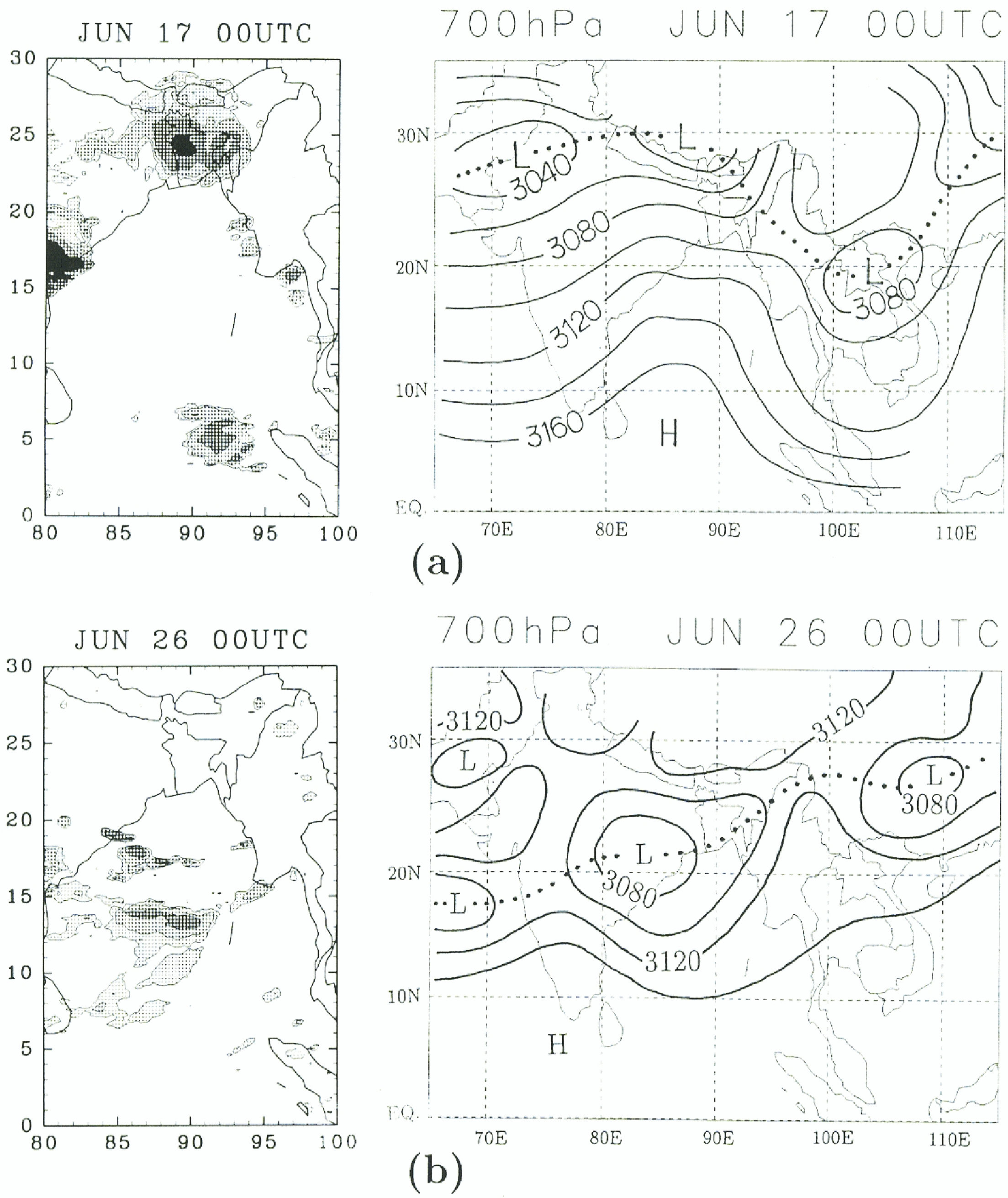

Fig. 6 TBB distribution and 700 hPa isobaric chart **(a)** on June 17, **(b)** on June 26. Dotted line indicates the 700 hPa trough (monsoon trough).

When the monsoon trough shifts northward to the Himalayas, Bangladesh is covered with the deep convective area, where the strong southwesterly wind prevails in the lower layer. In this situation the rainfall increases over Bangladesh and this period is just BAM phase. On the other hand, in BBM phase, the monsoon trough is located over or to the south of Bangladesh, and the week southeasterly wind prevails with no deep convection over Bangladesh. After all, the temporal variation such as BAM and BBM phase over Bangladesh can be interpreted, to some extent, in terms of the spatial structure of monsoon circulation relative to the monsoon trough.

However, it is interesting that there was little difference between both phases in the vertical profiles of equivalent potential temperature (θ_e), potential temperature (θ) and water vapor mixing ratio, as shown in Fig.8.

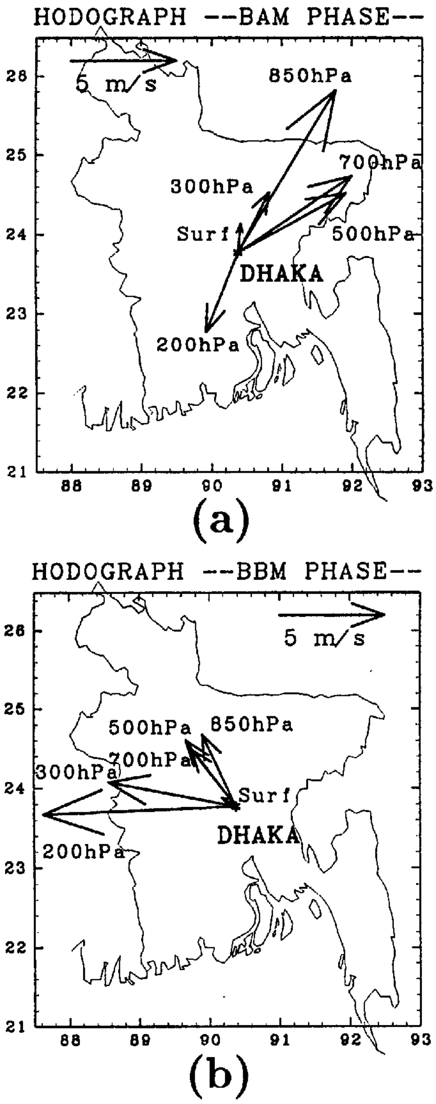

Fig. 7 Mean hodograph at Dhaka at 00 UTC in **(a)** BAM phase, **(b)** BBM phase.

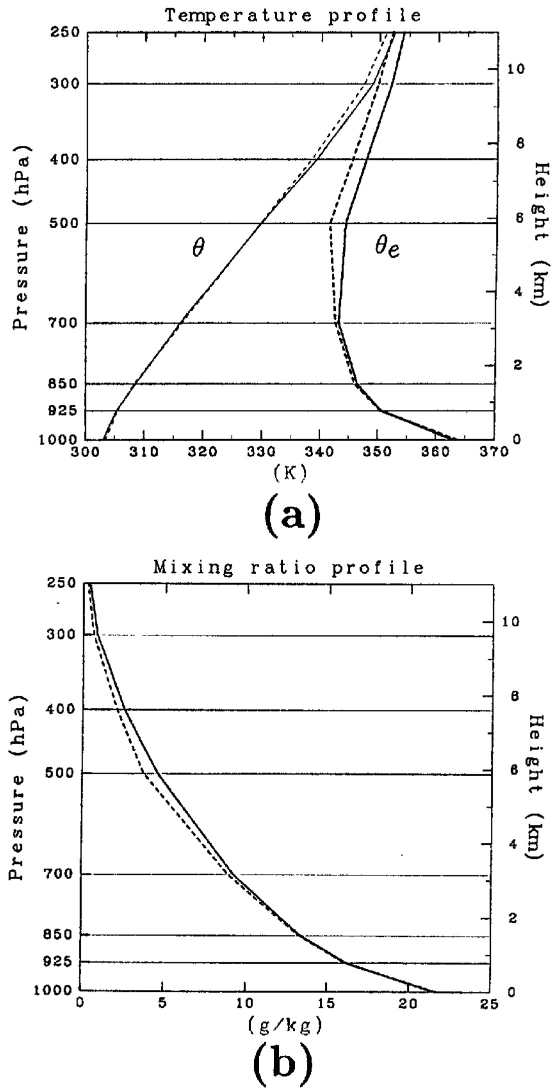

Fig. 8 **(a)** Vertical profile of potential temperature and equivalent potential temperature. Thick line indicates the former, and thin one indicates the latter. Solid line indicates BAM phase and dotted line indicates BBM phase. **(b)** Vertical profile of water vapor mixing ratio. Solid line indicates BAM phase and dotted line indicates BBM phase.

Although θ_e and θ were slightly higher in BAM phase than in BBM phase above the middle layer, the profile in BAM phase was almost identical with the one in BBM phase especially in the lower layer which is closely related to convective activities. No significant difference is recognized between the profiles of water vapor mixing ratio for BAM and BBM phase, which suggests that the strong southwesterly wind in BAM phase did not contain more moisture than the southeasterly wind did in BBM phase. Therefore, these features imply that the vertical thermodynamic structures of the atmosphere such as the plofile of θ_e and θ are not important for convective activities producing heavy rainfall in BAM phase. Probably, the mechanical structure such as wind speed, wind direction or wind shear is more important for understanding the mechanism of rainfall in this region than thermodynamic one.

5. Meso-scale Disturbance in BAM phase

During the periods in BAM phase of June and July, the rainfall was modified by the meso-scale disturbances which seemed to be embedded in the deep convective area. They tended to develop at night and had a life time of less than or equal to a day.

Here, we mention an event on June 17 (including the evening on June 16) as the case of the heavy rainfall caused by such a meso-scale disturbance. On June 17 there Rainfall was observed at all 30 points over the country and 17 stations had daily rainfall above 50mm. The disturbance appeared at about 21 local time (LCT) on June 16 as several clusters of cumulonimbus over the area approximately from Dinajipur to Srimongal in the northern part of the country (Fig.9). It is seen in the the surface wind field that there was a convergence line which formed between the strong southerly wind from the bay of Bengal and the easterly wind around the Shillong plateau. The formation of this disturbance seems to be closely associated with this convergence line.

The disturbance developed at night and shifted southward with the speed of about 20 km/h. At 9 LCT on June 17 the disturbance, whose center was located around 89°E, 24°N, had a cyclonic circulation in the surface wind field, although there was no obvious convergence line. The 3-hourly rainfall of 96mm, which was the maximum value of all the points on this day, was observed between 12 to 15 LCT at Satkhra in the southwestern part of the country. After that, the disturbance merged with another one (shown around 88°E, 21°N at 15 LCT in Fig.9) that developed to the west of the former disturbance in the afternoon. The high cloud area spread out temporarily, but the disturbance decayed almost by the end of this day.

The heavy rainfalls on June 16, June 19, July 4, July 5 and July 6 were also caused by such meso-scale disturbances. The formation of these meso-scale disturbances seemed to be closely associated with the convergence between the strong southwesterly wind and the orography (or the local circulations caused by the orography) , as shown in Fig.9. Therefore, the strength of the wind is important for the formation of the meso-scale disturbance, and the strong wind in BAM phase is more advantageous than the week wind in BBM phase. The direction of wind is also important to the occurrence of the meso-scale disturbance. Considering mountains and hills to the north and the east of Bangladesh, the southwesterly wind in BAM phase probably makes it easier for the meso-scale disturbance to be formed by the convergence associated with the orography, than the southeasterly wind in BBM phase does.

Of course, in general, a meso-scale disturbance is not always formed near mountains, so we can't explain the formation of all meso-scale disturbances only in terms of the interaction between the wind and the orography. In any case, it is undoubted that the rainfall caused by meso-scale disturbances contributed considerably to the total monsoon rainfall over Bangladesh during the monsoon season.

6. Conclusion and Discussion

The main results in this study are as follows:

1. The variation of rainfall over Bangladesh was dominated by the movement of the deep convective area to the south of the monsoon trough.
2. The difference between BAM and BBM phase can be interpreted in terms of the spatial structure of monsoon circulation relative to the monsoon trough.
3. The vertical mechanical structure of the atmosphere such as a profile of wind is more important to the interpretation of heavy rainfall in BAM phase than the vertical thermodynamic structure.
4. The meso-scale disturbance formed by the interaction between the strong southwesterly wind and the orography sometimes caused heavy rainfall, that contributed considerably to the total monsoon rainfall.

Although it is shown in this study that the position of the monsoon trough and the deep convective area to the south of it had a great influence on the rainfall over Bangladesh, there are still points of contention on the monsoon trough itself. Sikka and Gadgil (1980) described the movement of the deep convective area and the monsoon trough at 700 hPa at 90°E, and showed that the deep convective area and the monsoon trough moved together northward from near equator to around 25°N. In the present study, however,

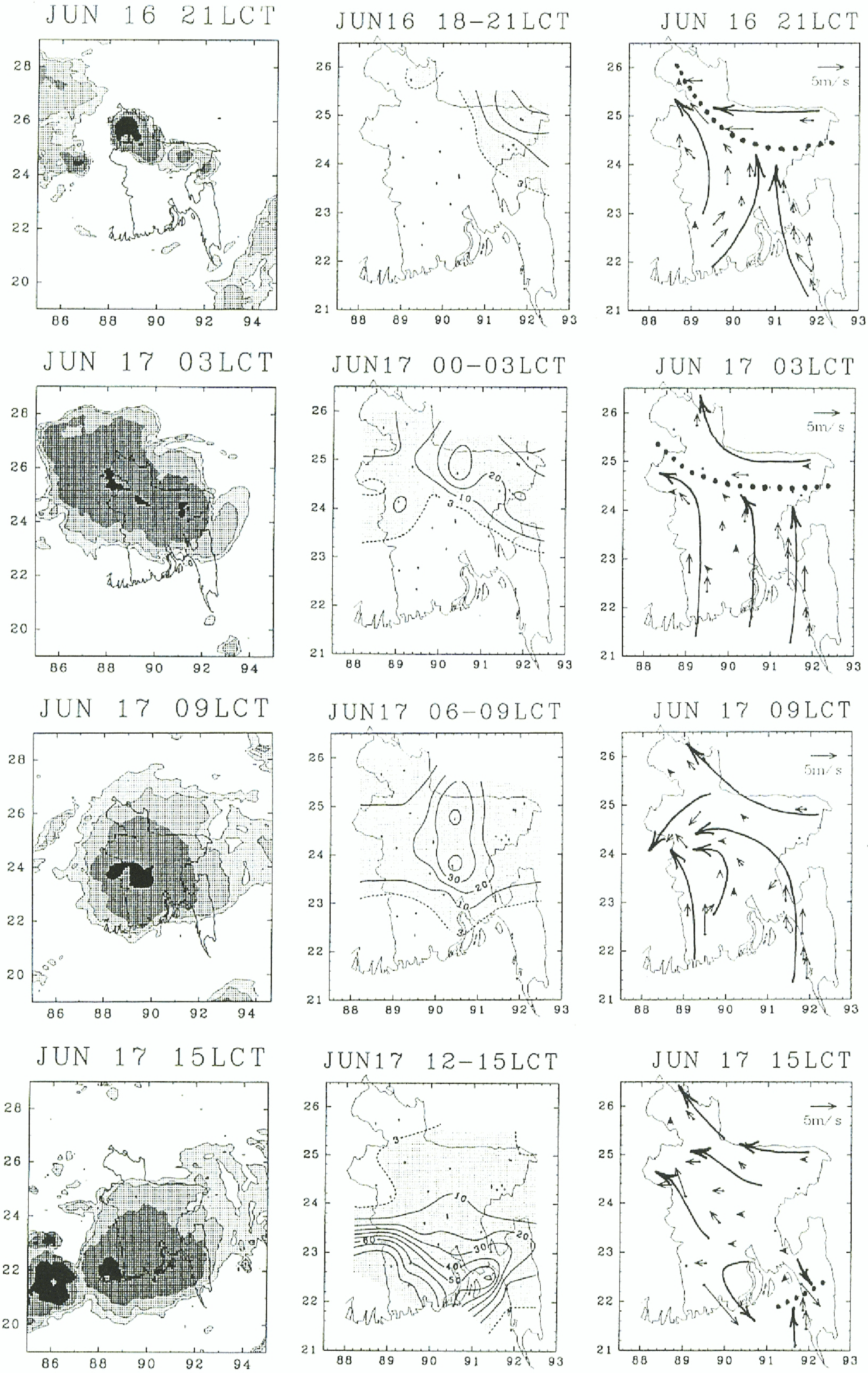

Fig. 9 Analysis of the rainfall event on June 17. **(Left)** TBB distribution with -30°C, -40°C,-50°C and -60°C contours. **(Middle)** 3-hourly rainfall distribution. **(Right)** Streamline based on the surface wind field.

it is shown that the monsoon trough moved only within the range from 15°N to 30°N, though the movement of the deep convective area was as same as their results. That is, the monsoon trough associated with the movement of the deep convective area was not seen south of 15°N. We have no idea whether this difference attributes to the difference of analytical method, used data or analyzed year.

Sikka and Gadgil also mentioned that their data indicated a high correlation between the axis of the MCZ and 700hPa trough, and considered the MCZ as a manifestation of an ITCZ (Inter Tropical Convergence Zone). That is, they did not consider the positional relation between the MCZ and 700hPa trough. In the present study, however, the deep convective area obviously was located to the south of the monsoon trough in both phases. Actually, significant rainfalls were brought rather to the south of the monsoon trough than in the axis of the monsoon trough. These facts mean that the synoptic convergence zone (the ITCZ) differs from the 700hPa trough (the monsoon trough). The positional difference among the monsoon trough, the deep convective area and the convergence zone can't be discussed minutely in the present study, because of the lack of data.

This positional difference may be influenced, to some extent, by the assumption that the monsoon trough has its axis in the longitudinal direction and has only a structure in the latitudinal direction. In the previous and present study, the position of the monsoon trough is defined as the position of the minimum pressure at 90°E. Actually, the monsoon trough often winds and has a structure in the longitudinal direction, as seen on a daily isobaric chart. In that connection, Mak(1987) stated that it was reasonable to interpret the monsoon trough as a spatial envelope of the monsoon disturbances. That is, when the positional difference between the deep convective area and the monsoon trough is discussed, the longitudinal asymmetry must be taken into account. We must consider the monsoon trough in terms of a dynamical aspect in the future investigation.

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1995年モンスーン期間中のバングラデシュでの降雨特性

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要 旨

本研究では、地上観測データ、高層観測データ、雨量計データ、GMSデータ、南アジア天気図を用いて、1995年のモンスーン期間中（6月～9月）のバングラデシュでの降雨特性について調べた。バングラデシュにおける1995年のモンスーン期間中の降水量はほぼ平年並であった。バングラデシュ国内の地上気象観測点の降水量に基づいてモンスーンの活動期（BAM phase）及び休止期（BBM phase）を定義した結果、活動期が4期間と休止期が3期間選択された。この活動期と休止期の状況を比較したところ、モンスーントラフの位置や風の鉛直構造には明確な違いが見られたが、熱力学的な鉛直構造にはほとんど違いがなかった。活動期や休止期といった時間的な変動は、ある程度モンスーントラフに相対的な循環の空間構造という観点から理解でき、バングラデシュの降水量は、下層で強い南西風が卓越するモンスーントラフ南側の対流活動の活発な領域の動きに関連して変動していると言える。

キーワード ：バングラデシュ、モンスーントラフ、活動期・休止期