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APPLICATION OF NWP MODEL AND ITS VALIDATION IN PREDICTION OF HEAVY RAINFALL IN BANGLADESH

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ABSTRACT

During 8-9 August of 2011 wide spread heavy rainfalls occurred over Bangladesh and hampered the life and livelihood of the people. As such, it is badly in need to understand the real dynamic processes associated with this event. In this regard WRF-ARW model with the grid resolution of 9 km is used for diagnosis the event. Analysis reveals that a low pressure system initiated over southwestern part of Bangladesh (Khulna and Satkhira regions and adjoining North Bay) at 0300 UTC of 8 August 2011 which moved north/northeastwards initially and intensified into a Depression over central part of Bangladesh. Then it recurved northwestwards and located over Rajshahi and its adjoining areas of Bangladesh at 0000 UTC of 9 August 2011 and moved slowly westward further to West Bengal of India. After reaching West Bengal and adjoining western part of Bangladesh the central pressure of the system dropped off rapidly and intensified once more into a Deep Depression. The system weakened afterward gradually by giving precipitation. During the life cycle of the system the pressure, wind, humidity, vorticity fields were very much supportive for generating high intensity rain bands over Bangladesh and adjoining North Bay of Bengal. On the basis of the initial conditions of 0000 UTC of 8 August 2011 model simulates high intensity of rain over Bangladesh which comply with the observation but model failed to simulate strong rain bands for 9 August 2011. It successfully simulated the high intensity rain bands for 9 August 2011 with the delayed initial conditions of 0000UTC of 9 August 2011. Simulated rainfalls for combinations of KF scheme and considered MPs are very close to observation as well as TRMM though there are little variations in space and time.

Keywords: *Heavy rainfall, Moisture, Numerical Weather Prediction, TRMM, Vorticity*.

1. INTRODUCTION

One of the most challenging and difficult problems in weather prediction is quantitative precipitation forecasting, especially the prediction of orographically induced heavy precipitation (Smith *et al.*, 1997). The current status of relatively low forecast skill for heavy rain events poses a challenging problem for both scientific research and operational forecasting (His-Chyi Yeh and George Tai-Jen Chen, 2003). Chu and Lin (2000) identified three moist flow regimes for conditionally unstable flow over a two-dimensional mesoscale mountain: (i) upstream propagating convective systems, (ii) quasi-stationary convective systems, and (iii) quasi-stationary and downstream propagating convective systems.

In the tropical and subtropical 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 (Kharin *et al.,* 2005; Chen *et al.,* 2007; Chokngamwong and Chiu, 2008). While tropical cyclones account for many of these events, others occur in conjunction with monsoon horizontal wind regimes (Chen *et al.,* 2007). Despite the synoptic-scale character of the monsoon, numerous local effects ultimately conspire to determine the location of heavy rainfall. Climatology points to the maxima in mesoscale convective system (MCS) stratiform over coastal regions, within which most of the heaviest widespread rain events occur across much of southern Asia during the monsoon (Romatschke *et al.,* 2010). Because of a general lack of mesoscale observations of lower-tropospheric wind, temperature, and water vapor, it is challenging to document the mesoscale processes in such regions, but such processes determine the all-important location of heavy rainfall and its societal consequences.

As a disaster prone country, Bangladesh experiences heavy rainfalls causing heavy loss of lives and damages to properties. During monsoon seasons when moist and unstable southerly air flows from the Bay of Bengal meet with the comparatively dry and stable continental air over Bangladesh and its adjoining areas, heavy rainfall occurs within a very short span of time over Bangladesh and affects agriculture, food security, urban/town planning and construction, energy, water resource management, fisheries, forestry, human health and social services, disaster management, transportation, tourism, sports and leisure etc.

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Dhar and Nandargi (1993a) have found that the severe rainstorms i.e., heavy rainfall over Indian region do not occur uniformly. They have found that all the rain storms, which have occurred over this region, have taken place during monsoon and pre-monsoon season only. Also the break up of meteorological disturbances causing the rainstorms indicates that 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.

During 8-9 August 2011 widespread heavy rainfalls recorded at different places of Bangladesh and its adjoining areas. Most of the rain gauge stations of Bangladesh Meteorological Department (BMD) recorded heavy (>44 mm/day) to very heavy (>88 mm/day) rainfall with the maximum of 254 mm at Hatiya followed by 218 mm at Cox's Bazar on 8 August. Likewise, on 9 August the maximum 207 mm rainfall was recorded at Teknaf followed by 169 mm at Mymensingh. TRMM Version 7 (TRMMV7) and TRMM 3B42RT (3B42RT) products have also the signature of high amounts of rainfall over Bangladesh. The spatial distribution of BMD recorded rain gauge rainfalls and the TRMM rainfalls of same locations are depicted in Figure 1. The event had significant socio-economic impact and for that attempt has been made to find out the reason(s) with the possibilities of timely and accurate issuance of forecast and warning along with the validation of model rainfall.

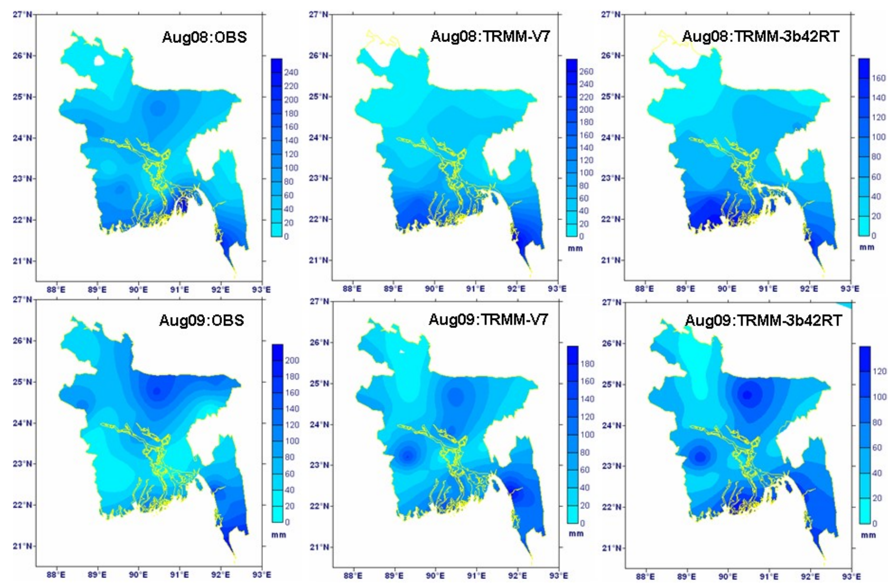

Figure 1: BMD Observed and TRMM rainfall in Bangladesh during 8-9 August 2011

2. METHODOLOGY

WRF ARW model (version 3.2.1) with the grid resolution of 9 km is used to diagnose the event using Ferrier (FR), Kessler (KS), Lin et al. (LN), WRF Single-Moment 3 Class (WSM3), WRF Single-Moment 5 Class (WSM5) and WRF Single-Moment 6 Class (WSM6) microphysics schemes (MPs) with the combination of Kain-Fritsch (KF) cumulus parameterization scheme for finding out the insight physical processes. The coverage area of model domain is 12-30ºN and 80-100ºE. The topography 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 23 sigma levels in the vertical direction from the ground to the 100 hPa level to simulate and analyze the parameters of sea level pressure (SLP), relative humidity (RH), wind, vorticity, convergence and divergence, cloud water mixing ratio (CWMR), rain water mixing ratio (RWMR), convective rain and non-convective rain etc. GrADS software is used for displaying the simulated and derived parameters of the model and TRMM data. WRF model, TRMM and observed rainfall at BMD's 35 rain gauge locations are used to calculate the temporal variation of area average, station average and point rainfall as well as and spatial variation of stations rainfall. For better understanding of the model rainfall variability, Bangladesh has been divided into the following regions: Northeast (NE), Northwest (NW), East-central (EC), West-central (WC), Southeast (SE), Southwest (SW), Chittagong and Sylhet regions. The ratio between model simulated and observed rainfall, correlation coefficient (CC) and frequency distribution of model simulated and observed rainfall are calculated using MS Excel based statistical package for finding out the deficiencies of the model and calculating the actual amounts of predicted rainfall on an area and location basis. Kringing Method facilitated by Win Surfer (version 7.0) software has been used for preparation of all kinds of spatial distributions.

3. RESUTS AND DISCUSSION

Simulated mean sea level pressure, surface and upper air relative humidity, wind at 10 m and upper levels, vorticity (x10^5 s^{-1}), rain water mixing ratio (x10^5 kg/kg), model simulated rainfall for different MPs with KF scheme, regional and country average rainfall, area specific station average rainfall according to the BMD's rain gauge location, spatial distribution of model simulated rainfall on the basis of BMD's rain gauge location, cloud water mixing ratio, vorticity for different MPs with KF scheme are plotted, presented and discussed in the following sub-sections. In order to examine the contribution of model simulated rainfall to observed rainfall, the ratio between model rainfall for different MPs with KF scheme and observed rainfall are also plotted and analyzed.

3.1 Mean sea level pressure and surface wind fields

A low pressure system is initiated over southwestern part of Bangladesh (Khulna and Satkhira regions and adjoining North Bay) at 0300 UTC of 8 August 2011. Then it moved north-northeastwards initially and intensified into Depression over Dhaka and adjoining areas. It then recurved northwesterly direction and located over Rajshahi and its adjoining areas of Bangladesh at 0000 UTC of 9 August 2011 and moved slowly westwards to West Bengal of India. The system intensified further into a Deep Depression at about 2100 UTC of 9 August 2011 over the same area and weakened afterwards gradually by giving precipitation. The track of the system, estimated minimum central pressure and pressure fields (with wind field at 10 m) for all combination of KF scheme and MPs are given in Figs. 2-4 respectively.

Analysis reveals that after reaching the system over West Bengal of India and adjoining western part of Bangladesh, the central pressure decreased rapidly; the system intensified into a Deep Depression and the lowest central pressure lowered to 981.9 hPa for KFFR at 2200 UTC of 9 August 2011 and after that the central pressure of the system increased. When the system recurved towards northwest and then west over Bangladesh, its isobaric pressure distribution at surface level was circular; associated wind distribution turned into strong and converged to the centre of the system strongly which helped to carry enormous amounts of moisture for heavy precipitation.

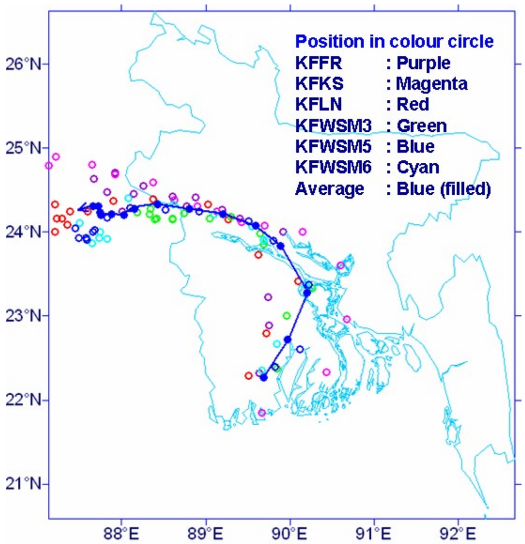

Figure 2: Track of the depression for different MPs with KF scheme

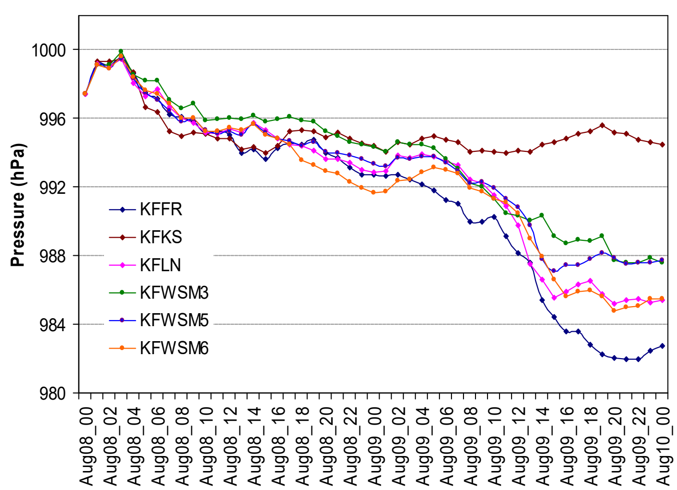

Figure 3: Minimum central pressure of depression for different MPs with KF scheme

3.2 Surface relative humidity and wind

When the low pressure system was over the southwestern part of Bangladesh and weak, its associated maximum moisture tongue at surface level was over North Bay of Bengal though there were sufficient moistures over Bangladesh and its adjoining areas. But with the progress of time and movement and intensification of the system the moistures were accumulating in and around the system over Bangladesh. The maximum moisture tongue also followed the system's movement. The zonal components of surface wind field over Bangladesh and its adjoining areas were negative but the meridional components were positive. The maximum moisture tongue was either the right side or over the central part of the system caused high amounts of rainfall over Bangladesh. This situation is found for all combinations of KF scheme and MPs as in Figure 5. On 9 August, the system moved northwestwards further along the monsoon axis and weakened gradually. Following this the associated moisture field also weakened. But in the afternoon of 9 August 2011 a micro-scale vortex formed within monsoon trough over southern coastal areas of Bangladesh and moved northward and accumulated moistures further over Bangladesh for occurrence of heavy rainfall.

3. 3 Upper air relative humidity and wind

With the progress of time the system extended in the vertical direction rapidly and accumulating moisture. In this regard associated cyclonic circulation extended from lower level to as high as 300 hPa level and moved following the path of its surface position with eastward slanting as westerly was not present upto 100 hPa level over Bangladesh and adjoining areas during this period. But the maximum strength of the system was within the layer of 850-700 hPa. The vertical distribution patterns were almost similar (Figure 6) and the vortex extended upto 250 hPa level for KFFR, KFKS, KFLN, KFWSM3, KFWSM5 and KFWSM6 respectively. This situation helped the system to carry moisture up to an unprecedented higher level for occurring heavy rainfall.

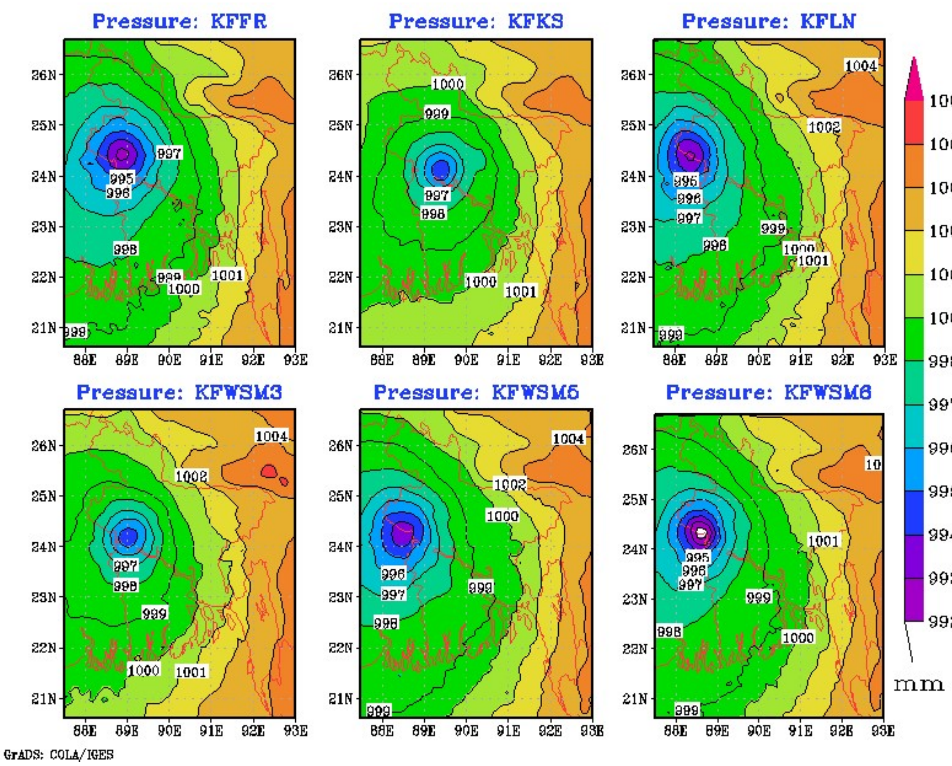

Figure 4: Surface pressure fields over Bangladesh and adjoining areas at 0000 UTC of 9 August 2011

3.4 Vorticity

Area average vertically integrated vorticity of 950-100 hPa level was positive over Bangladesh and adjoining areas during 8-9 August 2011. But it increased with the progress of time on 8 August 2011 and reduced to a lower value on 9 August of 2011 (Figure 7). Area average vorticity extended up to 350 hPa level in the morning of 8 August 2011 when the system was weak and located over southwestern part of Bangladesh. But with the progress of time positive vorticity extended upward and reached as high as 150 hPa level at 1200 UTC of 8 August when the maximum vorticity was at 800 hPa level (Figure 8). During the remaining period of the day positive vorticity remained extended upto 200 hPa levels for KFFR. Similarly it extended up to 150 hPa level during 0800 UTC to rest period of the day for KFKS, up to 200 hPa level during 1000 to 1700 UTC for KFLN, up to 200 hPa level during 1000 UTC to remaining period of the day for KFWSM3, KFWSM5 and KFWSM6 (Figure 9).

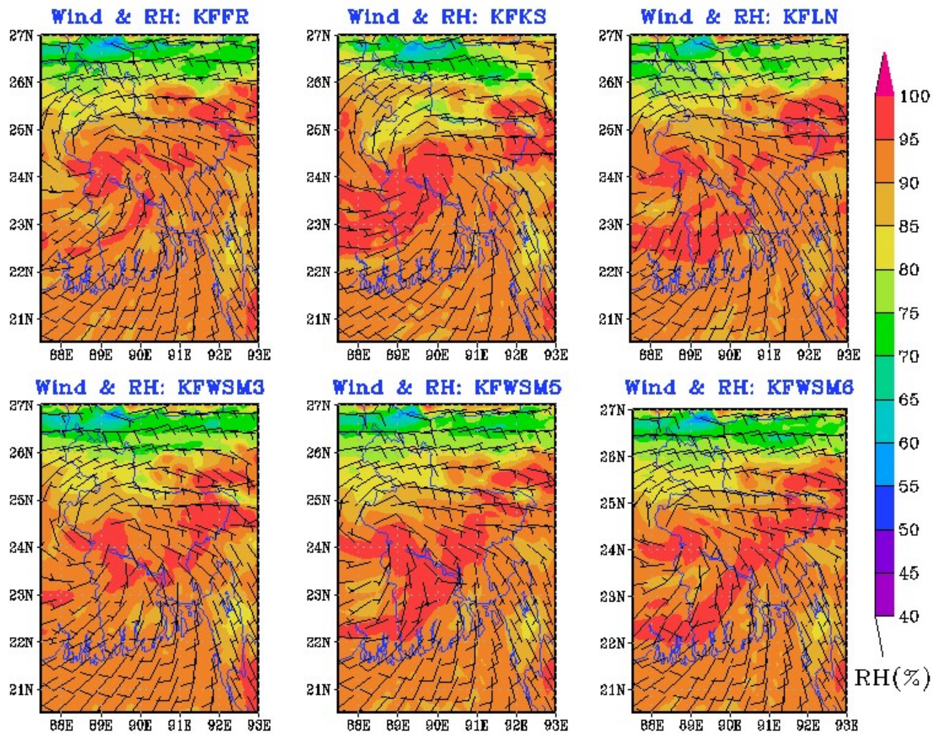

Figure 5: Surface RH and wind fields over Bangladesh and adjoining areas at 0000 UTC of 9 August 2011

3.5 Rain water mixing ratio

Integrated amount of area average rain water mixing ratio ($x10^5$, kg/kg) in the lower troposphere increased with the movement and intensification of the system over Bangladesh on 8 August 2011. KFWSM3 shows higher amounts rain water mixing ratio but it is lower and closer to each other for all other combinations (Figure 10(a)). It was lower on 9 August than that of 8 August 2011 but it was high in the morning and late hours of the day (Figure 10). The significant amount of rain water mixing ratio are mainly composed in the lower levels (below 500 hPa level) for KFFR, KFLN, KFWSM5 and KFWSM6 but for KFKS and KFWSM3 it extended up to 100 hPa level, this may be due to some sort of deficiencies associated with WSM3 MP (Figure 11). Similar situation with lower rain water mixing ratio are observed on 9 August 2011.

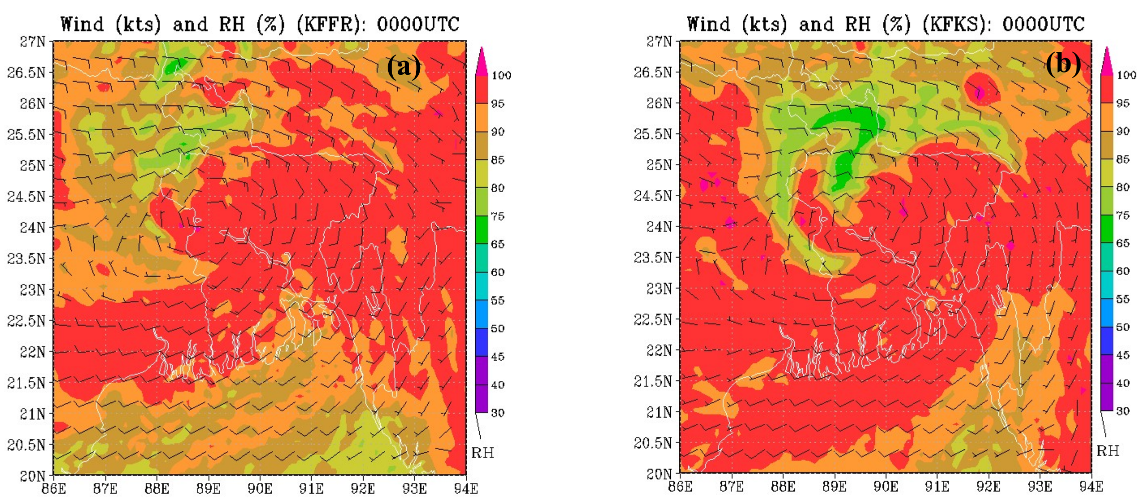

Figure 6: Wind and RH at 500 hPa level for (a) KFFR and (b) KFKS at 0000 UTC of 9 August 2011

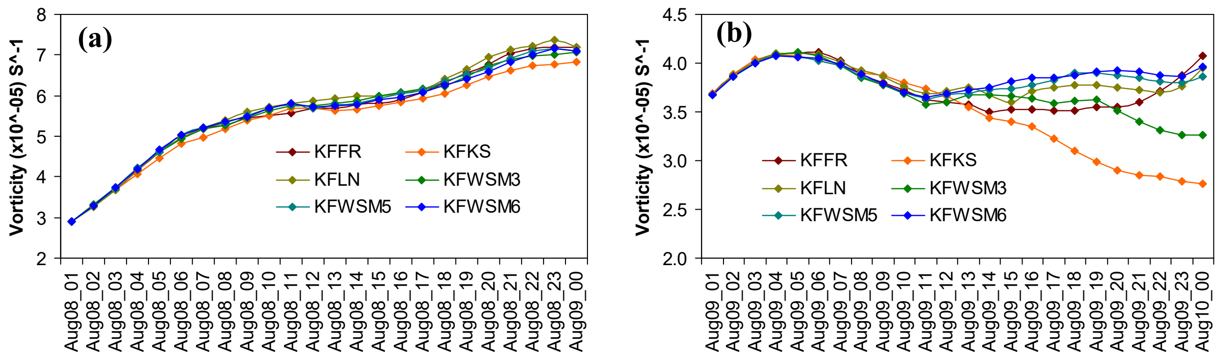

Figure 7: Area average vertically integrated vorticity for (a) 8 August and (b) 9 August 2011

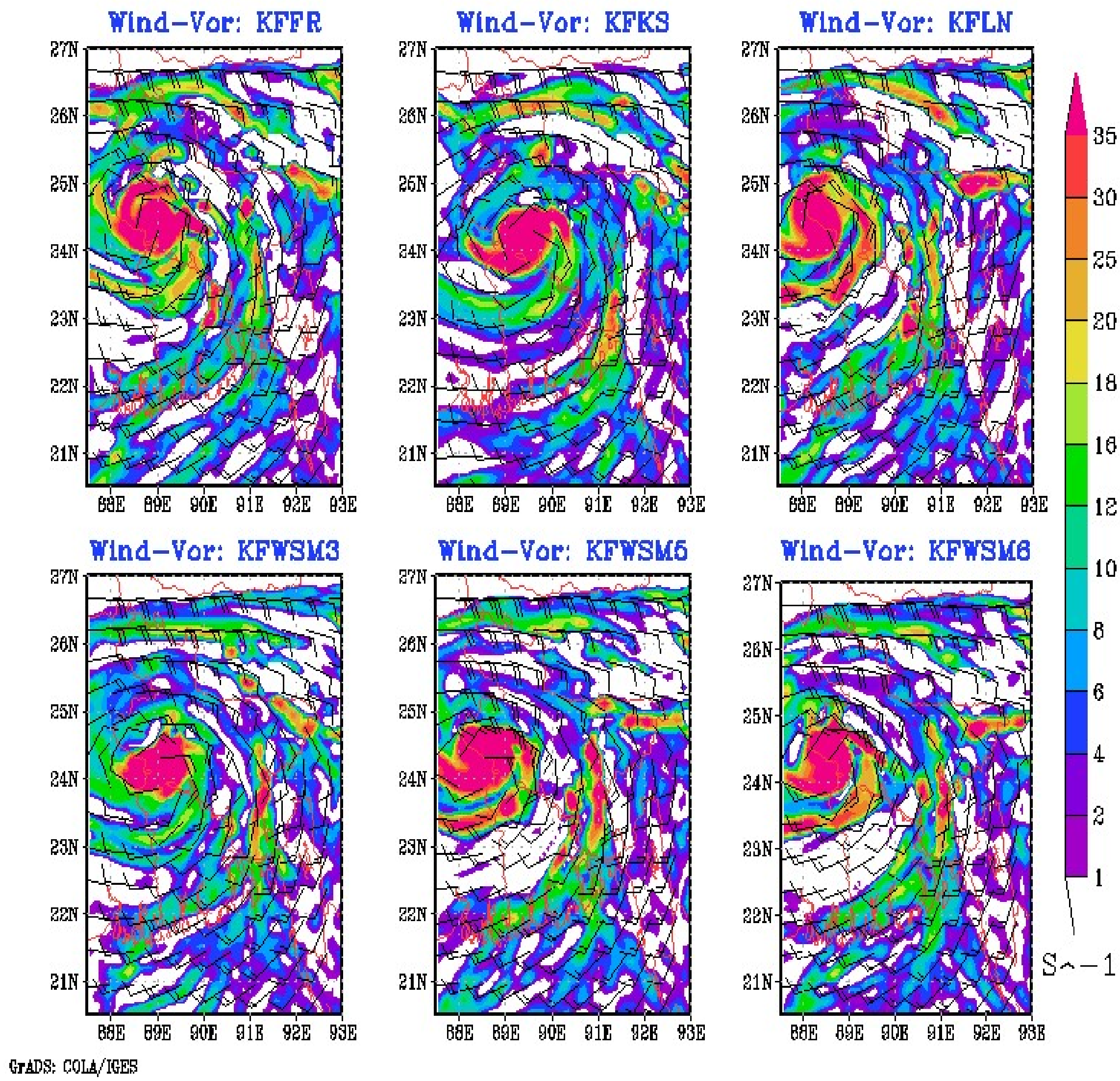

Figure 8: Vorticity and wind field at 800 hPa level over Bangladesh at 0000 UTC of 9 August 2011

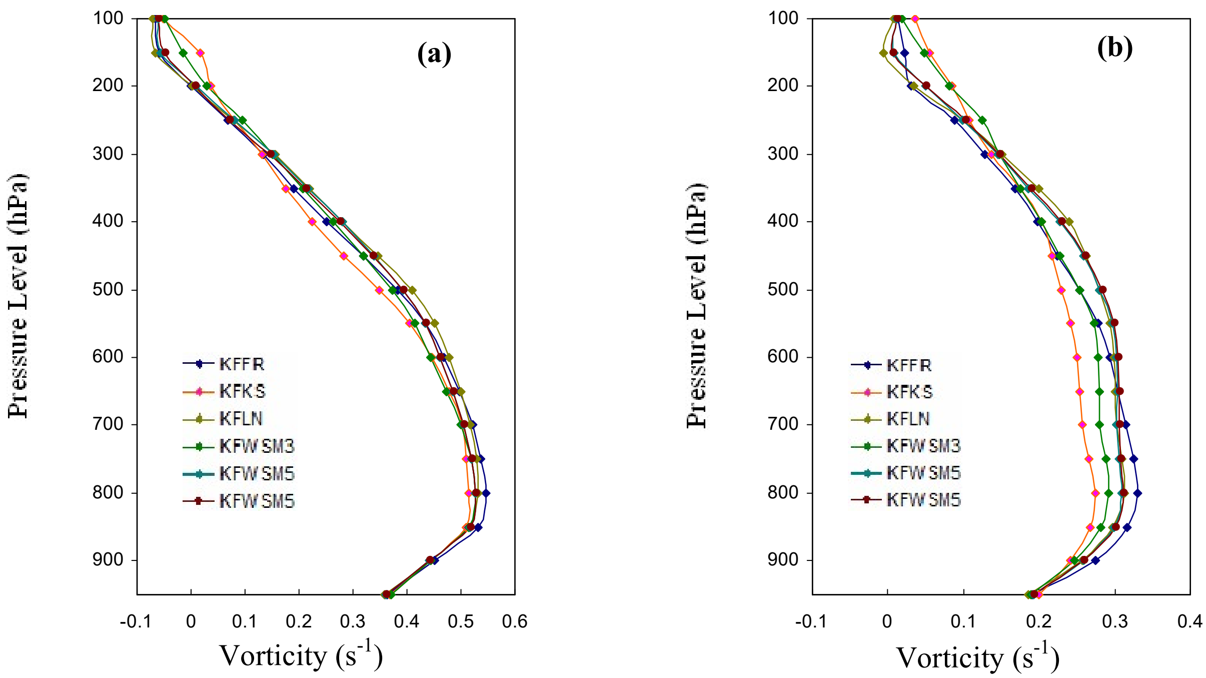

Figure 9: Vertical distribution of area average vorticity (x10^5 s^{-1}) for (a) 8 August, and (b) 9 August 2011

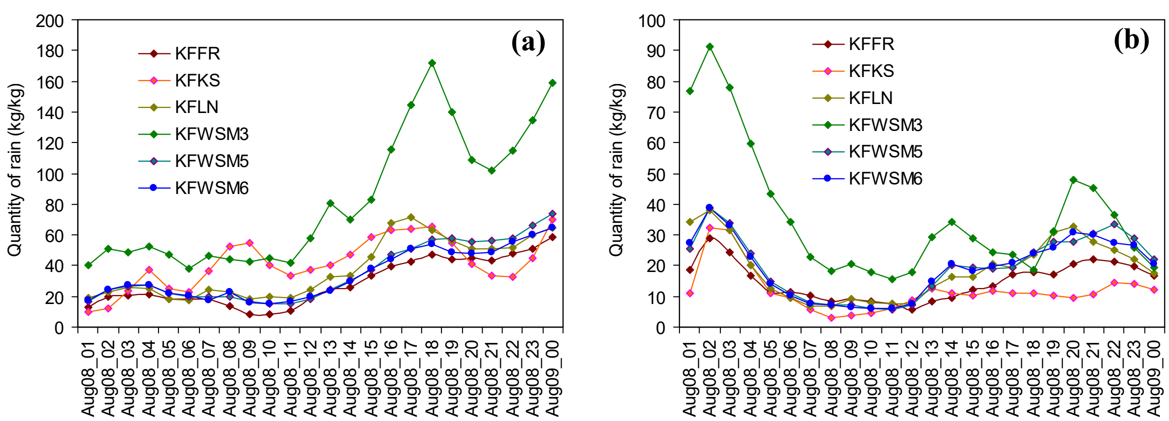

Figure 10: Temporal variation of vertically integrated area average quantity of RWMR (x10^5 kg/kg) of lower troposphere for (a) 8 August, and (b) 9 August 2011

3.6 Surface wind and Rain band

According to the surface moisture and wind field, the rain band associated with the system moved towards Bangladesh which was observed initially over the Bay of Bengal. During morning period of 8 August, the rain bands were weak and widely distributed over the North Bay of Bengal but with the progress of time and movement of the system it became strong, squeezed and linked with the low pressure system and located either over the southern or eastern side of the system. This situation is very much correlated with the occurrences of heavy rainfall over Bangladesh. The distribution patterns of wind and rain band of each combination are almost similar to each other (Figure 12).

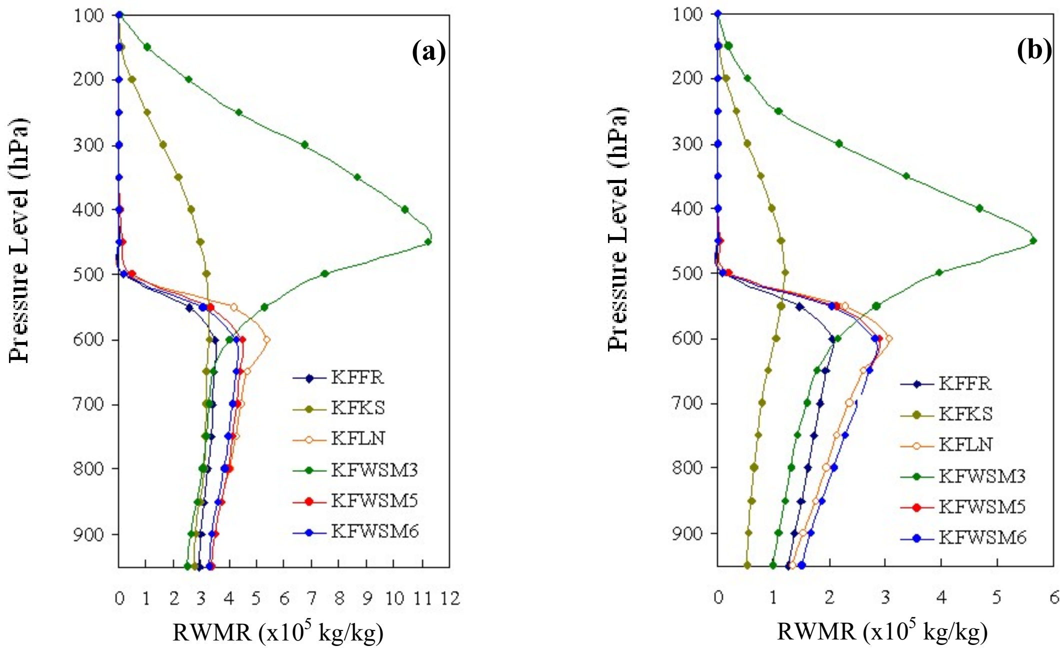

Figure 11: Vertical distribution of area average RWMR (x10^5 kg/kg) for (a) 8 August, and (b) 9 August 2011

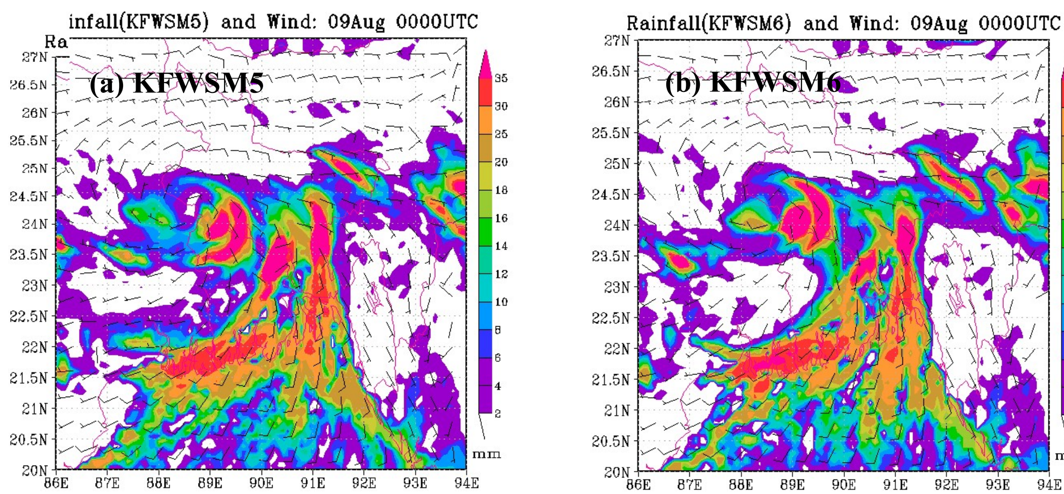

Figure 12: Rain band for (a) KFWSM5, and (b) KFWSM6 at 0000 UTC of 9 August 2011

4 RAINFALL ANALYSES AND COMPARISON WITH TRMM

4.1 Regional average rainfall

Model rainfall over Chittagong region is lower than TRMM (TRMMV7 and 3B42RT) with an exception of KFWSM5 rainfall which is higher than 3B42RT but lower than TRMMV7. In EC region, rainfalls for all combinations are higher than TRMM. In NE region, rainfalls for KFWSM3, KFWSM5 and KFWSM6 are very close to TRMM; KFKS rainfall is lower and KFFR and KFLN rainfalls are slightly higher than TRMM as in Figure 13(a). In the NW region, KFKS rainfall is very close to TRMM but for other combinations it is higher than TRMM. In the SE region rainfalls of all combinations are slightly lower than 3B42RT and TRMMV7. In the SW region, KFKS rainfall is the lowest but rainfalls of all other combinations are close to TRMM. In Sylhet region KFKS rainfall is lower than TRMM; KFFR and KFLN rainfalls are higher than TRMM but for other combinations it is close to TRMM. In the SW region, KFKS rainfall is very comparable to TRMM but in other cases it is higher than TRMM. In brief, the regional average of KFKS rainfalls are Bangladesh are lower by 12% than TRMM but for other combinations it is higher by 17-36% on 8 August 2011. In Chittagong, SE, SW and NE regions model rainfalls are lower by 45, 25, 12 and 5% respectively but in the Sylhet, EC, WC and NW regions it is higher by 5, 72, 76 and 111% respectively than TRMM. Accordingly the regional average model rainfall is 21% higher than TRMM in Bangladesh on 8 August 2011.

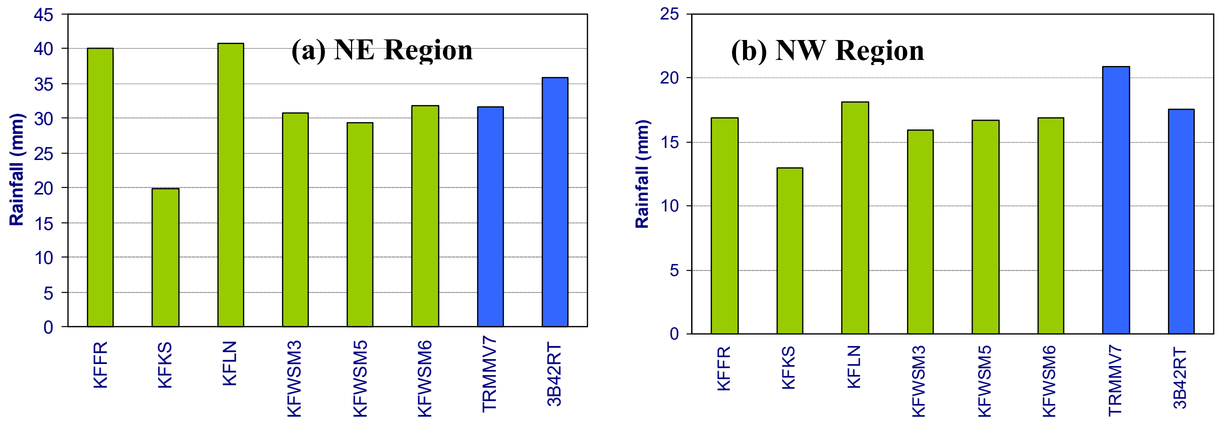

Figure 13 Rainfall over (a) NE region on 8 August, and (b) NW region on 9 August 2011

On 9 August model simulated average rainfall over Chittagong region is lower than TRMM for all combinations. In EC region model simulated rainfall is slightly lower but comparable to TRMM. In NE region model simulated rainfall for each combinations are lower than TRMM but in the case of KFKS it is very low. In NW region model simulated rainfall for KFKS is lower than TRMM but it is very close to TRMM in all other combinations as in Figure 13(b). In SE region rainfall for all combinations are close to each other but the amounts are lower than TRMM. In SW region rainfall accounted for KFFR is the maximum and KFKS is the minimum but the amounts for all combinations are lower than TRMM. In Sylhet region, rainfall for KFKS is the lowest followed by KFWSM3 but the amounts for all other combinations are higher, closure to each other and are comparable to TRMM. In SW region, model simulated rainfall for KFKS is the lowest and it is higher in all other combinations but the amounts are lower than TRMM. The regional average rainfalls of Bangladesh on 9 August are lower than TRMM by 66% for KFKS, 50% for KFWSM3, 38% for KFFR, KFWSM5 and KFWSM6 and 34% for KFLN. In Chittagong, NE, SW, WC, SE, Sylhet, EC and NW regions model simulated rainfall deviations are -68, -59, - 54, -52, -42, -36, -34 and -15%, respectively. As a result the regional average rainfall is 44% lower than TRMM in Bangladesh on 9 August 2011.

4.2 Station average rainfall

Station average rainfalls for different MPs with KF scheme are given in Figure 14. Figure 14 (a) illustrates that the amount of station average KFKS rainfall of 8 August is the lowest which is quiet lower than observation. The amounts of rainfall simulated by KFFR, KFWSM3 and KFWSM are very close to observation and TRMMV7 but others are slightly lower. The standard deviation for each combination is lower than mean value. On 9 August, the amounts of simulated rainfalls are much lower than observation and TRMM with the lowest amount for KFKS as in Figure 14(b). Amounts of rainfall at station point on 8 August are very close to observation in most of the cases but on 9 August it is very much lower than observation in most of the cases (Figure 15).

4.3 Rainfall over Bangladesh and its surroundings

Model has successfully simulated the signature of heavy rainfall with strong rain bands over central to southern parts of Bangladesh and adjoining North Bay of Bengal on 8 August 2011 (Figure 16) which is very much associated with the humidity and vorticity field. It failed to simulate the rain band on 9 August 2011 properly with the initial condition of 0000 UTC of 8 August 2011 done that with the delayed initial condition of 0000 UTC of 9 August 2011 (Figure 17).

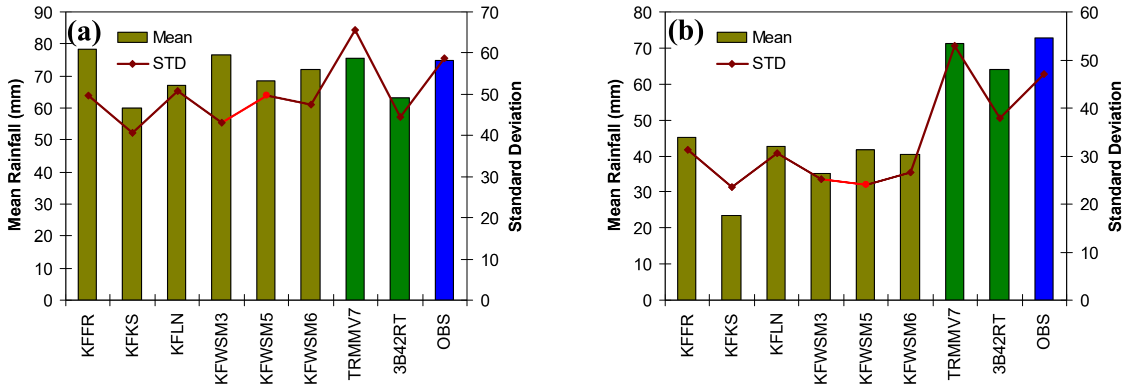

Figure 14: Station average rainfall and their standard deviation for (a) 8 August and (b) 9 August 2011

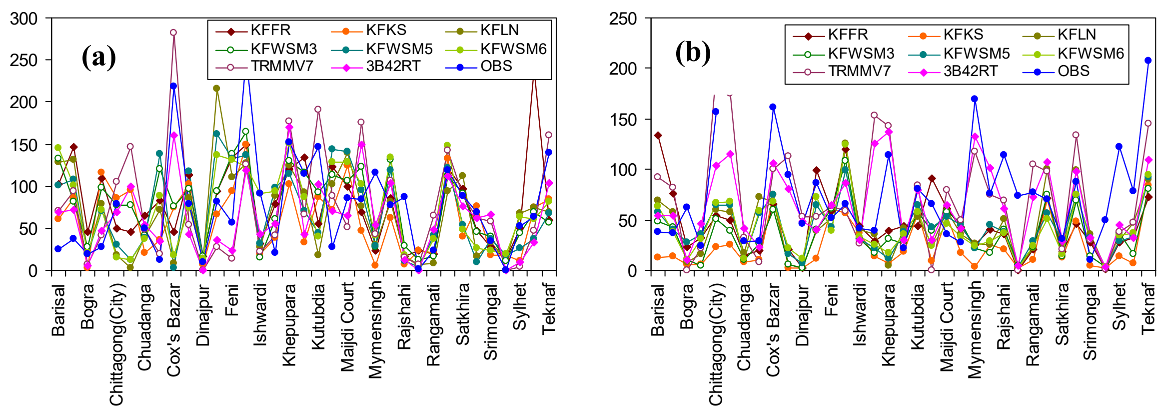

Figure 15: Model, TRMM and observed rainfall of (a) 8 August 2011, and (b) 9 August 2011

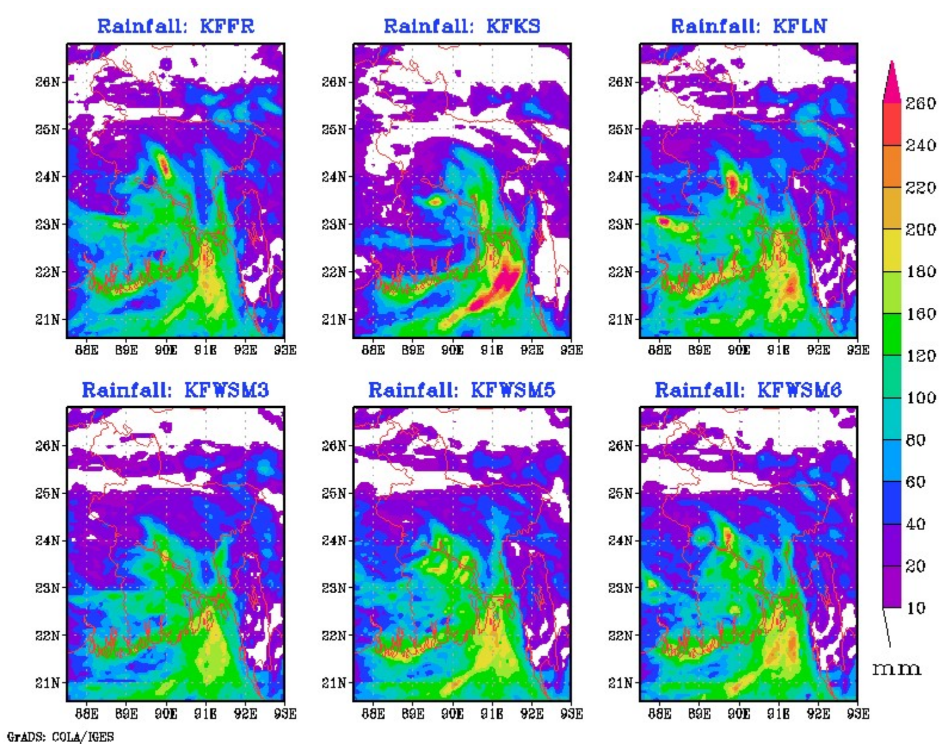

Figure 16: Model rainfalls for different MPs with KF scheme over Bangladesh on 8 August 2011

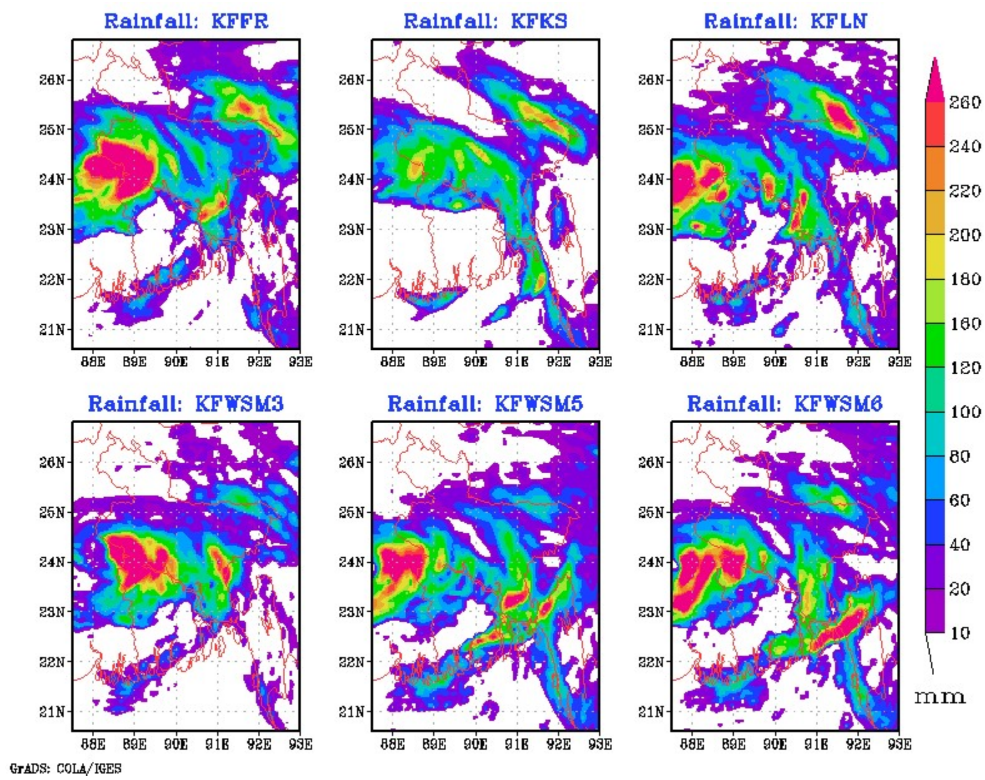

Figure 17: Model rainfalls for different MPs with KF scheme on 9 August 2011

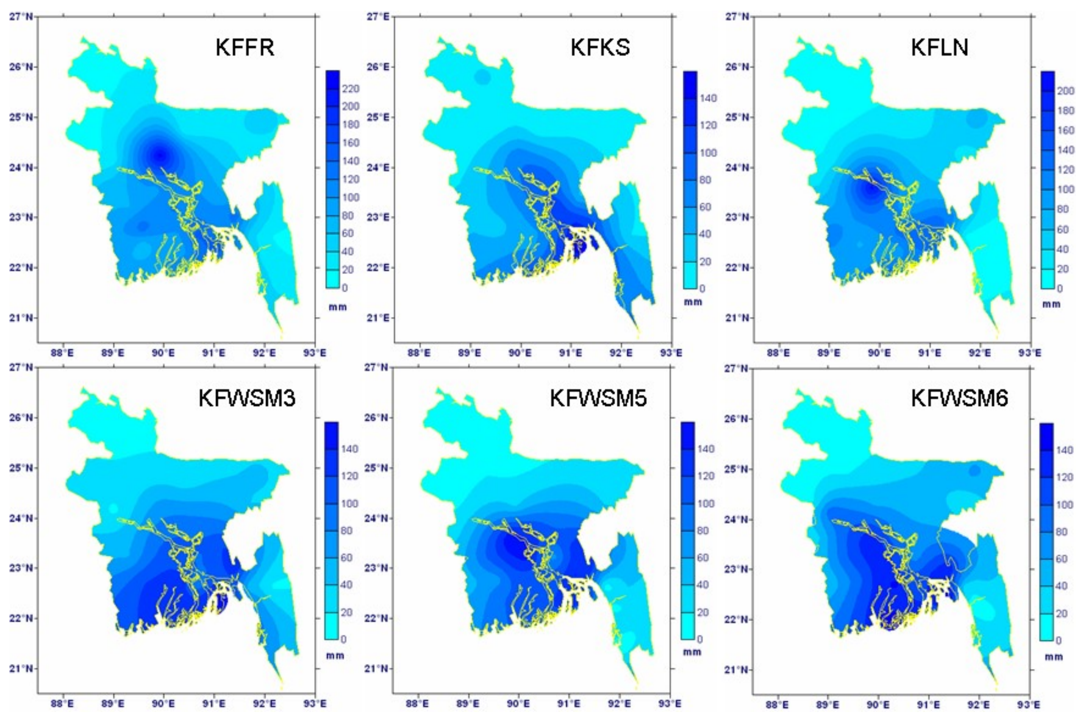

Figure 18: Model rainfall distributions for 8 August 2011 on the basis of BMD rain gauge location

4.4 Spatial distribution of model simulated rainfall on the basis of rain gauge location

On the basis of the model simulated rainfall at rain gauge location, spatial distributions of rainfall on 8 August and 9 August 2011 of Bangladesh have been prepared and depicted in Figure 18. Analysis exposes the signature of higher rainfall over central and south-central parts of Bangladesh but observation and TRMM denotes signature over north-central and south-central regions. It is also noticed that the amounts of maximum rainfalls are close to observation in most of the cases but TRMM shows lower amounts than simulation and observation on 8 August. On 9 August model has simulated the signature of high amounts of rainfall over southeastern part but fails to simulate the signature of high rainfall over north-central region where observation and TRMM has the signature.

5. VALIDATION OF MODEL RAINFALL

5.1 Correlation coefficients (CC) between model simulated and rain gauge rainfall

CC between model and observed rainfall at rain gauge locations varies highly and for some MPs it is very low. The maximum CC is found for KFKS. On 8 August it is 0.50, on 9 August it is 0.36 but for the duration of 8-9 August it is 0.46. TRMM rainfall shows higher CCs than model as given in Table 1.

Table 1: CC between model and observed rainfall at rain gauge location

Date	Model						TRMM	
	KFFR	KFKS	KFLN	KFWSM3	KFWSM5	KFWSM6	TRMMV7	3B42RT
8 August	0.21	0.50	0.16	0.41	0.12	0.21	0.72	0.70
9 August	0.10	0.36	0.19	0.34	0.32	0.34	0.59	0.59
8-9 August	0.18	0.46	0.23	0.37	0.19	0.30	0.57	0.59

5.2 Frequency distribution of model simulated and observed rainfall

Frequency distribution of model simulated and observed rainfall expose that biases of model rainfall frequency are higher in the low intensity rainfall and distribution pattern is similar for all MPs and TRMM. On 8 August the maximum biases are found in less than 150 mm rainfall, on 9 August it is found for less than 120 mm and during 8-9 August it is found for less than 220 mm. Bias of average frequencies of different MPs leads close value of observation. The cumulative density function (CDF) for model rainfall of 8 August is above but dose to CDF of observation. On 9 August CDF moves far apart. The CDFs of model simulated and observed rainfall during 8-9 August are apart than that of 8 August whereas it is close than 9 August. However, average CDF of model simulated rainfall for different MPs are close to the CDF of the observed rainfall than the CDFs of each individual combination rainfall CDF.

5.3 Correlation coefficients (CC) between area averaged model simulated and observed rainfall

Area averaged model simulated rainfalls are lower than observation and TRMM in each region but the phase shifts of rainfall cycles are almost collinear to observation and TRMM. Accordingly the magnitudes of the CCs are low. The maximum CCs of model simulated rainfall and observation over Bangladesh, Chittagong, EC, NE, NW, SE, SW, Sylhet and WC regions are 0.48 (KFWSM5), 0.39 (KFWSM5), 0.16 (KFFR), 0.40 (KFKS), 0.73 (KFFR), 0.27 (KFKS), 0.49 (KFKS), 0.50 (KFFR) and 0.35 (KFFR) respectively. The CCs of model rainfall with TRMM are higher and the magnitudes of CCs are 0.71 (KFKS), 0.53 (KFWSM6), 0.35 (KFWSM3), 0.58 (KFWSM5), 0.45 (KFKS), 0.55 (KFFR), 0.53 (KFWSM3), 0.28 (KFWSM6) and 0.19 (KFWSM5).

5.4 Temporal variation of model simulated and observed rainfall

Temporal variations of model simulated rainfall at station locations are not consistent with the observation and TRMM. It shows significant correlation with some isolated location. The maximum CCs 0.74 (Comilla), 0.83 (Sylhet), 0.73 (Rangpur), 0.66 (Mongla), 0.66 (Sylhet), and 0.78 (Rangpur) are observed respectively for KFFR, KFKS, KFLN, KFWSM3, KFWSM5 and KFWSM6 respectively. Similarly the maximum CCs of average model simulated rainfall for different MPs during the observed period are 0.59 (Sylhet), 0.57 (Mongla), 0.44 (Comilla) and 0.43 (Feni). But the station average model simulated rainfall leads better correlation with the observation.

5.5 Ratio of model simulated and observed rainfall

The spatial distribution of the ratio of model simulated and observed rainfall are higher in the EC and adjoining WC part for all MPs on 8 August. In addition to this isolated high ratio zones are found in the northwestern part for maximum cases. On 9 August, it is higher in the Srimongal in sylhet region and some parts of EC region. But the ratios of rainfall during 8-9 August are higher in the EC and adjoining WC regions for all MPs (Figure 19).

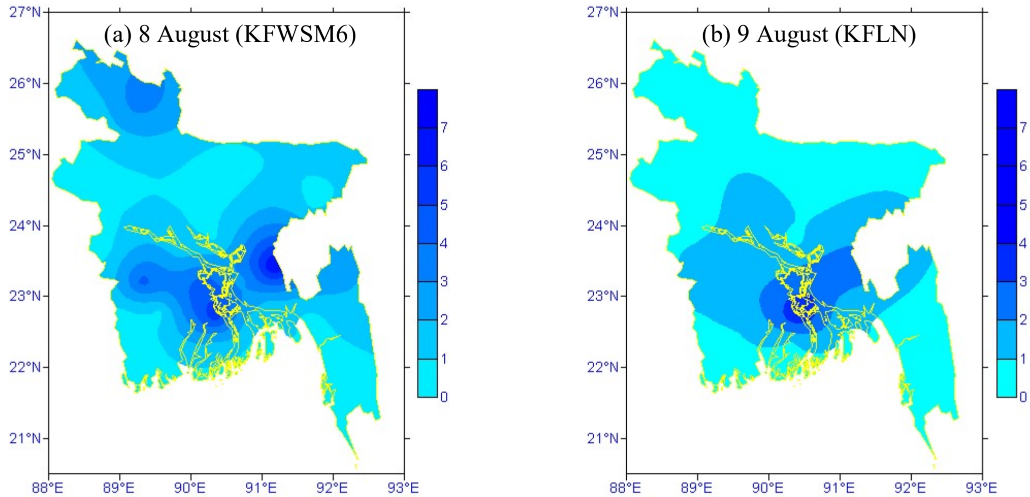

Figure 19: Spatial distribution of the ratio of model and observed rainfall of (a) 8 August 2011 (KFWSM6) and (b) 9 August 2011 (KFLN)

5.6 Estimation of model predicted rainfall

Model simulated rainfalls are not exactly equal to the observation but there is a close relationship between model simulated and observed rainfall. Prediction of actual amount of rainfall over an area or a location is a challenging job to the meteorologists. Simulated rainfalls for cumulus parameterization scheme with different MPs are sometimes case dependent. It is better to use a number of cumulus parameterization scheme with different micrphysics schemes which is also time consuming but it requires high computing facilities. Due to the improvement of information technology, computing facilities are increased remarkably in the recent years. Therefore, establishment of multiple regression equation(s) with the combinations of cumulus parameterization schemes with MPs may be one of the best solutions for accurate prediction of an area average and location specific rainfall. In this regard the following regression equations are attempted to set up under this study:

(i) Area average rainfall

a. NE region: $y= 0.98x_1-1.64x_2+ 0.19x_3-0.86x_4+2.76x_5-1.13x_6+4.97$

b. NW region: $y= 1.32x_1+0.08x_2+0.17x_3-2.41x_4+0.31x_5+0.69x_6+2.48$

c. EC region: $y = -0.06x_1-0.25x_2-0.18x_3+0.59x_4- 0.39x_5+0.21x_6+5.82$

d. WC region: $y = -0.11x_1-0.96x_2+0.94x_3-0.13x_4-0.87x_5+0.30x_6+13.54$

e. SE region: $y = 5.48x_1+1.31x_2-2.18x_3-5.31x_4+4.43x_5-3.69x_6+17.50$

f. SW region: $y = -0.07x_1-1.29x_2+1.19x_3+1.41x_4-5.12x_5+3.48x_6+8.02$

g. Chittagong region: $y = -3.21x_1-1.30x_2-2.35x_3+5.41x_4+0.12x_5+1.17x_6+12.54$

h. Sylhet region: $y = 1.09x_1+0.16x_2-0.43x_3-0.60x_4-1.18x_5+1.71x_6+1.08$

i. Bangladesh : $y = 0.14x_1-2.88x_2+2.60x_3-1.31x_4+0.85x_5-0.42x_6+10.00$

(ii) Location specific rainfall

a. For 8 August 2011: $y= -0.39x_1+0.79x_2+ 0.30x_3+0.86x_4-1.15x_5+0.33x_6+28.98$

b. For 9 August 2011: $y= -0.62x_1+0.35x_2-1.60x_3+1.26x_4-0.14x_5+1.66x_6+55.42$

c. For 8-9 August 2011: $y= -0.45x_1+0.84x_2+0.10x_3+0.74x_4-1.30x_5+0.78x_6+97.38$

where, y is actual amount of predicted rainfall over an area or a location; x_1, x_2, x_3, x_4, x_5 and x_6 are the model simulated rainfalls for the combination of KFFR, KFKS, KFLN, KFWSM3, KFWSM5 and KFWSM6 respectively.

6. CONCLUSION

Model efficiently identify the genesis, intensity and track of the low pressure system over Bangladesh during 8-9 August 2011 on the basis of initial and boundary conditions of 0000 UTC of 8 August 2011. The pressure fields, central pressures of the system, surface and upper air wind fields, surface and upper air humidity fields, vorticity fields and vertical profiles are very much supportive to the life cycle of the system. Following these properties, model generates the high intensity rain bands over central to northern part of Bangladesh and adjoining north Bay of Bengal on 8 August 2011 the amount of rainfall for 9 August 2011 is not, may be due to limitation of the model or to the shortfall with the boundary conditions. But it simulates the high intensity rain bands over Bangladesh and adjoining areas with the initial conditions of 0000 UTC of 9 August 2011 which has the signature over Bangladesh. Model simulated rainfalls are not exactly equal to the observation and therefore multiple regression equation with the combinations of CPs and MPs is one of the best solutions in the prediction of area average and location specific rainfalls.

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