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PREDICTION OF HEAVY RAINFALL OVER NORTHEASTERN PART OF BANGLADESH USING WRF-ARW MODEL

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ABSTRACT

Prediction of Heavy Rainfall Events (HREs) and quantitative rainfall prediction is very essential and challenging task to the meteorologists. An attempt is, therefore, made to understand the climatic condition in respect of rainfall and HR situation in the northeastern part of Bangladesh (NE-BD). The linear and Mann-Kendal trends of monsoon rainfall and the number of HR are found decreasing during 1981-2016. In total 44 HR events are selected during 2005-2014 based on the record at Sylhet meteorological station. All of the events are simulated using WRF-ARW model (version 3.5.1). It is found that six synoptic patterns are responsible for the occurrence of HR over NE-BD. Presence of these synoptic patterns leads vorticity and CAPE fields in the lower troposphere, which are enhanced in the upper levels due to high topography surrounding to NE-BD. Analysis reveals that the positive vorticity is found to extend upto 400 hPa level and its above in some cases in parallel to negative vorticity field existing side by side. This situation is liable to carry sufficient moisture particle as an ingredient for the HR event in the upper levels. Model is able to simulate 47% events properly but it could not capture 5% events. WRF-ARW model (version 3.8) shows improved performance than the earlier version for location specific rainfall prediction. As such, New Tiedke cumulus parameterization (CP) scheme with WSM3 microphysics (MP) shows best performed combination for location specific rainfall prediction.

Keywords: CAPE, Heavy Rainfall, Humidity, Trend, Vorticity and WRF Model.

INTRODUCTION

The northeastern part of Bangladesh (NE-BD) has a number of topographical features like rivers, hills and hillocks (tilas), haors (wetland) and high flood plain; which made it quite different from the rest part of Bangladesh. NE-BD not only plays an important role in the socio-economic development of Bangladesh but is also important for ecological balance of the country. The beautiful panorama of the region with vast reserve forest, intense tea gardens and growing rubber gardens in the hillocks, lakes and wetlands as well as sands and stones of the border areas made it attractive for tourists from both home and abroad. Among

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the topographical features of the region, hills are the most dominating ones, which is determining its climatic and morphological features (Mallika, 2013).

Heavy rainfall (HR), tea garden, dense bamboo and cane bushes, high flood plain and the flashy rivers- all the features are very related and contributed by the hills of this region (Islam *et al.*, 2005). Haor basin extends from two rivers to the high plain of central Sylhet. The basin generally goes under water for several months during monsoon. The flood plain is higher at this region than the rest of the part of the country (Islam *et al.*, 2005). The networks of the rivers, streams and channels overflow during the monsoon and fill the haors. Any change of the hydro-climatic pattern in this region significantly affects the balance among these natural resources of the NE-BD. Mannan *et al.* (2015) studied on the aspect of rainfall prediction over northeastern part of Bangladesh during monsoon season but it was not sufficient. Similarly, some studies are conducted on the monsoon rainfall (Ahasan *et al.*, 2010; Islam *et al.*, 2005; Mannan and Karmakar, 2008; Mannan *et al.*, 2013, 2014, 2015, 2016 and 2017; Rahman *et al.*, 1997; Rafiuddin *et al.*, 2010; Shahid, 2009) but very limited studies are conducted on prediction of heavy rainfall over NE-BD. Hence, a comprehensive understanding of the rainfall variability and rainfall prediction over this region is greatly needed. As such, the present study focuses mainly on the variability of the monsoon rainfall and extreme rainfall (as measured through 95th and 99th percentiles of monsoon rainfall) over NE-BD. The aim of this study is to predict the HR events with the amounts of rainfall in a specific location over NE-BD.

DATA USED AND METHODOLOGY

As of now there are two observatories at Sylhet (24.90°N and 91.88°E) and Srimangal (24.30°N and 91.73°E) under Bangladesh Meteorological Department (BMD) over NE-BD from where regular observations have been conducted. To know the variability and trend of monsoon rainfall over NE-BD, recorded rainfall from these stations for the period of 1981-2016 are used.

The 95th and 99th percentiles of rainfall days can be defined as 'heavy' and 'very heavy' rainfall days or events (Groisman *et al.*, 2001). As such 95th and 99th percentiles of rainfall for each station during each of the monsoon season of 1981-2016 are calculated and analyzed. Linear and Mann-Kendall trends are calculated to see the variability over the time. To fulfill the aim of this study 44 HR events (≥44 mm/24 hour) are selected based on the records available at Sylhet (Table 1) during monsoon season of 2005-2014. All of these 44 events are simulated using WRF-ARW model (version 3.5.1) with the detailed configuration given in Table 2. Analysis of results is based on this version of the model. For further understanding, WRF-ARW model (version 3.8) is utilized for simulating the events recorded during 2014 as given in Table 1.

Table-1: Records of Significant Heavy Rainfall at Sylhet in Monsoon Season of 2005-2014

Sl No	Dates	Rainfall at Sylhet (mm)	Sl No	Dates	Rainfall at Sylhet (mm)
1	17 July 2005	95	23	10 June 2010	90
2	18 July 2005	166	24	28 June 2010	108
3	18 August 2005	103	25	13 August 2010	138
4	27 August 2005	107	26	24 September 2010	128
5	10 June 2006	122	27	10 June 2011	131
6	11 June 2006	98	28	23 June 2011	92
7	12 June 2006	144	29	30 June 2011	141
8	13 June 2006	136	30	09 July 2011	110
9	21 June 2006	112	31	09 August 2011	122
10	27 June 2006	168	32	14 September 2011	113
11	08 July 2006	113	33	12 June 2012	124
12	16 June 2007	146	34	13 June 2012	91
13	17 June 2007	152	35	17 July 2012	114
14	25 July 2007	106	36	20 July 2012	93
15	31 July 2007	195	37	21 August 2012	106
16	08 September 2007	109	38	07 June 2013	109
17	09 September 2007	144	39	08 June 2013	154
18	04 June 2008	105	40	13 June 2013	131
19	05 July 2008	137	41	09 June 2014	138
20	03 August 2008	97	42	07 August 2014	94
21	05 August 2009	117	43	23 August 2014	100
22	21 September 2009	101	44	06 September 2014	94

Details of model configuration of the experiment are given in Table 2. Analysis of results is based on WRF-ARW model (version 3.8) with the configuration as given in Table 3. The parameters like sea level pressure, surface and upper levels wind, vorticity, convective available potential energy (CAPE), relative humidity, convective and non-convective rain are extracted. These parameters are analyzed and compared with the observations.

Table-2: Overview of WRF Model (version 3.5.1) Configurations

Domain and Dynamics	WRF core	ARW
	Data	NCEP FNL
	Input data interval	6 hour
	Number of domain	1
	Domain central point	22.0°N, 87.5°E
	Resolution	9 km
	Covered area	16.6° to 30.9° N & 79.4° to 95.6° E
	Map projection	Mercator
	Integration time step	60s
	Vertical coordinates	Pressure coordinate
	Time integration scheme	3rd order Runge-Kutta
	Spatial differencing scheme	6th order centered difference
Physics	Microphysics	Kessler scheme
	PBL Parameterization	Yonsei University (YSU) scheme
	Surface layer physics	Revised MM5 scheme
	Land-surface model	Unified Noah LSM
	Short wave radiation	Dudhia scheme
	Long wave radiation	RRTM scheme
	Cumulus parameterization	Kain–Fritsch (new Eta) scheme

RESULTS AND DISCUSSION

Variability of Monsoon Rainfall and Number of Heavy Rainfall

There are two observatories of Sylhet and Srimangal under Bangladesh Meteorological Department (BMD) over NE-BD from where regular observation has been conducted. As per the record, NE-BD is vulnerable for high monsoon rainfall with HR activity. Analysis reveals that the average amounts of monsoon rainfall during 1981-2016 at Sylhet and Srimangal are 2717.3 and 1328.9 mm and their standard deviations are 482.9 and 230.6 mm. Similarly, the number of HREs at Sylhet and Srimangal are 18.7 and 7.8 and their standard deviations are 5.1 mm and 2.4 mm respectively. The linear trends of monsoon rainfall at Sylhet and Srimangal indicate decreasing trends of -15.2 mm/year and -0.5 mm/year. Similarly, there are decreasing trends of the number of HR at Sylhet and Srimangal. Mann-Kendal test also shows decreasing trends monsoon rainfall at -13.5 mm/year at Sylhet, which is statistically significant (Fig. 1) and at -1.3 mm/year at Srimangal.

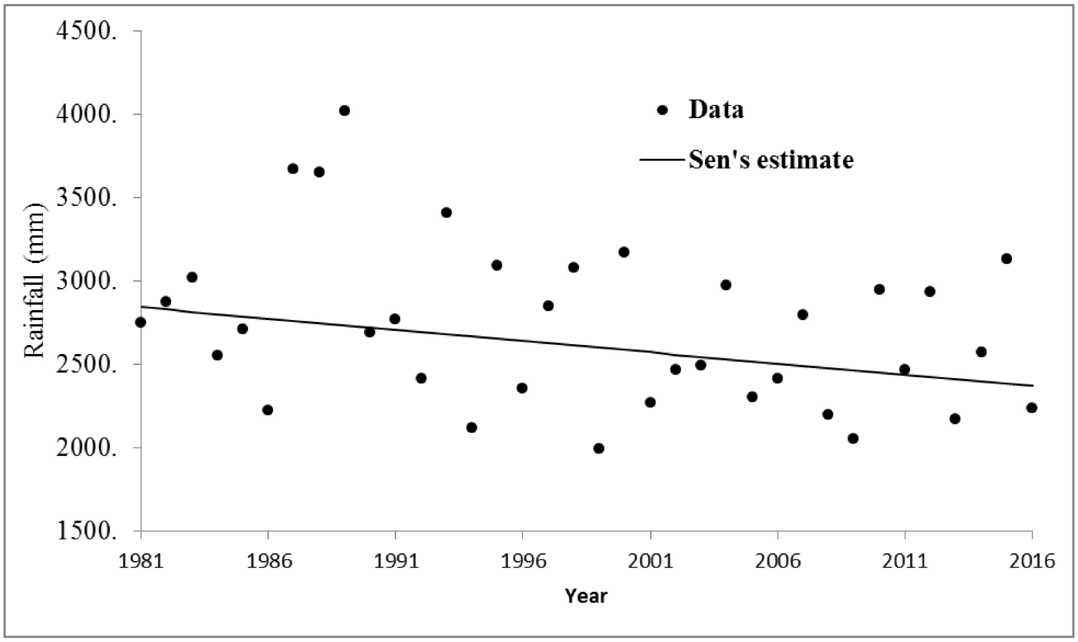

Fig. 1: Temporal Variation and Trend of Monsoon Rainfall (mm) at Sylhet During 1981-2016

Trends of 95th and 99th Percentiles of Rainfall During Monsoon Season

The 95th and 99th percentiles of rainfall during monsoon season of 1981-2016 at Srimangal are 49.0 and 90.0 mm and their STDs are 9.5 and 20.2 mm respectively. Their trends are negative as depicted in Fig. 2a.

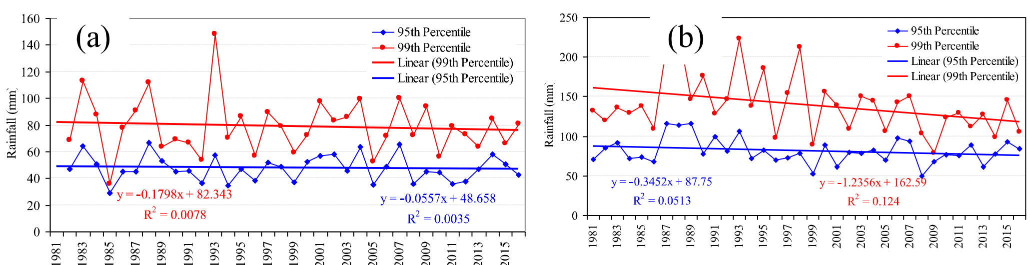

Fig. 2: Temporal Variation of 95th and 99th Percentiles of Rainfall for (a) Srimangal and (b) Sylhet During Monsoon Season of 1981-2016

Similarly, the 95th and 99th percentiles of rainfall during monsoon season at Sylhet are 85.0 and 148.0 mm and their STDs are 16.7 and 39.1 mm respectively. The trends of 95th and 99th percentiles of rainfall at Sylhet are also negative during 1981-2016 (Fig. 2b) as it has been found at Srimangal.

Synoptic Condition During the Days of Heavy Rainfall

Analysis of synoptic pattern associated with 44 rainfall events (Table 1) reveals that wind discontinuity or convergence over Bangladesh territory with the facility of the accumulation of moisture over NE-BD from the Bay of Bengal is the common feature associated with HR events occurred over NE-BD. As per the simulation, presence of notable synoptic patterns or systems are- (i) an induced low over Sub-Himalayan West Bengal and adjoining northwestern part of Bangladesh, (ii) an induced low over northwestern part of Bangladesh, (iii) west to east directional pressure trough extended from West Bengal to central part of Bangladesh, (iv) low over North Bay or Northwest Bay of Bengal and adjoining coastal areas of Bangladesh, (v) low over central part of Bangladesh and (vi) northwest to southeast directional monsoon pressure trough over Bangladesh as shown in Fig. 3.

Vorticity

Due to position of the surface synoptic systems as indicated in Fig. 3, there are south, southeasterly or easterly flow over NE-BD during the days of HR which has been accelerating upward by high topography over this region and creates positive vorticity. It has been found that the magnitude of the vorticity increases with the increment of height (Fig. 4). This situation is responsible for carrying sufficient moisture upward as a gradient for the HR.

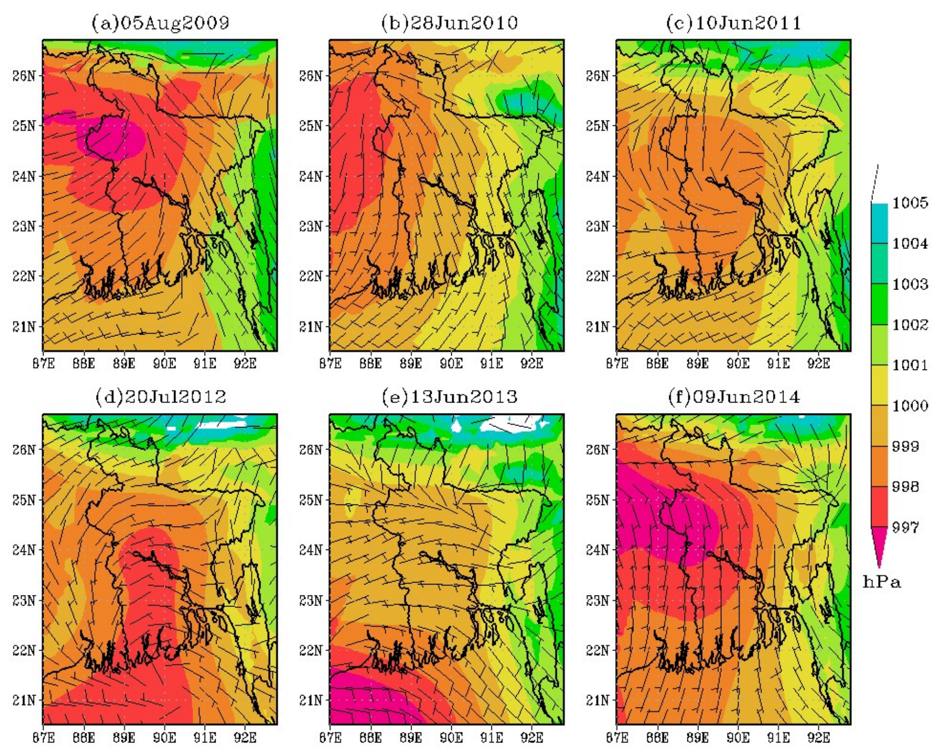

Fig. 3: Surface Atmospheric Conditions (MSLP and Surface Wind) at 0000UTC of the days of Heavy Rainfall in Bangladesh

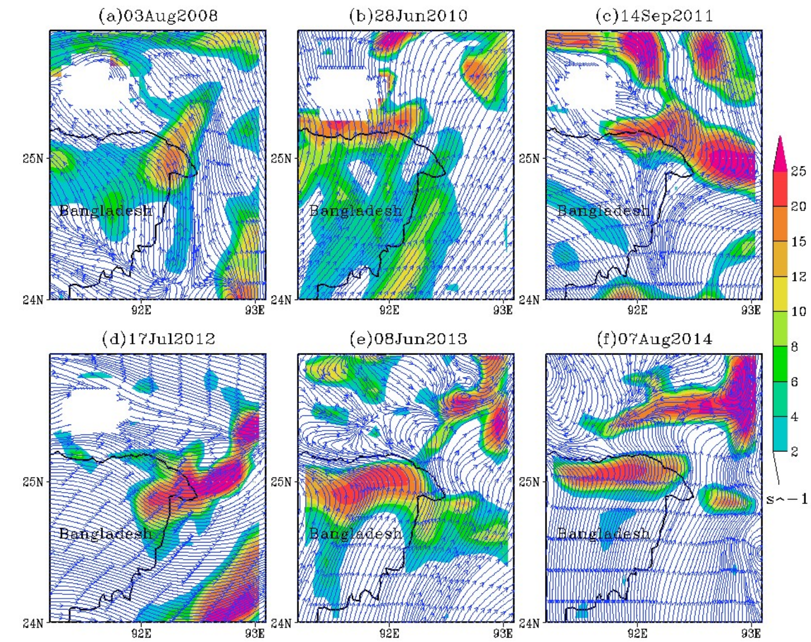

Fig. 4: Atmospheric Flow and Vorticity (x10^{-5} s^{-1}) Field at 850 hPa Level During the Days of Heavy Rainfall over NE-BD and Adjoining Areas

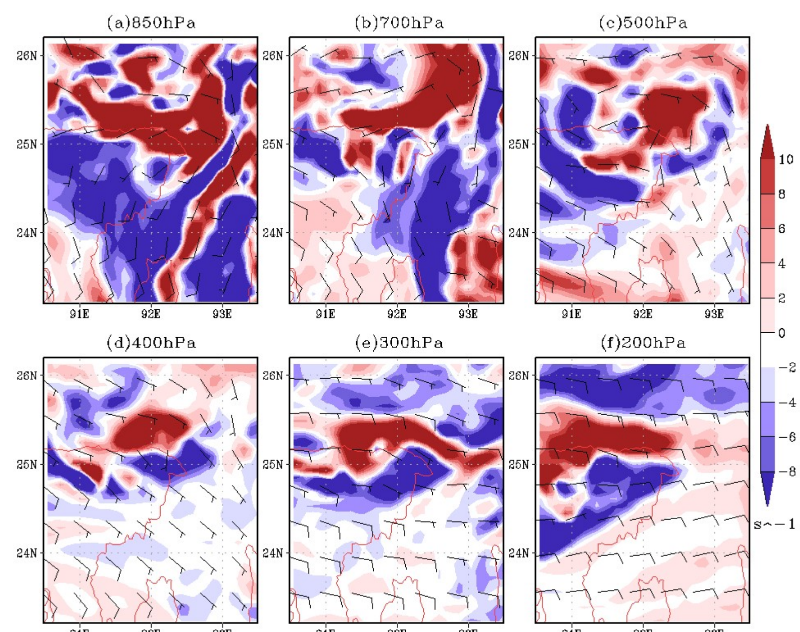

Fig. 5: Vorticity (x10^{-5} s^{-1}) Field at Different Vertical Levels Over NE-BD and Adjoining Areas on 06 September 2014

During the days of heavy rainfall weak, positive vorticity fields are detected to generate at surface level over or near the convergence zone of northwestern and central parts of Bangladesh, which then shifted eastward to NE-BD and adjoining areas. The vorticity fields are enhanced by the high topography located over the surrounding areas of NE-BD. This weak vorticity is found to be strengthening over NE-BD and adjoining areas. But the strength of the vorticity fields is found to be enhanced with height over or near NE-BD. In addition, the zones of negative and positive vorticity are found side by side, which becomes stronger towards the upper tropospheric levels as maximum as upto 200 hPa level. This situation indicates the existence of upward motion along the positive vorticity zones and downward motion along the negative vorticity zones. Upward motion is responsible for creation of unstable atmosphere and carrying moisture to upper tropospheric levels for formation of convective cloud for the occurrence of HR (Fig. 5).

Convective Available Potential Energy (CAPE)

Generation of CAPE is the indication of the unstable atmosphere. Strong CAPE is found to be generated in the lower troposphere over northwestern and central parts of Bangladesh first in the early hours of the day. Zone of strong CAPE is found to extend or move to NE-BD and adjoining areas afterwards due to high topography located surrounding this area well ahead of the occurrence of the events. Similarly, during the presence of Bay originated system, strong CAPE is found to expand from south to NE-BD first and then intensified over NE-BD and adjoining areas before the occurrence of the event (Fig. 6).

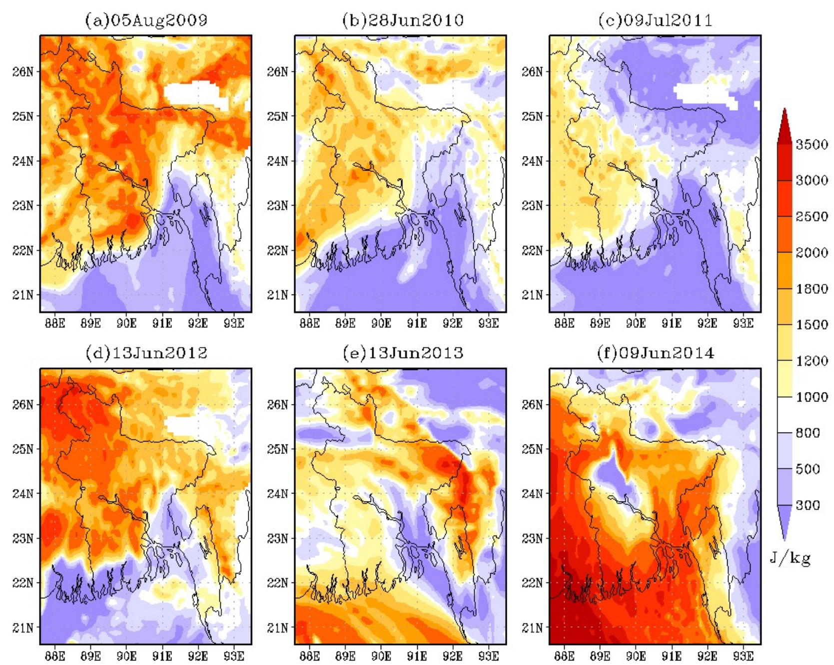

Fig. 6: CAPE at 925 hPa Level on (a) 05 August 2009, (b) 28 June 2010, (c) 09 July 2011, (d) 13 June 2012, (e) 13 June 2013 and (f) 09 June 2014

Relative Humidity

Analysis reveals that the responsible synoptic systems are having facility to carry high amounts moisture due to favourable wind fields. The synoptic patterns are found to move eastward with the progress of time and carry moisture finally to NE-BD and adjoining area. Similarly, due to presence and movement of the other synoptic patterns, strong moisture band are found to move towards NE-BD. Due to the presence of favourable wind fields and convergence field, sufficient moisture is found to accumulate over NE-BD during the days of HR which has been transported upward because of the positive vorticity condition. In this context, sufficient moisture is found to lift upto 400 hPa in some cases (Fig. 7). Availability of sufficient moisture or expressed as RH before incident of the events is found to play vital role for the occurrence of HREs.

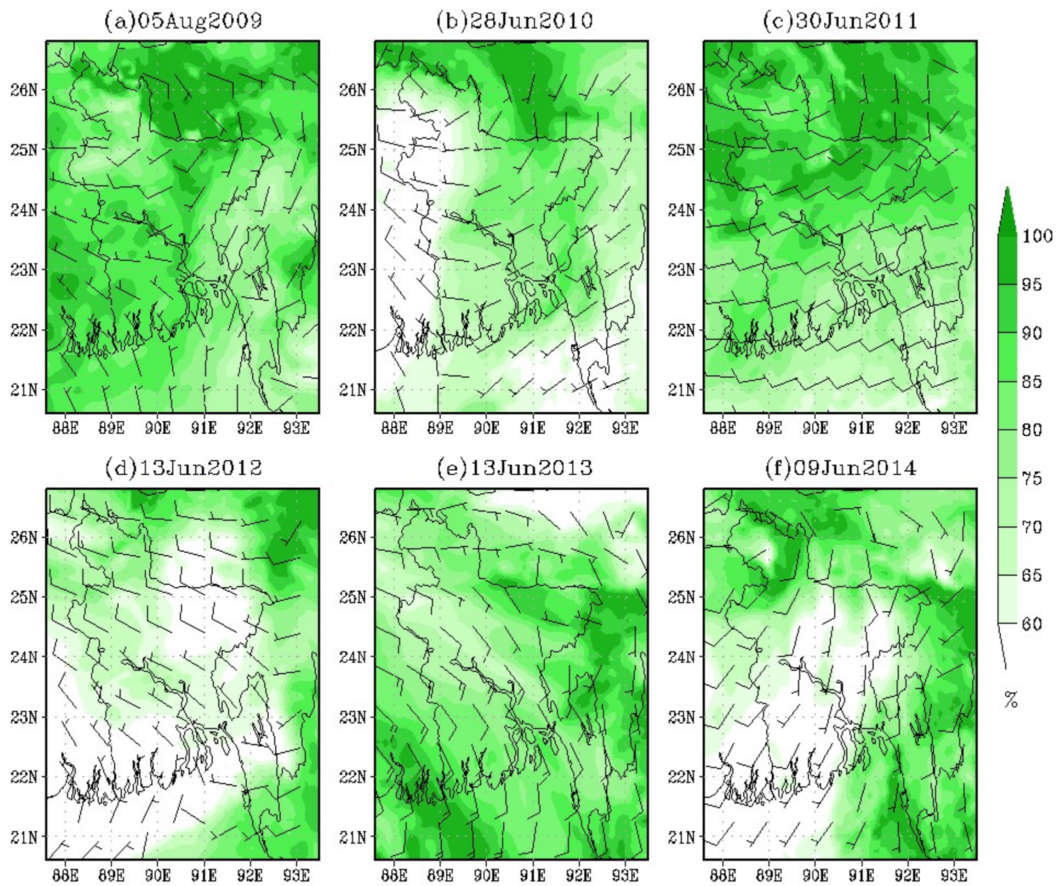

Fig. 7: RH at 700 hPa Level on (a) 05 August 2009, (b) 28 June 2010, (c) 09 July 2011, (d) 13 June 2012, (e) 13 June 2013 and (f) 09 June 2014

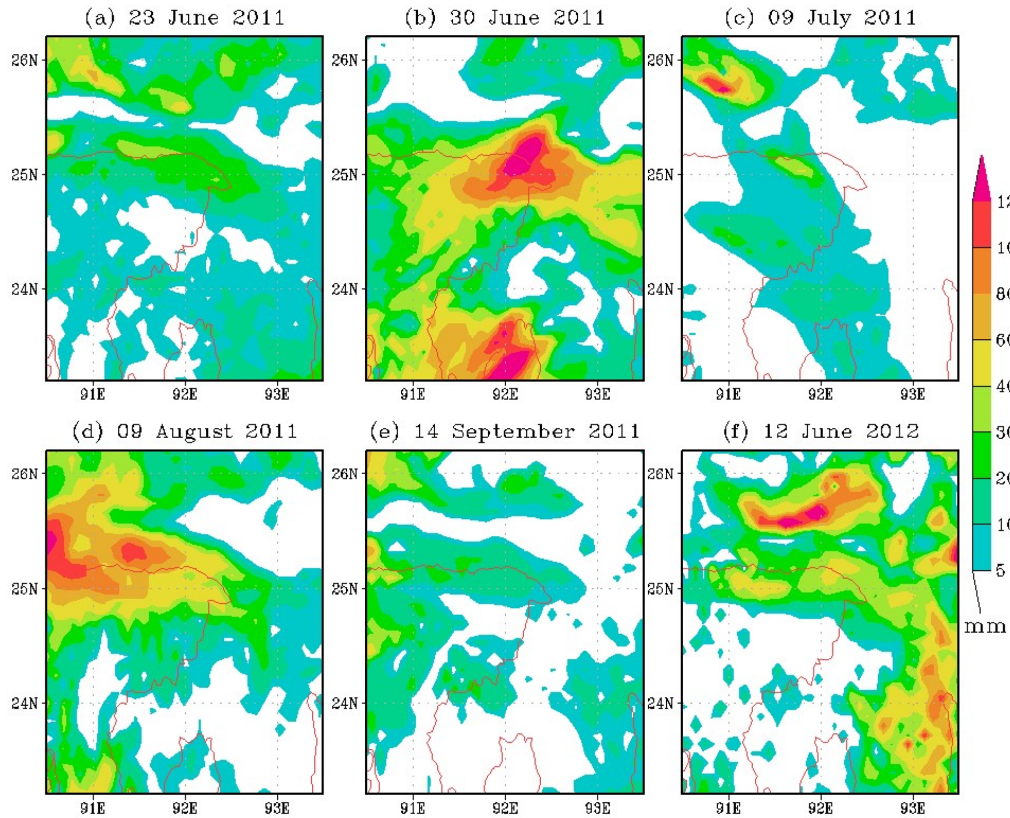

Fig. 8: Simulated Rainfall on the Days of HR over NE-BD and Adjoining Areas During 2011-2012

Prediction of Heavy Rainfall Over Northeastern Part of Bangladesh

Model simulates high amounts of rainfall over Sylhet region for maximum number of days; model simulates HR near to Sylhet region for a few numbers of cases but it simulates HR at a place which is quite far away from Sylhet for a few cases. Out of the selected 44 events, model could not simulate HR for two cases whereas HR is recoded at Sylhet on these dates. Statistically, 47% HR events are simulated over Sylhet, 28% events are simulated near to Sylhet, 19% events are simulated far away from Sylhet by the model. Model fails to simulate HR in 5% events (Fig. 8).

Simulation using WRF-ARW Model with Nested Domain

For further analysis, selected events of 2014 are simulated with nested domain by using WRF-ARW Model (version 3.8). Model depicts similar result and it is found that model could not simulate HR at Sylhet well for three events of 2014 but it could capture HR event occurred on 23 August 2014 and the amount of rainfall is much lower than observation (Table 3).

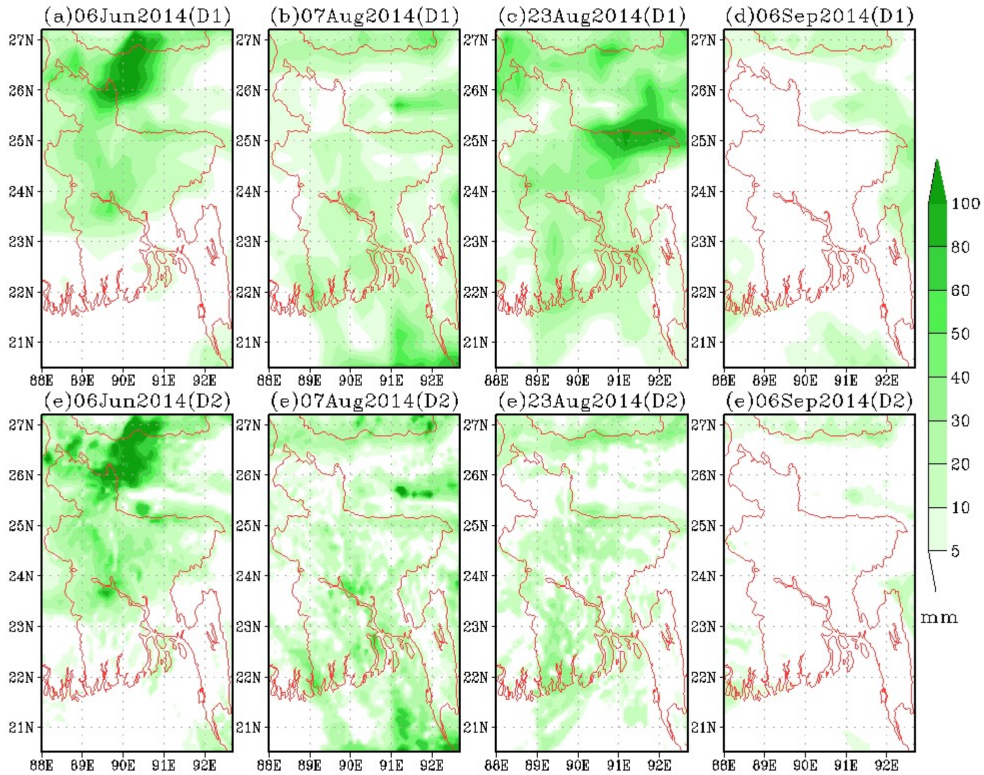

Fig. 9: Simulated Rainfall (mm) of Four Selected Events during 2014 (D1 Indicates Outer Domain and D2 Indicates Inner Domain)

Table-3: Comparison of Simulated Rainfall (mm) at Sylhet with Observation During the Selected Dates of 2014

Parameter	Dates			
	09 June 2014	07 August 2014	23 August 2014	06 September 2014
Observation	138.0	94.0	100.0	94.0
Model rainfall (Ver: 3.5.1)	48.7	14.3	65.1	0.0
Model rainfall (Ver: 3.8, D1)	0.1	16.1	76.8	0.1
Model rainfall (Ver: 3.8, D2)	0.1	8.0	71.3	0.0

To detect one of the most suitable option of WRF Model (Version: 3.8) for simulating the event recorded on 23 August 2014, combinations of different CP and MP are used. In this regard, eight combinations are chosen and defined as Case-I (Betts-Miller-Jangic and WSM3), Case-II (Grell-Freitas and WSM3), Case-III (Simplified Arakawa-Schubart and WSM3), Case-IV (Grell-3 and WSM3), Case-V (KF-CuP and WSM3), Case-VI (Multi-scale

KF and WSM3), Case-VII (New Tiedke and WSM3) and Case-VIII (KF-CuP and WSM6). Simulated rainfalls for these combinations are shown in Fig. 10. Comparison of the simulated rainfalls at Sylhet is given in Table 4. It is found that the simulated rainfall for Case-VII is the most closest to observation.

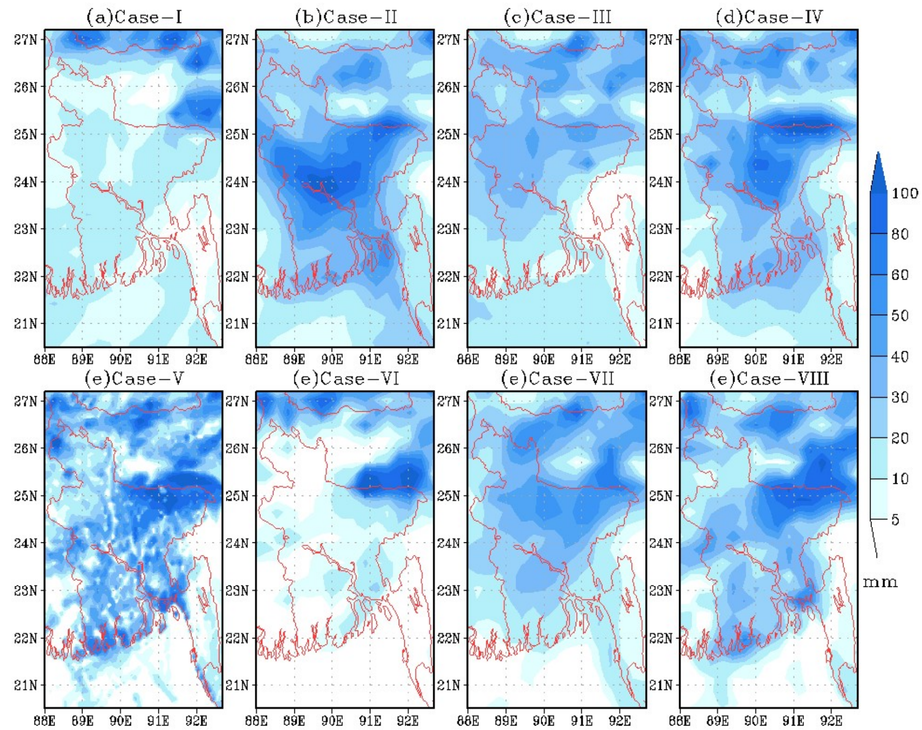

Fig. 10: Simulated Rainfall (mm) of 23 August 2014 for Different CPs and MPs

Table 4: Comparison of Simulated Rainfall (mm) for Different Groups of CP and MP at Sylhet with Observation

Date	**Observed Rainfall**	**Model rainfall (mm) for different cases**									
		Case-1	**Case-II**	**Case-III**	**Case-IV**	**Case-V**	**Case-VI**	**Case-VII**	**Case-VIII**	**Case-IX**	**Case-X**
23 August 2014	100.0	65.1	10.1	39.7	34.1	61.4	8.9	83.7	40.5	45.6	74.2

CONCLUSIONS

From this investigation the following conclusions may be drawn:

(i) The linear trends of monsoon rainfall at Sylhet and Srimangal are -15.2 mm/year and -0.5 mm/year respectively. Number of HR at these places depicts decreasing trends during 1981-2016. Mann-Kendal test also shows decreasing trends of monsoon rainfall at -13.5 mm/year at Sylhet, which is statistically significant and at -1.3 mm/year at Srimangal.

(ii) The 95th and 99th percentiles of monsoon rainfall of 1981-2016 at Srimangal are 49.0 and 90.0 mm, at Sylhet are 85.0 and 148.0 mm and their trends are negative.

(iii) Based on the simulation, six synoptic patterns are found responsible for the occurrence of HR over NE-BD.

(iv) Low level positive vorticity are found to generate over NE-BD and its surrounding areas during the days of HR which has been accelerating moisture upward by high topography over this region. The magnitude of the vorticity is found to increase with height. This situation is responsible for carrying sufficient moisture upward as a gradient for the HR.

(v) Strong CAPE is found to extend from west or south to NE-BD first and then intensify due to high topography of the surrounding of this area.

(vi) Due to the presence of favourable wind field and convergence field, sufficient moisture is found to accumulate over NE-BD during the days of HR which has been transported upward because of the existence of positive vorticity. Sufficient moisture is found to lift up to 400 hPa and in some cases it is above of this level. Availability of sufficient moisture has played vital role for the occurrence of HR.

(vii) Model shows strong predictability of HR over NE-BD but it shows weak predictability of simulating location specific HR. Accordingly, 47% HR events are simulated over Sylhet, 28% events are simulated near to Sylhet, 19% events are simulated far away from Sylhet. Model fails to simulate 5% HR events.

(viii) WRF model (version 3.8) shows superior performance than the earlier version for the prediction of location specific rainfall amount. In addition, combination of New Tiedke and WSM3 shows the highest performance of location specific rainfall prediction for particular event.

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