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Seasonal variations of temperature and rainfall characteristics in the northeastern part of Bangladesh around Sylhet

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Abstract: Utilizing surface and satellite observations, we showed some characteristic climatic aspects in and around Sylhet area, northeastern part of Bangladesh. The 14-year climatological rainfall in pre-monsoon and monsoon seasons was calculated from TRMM-PR surface rain data. In pre-monsoon season, rainfall amount in the upper catchment of the Meghna river in India was high. The location of rainfall maximum on the Meghalaya Plateau in pre-monsoon season shifted westward relative to the monsoon season. Analysis of year-to-year variation of rainfall amount in BMD Sylhet observatory showed that the pre-monsoon rainfall contributed the year-to-year variation of the annual rainfall in Sylhet as much as the monsoon rainfall. Rainfall within 20-99 mm/h intensity range strongly affected the total rainfall for pre-monsoon season, while it was 50-499 mm/h for monsoon season. The analysis of the maximum temperature variation indicated that the temperature variation in Sylhet was largely different from that in other part of Bangladesh, especially in the rainy seasons. This was likely to be due to the cold air mass originated from the Meghalaya Plateau associated with strong rainfall activity in pre-monsoon and monsoon seasons. Recent warming trend in daily maximum temperature was prominent in Sylhet compared with other sites.

Key words: Seasonal variations, temperature, rainfall northeastern part, Sylhet.

Introduction

Sylhet, one of the divisional cities of Bangladesh is located in the north-eastern part of the country. It has a number of topographical features like hills and hillocks (tilas), wetland (haors) and high flood plain; which made it quite different from the rest of the parts of Bangladesh. Sylhet region has a significant numbers of hills all around. Small areas of the Meghalaya Plateau foothills falls within Bangladesh situated mostly near the border areas of Sylhet (Fig. 1). However, small hills, locally known as tilas are found scattered around many places along the Sylhet city up to Srimangal and Moulvibazar. Northern branch of river Barak (comes from India) gets the name the Surma which is one of the main rivers of Bangladesh passed through Sylhet city. Southern branch of Barak gets the name Kushiara in Bangladesh, which is another major river of Sylhet. The Surma and the Kushiara make unification as Kalani, which is renamed as the Meghna and finally merges in the Bay of Bengal.

It is about 197 km northeast of the capital city of Dhaka. It is noted for having average annual precipitation levels in Sylhet, about 4195.9 mm. In addition, it had the greatest recorded total single year rainfall 5620 mm in 1988 and the greatest one month total rainfall was recorded 1294.7 mm in July 2004. Long lasting heavy rainfall over the large catchment area causes severe floods in Bangladesh. Prediction of pre-monsoon and monsoon rainfall amount has been a focus of the researchers (Terao and Kubota, 2005; Rana *et al*., 2007; Terao *et al*., 2013). The understanding of the characteristics of rainfall variability is important for the mitigation of disaster damage.

In Bangladesh, climatically four seasons prevail, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter-monsoon (December-February) (Ahasan *et al*., 2010). Most of the rain in Bangladesh occurs in monsoon season. Sylhet receives rains from the Bay of Bengal arm during the monsoon. The normal annual rainfall of Sylhet is 4195.9 mm. Major portion 66.40 % of the rainfall is contributed by the monsoon, the pre-monsoon 26.23 %, the post-monsoon 6.06 % and winter-monsoon 1.31 %. The contribution of pre-monsoon was larger than that of all Bangladesh rainfall. The onset distribution of rainfall and end of monsoon season are important in crop production in this region.

For the detailed observation of distribution of rainfall, the space borne radar, the Tropical Rainfall Measurement Mission (TRMM) precipitation radar (PR) data are accurate and useful (Kummerow *et al*., 2000). The TRMM covers earth's surface with highly homogeneous quality. Especially for the topographically complex areas, satellite radar is suitable for the observation, since the measurement from the space avoids the radar beam occultation by the topography. On the other hand, the TRMM-PR data has a weakness in its long return period, almost several days. However, the observation continued for more than 14 years from the launch of the satellite on 28 Nov. 1997. The long accumulation of data facilitates the estimation of climatological rainfall with its full spatial resolution (Biasutti *et al*., 2012). In the present paper, climatological rainfall distributions over Sylhet area in pre-monsoon and monsoon seasons were estimated for the first time using reliable TRMM-PR data. We labeled recent 14 years from 1998 to 2011 as the TRMM period.

As for the rainfall in Sylhet, Terao *et al*. (2006) suggested that the low level nocturnal jet intensified the rainfall at midnight to early morning. Kataoka and Satomura (2005) suggested that cool air mass was produced through the heavy rainfall cloud activity over the Meghalaya Plateau, covering the lower layer over Sylhet area. The low level jet with moist air mass may run over this cool air mass to trigger strong convection over Sylhet area. Murata *et al*. (2011) have shown the existence of such cool air mass for the pre-monsoon season. In the present study, we will check the development of cool air mass which covers Sylhet area using simple comparison of surface maximum temperature at Sylhet and other sites. We will also present recent warming trend especially prominent in Sylhet by comparing averaged maximum temperature for recent 14 years, the TRMM period, with that for the normal.

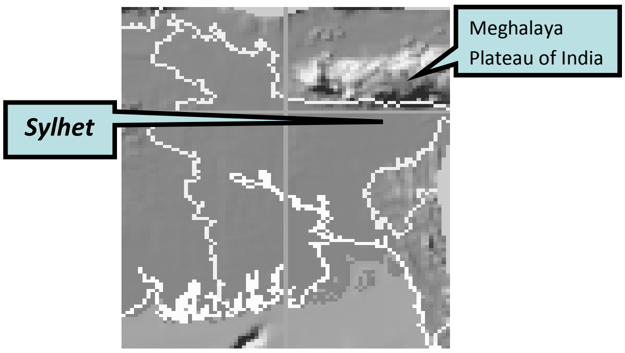

Fig. 1. Aerographic condition of Sylhet, Source: International Tsunami Data Base-1 (Fujii, 2007)

Materials and Methods

Daily and monthly rainfall data of Sylhet rain gauge station (91.88°E, 24.90°N, 33.53 m ASL) of Bangladesh (Fig. 2), during the TRMM period have been collected from the Bangladesh Meteorological Department (BMD). For the comparison, we gathered the normal rainfall amount from the web site of BMD (BMD, 2013). The normal was defined as the average for the period from 1971 to 2000 in the present paper.

Fig. 2. Location of 6 selected BMD observatories. Topographic data provided with GMT; the Generic Mapping Tools

Daily maximum temperature data of 6 selected observatories Sylhet, Dhaka, Bogra, Rajshahi, Jessore and Khulna (Fig. 2) are utilized to analyze the characteristics of weather in Sylhet. Since we found some erroneous data in maximum temperature datasets for years before 1982 for Dhaka, Rajshahi, Jessore, Khulna, and Srimangal, we analyzed data only after 1982 for the daily maximum temperature data. For the purpose of detection of recent warming trends, we utilized only recent 14-year data 1998-2011, the TRMM period, and we compared with the climatological normal (1971-2000) given in the web site of BMD (BMD, 2013).

We compared the rainfall averaged for monsoon season from 1998 to 2011 observed by the TRMM-PR and BMD Sylhet observatory. We calculated the average rainfall intensity for the pixel that covers Sylhet observatory at 24.90°N, 91.88°E. The TRMM-PR estimation was 0.72 mm/h, corresponding with 2116.6 mm. The ground truth was 2550.9 mm according to the BMD observation. The same comparison was made for pre-monsoon season also. The TRMM-PR and surface observations were 1011.8 and 1066.6 mm, respectively. The TRMM rainfall estimates tend to be somewhat underestimated. Islam and Uyeda (2007) pointed out the underestimation of rainfall in TRMM-3B42 V6 data for monsoon months. The bias of TRMM-PR and other recent product should be clarified more in future.

Surface rainfall data from the TRMM satellite was also utilized for the estimation of detailed spatial distribution associated with the topographical features. The TRMM platform has precipitation radar (TRMM-PR) which measures rainfall rate (mm per hour) with horizontal and vertical resolution of 5km and 250m, respectively. For the present paper, we utilized the near surface rain data which is included in TRMM-2B25, which is an estimate of rainfall rate at the ground level for each radar beam. We collected the TRMM satellite data for all valid swaths, and averaged over the all observations to get rainfall rate to obtain averaged rainfall rate for averaged period. We estimated the rainfall rate for pre-monsoon (March to May) and monsoon (June to September) periods for each pixels with 0.05 times 0.05 degree size for the area 90-94°E and 23-26°N. For the monsoon periods, each pixel catches more than 1000 original pixels with 100 rainy pixels during 14-year observations on average. For the pre-monsoon periods, they were 800 and 40, respectively.

Results

Satellite Analysis: Firstly we analyzed fine scale surface rainfall distribution utilizing TRMM-2A25 surface rainfall data for recent 14 years from 1998 to 2011, the TRMM period (Fig. 3). This is the first attempt to show reliable climatological meso-scale rainfall distribution over this region with 5 km spatial resolution.

In the pre-monsoon season (Fig. 3a), the rainfall enhancement over the eastern hilly area in India is prominent. The river flow through the Meghna may be influenced by rainfall in Tripla, western Mizoram and southern Assam. Therefore, for the flood and river water monitoring in the pre-monsoon season, the rainfall in the Indian side is also important. It is well known that the pre-monsoon rainfall is associated with severe local storms that accompany strong northwesterly gusts (Yamane and Hayashi, 2011a, b; Yamane *et al.*, 2012). Rainfall distribution in the pre-monsoon season implies that the topographical uplift associated with the westerly gust enhances rainfall in these areas.

In the monsoon season (Fig. 3b), strong rainfall area around the Meghalaya Plateau was somewhat wide compared with the pre-monsoon season. The heaviest rainfall area shifted to the west. This may partly due to the difference of the wind direction in the monsoon season. Just only 10 km to the northeast of Sylhet, there was a heavy rainfall area greater than 3500mm. Interestingly, this area roughly corresponded with an area with a forest and small hills along the Sylhet-Tamabill Highway. Just to the west of Sunamganj, there was small area with higher rainfall intensity both in pre-monsoon and monsoon seasons. Rainfall amount was not uniform not only in the meridional direction but also in the zonal direction. There were several rainy bands that oriented northeast-southwest direction. The effect of very small topography like tilas was another topic we will focus on in the future research.

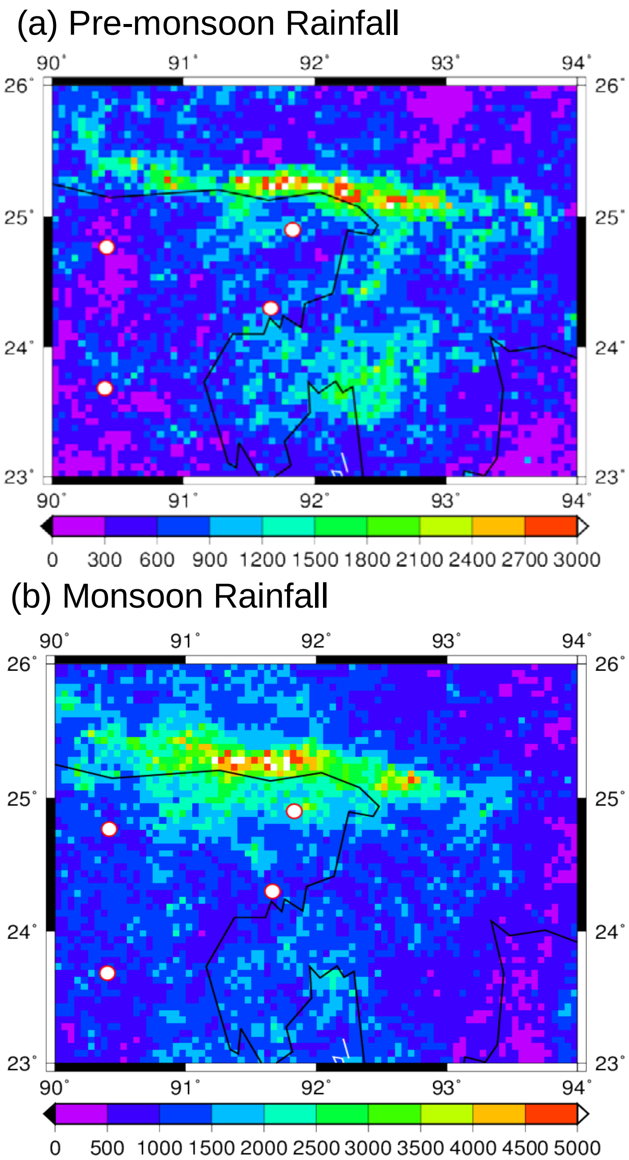

Fig. 3. Climatological rainfall amount (mm) averaged for the TRMM period (1998 to 2011) calculated from TRMM-PR surface rainfall intensity data for (a) the pre-monsoon (March to May) and (b) monsoon (June to September) seasons, respectively. Circles are locations of Sylhet, Srimangal, Mymensingh and Dhaka from east to west.

Rainfall Analysis: Fig. 4 depicts the annual rainfall variations of Sylhet for the period of 14 years (1998-2011). It indicates that the mean annual rainfall was less than the normal (i.e. 4195.9 mm) during the year 1999, 2001, 2002, 2003, 2005, 2006, 2008, 2009 and 2011. The most deficit rainfall year was 2011 in which annual rainfall was 3101 mm. The prime excess annual rainfall was 4939 mm in 2010 and other four years 1998, 2000, 2004 and 2007 were above normal.

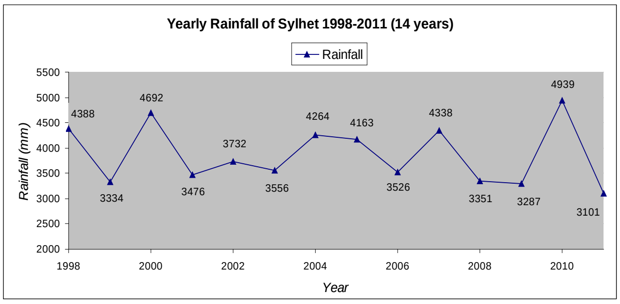

Fig. 4. Annual rainfall in Sylhet

Red bars in Fig. 5 shows the normal seasonal rainfall variation pattern of Sylhet. Here we introduce normal rainfall during winter monsoon, pre-monsoon, monsoon and post-monsoon. Rainfall amount in the pre-monsoon and monsoon seasons explained most of annual rainfall. However, it is well known that the characteristics of the pre-monsoon rainfall and monsoon rainfall in Bangladesh are different. More short and intense rainfall is seen in the pre-monsoon season, than in the monsoon season (Terao *et al.*, 2008). This transition of rainfall characteristics around May to June coincides with the Asian summer monsoon onset, at which the large scale circulation over the south Asia also drastically changes associated with the large temperature increase over Eurasia (Li and Yanai, 1996; Hoque *et al.*, 2011).

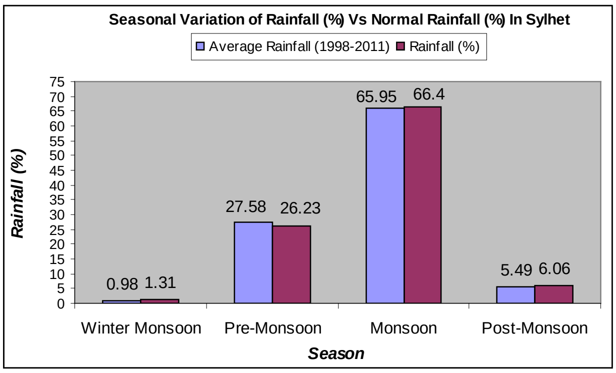

Fig. 5. Seasonal contribution of rainfall in Sylhet for the TRMM period (1998-2011, blue bars) and the normal (1971-2000, red bars).

In Fig. 5, we were getting recent trend of the seasonal variation of rainfall. Generally, rainfall of Bangladesh was dominant during the monsoon and pre-monsoon seasons. But nowadays for the TRMM period from 1998 to 2011, pre-monsoon rainfall had small uprising trend, but during the monsoon season it had downward tendency consistent with Ahasan *et al.*, (2010). Generally it was discussed that the rainfall intensity is increasing globally. Yamane *et al.*, (2013) discussed that the trend of rainfall at Dhaka after 1953 was positive in the pre-monsoon and monsoon seasons. Interestingly, the tendency shown in Fig. 5 was consistent with global trend, although the tendency was not yet statistically significant. It was suggested that the heavy rainfall in the pre-monsoon season increased, and the moderate rainfall in the monsoon season decreased. We need much more observation to confirm this trend.

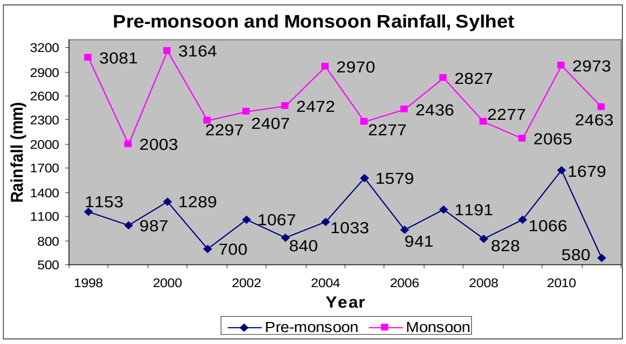

Fig. 6. Variation of the pre-monsoon and monsoon rainfall in Sylhet

Fig. 6 showed the rainfall variation of recent 14 years. The variability of rainfall amount was higher in the pre-monsoon season (C.V.=28.6%) than that in the monsoon season (C.V.=14.9%). The correlation coefficient of the pre-monsoon and monsoon rainfall against the annual rainfall were 0.81 and 0.84, respectively, showing almost equal contribution to the annual rainfall variability. It was noteworthy that the pre-monsoon rainfall had rather large contribution to the year-to-year variation of annual rainfall in Sylhet area. On the other hand, the correlation coefficient between the pre-monsoon and monsoon rainfall was 0.40, moderately high, but much below 5% significant level. In these years, data less than yearly normal rainfall year was numbering nine but only five showed above normal, as discussed above. Among these five years, the sums of the pre-monsoon and monsoon rainfall were greater than the annual normal for three years, 1998, 2000 and 2010, and were above 4000 mm for other two years, 2004 and 2007. Here we should remember that total yearly normal rainfall was 4195.9 mm. From this figure also, we confirmed that the rainfall in Sylhet had reducing trend.

In Figs. 7 and 8, the number of days within 6 classified daily rainfall amount were shown for 1-9, 10-19, 20-49, 50-99, 100-199 and 200-499 mm/day rainfall intensity ranges for pre-monsoon and monsoon seasons, respectively.

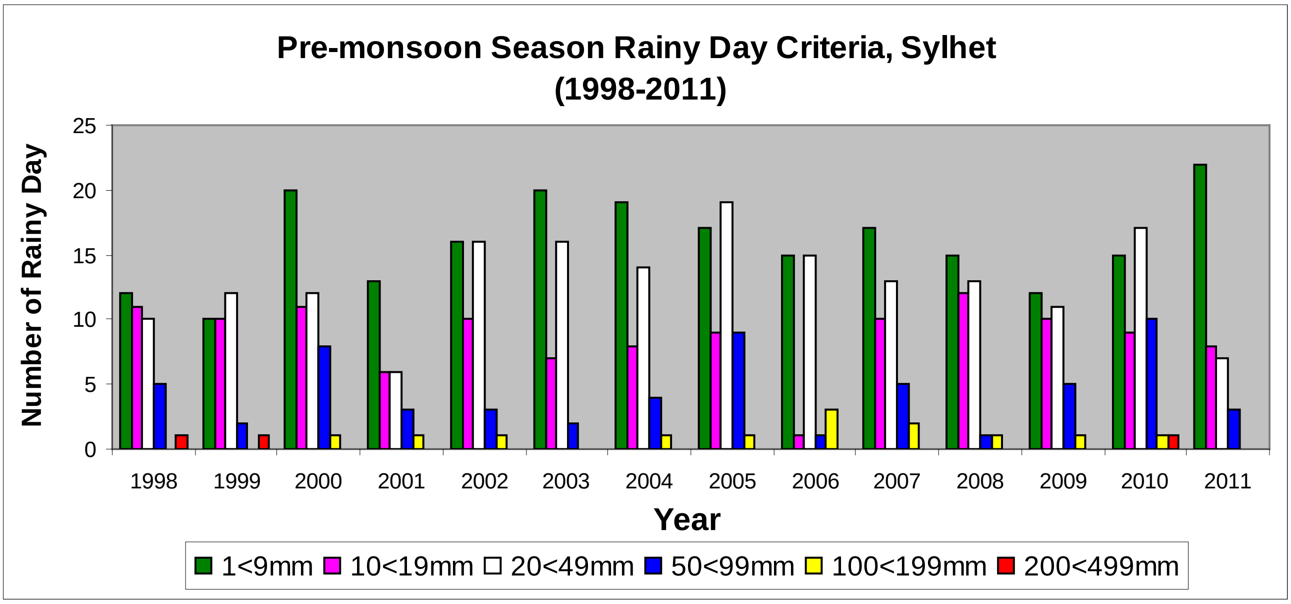

Fig. 7. Pre-monsoon year-to-year variations of number of rainy days within 6 rainfall intensity classifications in Sylhet

Comparing with Fig. 6, the year-to-year variation of pre-monsoon rainfall well corresponded with the number of rainy day with 50-99 mm/day rainfall amount. The correlation coefficient of the year-to-year variation of number of rainy day in each class against the pre-monsoon rainfall was highest for 50-99 mm/day class (0.87; significant in 99% confidence level). The 20-49 mm/day class also had 99% significant correlation coefficient against pre-monsoon rainfall (0.66). On the other hand, in the monsoon season, highest correlation was found for both 50-99 mm/day class (0.60) and 200-499 mm/day class (0.63), which were significant in 95% confidence level. As for the monsoon season, major rainfall contribution came from 50-499 mm/day range, which was 50-99 mm/day for the pre-monsoon season in Sylhet area.

Recent warming trends in Sylhet: In Fig. 9, the deviations of daily maximum temperature in recent TRMM period from the normal for six (6) selected observatories, Sylhet, Dhaka, Bogra, Rajshahi, Jessore and Khulna (Fig. 2) were shown. We found that only Sylhet had a warming trend whole year around. On the other hand, in other observatories, in at least some of the winter and pre-monsoon months (December, January, March or April), the trends were negative. This warming trend in Sylhet was prominent especially in dry months. This implied that the warming trend in Sylhet was mainly due to any local factors such as urbanization, or local circulation. The cooling trends commonly seen in December, January, March and April in all Bangladesh were interesting feature that have to be confirmed in future. Yamane *et al.* (2013) calculated the trend of temperature at Dhaka after 1953 in pre-monsoon and monsoon seasons as +0.9 ^{o}C/100 years and +1.7 ^{o}C/100 years, respectively. The cooling trend might be seen mainly in the daily maximum temperatures.

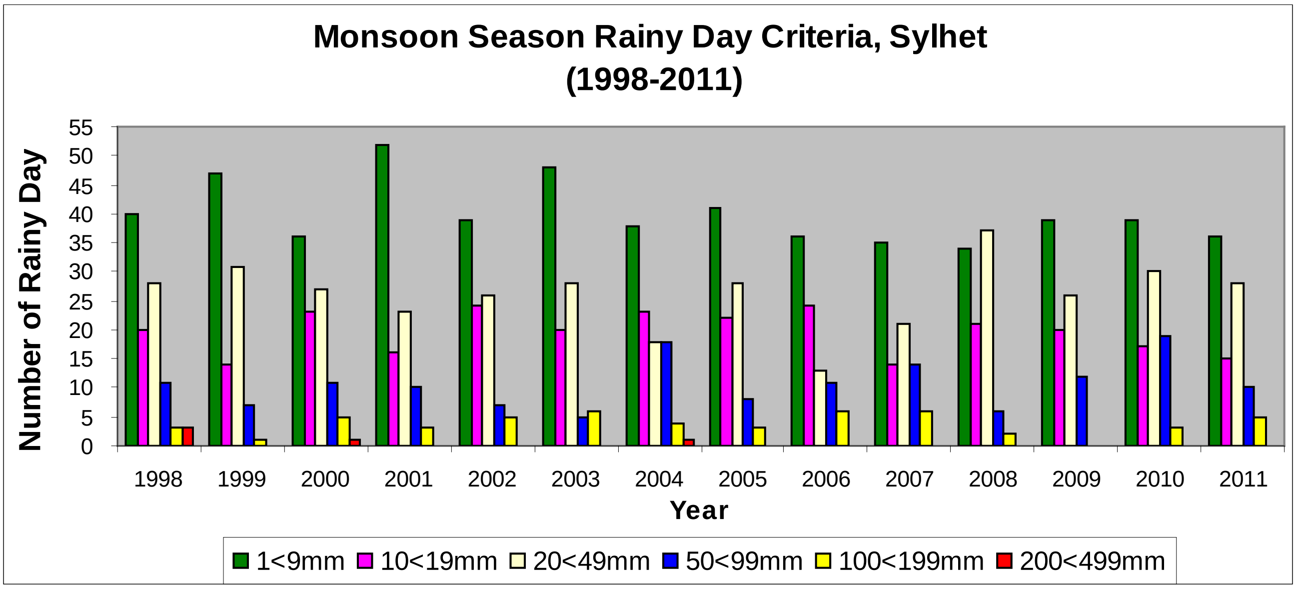

Fig. 8. Same as Fig. 7 except for the monsoon season

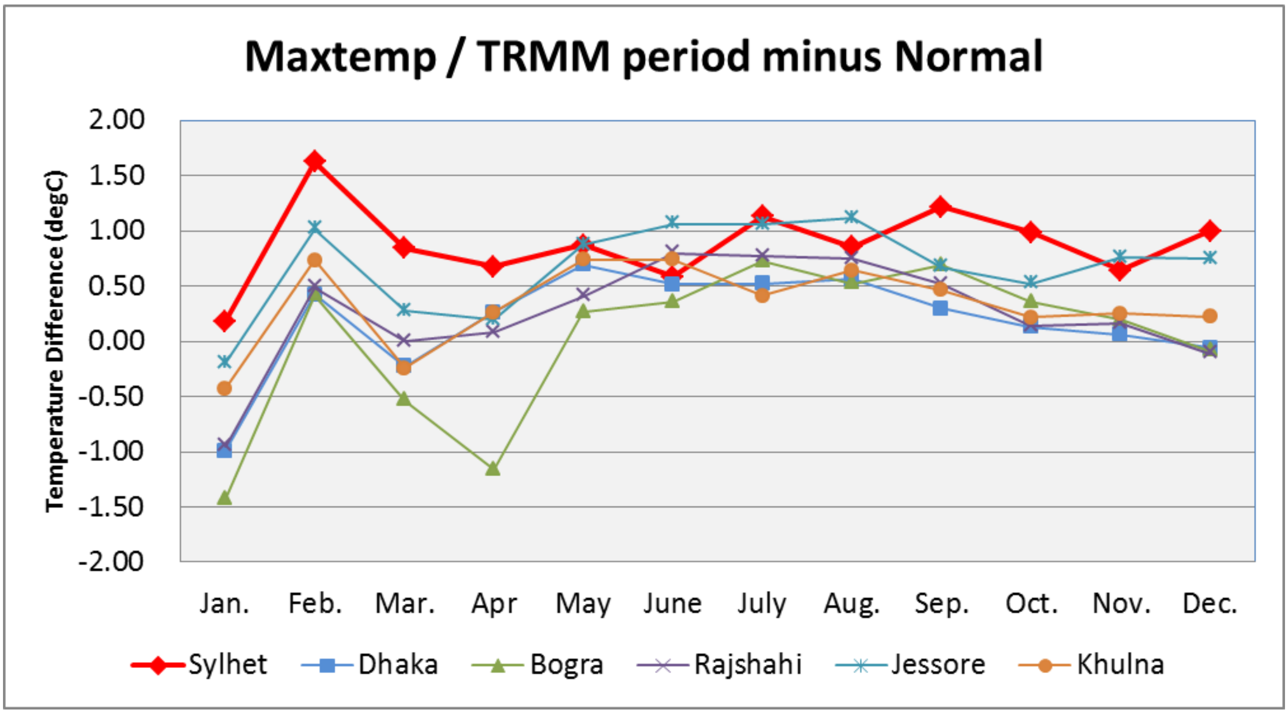

Fig. 9. Recent (1998-2011) maximum daily temperature trend Sylhet, Dhaka, Bogra, Rajshahi, Jessore and Khulna.

Daily maximum temperature variation in Sylhet: As we have discussed in introduction, air mass covering Sylhet region seemed to be different from other part of Bangladesh. The air mass in this region might be produced through the local circulation associated with the Meghalaya Plateau. If so, variations of the temperature or other parameters in Sylhet should be different from other locations in Bangladesh. If rainfall events play crucial role in the production of the air mass in Sylhet area, the difference of parameters should be prominent especially in rainy season. Therefore, we analyzed the correlation of daily maximum temperatures between different observatories (Sylhet, Dhaka, Bogra, Rajshahi, Jessore and Khulna, Fig. 2), for each month. Correlations were calculated for all daily maximum temperature data for the 30-year period between 1982 and 2011 without subtracting annual average.

Fig. 10 shows correlation coefficient of the daily maximum temperature in Sylhet against those for other five observatories in Bangladesh. Correlation coefficients dropped below 0.4 from April to September (one exception was in August at Bogra), corresponding with rainy seasons over the Meghalaya Plateau. Correlation was smaller for the observatories in southern parts. Interestingly, in the period from November to March, the correlation coefficients were all larger than 0.4.

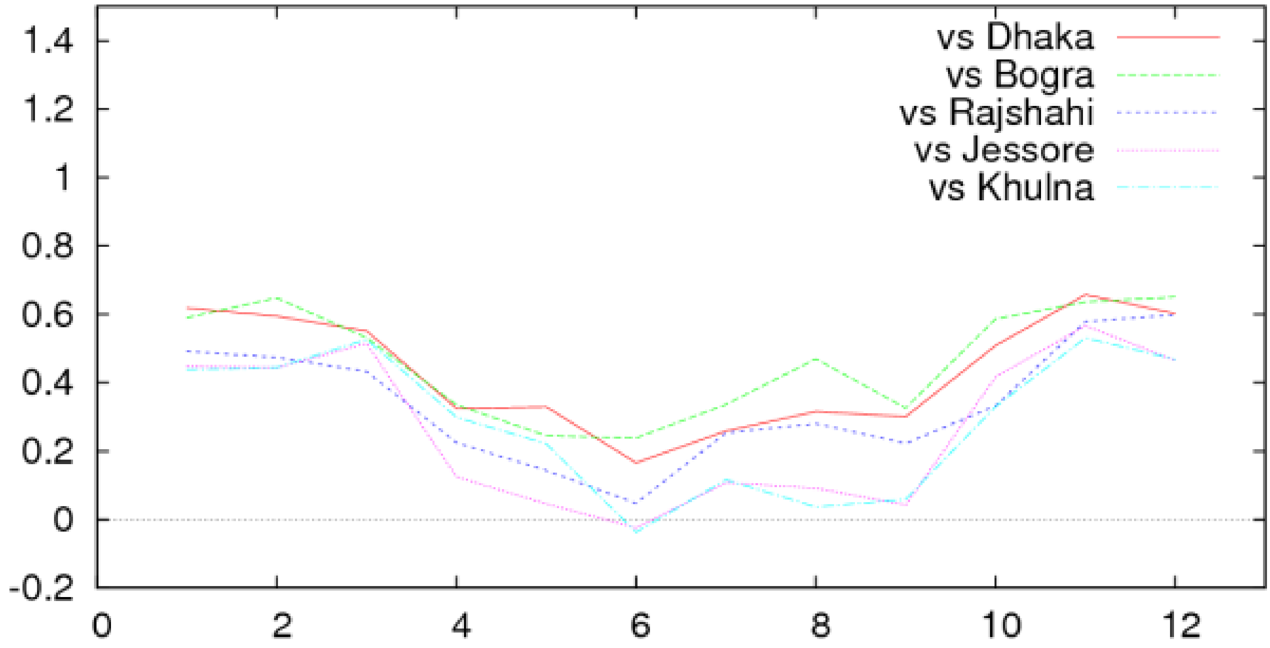

Fig. 10. Correlation coefficient of the daily maximum temperature in Sylhet against those for other five BMD observatories, Horizontal axis indicates month

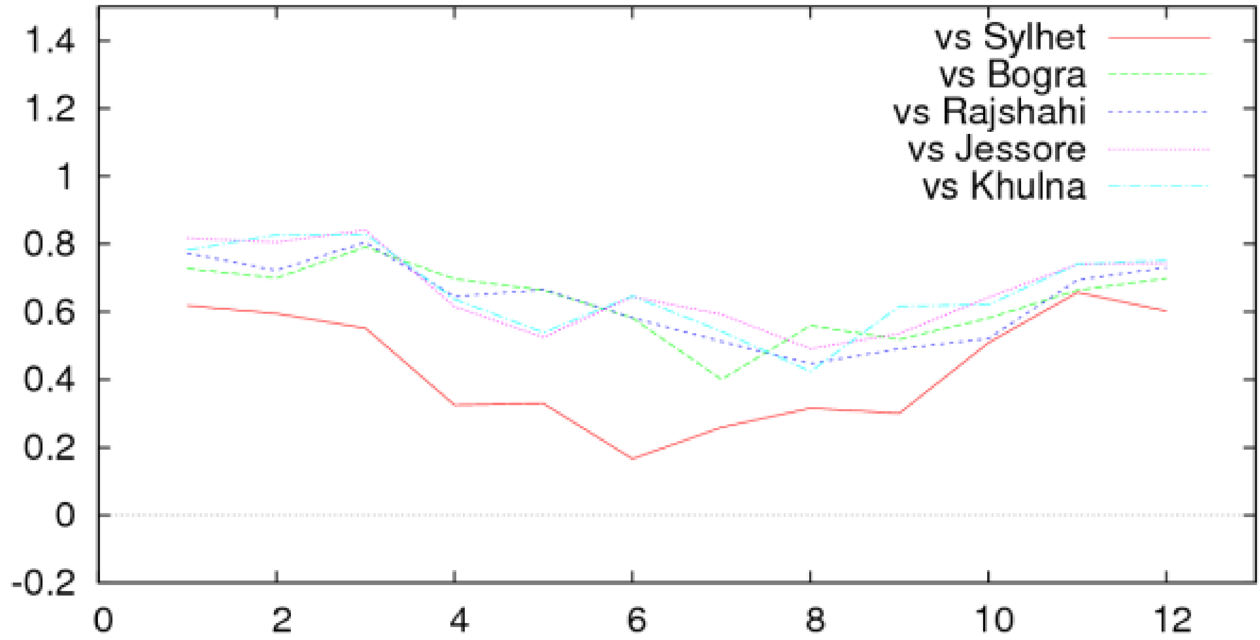

Fig. 11. Same as Fig. 10 except for Dhaka.

Fig. 11 is the same as Fig. 10 except for Dhaka. A weak reduction of the correlation coefficients in rainy season was seen in the relation between Dhaka and the cities other than Sylhet, possibly reflecting the activity of various scales of atmospheric disturbances. However, the reduction of correlation in the rainy season was the clearest in the correlation against Sylhet, indicating the difference of the air mass characteristics covering Sylhet.

Conclusions

Utilizing surface and satellite observations, we showed some characteristic climatic aspects in Sylhet area, northeastern part of Bangladesh. This area was known as one of the heaviest rainfall area in Bangladesh. Our present paper supported this knowledge, and also showed that the climate in Sylhet had several distinct characteristics in Bangladesh.

The 14-year (1998-2011, the TRMM period, henceforth) climatological rainfall in pre-monsoon and monsoon seasons calculated from TRMM-PR snapshots partly uncovered the fine scale structure of the rainfall distribution in and around Sylhet division. In pre-monsoon season, rainfall amount in Tripla, Mizoram and Assam states of India was high. Thus, for the water and flood management in Sylhet area, the rainfall in the upper catchment of the Meghna river in India such as Barak Basin (Deka *et al*., 2012) has to be monitored much before the beginning of the monsoon season in the main part of Bangladesh. The location of rainfall maximum on the Meghalaya Plateau in pre-monsoon season shifted westward relative to the monsoon season associated with the onset of local monsoon circulation.

Characteristics of year-to-year variation of rainfall amount were consistent with Ahasan *et al*. (2010). In Sylhet, the pre-monsoon rainfall contributed the year-to-year variation of the annual rainfall in Sylhet as much as the monsoon rainfall. Furthermore, the rainfall intensity classification analysis using raingauge observations in BMD Sylhet observatory in the TRMM period, 1998-2011, showed interesting characteristics of rainfall variation in this area. Rainfall within 20-99 mm/hour intensity range strongly affected the total rainfall for pre-monsoon season, while it was 50-499 mm/h for monsoon season.

The analysis of the maximum temperature variation indicated that the temperature variation in Sylhet reflected different factors from other part of Bangladesh, especially in the rainy seasons. This supported the conclusion by Kataoka *et al*. (2005) and Murata *et al*. (2011), which discussed that the lower tropospheric cooler air mass that frequently covered the Sylhet area. This cooler air mass might be originated from the Meghalaya Plateau associated with strong rainfall activity in pre-monsoon and monsoon seasons. The comparison of recent (1998-2011; TRMM period) and normal (1971-2000) daily maximum temperature suggested that recent warming was prominent in Sylhet compared with other sites.

The evaluation of the sampling errors in TRMM-PR data associated with the asymmetric distribution of rainfall intensity should be done in near future. Especially in the pre-monsoon season, the frequency of rainfall events was turned out to be rather small. We should distinguish the signal from the noise in the fine scale rainfall data. TRMM data were also useful for the classification of rainfall systems over Bangladesh in different seasons and different areas (Rafiuddin *et al*., 2007, 2011). The origin and the horizontal and vertical structures of the air mass covering lower troposphere in Sylhet area especially in rainy seasons are another interesting issue that should be solved in near future. We are now accumulating rawin sonde data at Sylhet observatory (Murata *et al*., 2011). Meso-scale model calculations will be powerful method to investigate the three dimensional structure of atmosphere in Sylhet area.

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