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CLASSIFICATION OF ARC SHAPED PRECIPITATION SYSTEMS DURING PREMONSOON AND MONSOON IN BANGLADESH

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ABSTRACT

Arc shaped precipitation systems are classified to know their seasonal and regional variation in Bangladesh. In this study, six-year (2000-2005) radar data are used from the Bangladesh Meteorological Department. Arc shaped precipitation systems are classified as symmetric type precipitation system (STPS), asymmetric type precipitation system (ATPS), combination of symmetric and asymmetric type precipitation system (CSATPS) and unclassified type precipitation system (UTPS). The occurrence frequency of STPS, ATPS, CSATPS and UTPS is found 23%, 43%, 21% and 13%, respectively. Seasonal analysis showed that ATPS (STPS) is dominant in the pre-monsoon (monsoon) period. Regional analysis of the arc shaped precipitation systems indicate that at the mature stage of their life cycle, STPS, ATPS, and CSATPS is dominated in southwest (northwest), northeast (southeast) and northwest (northwest) quadrants during the pre-monsoon (monsoon) period. The maximum occurrence frequency of UTPS is found in the northeast and the southwest quadrants during the pre-monsoon season and in the southwest quadrant during the monsoon season.

Keyword: Arc shaped precipitation systems, Bangladesh, Pre-monsoon, Monsoon and Radar.

1. INTRODUCTION

Pre-monsoon season (March to May) is a transition period from the winter circulation to the monsoon circulation in Bangladesh. The thunderstorms are frequently observed over northern and eastern parts of Bangladesh. During the pre-monsoon period these severe thunderstorms locally called Kalbaishakhi, develop due to the interaction between moist and dry air masses coming from the Bay of Bengal and India, respectively. These severe local storms sometimes associated with tornadoes, damaging hail, strong gust wind, and lightening [1-3]. Such kind of the disturbance during the pre-monsoon season causes severe damage almost every year and lead to prevalent agriculture and property destroy and the loss of life. The socio economic condition of the people of Bangladesh is greatly dependent on the development of agriculture, which is in turn dependent upon rainfall. During the monsoon period (June to September), a large number of mesoscale

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convective systems (MCSs) develop and produce heavy rainfall in Bangladesh. As an effect, it causes widespread flooding, flash flooding etc and in the other hand its lack lead to drought in the country. MCSs supply precious water resources and sometimes cause severe atmospheric disasters [4].

Various studies have been done about MCS using radar and other mesoscale data to determine the structure of individual convective events [5-9]. Maddox [10] first classified the MCS using satellite image and termed it as mesoscale convective complex (MCC). Bluestein et al. [11] and Bluestein and Jain [12] analyzed the evolution of mid-latitude MCSs using radar data and they classified the precipitation structure during the formative stage of mid-latitude squall lines (one kind of MCS) identifying four common modes of development: broken lines, back building, broken areal, and embedded areal. In a later, comprehensive study on precipitation structure done by Houze et al. [13] and established the classification of two distinct categories with more common types of organization: symmetric and asymmetric. Although the various researches have been done on the MCS pattern in several regions in the world, there is much lacking to learn about the precipitation structure in and around Bangladesh. A few number of studies have been done about the precipitation systems in this region. Using 1 year radar data, Islam et al. [14] studied the characteristics of precipitation area and size of echoes that is related to the cloud activity over Bangladesh. They classified the precipitation area into two types: solitary and merged types. Both types again sub-categorized into an oval, line and arc types. Rafiuddin et al. [15] introduced the details characteristics of precipitation systems based on 6 years radar data during the monsoon period in Bangladesh. They classified precipitation systems into arc, line and scattered types according to their shape and found development of these systems is 29%, 15% and 56%, respectively. Rafiuddin et al. [15] also revealed that the arc and scattered types precipitation systems are dominant in the pre-monsoon and monsoon seasons, respectively. The present work is an attempt to classify the arc type precipitation systems and reveal their regional and seasonal variations in Bangladesh.

2. MATERIALS AND METHOD

Data were obtained from an S-band weather radar (wavelength ~ 10 cm, beam width 1.7°, elevation angle 0°) placed on a building roof of ~60 m height in the vicinity of the Bangladesh Meteorological Department (BMD) office in Dhaka (23°42′0′N and 90°22′30″E). The BMD radar is designed to cover a radius of 400 km that scans 600 km × 600 km area (21.08-26.45°N, 87.44-93.33°E) on a regular scanning scheme, which includes almost all of Bangladesh and some neighboring parts of India and Myanmar. The regular scanning scheme is one hour at 'ON' and two hours at 'PAUSE', and the pixel resolution is 2.5 × 2.5 km. The BMD does not conduct radar operations from 00 to 05 LST (LST=UTC +6 hours). Sometimes it collects the data for a few hours without any split. The reflectivity data collected by the BMD radar are automatically converted to the precipitation rate (mm/h) and output is provided only plan position indicator (PPI) in six statuses: 1 (1 mm/h ≤ rain rate < 4 mm/h), 2 (4 mm/h ≤ rain rate < 16 mm/h), 3 (16 mm/h ≤ rain rate < 32 mm/h), 4 (32 mm/h ≤ rain rate < 64 mm/h), 5 (64 mm/h ≤ rain rate < 128 mm/h), and 6 (128 mm/h ≤ rain rate). Because of radar data availability issues, analysis is made only for the pre-monsoon and monsoon periods. The BMD did not properly archive radar data for the postmonsoon months during the analysis period. Also for the same reason, March data are excluded from the pre-monsoon period. Thus, April and May data are analyzed to represent the pre-monsoon period. In total 91,673 PPI scans from April to September 2000–2005 (no data are available for April 2001 and 2005, August 2002, and September 2000, 2001, and 2003) are analyzed.

The study area (21.08-26.45°N, 87.44-93.33°E) is shown in Fig. 1, this area is subdivided into four quadrants such as northwest (NW), northeast (NE), southwest (SW) and southeast (SE). Some parts of the northeast and southeast quadrants have high elevation.

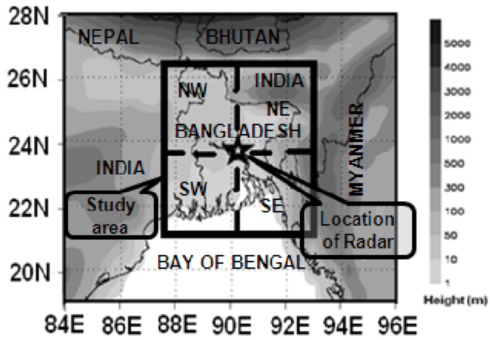


Fig. 1. Regional map showing the BMD radar coverage of 600 km × 600 km (solid rectangle). The star indicates the location of the BMD radar. The radar coverage is divided into the northwest (NW), northeast (NE), southwest (SW) and southeast (SE) quadrant. The topography is shown by gray shading.

Precipitation systems which are developed within the study area, having lifetime equal to or longer than 3 hours and a dimension equal to or longer than 100 km (at least in one direction) are considered for analysis. According to Houze [16], there are four stages of the life cycle of MCS: formative, intensifying/developing, mature and decaying stages. In this study, three stages of life cycle of MCS are considered: (i) intensifying/developing stage, when cells grow and merge to form a contiguous rain area in which several relatively intense cores of precipitation are interconnected by lighter precipitation, (ii) mature stage, the highest intensity of rain area with a large stratiform region develops from older cells blending together as they begin to weaken, and (iii) decaying stage, the formation of new convective cells diminishes and the stratiform area begins to weaken and dissipate [16]. The formative stage is excluded due to the radar data availability issues. In this paper, arc type (having an arc-shaped strong leading edge and stratiform region behind) precipitation systems [15] are classified to know the regional and seasonal variations of precipitation systems in Bangladesh.

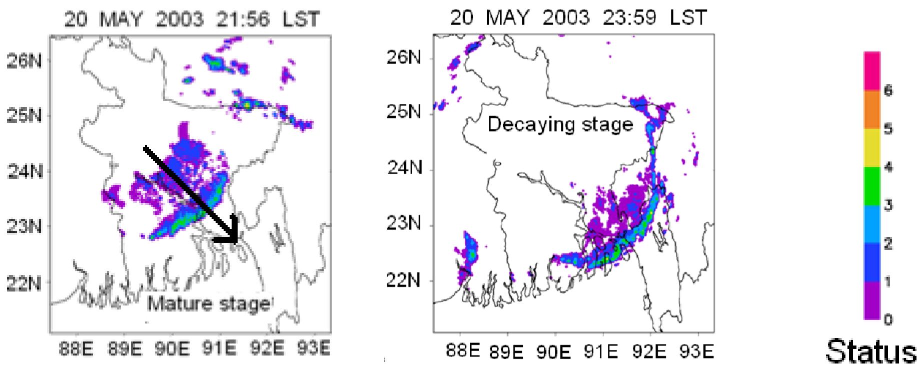
In this study, a normalized technique is used to find the relative frequency of occurrence of system, which is a completely different method from Rafiuddin et al. [15]. This simplified normalized technique is based on the idea proposed by Aragoa et al. [17] for irregular PPI scan (time of observation). The relative frequencies of each type were separately obtained for each month, season, and year, based on the formula.

$$\text{Relative number of system}(RNS)_x(m) = \frac{\text{Absolute number of system}(ANS)_x}{\text{Total PPI in the month}(m)} \quad (1)$$

$$\text{Relative frequency of system}(RFS)_x(m) = \frac{\text{Relative number of system}(RNS)_x(m)}{\text{Total relative number of system}(TRNS)_x(p)} \times 100\% \quad (2)$$

$$\text{where, } x = \text{type of system},\ m = \text{month},\ \text{and } p = \text{total period}$$

The arc type precipitation systems are classified into four sub-categories: symmetric, asymmetric, combination of symmetric and asymmetric, and unclassified type precipitation systems according to Houze et al. [13]. (i) Symmetric type precipitation system (STPS): there is no preferential particular location for the most intense convective cells along the leading edge of the line and the trailing stratiform region has located directly behind the center of the convective line (Fig. 2). In Fig. 2, the development stage is not shown because of the radar data availability issues. (ii) Asymmetric type precipitation system (ATPS): the most intense convective cells are preferentially occured towards the south, southwestern, or the western end of the line, while weaker, dying cells on the verge of becoming stratiform are found toward the other end of the line and located toward the north, northeast, or east end of the line, rather than centered behind the line (Fig. 3). (iii) Combination of symmetric and asymmetric type precipitation system (CSATPS): symmetric and asymmetric both patterns are observed during different stages of the entire life cycle of a system. For instance, from mature stage to the dissipating stage of a system, some PPI scans of mature stage were similar to the pattern of symmetric system and some of PPI scans of dissipating stage with the asymmetric system and *vice versa* (Fig. 4). (iv) Unclassified type precipitation system (UTPS): Without these three categories, the remaining systems labeled unclassified type precipitation system (Fig. 5). Actually, this system does not belong to the structure of symmetric and asymmetric systems. For example, in some cases when they appear to be mature stage there was no stariform region and some other cases the convective lines were not similar to the asymmetric characteristics and stratiform regions with symmetric characteristics and *vice versa*.



(a) (b)

Fig. 2. An example of different stages of a symmetric type precipitation systems on 20 May 2003. (a) Mature stage and (b) decaying stage.

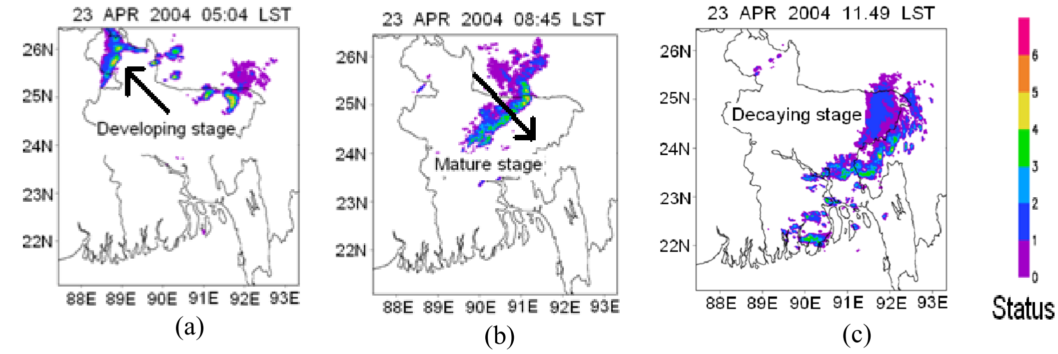


Fig. 3. An example of different stages of an asymmetric type precipitation systems on 23 April, 2004. (a) Developing stage, (b) mature stage and (c) decaying stage.

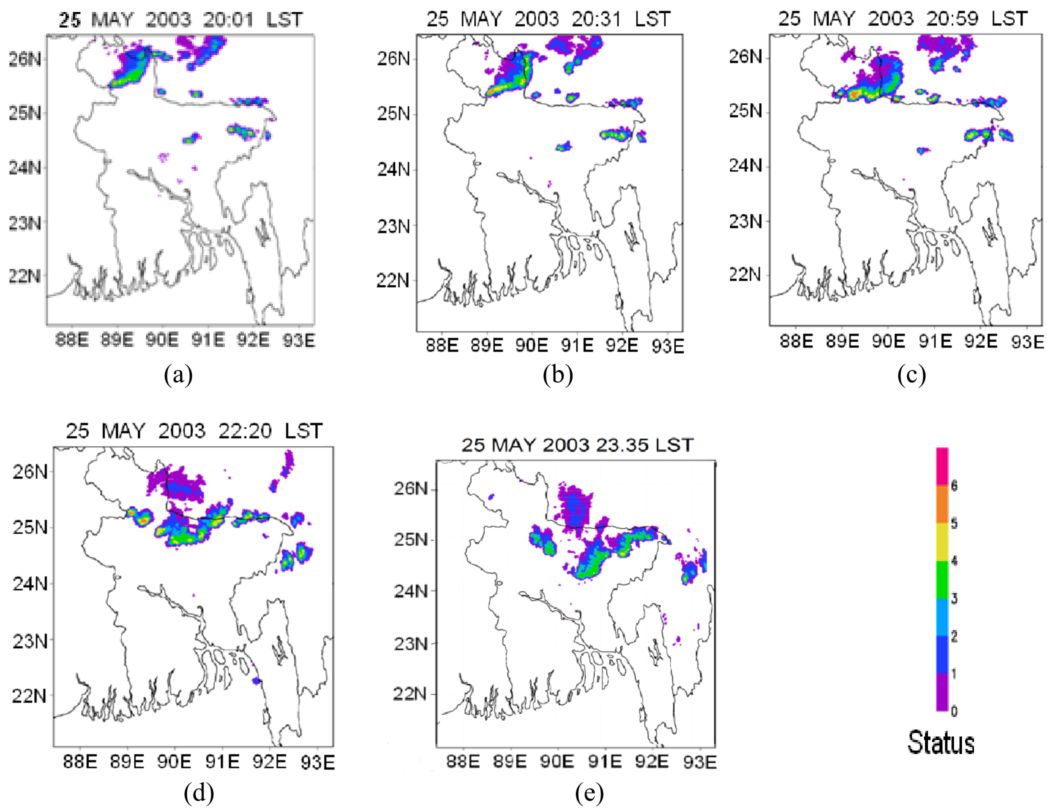
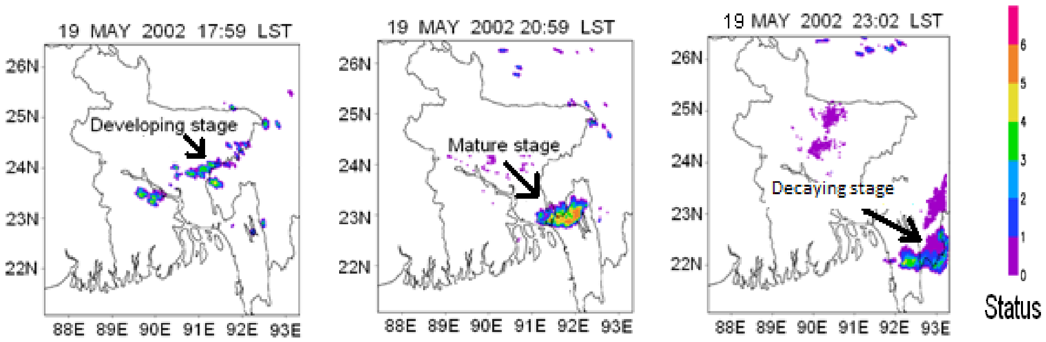


Fig. 4. An example of different stages of a combination of symmetric and asymmetric type precipitation systems on 25 May 2003. Developing stage [a (asymmetric pattern)], mature stage [b (symmetric pattern), c (asymmetric pattern) and d (symmetric pattern)], decaying stage [e (symmetric pattern)].



(a) (b) (c)

Fig. 5. An example of different stages of an unclassified type precipitation systems on 19 May 2002. (a) Developing stage, (b) mature stage, and (c) decaying stage.

The above classifications are made subjectively after careful observation of the pattern of a system in its mature stage during their life cycle. The status ~ 2 (1 mm/h ≤ rain rate < 4 mm/h) is considered a stratiform region with relatively weak intensity while the convective cell is considered from status ~ 3 (16 mm/h ≤ rain rate < 32 mm/h) of the systems. The environmental wind field for individual case studies is obtained using National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) 6-hourly reanalysis data on a 2.5 degree × 2.5 degree global grid. The seasonal 6-year average (mean) environmental wind field is obtained from the same dataset.

3. RESULTS AND DISCISSION

There are 160 and 70 arc shaped precipitation systems found during the pre-monsoon and monsoon periods, respectively from 2000 to 2005 and this arc shaped precipitation systems are classified into four basic types: i) symmetric type precipitation system (STPS), ii) asymmetric type precipitation system (ATPS), iii) combination of symmetric and asymmetric type precipitation system (CSATPS) and iv) unclassified type precipitation system (UTPS). The occurrence number and relative frequency of different arc type precipitation systems developed in the pre-monsoon and monsoon seasons are shown in Table 1.

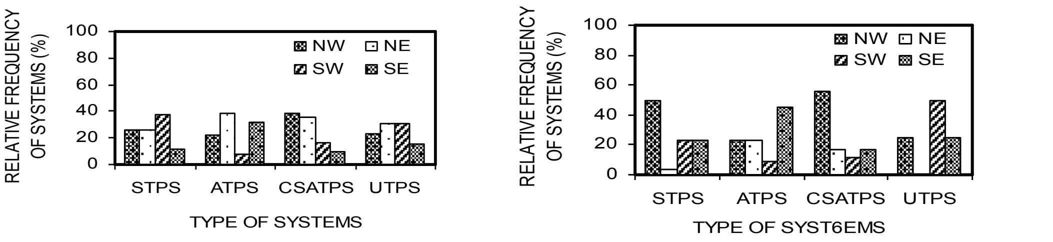
Table 1. Number and relative frequency of different arc types precipitation systems.

Season	STPS	ATPS	CSATPS	UTPS
Pre-monsoon	27	76	31	26
Monsoon	26	22	18	4
Total	53	98	49	30
Relative frequency (%)	23	43	21	13

Fig. 6 represents the regional distribution of STPS, ATPS, CSATPS and UTPS in the pre-monsoon and monsoon periods. During the pre-monsoon period, the maximum occurrence frequency of STPS, ATPS, and CSATPS is found in the southwest, northeast and the northwest quadrants, respectively while the UTPS dominate in the northeast and southwest quadrants. The relative frequency of occurrence (RFO) of UTPS in the northeast and southwest quadrants is same. However, there is little difference between the occurrence frequency of CSATPS in the northwest and northeast quadrants. During the monsoon period, the maximum occurrence frequency of STPS, ATPS, CSATPS and UTPS is found in the northwest, southeast, northwest and southwest quadrants, respectively. However, the contribution of STPS is less in the northeast quadrant, while the UTPS is completely absent in the same quadrant during the monsoon period.

Fig. 7 shows the monthly relative frequency of occurrence of STPS, ATPS, CSTPS and UTPS from 2000-2005. The total percentage of each type is assumed to be 100%. The occurrence frequency of STPS shows highest peak in the month April (31.36%) and afterward this frequency decrease. However, in the month of June and July the occurrence frequency of STPS is same. ATPS and UTPS start to develop from the beginning of the pre-monsoon month of April, peak in May, and radically decrease in the months of monsoon. The maximum occurrence frequency of ATPS (UTPS) is found 47.34% (53.12%) in the month of May. The highest peak of CSATPS (44.76%) is found in the month of April and with the progression of monsoon, the frequency of CSATPS decreases significantly. There is no CSATPS is found in the month of August and September during the study period 2000-2005.

Fig. 8 shows the intra-seasonal variation of the occurrence frequency of STPS, ATPS, CSATPS and UTPS from 2000-2005. It is observed from the figure that there have strong intra-seasonal variations of precipitation systems in different years. The occurrence of all types of systems is very strong in the pre-monsoon than monsoon season. The occurrence frequency of STPS and ATPS are largest for the year 2002 during monsoon period except CSATPS and UTPS. The presence of a weak low-level jet and penetration of strong mid-latitude westerlies [18] helped to develop STPS and ATPS. In this study, the 230 arc shaped precipitation systems are examined during the analysis period (2000-2005). Arc shaped precipitation systems are classified as STPS, ATPS, CSATPS, and UTPS. Within classifiable systems (in total 200 systems without the UTPS), the occurrence frequency of STPS, ATPS, and CSATPS is 27%, 49%, and 24%, respectively. These results differ with Houze et al. [13], who studied the 63 MCS from Oklahoma city and found approximately two by a third is classifiable and remaining unclassifiable. Within the classified systems, they found 26%, 35% and 38% is symmetric, asymmetric, and intermediate combination of symmetric and asymmetric, respectively. From the above results, it is clear that ATPS is dominated in Bangladesh whereas an intermediate combination of symmetric and asymmetric type systems is dominated in the Oklahoma (mid latitude).



(a) (b)

Fig. 6. The variation of relative frequency of different arc types precipitation systems by quadrant at mature stage: (a) pre-monsoon and (b) monsoon. Considering total percentage 100%.

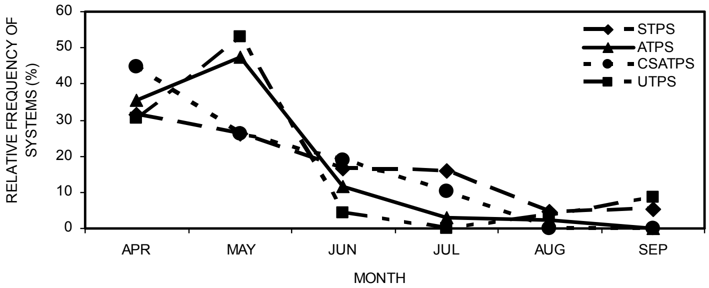
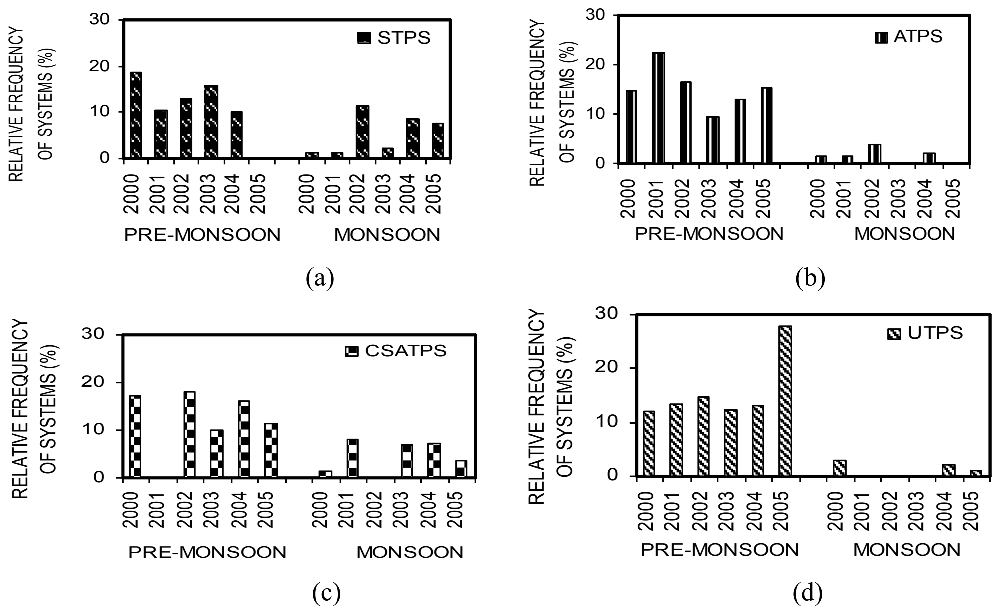


Fig. 7. Monthly relative frequency of occurrence of STPS, ATPS, CSTPS and UTPS from 2000-2005. The total percentage of each type is assumed to be 100%.



(c) (d)

Fig. 8. The intra-seasonal variation of the relative frequency of different arc types precipitation systems in different year: (a) STPS, (b) ATPS, (c) CSTPS and (d) UTPS. The total percentage of each type is assumed to be 100%.

In this analysis, it is observed that the occurrence frequency of ATPS is dominant (48%) in pre-monsoon season and STPS is dominant (37%) in the monsoon season (Fig. 9). In and around Bangladesh during the pre-monsoon period, the average low-level (925 hPa) wind is southwesterly or southerly and mid-level (500 hPa) wind is strong westerly or northwesterly (Fig. 10 (a, b)). The vertical wind shear is 2.6×10^{-3} s^{-1} over the radar domain between the low-level (925 hPa) and mid-level (500 hPa). These environmental conditions helped for the development of ATPS during the pre-monsoon period. From climate condition of Bangladesh, it is well known that precipitation system is usually associated with intense convective thunderstorms in the pre-monsoon. Severe

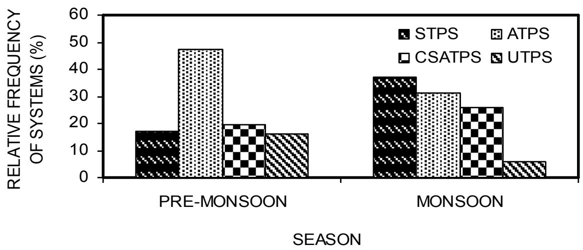
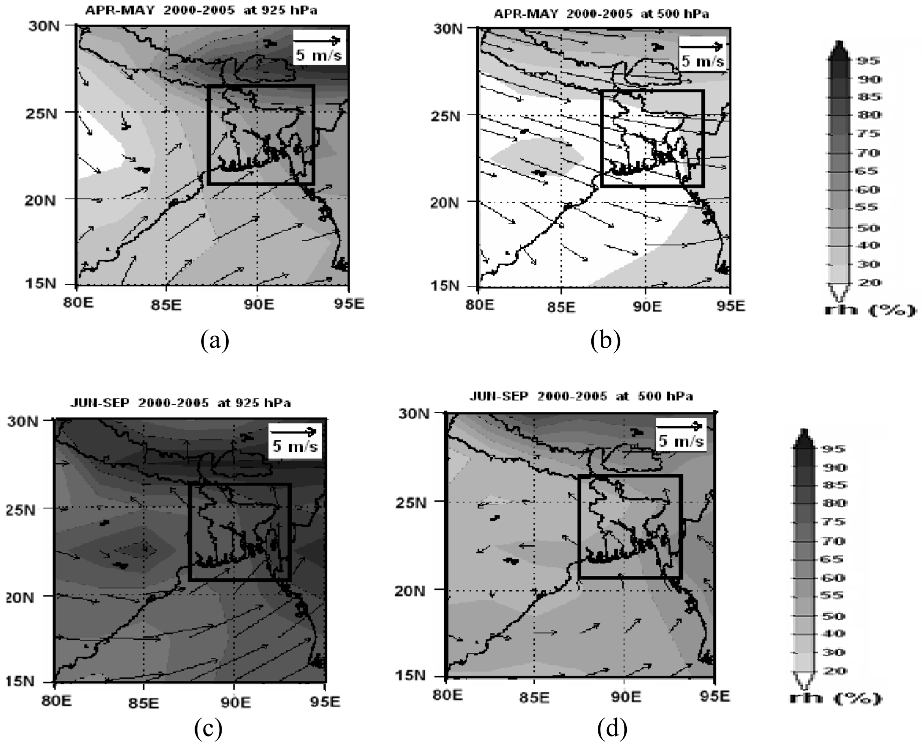


Fig. 9. Seasonal variation of different arc types precipitation systems. The total percentage of the four patterns is assumed to be 100% for each season.



(a) (b)

(c) (d)

Fig. 10. Average seasonal variation of relative humidity (color shading) and wind field (arrow) for (a, b) pre-monsoon and (c, d) monsoon periods at 925 and 500 hPa levels.

weather form of hail and tornadoes is more common with asymmetric systems, in which new cell formation is preferred on one (typically south) end of the line, and decaying cells accompanied by a larger stratiform region are found in other end [19]. Houze et al. [13] mentioned that STPS is organized in an environment of weak low to mid tropospheric shear with low-level jet. During the monsoon period, the average low-level (925 hPa) wind is strong southerly or southwesterly and the mid-level (500 hPa) wind is southerly or southwesterly and the vertical wind shear is 0.8×10^{-3} s^{-1} over the radar domain (Fig. 10 (c, d)). These monsoonal environmental conditions enhanced the development of STPS during the monsoon period. The horizontal structure of STPS is an important factor in determining the distribution of rainfall and the possibility of flooding. In addition, locations receiving both stratiform and convective rainfall have a greater risk of flooding than a location receiving only stratiform or convective rainfall [20]. The characteristics of ATPS and STPS help to produce gusty wind, damaging hail and tornadoes, and heavy rainfall (flash flood) in Bangladesh during the pre-monsoon and monsoon periods, respectively.

4. CONCLUSIONS

There are 230 arc type precipitation systems identified during the study period and classified into STPS, ATPS, CSATPS and UTPS. During the analysis period, the occurrence frequency of STPS, ATPS, CSATPS and UTPS is 23%, 43%, 21% and 13%, respectively. Seasonal analysis showed that the ATPS and STPS is dominant in the pre-monsoon and monsoon period, respectively. During the pre-monsoon period, the ATPS may develop through interaction between warm and dry air masses in the presence of strong vertical wind shear between the low level (southwesterly or southerly) and mid level (strong westerly or northwesterly). During the monsoon period, the STPS may develop with presence of plenty of moisture and very weak or no remarkable wind shear between low level (strong southerly or southwesterly) and mid level (southerly or southwesterly). Regional analysis of different arc shaped systems indicate that at the mature stage of their life cycle, STPS, ATPS, and CSATPS is dominated in southwest (northwest), northeast (southeast) and northwest (northwest) quadrants during the pre-monsoon (monsoon) period. The maximum occurrence frequency of UTPS is found in the northeast and the southwest quadrant during pre-monsoon and in the southwest quadrant during the monsoon season.

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