International Journal
of
Integrated Sciences & Technology (IJIST)

http://www.cuet.ac.bd/IJIST/index.html

International Journal of Integrated Sciences & Technology **1** (2015) 9-26

Study of Heavy Rainfall over Northwestern part of Bangladesh and its prediction using NWP Technique

M. A. Mannan[1,2*], M. A. M. Chowdhury[3] and S. Karmakar[4]

[1]*SAARC Meteorological Research Centre (SMRC), E-4/C, Agargaon, Dhaka-1207, Bangladesh*

[2]*Bangladesh Meteorological Department, Agargaon, Dhaka-1207, Bangladesh*

E-mail: mannan_u2003@yahoo.co.in

[3]*Department of Physics, Jahangirnagar University, Savar, Dhaka, Bangladesh*

[4]*Bangladesh Centre for Advanced Studies (BCAS), Dhaka, Bangladesh,*

Abstract

Daily rainfall data of Bogra, Dinajpur and Rangpur during 1 June to 30 September of 1980-2012 are collected from BMD and analyze for understanding the variability of monthly and seasonal rainfall, rainy days, frequency of monthly and seasonal rainfall with different categories namely Cat-I, Cat-II, Cat-III, Cat-IV, Cat-V, Cat-VI, Cat-VII, Cat-VIII, Cat-IX and Cat-X over northwestern part of Bangladesh. It is found that the monthly rainfall and the frequency of rainy days are the highest in July. The tendency of rainfall in July is -5.39 mm/year is only at 90% level of significance. The tendency of the frequency of rainy days in September is -0.11/year which is also at 90% level of significance. The trends of rainfall and number of rainy days in monsoon season are -0.523 mm/year and -0.129 day/year. The frequencies of Cat-I, Cat-II, Cat-III, Cat-IV, Cat-V, Cat-VI, Cat-VII, Cat-VIII, Cat-IX and Cat-X rainfalls are 35.9, 14.5, 10.8, 7.0, 2.6, 52.5, 10.5, 4.2, 1.7 and 1.9 respectively and their trends are +0.050, -0.008, -0.076, -0.022, -0.029, -0.024, -0.053, -0.015, -0.015 and -0.021/year respectively. But the trend of the frequency of Cat-III is only at 90% level of significance. Simulated result using WRF model depicts that the low level convergence with strong CAPE and vorticity fields over West Bengal of India and adjoining western part of Bangladesh is mainly responsible for the occurrence of heavy rainfall recorded at Dinajpur and Sayedpur of Bangladesh during 5 July 2012. Lin et al. (LN) microphysics with Kain-Fritsch (KF) cumulus parameterization scheme defined as KFLN is the most suitable for simulation of this event. The maximum prediction skills of PoD, FAR, PEC, FBI and CSI are 0.37, 0.54, 0.31, 0.70 and 0.28 respectively for Cat-III rainfall and are 0.31, 0.31, 0.31, 1.0 and 0.18 respectively for Cat-IV rainfall at rain gauge locations.

Keywords: Heavy rainfall; Monsoon; Numerical Weather Prediction; Rainy days and Variability.

1. Introduction

Bangladesh is a play-ground of natural calamities due to its geographical position, i.e., conical shaped Bay of Bengal in the south, the Himalayas in the north and passing of tropic of cancer through Bangladesh. Bangladesh experiences the meteorological disasters like tropical cyclones and their associated storm surges, monsoon depressions, floods, droughts, nor'westers, tornadoes, heavy rainfall etc. causing heavy loss of lives and damages to properties. The life-giving rain comes due to southwest monsoon which accounts for over 75% of the total annual rainfall. But most of the heavy rainfall events occur in Bangladesh during monsoon months and the northeastern, eastern and southeastern regions of the country are most susceptible for this meteorological phenomenon. Heavy rainfall is rare event over northwestern part of Bangladesh.

Earlier studies pointed out that the tropical and sub-tropical coastal regions of Asia, especially adjacent to prominent terrain features, episodes of heavy rainfall exceeding 100 mm/ day occur rather frequently and events of 300 mm/day or more are occasionally observed [1-3]. While tropical cyclones account for many of these events, others occur in conjunction with monsoon horizontal wind regimes [3]. Despite the synoptic-scale character of the monsoon, numerous local effects ultimately conspire to determine the location of heavy rainfall. Because of a general lack of meso-scale observations of lower-tropospheric wind, temperature and water vapor. It is challenging to document the meso-scale

* Corresponding author. Mobile: +88-01191177004
E-mail: mannan_u2003@yahoo.co.in (M. A. Mannan)
For color version visit:http://www.cuet.ac.bd/IJIST/index.html

ISSN : 0000-0000

processes in such regions, but such processes determine the all-important location of heavy rainfall and its societal consequences. Dhar and Nandargi [4] have found that severe rainstorms i.e., heavy rainfall over Indian region do not occur uniformly and most of the rainstorms are caused due to low pressure systems (LPS) which include low, depression, deep depression and cyclonic storm. Orography plays a significant role on intensity and distribution of heavy rainfall. Smith [5] has suggested the three independent mechanisms of orographic rainfall, viz. (i) large scale slope precipitation due to orographically forced vertical motion or convection triggered by smooth orographic ascent bringing the air to saturation resulting in precipitation, (ii) rainfall from the pre-existing clouds is partially evaporated before hitting low ground and (iii) the rainfall due to orographic control of the formation of cumulonimbus clouds in a conditionally unstable air mass. However, Dubey and Balakrishnan [6] have studied the frequency distribution of heavy rainfall days over different parts of India and the causative systems of these heavy rainfall events. Rakhecha and Pisharoty [7] have studied on point and spatial distribution of heavy rainfall over India during monsoon season. Dhar and Mhaiskar [8] have studied also on point and spatial distribution of rainfall over India in association with depression/ storm and found the occurrence of intense rainfall to the south of the monsoon trough extending from the centre of depression/ storm. Heavy rainfall in particular over Bangladesh is predominantly determined by the interaction of basic monsoon flow with the orography [9]. In addition, induced low pressure system within monsoon trough is one of the major causes for low level convection and heavy rainfall over Bangladesh and adjoining areas [10].

As per the record of Bangladesh Meteorological Department (BMD), heavy rainfalls (HRs) are recorded over northwestern part of Bangladesh and adjoining areas on 5 July 2012. As the prediction skill of this meteorological event is still insufficient it demands further study. The present study comprehensively examines the environmental conditions associated with this event. Accordingly, the variability of heavy rainfall (HR) over northwestern part of Bangladesh is studied and Weather Research and Forecasting (WRF) model simulated parameters are investigated. It is believed that the present study will greatly contribute to understand and forecasting of HR that occur rarely over northwestern part of Bangladesh.

1.1 Description of the event

During 5 July 2012 high amounts of rainfall are recorded over the northwestern part of Bangladesh. The significant amounts of rainfall of 247, 172 and 82 mm are recorded respectively at Dinajpur, Sayedpur and Rangpur. Widespread light to moderate rainfalls are also recorded at other places of Bangladesh. TRMM products of version 6 and 7 (hereafter referred as TRMMV6 and TRMMV7) have also the signature of high amounts of rainfall over the northwestern part of Bangladesh (Fig. 1).

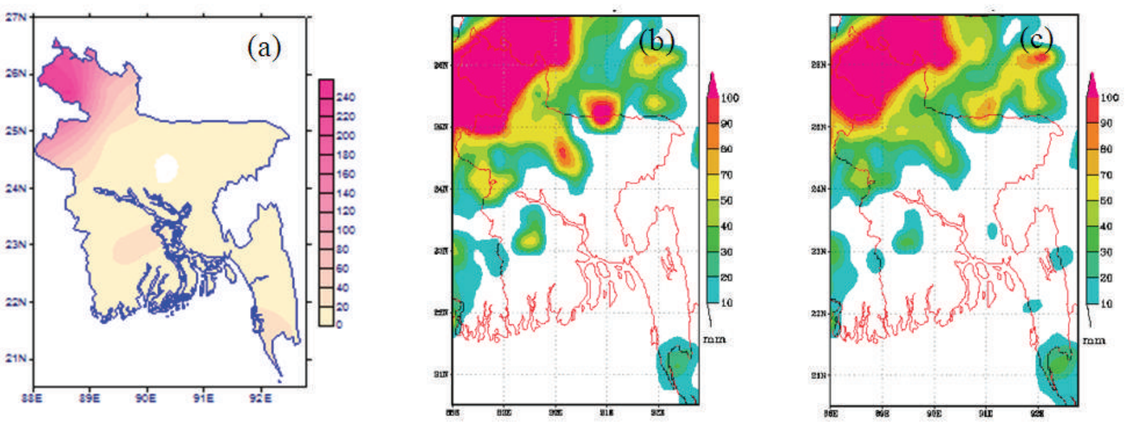

Fig. 1. Distribution of (a) observed, (b) TRMMV6 and (c) TRMMV7 rainfall over Bangladesh during 5 June 2012

2. Methodology

The rain gauge stations of Bogra, Dinajpur, Rangpur and Sayedpur are located for recording rainfall over the northeastern part of Bangladesh under Bangladesh Meteorological Department (BMD). But the stations of Bogra, Dinajpur and Rangpur are having longer and continuous records of rainfall. In this regard, daily rainfall data of these three stations during 1 June to 30 September of 1980-2012 are collected from BMD and used in this study for calculating the monthly rainfall, monthly rainy days, frequency of monthly and seasonal heavy rainfall for different category and their mean values and standard deviations (STD) over these locations as well as over the northwestern part of Bangladesh (averaged over these three stations) as per the criteria given in Table 1.

Intensity (mm/day)	Category of rainfall	Defined as	Comments
Non-measurable amount	Trace	-	Operationally used classification in Bangladesh
1 - 10	Category-I	Cat-I	
11 - 22	Category-II	Cat-II	
23 - 43	Category-III	Cat-III	
44 - 88	Category-IV	Cat-IV	
≥ 89	Category-V	Cat-V	Classification for the interest of better explanation
≤ 25	Category-VI	Cat-VI	
26-50	Category-VII	Cat-VII	
51-75	Category-VIII	Cat-VIII	
76-100	Category-IX	Cat-IX	
> 100	Category-X	Cat-X	

The significance of the trends has been studied with the help of F-distribution test given in equation 1 [12].

$$F = \frac{R^2(n-k)}{(k-1)(1-R^2)} \tag{1}$$

Where, n is the number of pairs of data, (n-k) is the degrees of freedom and R^2 is the co-efficient of determination.

In addition, NCEP reanalysis data with the resolution of 1°x1° has been collected and used to extract the synoptic scale feature over Bangladesh and adjoining areas on 5 July 2012. Advanced Research WRF (WRF-ARW) model (version 3.2.1) with the grid resolution of 9 km is used to diagnosis the event using Ferrier (FR), Kessler (KS), Lin et al. (LN), WRF Single-Moment 5 Class (WSM5), WRF Single-Moment 6 Class (WSM6) and Thompson Graupel (TH) microphysics (MPs) schemes with the combination of Betts-Miller-Janjic (BMJ), Grell-Devenyi ensamble (GD), Kain-Fritsch (KF) and New Grell (NG) cumulus scheme (CPs). Therefore, the 24 combinations of MPs and CPs are- BMJFR, BMJKS, BMJLN, BMJTH, BMJWSM5, BMJWSM6, GDFR, GDKS, GDLN, GDTH, GDWSM5, GDWSM6, KFFR, KFKS, KFLN, KFTH, KFWSM5, KFWSM6, NGFR, NGKS, NGLN, NGTH, NGWSM5 and NGWSM6. The coverage area of the model domain is 12-30ºN and 80-100ºE. The topographic data used in the model is obtained from USGS land covers data set. NCEP data have been provided at every 6 hours as initial and boundary conditions. The model has been run with 19 sigma levels in the vertical direction from the ground to the 100 hPa level to simulate the event. Sea level pressure (SLP), relative humidity (RH), wind at 10 m, u and v-components of upper wind, vorticity, divergence, CAPE, convective and non-convective rain are extracted on hourly basis for analysis using GrADS. The observed rainfall has been converted into grid data set with the resolution of 0.5° x 0.5° and compared with the simulated rainfall at same locations. The forecast skills of Probability of Detection (PoD), False Alarm Ratio (FAR), Percentage Correct (PEC), Frequency Bias (FBI) and Critical Success Index (CSI) are calculated [13] for Cat-III and Cat-IV rainfall at rain gauge locations for all of the experiments using Table 2 [14] and the equations 2-6 [15].

Table 2. Contingency table [14]

		Observation		
		Yes	No	Total
Forecast	Yes	Hits (A)	False alarms (B)	Forecast Yes (A+B)
	No	Misses (C)	Correct non-events (D)	Forecast No (C+D)
	Total	Observed Yes (A+C)	Observed No (B+D)	Total (A+B+C+D)

Where, the sum of these frequencies represents the total number of the forecast-observation pairs N=A+B+C+D)

$$POD = \frac{Hits}{Hits + Misses} = \frac{A}{A+C} \quad (2)$$

$$FAR = \frac{False\ Alarms}{Hits + False\ Alarms} = \frac{B}{A+B} \quad (3)$$

$$PEC = \frac{A+D}{A+B+C+D} = \frac{A+D}{N} \quad (4)$$

$$FBI = \frac{A+B}{A+C} \quad (5)$$

$$CSI = \frac{A}{A+B+C} \quad (6)$$

3. Results and Discussion

3.1 Variability of rainfall, rainy days and frequency of rainfall over northwestern part of Bangladesh

3.1.1 Variability of monthly rainfall and rainy days

The amount of rainfall among the monsoon months over northwestern part of Bangladesh is the highest in July and then in June and lowest in August. The variability of monthly rainfall is also the highest in July but lowest in June (Fig. 2a).

The tendency of rainfall in June, July, August and September are +1.57, -5.39, -0.73 and -3.21 mm/year respectively (Fig. 3). But the tendency of July rainfall is at 90% level of significance. Following the monthly monsoon rainfall, the frequency of rainy days is the highest in July and then in June but lowest in September during the observed period (Fig. 2b). The tendency of rainy days in June, July, August and September are +0.08, -0.07, -0.03 and -0.11/ year respectively (Fig. 4). The tendency of rainy days in September is also at 90% level of significance.

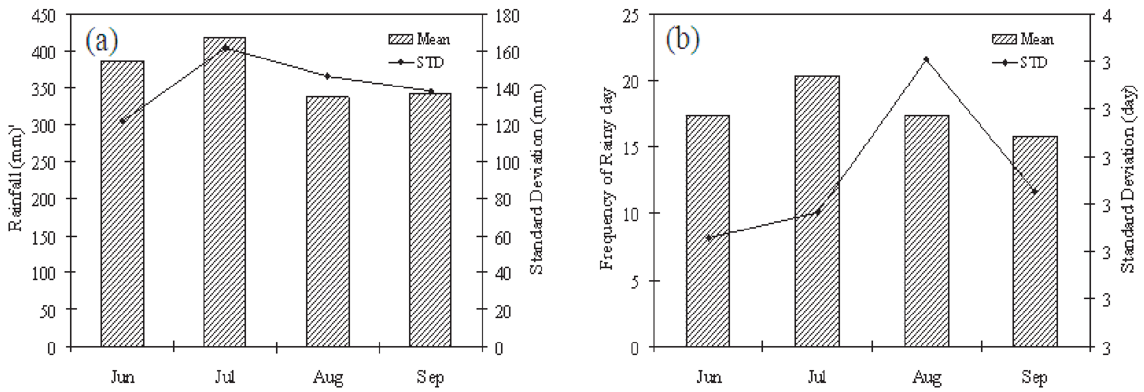

Fig. 2. Distribution of (a) monthly rainfall and (b) monthly rainy days over northwestern part of Bangladesh during 1980-2012

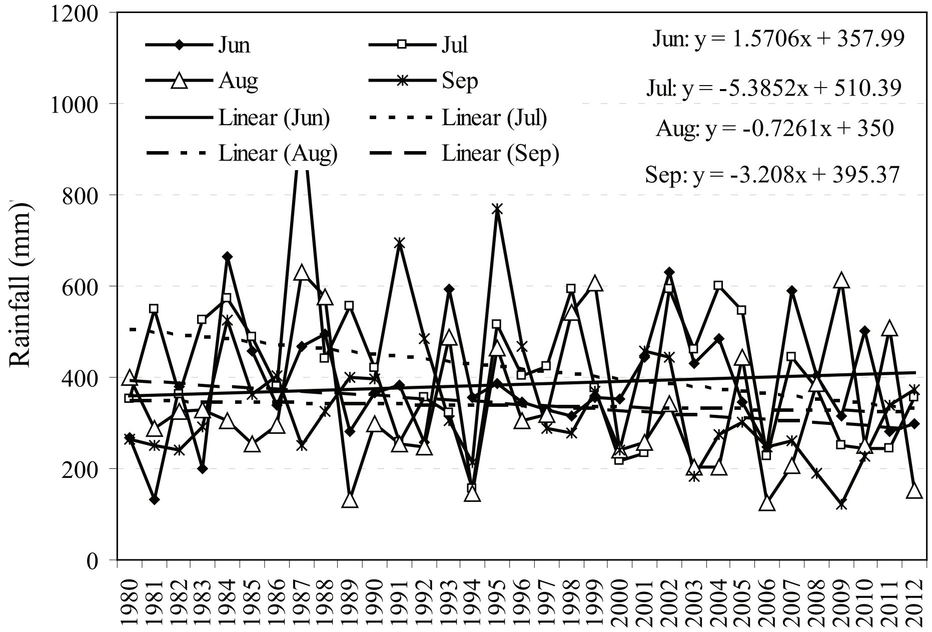

Fig. 3. Temporal variation of monthly rainfall over northwestern part of Bangladesh during monsoon season of 1980-2012

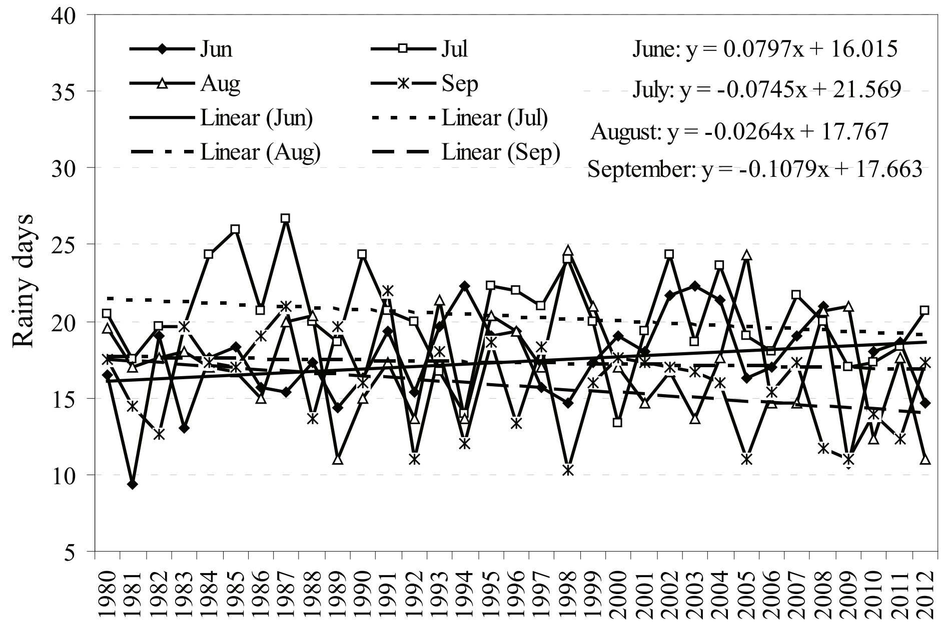

Fig. 4. Temporal variation of monthly rainy days over northwestern part of Bangladesh during monsoon season of 1980-2012

3.1.2 Variability of rainfall and rainy days during monsoon season

The amount of monsoon rainfall over northwestern part of Bangladesh varies between -43 to 57% during the observed period. It is the maximum with the deviation of +57% in 1987 followed by +44%, +40% and +36% in 1995, 1984 and 2004 respectively. It is the minimum with the deviation of -43% in 2006 followed by -41% and -29% in 1994 and 2000. The trend of monsoon rainfall during the observed period is -0.523 mm/year (Fig. 5a). Accordingly, the anomaly of the number of rainy days during monsoon season varies between -12.5 to 12.2. The positive and maximum anomaly with the magnitude of 12.2 is in 1987 followed by 9.5, 8.8, 8.5 and 7.8 in 1995, 2002, 1991 and 2004 respectively. But it is negative and minimum with the magnitude of -12.5 in 1981 followed by -11.2, -10.8 in 2009 and 1992 respectively. The trend during the observed period of it is -0.129 day/year (Fig. 5b).

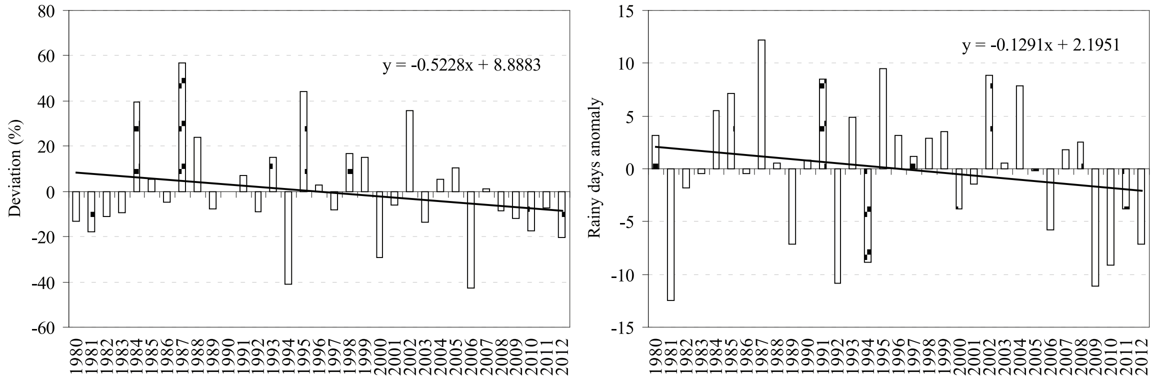

Fig. 5. Temporal variation of (a) deviation (%) of rainfall and (b) rainy days anomaly over northwestern part of Bangladesh during monsoon season of 1980-2012

3.1.3 Variability of rainfall frequency with different category

The frequency of Cat-I rainfall is the highest in July and then in August and lowest in September. The variability of it is the highest in September with STD 2.4 followed by July. Consequently, the frequency of this category in monsoon season is 35.9 with STD 3.0. Cat-I rainfall frequency depicts positive trend in June and July but negative in other two monsoon months (Table 3). Accordingly, Cat-I rainfall frequency in monsoon season demonstrates the tendency of +0.050/ year as depicted in (Fig. 7a).

The frequency of Cat-II rainfall is the highest in July and then in June and the lowest in September. The variability of it is the highest in August and lowest in July. Thus, the frequency of this category in monsoon season is 14.5 and its STD is 2.6. The trend of the frequency of Cat-II rainfall indicates positive in June and August but negative in other two monsoon months. The trend of the frequency of this category in June and September are at 90% and 95% levels of significance (Table 3). The tendency of the frequency this category in monsoon season is -0.008/ year (Fig. 7a). The frequency of Cat-III rainfall is the highest in June and July and then in August and the lowest in September. But the variability of this class is the highest in July followed by June and lowest in September (Fig. 6a). Consequently, the frequency of this category in monsoon season is 10.8 and its STD is 2.4. The trend of the frequency depicts positive in June but negative in other three monsoon months. The trend of the frequency of this category in September is at 90% level of significance (Table 3). The tendency of Cat-III rainfall frequency in monsoon season is -0.076/ year which is found at 90% level of significance as well (Fig. 7a).

The frequency of Cat-IV rainfall is the highest in July and then in June and the lowest & equal in August and September. But the variability of it is the highest in July with the STD of 1.2 followed by August and the lowest in June and September (Fig. 6b). Thus, the frequency of this category in monsoon season is 7.0 and its STD is 2.0. The trend of Cat-IV rainfall frequency depicts positive in June and August but negative in other two monsoon months (Table 3). The tendency of Cat-IV rainfall frequency in monsoon season is -0.022/ year (Fig. 7a).

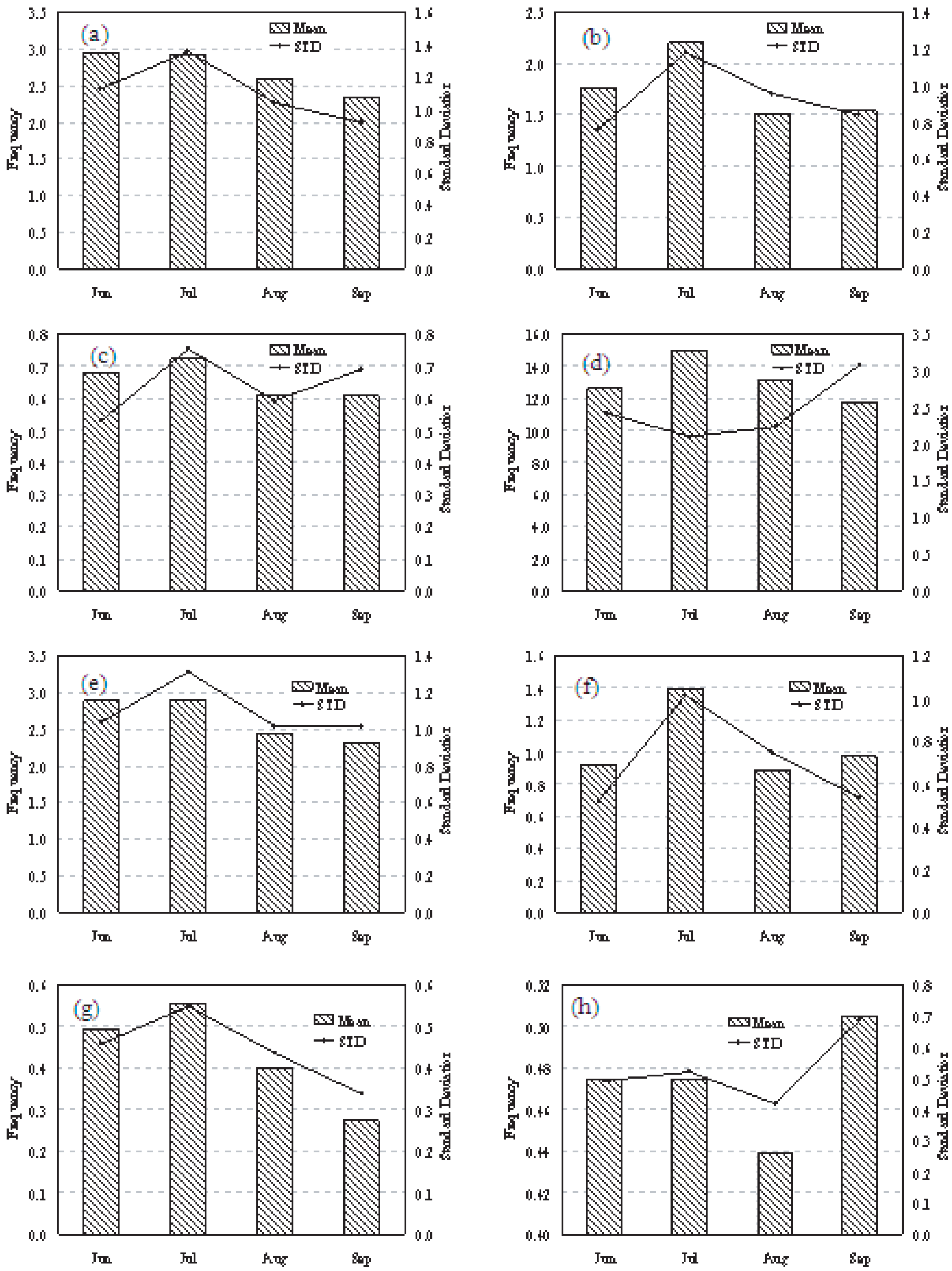

Fig. 6. Distribution of the frequency of rainfall for (a) Cat-III, (b) Cat-IV, (c) Cat-V, (d) Cat-VI, (e) Cat-VII, (f) Cat-VIII, (g) Cat-IX and (h) Cat-X over northwestern part of Bangladesh during 1980-2012

The average frequency of Cat-V rainfall is the highest and equal in June and July and then in August and September. But the variability of it is the highest in July with the STD of 0.8 followed by September and the lowest in June and July (Fig. 6c). Consequently, the frequency of this category in monsoon season is 2.6 and its STD is 1.5. The trend of the frequency of Cat-V rainfall depicts positive in June but negative in other three monsoon months (Table 3). Therefore, the tendency of Cat-V rainfall frequency in monsoon season is -0.029/year (Fig. 7a).

The frequency of Cat-VI rainfall is the highest in July and then in August and lowest in September. But the variability of it is the highest in September with STD of 3.1 and the lowest in July (Fig. 6d). Consequently, the frequency of this category in monsoon season is 52.5 with STD of 4.7. The trend of the frequency of Cat-VI rainfall depicts positive in June but negative in other three monsoon months (Table 3). Therefore, the tendency of Cat-VI rainfall frequency in monsoon season is -0.024/year (Fig. 7b).

The frequency of Cat-VII rainfall is the highest and equal in June and July and then in August and lowest in September. But the variability of it is the highest in July with STD of 1.3 and the lowest and equal in other three monsoon months (Fig. 6e). So, the frequency of this category in monsoon season is 10.5 and its STD is 2.4 during the observed period. The trend of the frequency of Cat-VII rainfall is positive in June but negative in other three monsoon months (Table 3). Hence, the tendency of Cat-VII rainfall in monsoon season is -0.053/year (Fig. 7b).

The average frequency of Cat-VIII rainfall is the highest in July and then in September and lowest in June and August. But the variability of it is the highest in July with the STD of 1.0 and then in August and the lowest & equal in other two monsoon months (Fig. 6f). So, the average frequency of this category in this season is 4.2 with STD of 1.5. The trend of the frequency of Cat-VIII rainfall is positive in June and August but negative in other two monsoon months and so the tendency of Cat-VIII rainfall in monsoon season is -0.015/year (Table 3 and Fig. 7b).

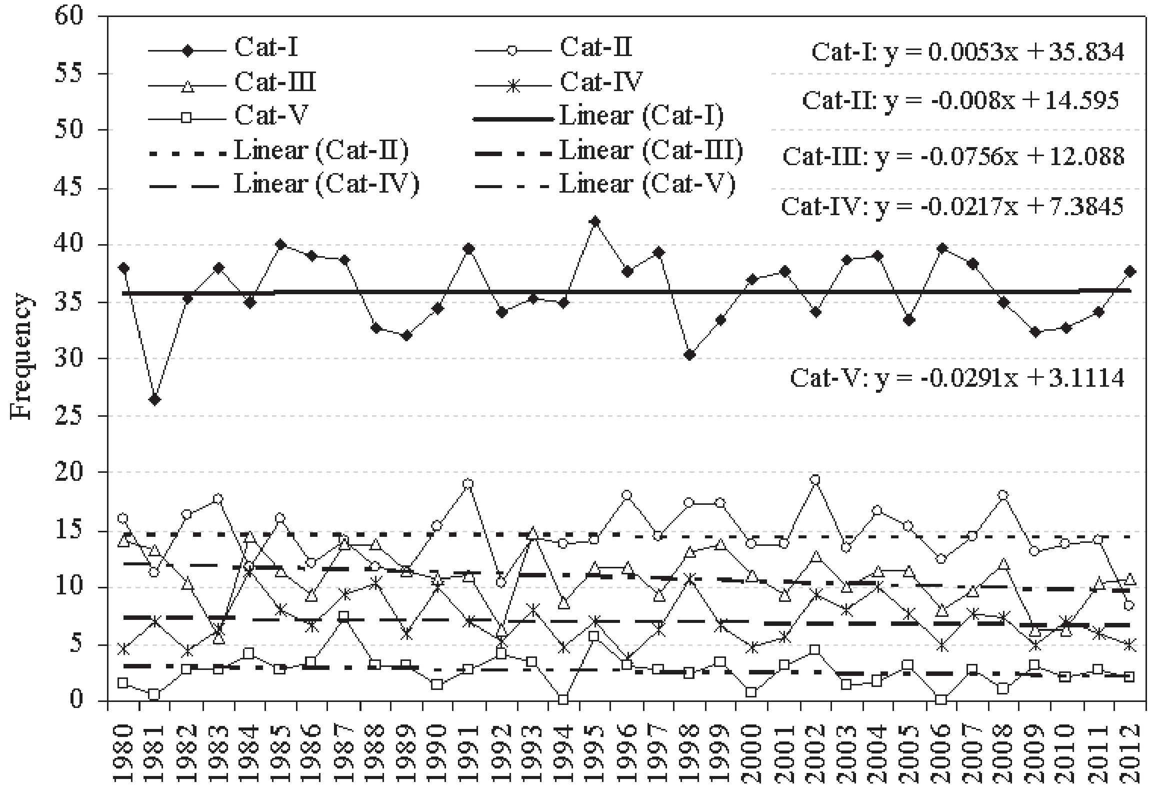

Fig. 7a. Temporal variation of the frequency and trend of Cat-I, Cat-II, Cat-III, Cat-IV and Cat-V rainfall over northwestern part of Bangladesh during 1980-2012

The average frequency of Cat-IX rainfall is the highest in July and then in June and the lowest in September. The variability of it is the highest in June and July with the STD of 0.5 and the lowest in September (Fig. 6g). The average frequency of this category in monsoon season is 1.7 and its STD is 0.9. The trend of the frequency of Cat-IX rainfall is positive September but negative in other three monsoon months (Table 3). Hence, the tendency of Cat-IX rainfall in monsoon season is -0.015/ year (Fig. 7b).

The average frequency of Cat-X rainfall is equal and higher in June, July and September and lower in August. But the variability of it is the highest in September with the STD of 0.7 and the lowest in August (Fig. 6h). The average frequency of this category in monsoon season is 1.9 and its STD is 1.3 during the observed period. The trend of the frequency of Cat-X rainfall is positive in June but negative in other monsoon months but the tendency of this category in July is at 90% level of significance (Table 3). Thus, the tendency of Cat-X rainfall in monsoon season is -0.021/year (Fig. 7b).

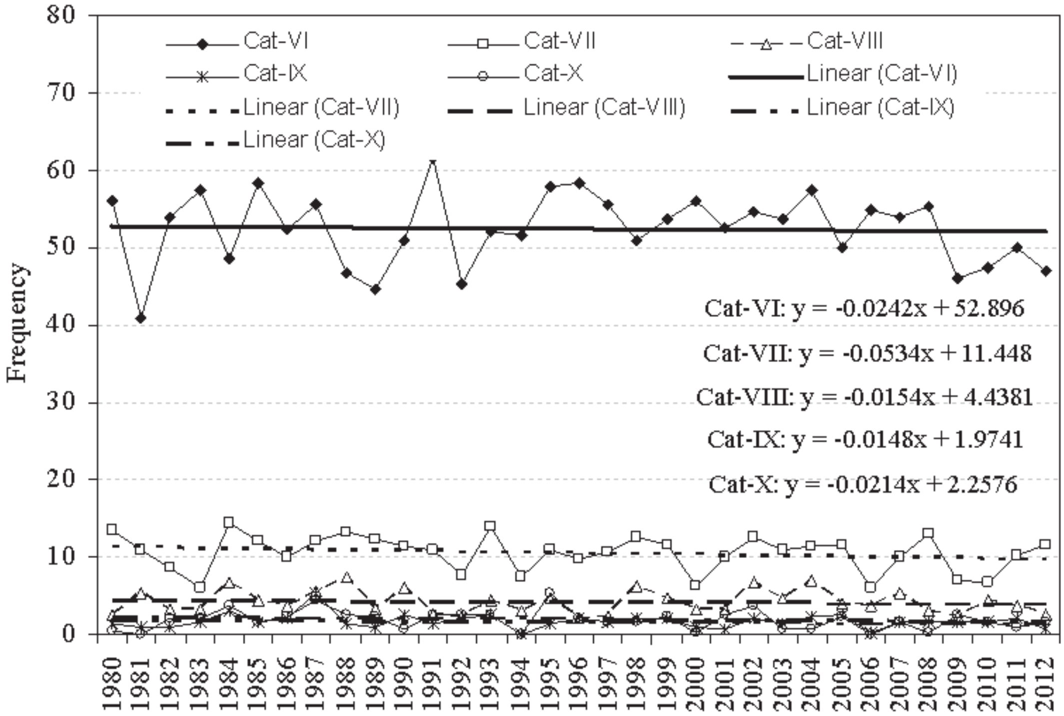

Fig. 7b. Temporal variation of the frequency of Cat-VI, Cat-VII, Cat-VIII, Cat-IX and Cat-X rainfall over northwestern part of Bangladesh during 1980-2012

Table 3: Frequency and trend of rainfall of categorized rainfall

Rainfall category	June		July		August		September		Monsoon	
	Freq.	Trend	Freq.	Trend	Freq.	Trend	Freq.	Trend	Freq.	Trend
Cat-I	8.1	+0.016	10.3	+0.027	9.1	-0.017	7.9	-0.030	35.9	+0.050
Cat-II	3.8	+0.044*	3.9	-0.021	3.3	+0.018	3.3	-0.049**	14.5	-0.008
Cat-III	2.9	+0.013	2.9	-0.039	2.5	-0.022	2.3	-0.028*	10.8	-0.076*
Cat-IV	1.8	+0.004	2.2	-0.024	1.5	+0.008	1.5	-0.010	7.0	-0.022
Cat-V	0.7	+0.002	0.7	-0.018	0.6	-0.013	0.6	-0.001	2.6	-0.029
Cat-VI	12.6	+0.060	14.9	-0.004	13.0	-0.005	11.7	-0.076	52.5	-0.024
Cat-VII	2.9	+0.015	2.9	-0.030	2.4	-0.019	2.3	-0.018	10.5	-0.053
Cat-VIII	0.9	+0.010	1.3	-0.020	0.9	+0.006	1.0	-0.011	4.2	-0.015
Cat-IX	0.5	-0.006	0.6	-0.005	0.4	-0.006	0.3	+0.001	1.7	-0.015
Cat-X	0.5	+0.475	0.5	-0.016*	0.4	-0.002	0.5	-0.004	1.9	-0.021

* Indicates the tend value is 90% and ** indicates the tend value is 95% level of significance

3.2 Synoptic condition during 5 July 2012 over Bangladesh and adjoining areas

NCEP reanalysis data depicts monsoon trough persists over Uttar Prodesh to Assam of India across Bihar, Sub-Himalayan West Bengal and northern part of Bangladesh with its extension up to Gangetic West Bengal of India and adjoining northwest Bay of Bengal & Bangladesh which intensifies at around 1200 UTC. An induced meso-scale low generates within the monsoon trough over Assam of India during the late hours of the day. Steep pressure gradient persists over North Bay of Bengal and Bangladesh (Fig. 8). NCEP reanalysis indicates the signature of high vorticity over West Bengal of India and adjoining western part of Bangladesh and North Bay of Bengal during 5 July 2012. Accordingly, the signature of high RH is observed over West Bengal of India and adjoining northwestern part of Bangladesh and adjoining areas (Fig. 9). NCEP reanalysis fields have also the signature of high CAPE over the same areas.

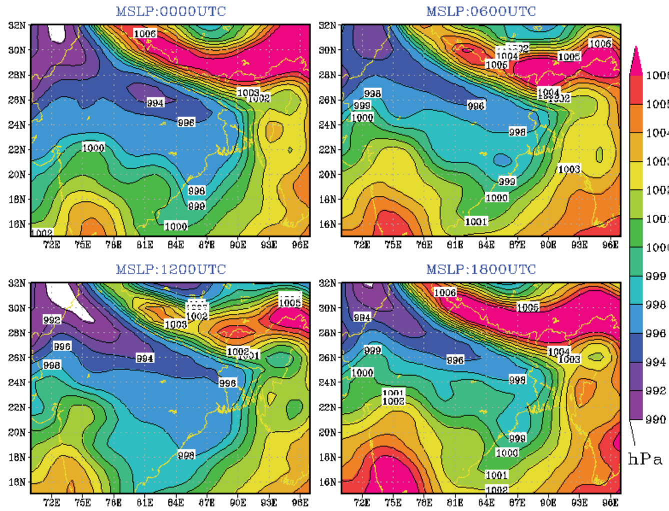

Fig. 8. Distribution SLP over Bangladesh and adjoining areas at (a) 0000, (b) 0600, (c) 1200 and (d) 1800 UTC during 05 July 2012 derived from NCEP data

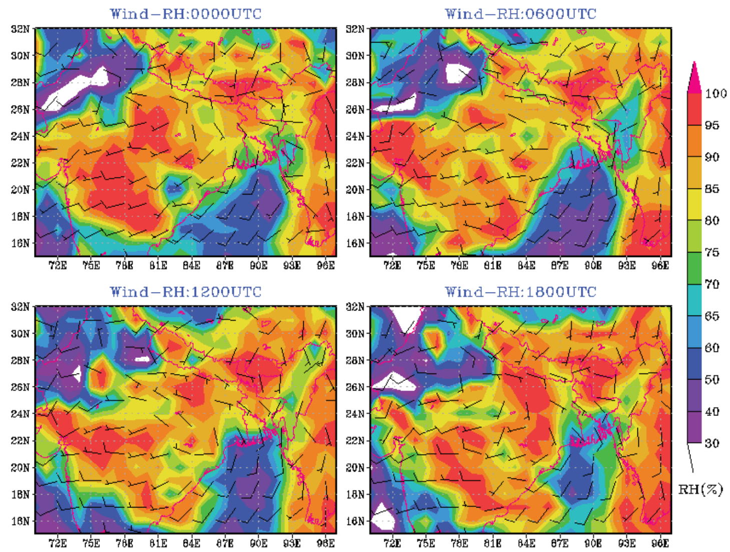

Fig. 9. Distribution RH over Bangladesh and adjoining areas at (a) 0000, (b) 0600, (c) 1200 and (d) 1800 UTC during 5 July 2012 derived from NCEP data

3.3 Simulated parameters

3.3.1 Wind and Relative Humidity

Within the monsoon trough over Bihar, West Bengal of India and adjoining western part of Bangladesh, a vortex has generated over West Bengal of India and adjoining western part of Bangladesh. To follow this vortex, wind at surface and near to surface levels has been flowing from the Bay of Bengal and converging over Bangladesh. When it reaches to northwestern part of Bangladesh, southerly flow has converged further with the downward flow from the hilly regions located over the outside region of the northern part of Bangladesh. Accordingly, the high amounts of moisture accumulated over Bangladesh and adjoining areas but the most moistening zone persist at surface and lower tropospheric levels over northwestern part of Bangladesh and adjoining areas for longer duration. This situation has been generated by all the combinations of MPs and CPs under this study (Figs. 10-11).

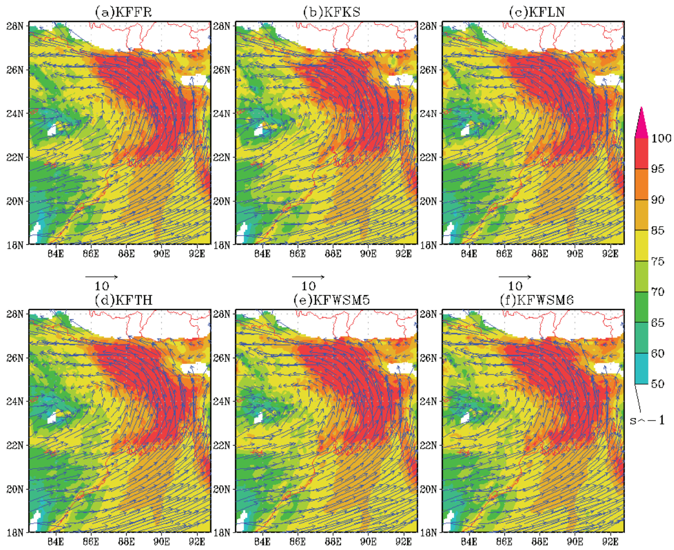

Fig. 10. Wind and RH at 900 hPa for (a) KFFR, (b) KFKS, (c) KFLN, (d) KFTH, (e) KFWSM5, and (f) KFWSM6 over Bangladesh and adjoining areas at 0800 UTC of 5 July 2012

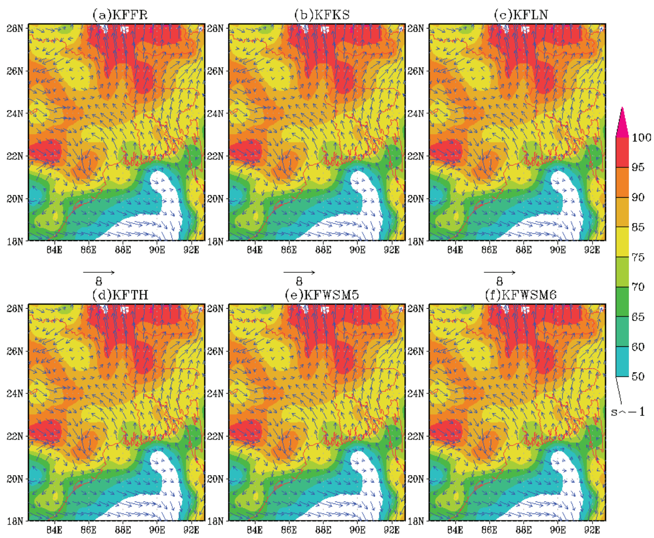

Fig. 11. Wind and RH at 500 hPa for (a) KFFR, (b) KFKS, (c) KFLN, (d) KFTH, (e) KFWSM5, and (f) KFWSM6 over Bangladesh and adjoining areas at 0100 UTC of 5 July 2012.

Similarly, induced vortex has persisted over the same areas, moisture content has been accumulated at the lower levels of troposphere but like surface level and it has been persisting in the lower trpospheric levels for long duration over northwestern part of Bangladesh and adjoining areas. Following the wind flow, the moisture content has been accumulated over northwestern part of Bangladesh and adjoining areas at surface level and vertically upto 700 hPa and accordingly, a band of high moisture persists over northern part of Bangladesh and adjoining areas. The vortex has the vertical extension upto 500 hPa level and moisture has accrued over the same areas. Following the lower levels flow south/ southeasterly flow has persisted up to 400 hPa and then 300 hPa levels and high amounts of moisture has persisted over or near the northwestern part of Bangladesh but vortex has not extended up to these levels. Above of these levels a divergence condition has persisted.

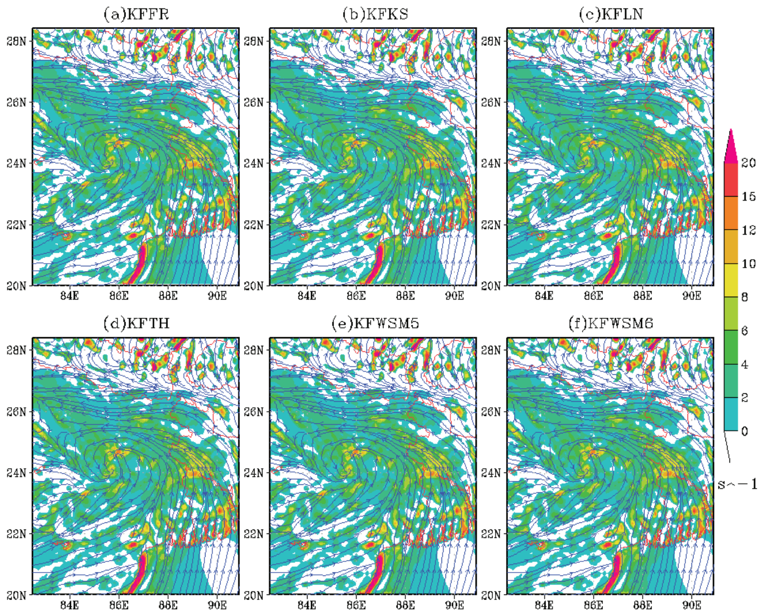

Fig. 12. Stream flow & vorticity at 10 m for (a) KFFR, (b) KFKS, (c) KFLN, (d) KFTH, (e) KFWSM5 and (f) KFWSM6 over Bangladesh and adjoining areas at 0600 UTC on 5 July 2012

3.3.2 Stream flow and vorticity

A vortex has generated over Bihar and adjoining sub-Himalayan West Bengal of India at 0300 UTC of 5 July 2012 at surface level which then intensifies and moves east-southeastwards and reaches to northwestern part of Bangladesh at about 1200 UTC (Fig. 12). It then intensifies and moves in the same direction. A strong confluence associated with this system extends up to 700 hPa level and moves following the surface vortex. Under this situation, strong positive vorticity persists at 700 hPa and its below but negative vorticity persists above of this level during 0900 to 1200 UTC over northwestern part of Bangladesh.

3.3.3 CAPE

Strong CAPE persists over West Bengal of India and adjoining western part of Bangladesh during 5 July 2012 which is associated with the low level convergence. The magnitude of the CAPE is also increased with the strength and vertical extension of the system. In the case of BMJ combinations the highest maximum CAPE of 2396.9 J/kg is found for BMJTH but the lowest maximum CAPE of 1707.9 J/kg is found for BMJLN. In the case of GD combinations the highest maximum CAPE of 3233.3 J/kg is found for GDTH but the lowest maximum CAPE of 2506.2 J/kg is found for GDKS. KF combinations reveal the highest maximum CAPE of 2836.3 J/kg for KFTH, however the lowest maximum CAPE of 2120.6 is found for KFKS. Similarly, the highest maximum CAPE of 3230.1 J/kg is found for NGTH but the lowest maximum CAPE of 2465.4 J/kg is found for NGKS. At Dinajpur, the highest maximum CAPE of 2354.5

J/kg is found for BMJKS followed by 2343.6 J/kg for NGLN. Similarly, at Sayedpur location the highest maximum CAPE of 2344.4 J/kg is found for KFFR followed by 2145.1 J/kg for BMJKS (Table 4). Simulated CAPE at Dinajpur and Sayedpur indicates the presence of sufficiently strong convection for the occurrence of heavy rainfall at these places as well as over northwestern part of Bangladesh. Simulation also reveals that the CAPE values have increased with the progress of the day at Dinajpur (Fig. 13) and at Sayedpur. But it attains higher values during 0400 to 2100 UTC.

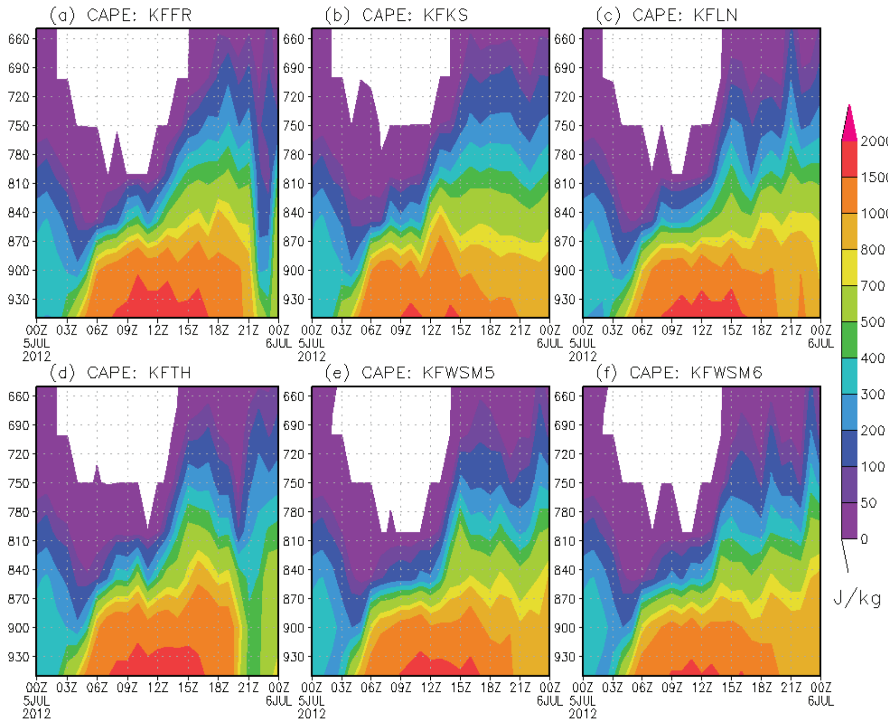

Fig. 13. Temporal variation of the vertical profile of CAPE for (a) KFFR, (b) KFKS, (c) KFLN, (d) KFTH, (e) KFWSM5 and (f) KFWSM6 at Dinajpur during 5 July 2014.

Table 4. Simulated CAPE for different combination of CPs and MPs at the centre of the system and at Dinajpur and Sayedpur locations during 5 July 2012

Group of CPs & MPs	Maximum CAPE (J/kg)			Group of CPs & MPs	Maximum CAPE (J/kg)		
	Centre	Dinajpur	Sayedpur		Centre	Dinajpur	Sayedpur
BMJFR	1946.0	2125.7	1909.4	KFFR	2832.4	2327.3	2344.4
BMJKS	2367.2	2354.5	2145.1	KFKS	2120.6	2020.5	1874.9
BMJLN	1707.9	2082.0	1808.6	KFLN	2509.1	2192.6	2071.2
BMJTH	2396.9	2030.8	1923.8	KFTH	2836.3	2228.9	2123.8
BMJWSM5	1921.9	2026.2	1912.1	KFWSM5	2819.4	2122.3	1986.1
BMJWSM6	1900.3	2041.1	1733.1	KFWSM6	2584.8	2127.8	2006.5
GDFR	3211.3	2240.1	1928.9	NGFR	3045.1	2299.5	2072.4
GDKS	2506.2	1698.9	1553.1	NGKS	2465.4	1573.5	1279.0
GDLN	2997.6	2064.8	1906.3	NGLN	2894.2	2343.6	1928.3
GDTH	3233.3	2137.5	1836.9	NGTH	3230.1	2270.2	1858.3
GDWSM5	2995.7	1942.0	1764.3	NGWSM5	3065.3	2152.9	1859.1
GDWSM6	3024.5	1919.9	1825.8	NGWSM6	3067.5	2185.5	1862.4

3.4 Simulated Rainfall

3.4.1 Rainfall distribution

Model simulates moderately heavy to heavy rainfall over northwestern part of Bangladesh but the amounts of rainfall are different for different combinations of CPs and MPs. Similarly, the locations of maximum rainfall patches are different. BMJ combination simulates maximum rainfall patch over northern boarder region of Bangladesh which is about 100 km north-northeast of Dinajpur, where maximum amount of rainfall is recorded.

The amounts of maximum simulated rainfall are 221.6, 145.6, 232.8, 225.4, 162.9 and 155.2 mm respectively for BMJFR, BMJKS, BMJLN, BMJTH, BMJWSM5, and BMJWSM6. GD combinations simulate maximum rainfall patches over West Bengal of India and adjoining Bangladesh which is about 100 km southwest of Dinajpur. The amounts of maximum simulated rainfall are 145.2, 91.6, 106.9, 110.8, 105.8 and 121.3 mm respectively for GDFR, GDKS, GDLN, GDTH, GDWSM5 and GDWSM6. KF combinations simulates maximum rainfall patches over the boarder region of West Bengal of India and Bangladesh which is about 50 km west-southwest of Dinajpur is the closest among simulated rainfall zone (Fig. 14).

The amounts of maximum rainfall are 311.7, 197.0, 276.9, 300.8, 347.3 and 377.6 mm respectively for KFFR, KFKS, KFLN, KFTH, KFWSM5 and KFWSM6. NG combinations simulate maximum rainfall area over West Bengal of India but a secondary zone is located over the boarder region of West Bengal of India and Bangladesh which is about also 50 west-southwest of Dinajpur. The amounts of maximum rainfall for this group are 185.8, 94.3, 131.4, 141.0, 151.9 and 147.4 mm respectively for NGFR, NGKS, NGLN, NGTH, NGWSM5 and NGWSM6. The maximum rainfall patches are located at a distance of about 90 km north-northeast of Dinajpur. But the maximum rainfall amounts of 315.3 and 273.1 mm are for TRMMV6 and TRMMV7. The maximum amount of rainfall for TRMMV6 is the closest to observation.

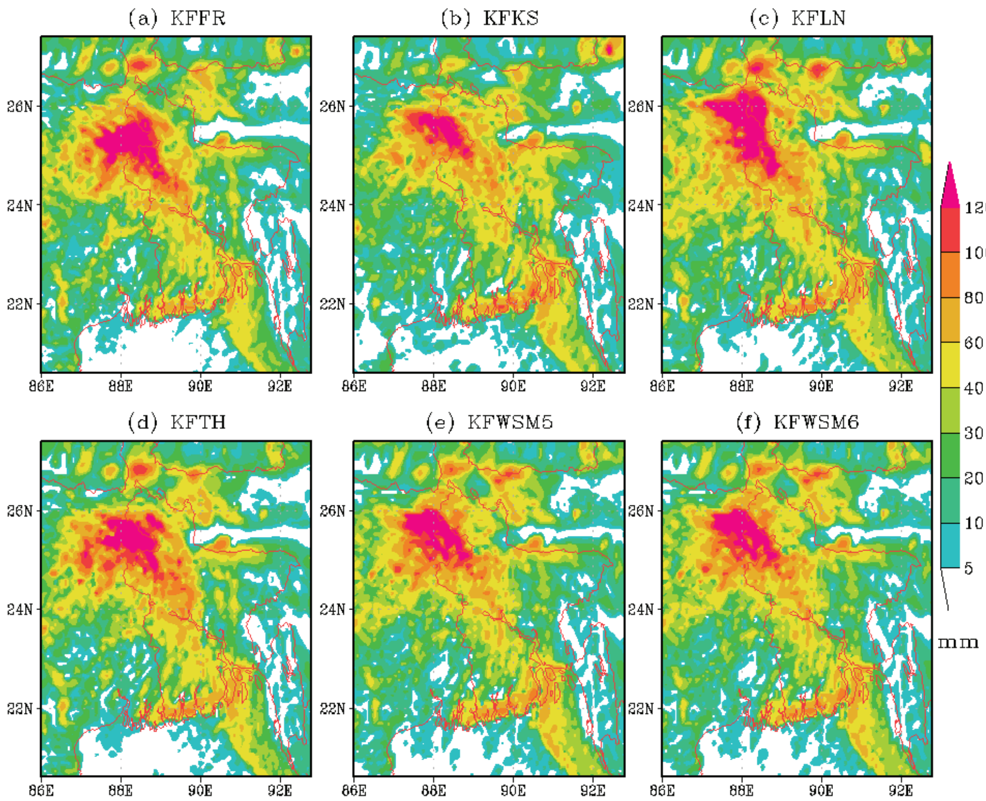

Fig. 14. Simulated rainfall for (a) KFFR, (b) KFKS, (c) KFLN, (d) KFTH, (e) KFWSM5 and (f) KFWSM6 over Bangladesh during 5 July 2012

3.4.2 Correlation between simulated and observed rain gauge rainfall

Simulated rainfall at station locations are very low compare to observation. At Dinajpur, the maximum amount of 122.9 mm is for KFFR followed by 89.0 mm for BMJLN (Fig. 15a) which are much lower than observation. At Sayedpur, the maximum amount of 132.8 mm is for KFTH followed by 70.5 mm for KFFR (Fig. 15b) which are also much lower than observation. But the correlation among the simulated and observed rainfall at rain gauge locations are quiet high. The maximum correlation coefficient (CC) of 0.69 is found for BMJLN rainfall (Fig. 16a) followed by 0.62 for KFFR rainfall (Fig. 16b). Similarly, correlation between simulated and TRMM rainfall at station locations are quiet high. The maximum CC among the simulated and TRMMV6 rainfall is 0.71 for KFTH followed by 0.70 for BMJLN. The maximum CC among the simulated rainfall and TRMMV7 rainfall is 0.69 for KFTH followed by 0.66 for BMJLN.

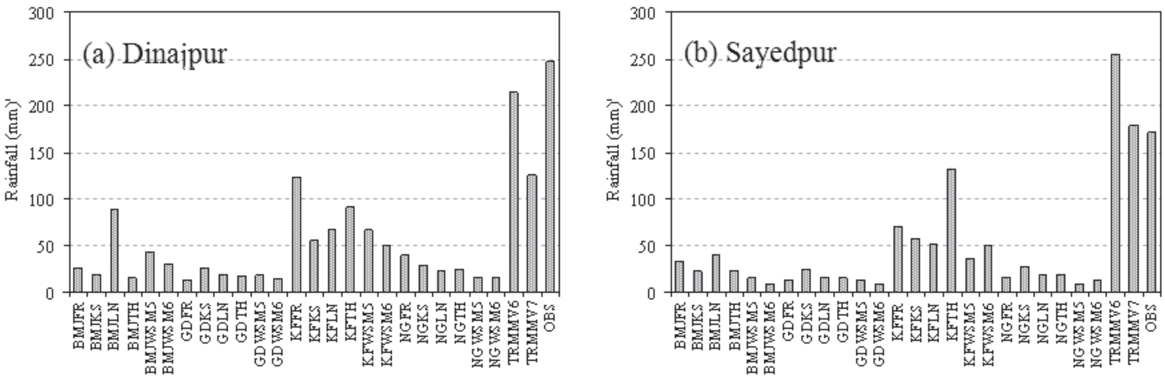

Fig. 15. Comparison of simulated and observed rainfall at (a) Dinajpur and (b) Sayedpur of Bangladesh during 5 July 2012

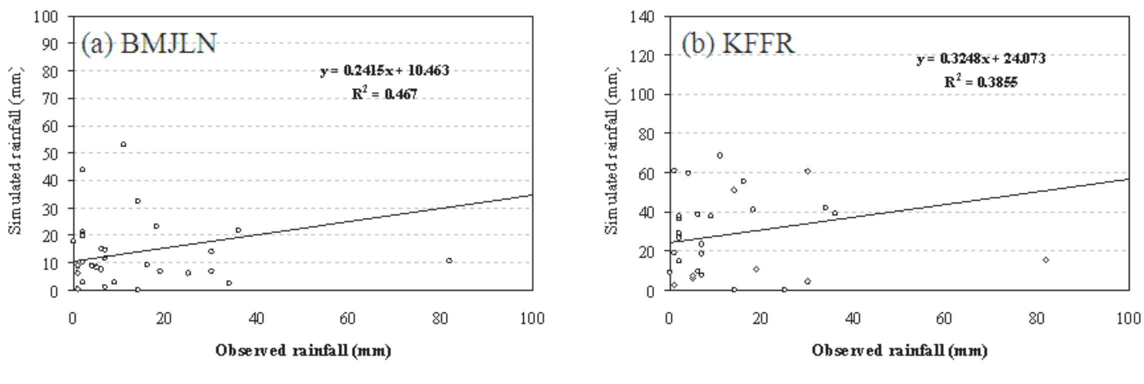

Fig. 16. Correlation between observed and simulated rainfall of Bangladesh for (a) BMJLN and (b) KFFR during 5 July 2012

3.4.3 Correlation between simulated rainfall and gridded station rainfall

Correlations among simulated and observed rainfalls (calculated at 0.5°x0.5° grid resolution) are not so high. The maximum CC among the simulated and observed rainfall is 0.52 (between KFLN and observed rainfall) followed by 0.50 (between KFWSM6 and observed rainfall) as depicted in Figs. 17a and 17b. Correlations among simulated and TRMM rainfalls are also low. The maximum CC is 0.42 (between KFLN and TRMMV6 rainfall) followed by 0.41 (between KFTH and TRMMV6 rainfall). Similarly, the maximum CC is 0.39 (between BMJFR and TRMMV7 rainfall) followed by 0.35 (between KFLN and TRMMV7 rainfall). But the CC between observed and TRMMV6 & TRMMV7 rainfall (calculated also at 0.5°x0.5° grid resolution) are 0.55 and 0.53 (Figs. 17c and 17d).

3.5 Skill scores of simulated rainfall

Model simulates rainfalls of Cat-III to Cat-V over northwestern part of Bangladesh but the amounts of rainfall are different for different combinations of CPs and MPs. Accordingly, the forecast skills of PoD, FAR, PEC, FBI and CSI are different. In the case of Cat-III rainfall prediction, PoD score is the highest for KFWSM6 and KFLN and then for KFWSM5 (Fig. 18a); FAR score is the highest for KFLN and then for KFWSM6 (Fig. 18b); PEC score is the highest for KFWSM6 and then for KFLN; FBI scores are low for KFLN and KFWSM6; CSI scores are high for KFLN and KFWSM6. In the case of Cat-IV rainfall prediction, PoD score is the highest for KFLN and then for NGFR (Fig. 18c); FAR score is the highest for KFLN and then for NGFR (Fig. 18d); PEC score is the highest for NGFR and then for KFLN; FBI scores are low for KFLN and NGFR; CSI score is the highest for KFLN and then for KFWSM5. The notable skill scores of PoD, FAR, PEC, FBI and CSI are 0.37 (for BMJLN and BMJWSM6), 0.54 (for KFLN), 0.31 (for KFWSM6), 0.70 (for KFWSM6) and 0.28 (for KFLN and KFWSM6) respectively for Cat-III rainfall prediction at rain gauge locations. Similarly, the prominent prediction skills of PoD, FAR, PEC, FBI and CSI are 0.31 (for KFLN), 0.31 (for KFLN), 0.31 (for KFLN), 1.0 (for KFWSM5) and 0.18 (for KFLN) respectively for Cat-IV rainfall at rain gauge locations over northwestern part of Bangladesh.

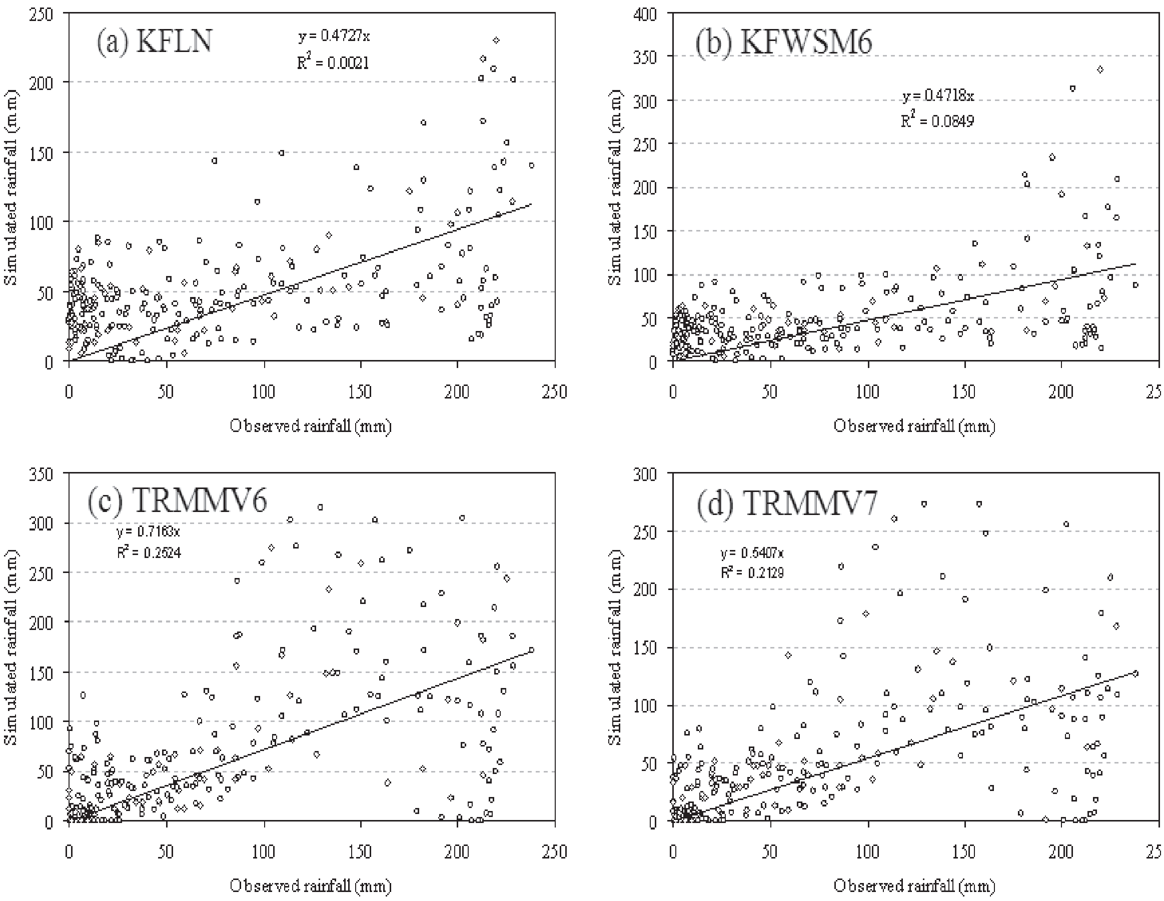

Fig. 17. Correlation between observed rainfall (0.5°x0.5° grid resolutions) with (a) KFLN rainfall, (b) KFWSM6 rainfall, (c) TRMMV6 rainfall and (d) TRMMV7 rainfall

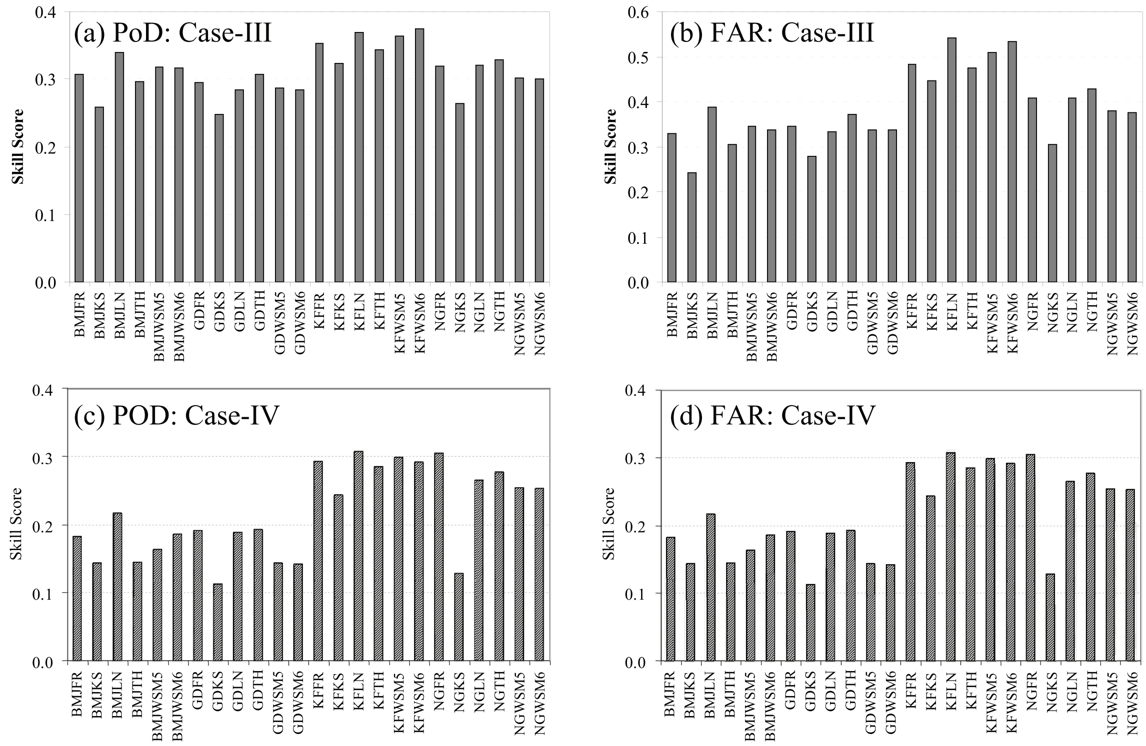

Fig. 18. Skill scores of (a) PoD and (b) FAR for Case-III rainfall prediction; (c) PoD and (d) FAR for Cat-IV rainfall prediction over northwestern part of Bangladesh and adjoining areas.

4. Conclusion

From this study the following conclusions can be drawn:

i. The variability of monthly rainfall over northwestern part of Bangladesh is the highest in July and lowest in June. The tendencies of rainfall in June, July, August and September are +1.57, -5.39, -0.73 and -3.21 mm/year respectively. The tendency of July rainfall is at 90% level of significance.

ii. The frequency of rainy days is the highest in July and then in June but the lowest in September. The trends of the frequency of rainy days in June, July, August and September are +0.08, -0.07, -0.03 and -0.11/year respectively. The trend of rainy days in September is at 90% level of significance.

iii. The deviation of monsoon rainfall over northwestern part of Bangladesh varies between -43 to +57% during the observed period but the trend of monsoon rainfall deviation is -0.523 mm/year. Accordingly, the anomaly of the number of rainy days during monsoon season varies between -12.5 to 12.2 and its trend is -0.129 day/year.

iv. The trends of Cat-II rainfall frequency in Juneand September are +0.044 and -0.049/year and they are at 90% and 95% levels of significance respectively. The tendency of Cat-III rainfall frequency in September is -0.028/year which is at 90% level of significance. The frequency Cat-III rainfall in monsoon season is 10.8 and its trend is -0.022/year which is also at 90% level of significance. The average frequency of Cat-X rainfall in July is 0.5 but its trend is -0.016/year which is at 90% level of significance.

v. The trend of Cat-IX rainfall frequency in June is negative but the trends for other categories are positive; the trend for Cat-I in July is positive but the trends for other categories are negative; the trends for Cat-II, Cat-IV and Cat-VIII in August are positive but the trends for other categories are negative; the trend for Cat-IX in September is positive but the trends for other categories are negative. The trend for Cat-I rainfall in monsoon season is positive but the trends for other categories are negative.

vi. Strong CAPE in association with the low level convergence persists over West Bengal of India and adjoining western part of Bangladesh during 5 July 2012 which is responsible for the occurrence of the event. Strong CAPE also persists during 0400 to 2100 UTC at Dinajpur and Sayedpur locations on the same day are caused for heavy rainfall.

vii. KF combinations simulate maximum rainfall patches over the boarder region of West Bengal of India and Bangladesh which is about 50 km west-southwest of Dinajpur is the closest to observation area among the simulated rainfall zones. As a result, simulated rainfalls at Dinajpur and Sayedpur are lower than observation.

viii. The maximum CC between the observed and simulated rainfall is 0.69 for BMJLN and then comes to 0.62 for KFFR. The skill scores for KFLN combination is the most rational for simulating this event.

References

[1] V. V. Kharin, F. W. Zwiers, and X. Zhang, J. Climate, 18, 5201 (2005).

[2] C.-S. Chen, Y.-L. Chen, C.-L. Liu, P.-L. Lin, and W.-C. Chen, Wea. Forecasting, 22, 981 (2007).

[3] R. Chokngamwong , and L. S. Chiu, J. Hydrometeor., 9, 256 (2008).

[4] O. N. Dhar and Nandergi, International J. Climatology 13, 301 (1993).

[5] R. B. Smith, Advances in Geophysics 21, 187 (1979).

[6] D. P. Dubey and T. K. Balakrishnan, Mausam, 43, 326 (1992).

[7] P. R. Rakhecha and P. R. Pisharoty, Current Science 71, 179 (1996).

[8] O. N. Dhar and P. R. Mhaiskar, Indian J. Met. Geophys., 24, 271 (1973).

[9] A. Mannan, A. M. Chowdhury and S. Karmakar and M. N. Islam, Journal of Engineering Science, 4(1), 127 (2013).

[10] A. Mannan, A. M. Chowdhury and S. Karmakar, Procedia Engineering, 56, 667 (2013), DOI: 10.1016/ j.proeng.2013.03.176

[11] M. A. Mannan and S. Karmakar, Proceedings of SAARC Seminar on Application of Weather and Climate Forecasts in the Socio-economic Development and Disaster Mitigation, 5-7 August, 2007, Dhaka, Bangladesh, pp 95-115 (2008).

[12] S. Karmakar and A. Mannan, The Atmosphere, 4 (1), 25 (2014).

[13] P. Kaufmann, F. Schubiger and P. Binder, Hydrology and Earth System Sciences, 7(6), 812 (2003).

[14] N. Aneja and T. George, Research Journal of Applied Sciences, Engineering and Technology, 8(10), 1255 (2014).

[15] C. A. Doswell, J. R. Davies and D. L. Keller, Weather Research and Forecasting, 5, 576 (1990).