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Study of Heavy Rainfall Event (HRE) over Bangladesh Using Weather Research and Forecasting (WRF) Model

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Abstract: *The HRE of 16-17 June 2011 over Bangladesh was chosen for the current study to simulate using WRF model. The FNL data of 1.0°×1.0° grids was considered as an initial and lateral boundary condition. A domain of 9 km horizontal resolution was considered for the study with using WSM6-MP scheme, KF-CP scheme and YSU-PBL scheme. To assess the model efficiency the SLP, wind flow, RH, relative vorticity and vertical wind shear are examined. The depression stays for a long term over the southwestern region and with the wind speed of 10-30 ms*$^{-1}$ *a cyclonic circulation is observed over that region up to 500 hPa level. The positive relative vorticity is about* 80×10^{-5} s^{-1} *which specify the presence of high convective action. A lots of moisture from the Bay of Bengal with the southwesterly flow reaches towards the south, southeastern and northern region and the RH is of the order of 90-100%, which intensify the convective activity. Due to the presence of the above sufficient favorable conditions for convective activity the area of Barisal, Bhola, Madaripur, Teknaf, Cox's Bazar, Hatiya, Khepupara, M. Court, Sandwip and Patuakhali experiences a huge amount of rainfall. The BMD observed data is overestimated by the model simulated data but the model is proficient to find the exact location where the rainfall event occurs or not.*

Keywords: *WRF model, HRE, MP scheme, RH, CP scheme.*

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I. Introduction

Bangladesh is a monsoonal country and experiences huge amount of rainfall in monsoon season [1]. Generally the northeast region of the country have faced higher precipitation during this season because from the Bay of Bengal the monsoon depressions moves towards the northward direction and also a strong southwesterly flow of winds carrying a lots of water vapor over these regions and adjoining area [2-3]. The heavy rainfall is the main reason for the flash flood which damage the properties and lives at a time. Again the lack of adequate rainfall is also influence the drought that can have a bad impact on economy [4]. So, the analysis and the precise forecast of Heavy Rainfall Event (HRE) is the challenging job for scientists but very essential in water resources, agricultural production and many other human life activities [5]. On the basis of the different numerical modeling system previously a plenty more ideas or study has been performed all over the world. These whole research works discussed about the rainfall estimation, forecasting and probabilities.

Almazroui *et al.* [6] studied extreme rainfall event over Jeddah and found that over Jeddah and adjoining regions a strong low level wind is present which greater the moisture and creates an unstable favorable situation for the mesoscale system. Adedejil *et al.* [7] have discussed the monthly deviation and annual trends of rainfall in Nigeria and refers to the rising rainfall pattern in Nigeria. Kirtsaeng *et al.* [8] have been used WRF model for the simulation of HRE over Mumbai. They suggested that the BMJ scheme simulates the precise location of the extreme rainfall over Mumbai. Srinivas *et al.* [9] also studied the local monsoon climate of Indian summer season with the help of WRF model and they reported that the GD had higher dry bias and smallest bias to dryness has found from BMJ scheme. Bhuyan *et al.* [10] studied about the tendency of temperature and rainfall of the northwestern area of Bangladesh for the climate change prediction and reported that temperature shows an increasing trend and rainfall shows a decreasing trend through per century. Ahasan *et al.* [11] studied the HRE that exceeds around the southeast part of Bangladesh by means of WRF model and found that the HRE and associated synoptic features are simulated quite better though some biasing is present in the observation of rainfall pattern. Hossain *et al.* [12] studied the temporal and spatial inconsistency of rainwater nearby the south-west coast of Bangladesh and they suggested that during the period of 1948-2007 the rainfall of the winter or post-monsoon season at most of the station follow the significant positive trends.

The goal of this study is to inspect some meteorological factors for instance, SLP, wind flow, relative vorticity, RH and vertical wind shear and discover the liability of these parameters for rainfall occurrence.

Another intents of this study is to check the proficiency of the model for finding the precise site for the happening of rainfall event.

II. Synoptic Situation

Above the northwest Bay of Bengal and its adjacent area, a low pressure region is created on 14 June 2011 and on 15 June this pressure is situated near the similar region as a well-marked low pressure zone. At 0300 UTC of 16 June it centralize into a depression closest to the lat. 21.5° N and lon. 89.0° E, after the increase of time it deepened into a deep depression around the similar area at 0600 UTC of 16 June. At 1200 UTC of 16 June it reach towards the Gangetic West Bengal and adjacent Bangladesh (22.0° N, 89.0° E) which is situated 100 km southeast of Kolkata. Traveling a little northwards, it hold nearby the position of 22.5° N and 89.0° E which is situated 80 km east of Kolkata at 0300 UTC of 17 June. Afterward going westwards, it stay above the Gangetic West Bengal, close to the position of 23.0° N and 88.0° E at 1200 UTC of 17 June. Also advancing westwards, then it situated around Gangetic West Bengal and adjacent zones of Jharkhand, positioned near 23.0° N and 87.0° E which is 25 km away from south of Bankura at 0300 UTC of 18 [13]. Due to this deep depression Bangladesh and the adjoining area experiences HRE.

III. Data Used

The National Centre for Environmental Prediction (NCEP) high-resolution Global Final (FNL) analysis data was used for the initial and lateral boundary condition. This FNL data cover the whole world every six hours with 1.0°×1.0° grids. The 30 second United States of Geological Survey (USGS) data was used for the simulation of terrain or topography. By means of the vegetation or land use coverage the 25 categories USGS data was used. In this study we introduce the BMD observed data to make a comparison with the model simulated data.

IV. Model Setup And Methodology

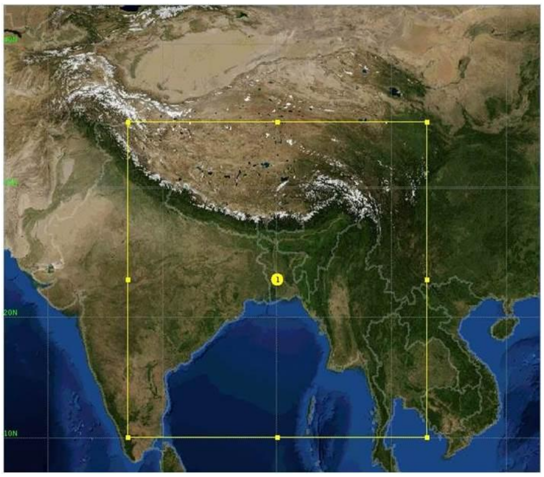

Figure 1. Domain for the present study.

There are several mesoscale models are used for simulation but here the Weather Research and Forecasting (WRF) model that is consists of fully compressible non-hydrostatic equations and different prognostic variables have been used for the present research work. The terrain following hydrostatic pressure is used by means of the model vertical coordinate. The Arakawa C-grid staggering is the horizontal grid of the model. In the model the 3^{rd} order Runge-Kutta time integration is used. A domain was used with the horizontal resolution of 9 km for capturing the area of HRE. 295 grid points are consisted in the east west and 304 grid points are consisted in the north south direction of the domain. The configuration of the domain is also consists of the similar vertical structure of 38 asymmetrically spaced sigma (non-dimensional pressure) levels. The canter (23.5^0 N, 90^0 E) of the domain was taken over Bangladesh. There are different physical schemes are used in this study. As a Microphysics (MP) scheme the WRF Single Moment 6-class (WSM6) scheme [14], as a Cumulus Parameterization (CP) scheme the Kain-Fritsch (KF) scheme [15] and as a Planetary Boundary Layer (PBL) scheme the Yonsei University (YSU) scheme [16] was used. On the basis of the initial condition 0000 UTC on 16 June 2011 the model was run for 48 hours. The synoptic situations valid for 1800 UTC of 16-17 June 2011 are analyzed in the present paper. The model configurations are shown in following Table 1 and also the domain for the present study is given in Fig. 1.

Table 1. Table for the model configurations.

Number of domain	1	Time integration	3rd order Runge-Kutta
Domain central points	23.5^{0}N*90^{0}E as Lat*Lon	Initial conditions	FNL Data (1° × 1°)
Horizontal grid distance	9 km	Microphysics	WSM 6-class
Integration time steps	50s	CP scheme	Kain-Fritsch (KF)
Total grid points	295*304 points along X*Y direction	PBL scheme	YSU scheme
Map projection	Mercator	Land surface parameterization	5 Layer Thermal diffusion scheme
Horizontal grid	Arakawa C-grid	Radiation scheme	RRTM for long wave
Vertical co-ordinate	38 sigma levels	Surface layer	Monin-Obukhov similarity theory scheme

V. Results And Discussion

The heavy rainfall event of 16-17 June 2011 is simulated by the WRF model with evaluating different meteorological parameters and describe briefly in the next section.

5.1 Sea Level Pressure (SLP)

The model simulated SLP (hPa) valid for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011 are presented in Fig. 2. From Fig. 2(a) it is understood that the center of the depression is present in the southwestern region of the country. The pressure of the depression at its center at 1800 UTC of 16 June 2011 is about 980 hPa. From Fig. 2(b) it is found that, after the passage of time the depression moves from southwestern region to the western region of the country. The center of the depression is present in the northeast India near to the western region of the country at 1800 UTC 17 June 2011. The pressure of the depression at its center is approximately 981 hPa at 1800 UTC of 17 June 2011. It is observed that from the figure is, the depression remains fixed in the southwestern to western region and its neighboring area of the country for almost 48 hours. So the period of existence of low pressure depression is much extended in that region because a high SLP present over the Tibetan plateau. The central pressure over Tibetan plateau varies from 996 to 1008 hPa up to the 1800 UTC of 17 June 2011. The most important fundamental situation for the weather instabilities are the establishment of low pressure area. When the satisfactory atmospheres are acting on the area of low pressure then, it may amplify into a tropical depression i.e., monsoon depression.

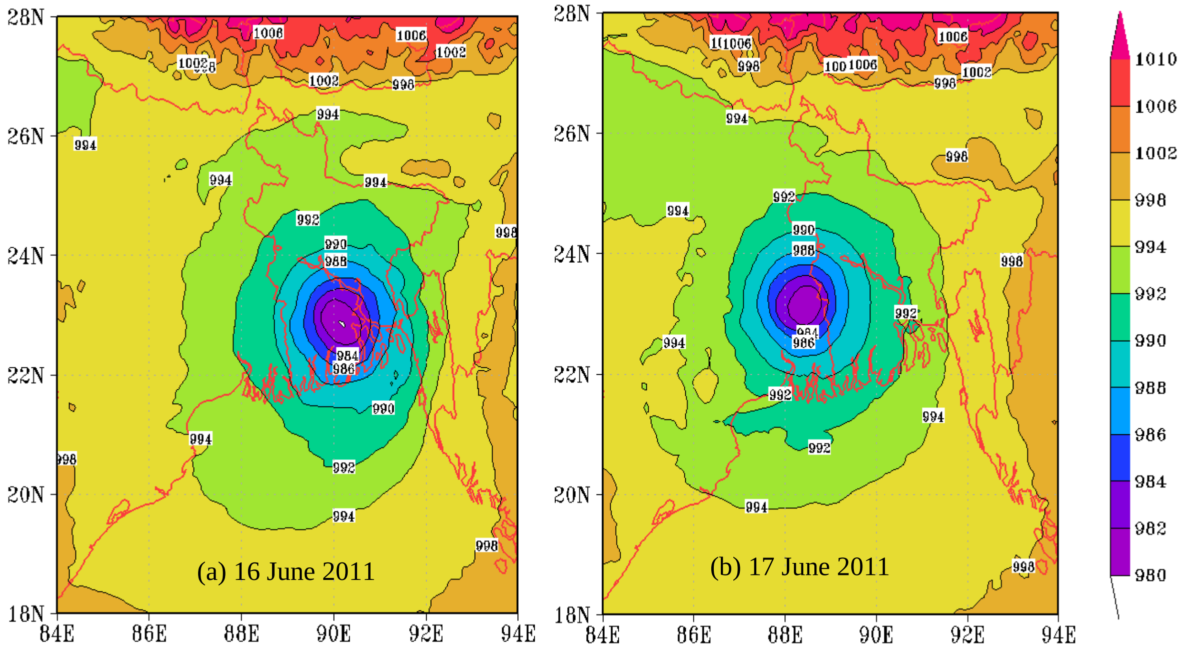

Figure 2. The SLP (hPa) distribution effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011.

5.2 Wind Flow Distribution

The Wind flow (ms^{-1}) distribution at 850 and 500 hPa level effective for 1800 UTC of (a-b) 16 June 2011 and (c-d) 17 June 2011 are displayed in Fig. 3. From Fig. 3(a) it is detected that a cyclonic movement of wind is appeared above the southern region and its adjacent area at 850 hPa level and this cyclonic motion of wind is expanded till 500 hPa level over the southern region of the country. From Fig. 3(b) it is also observed that this cyclonic flow of wind is shifted towards the southwestern region and its adjoining area and this cyclonic flow valid till 500 hPa level of 17 June 2011. The center of the depression is situated over 23^0 N, 90^0 E at 850 hPa level of 16 June 2011 and the center of the circulation is slightly shifted towards the southwestern region (22.8^0 N, 89.8^0 E) up to 500 hPa level of 16 June 2011. Again the center of the depression is shifted over southwestern region (23.2^0 N, 88.3^0 E) at 850 hPa level and shifted towards 22.8^0 N, 88^0 E up to 500 hPa level of 17 June 2011. From the Figure 3, it is also observed that a huge amount moisture is transported from the Bay of Bengal with the strong southwesterly flow towards the south southeastern region of the country. This huge quantity of moistness and the existence of the cyclonic circulation over the south southwestern region of the country indicates the existence of the convective activity over that region. Over the region of the southeastern part of the depression such that Madaripur, Barisal, Bhola, Khepupara, Patuakhali, Teknaf, Cox's Bazar, Hatiya, M. Court and Sandwip the high convective activity was observed. The speed of wind is around 10-30 ms^{-1} above the region of the zone of convective activity. This convective activity is found up to 850 hPa to 500 hPa level, no convective activity is originate over the southwestern and neighboring region of the country at 200 hPa level because there is no anticyclonic movement of the wind is observed (not shown in figure).

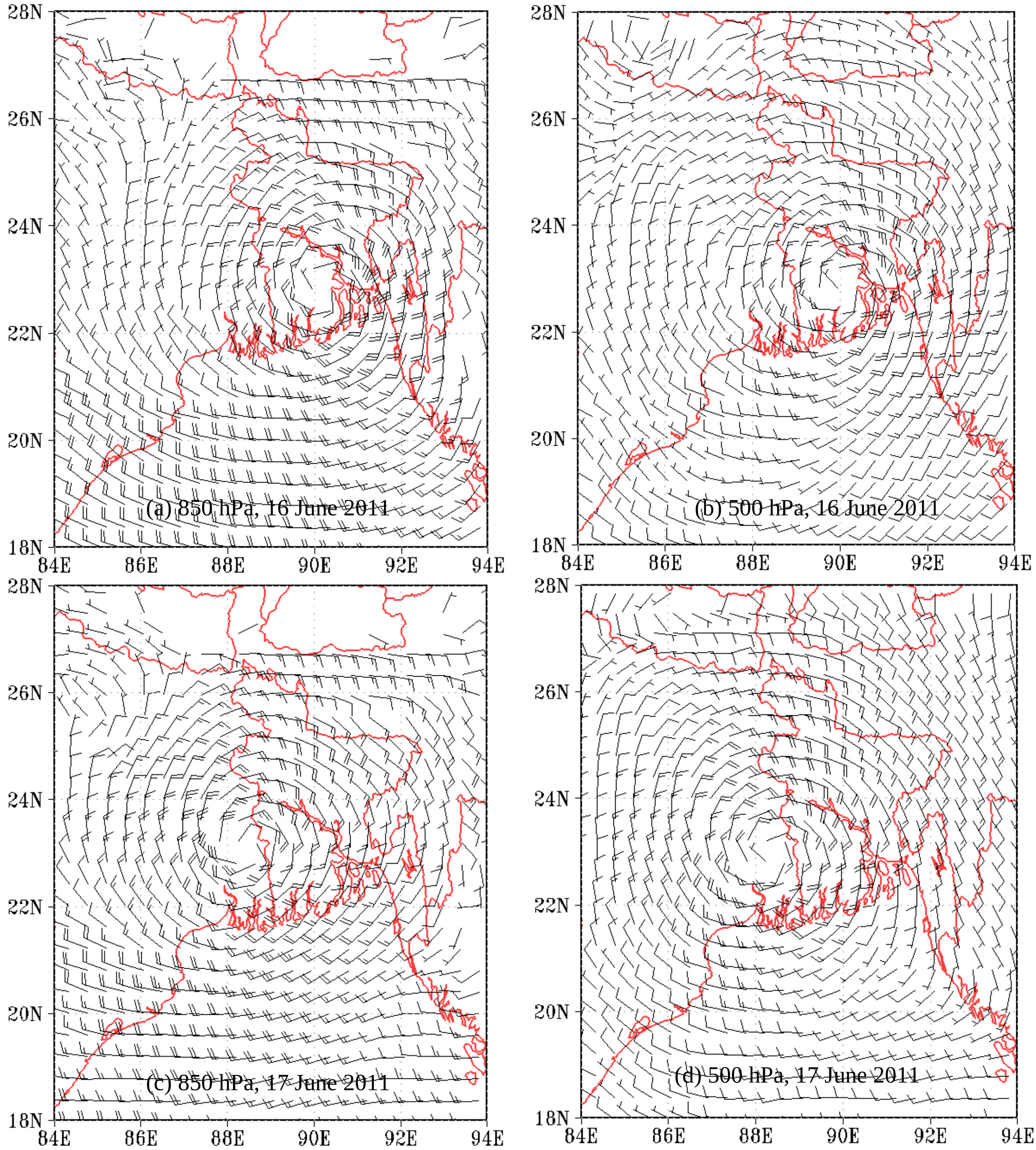

Figure 3. The Wind flow distribution at 850 and 500 hPa level effective for 1800 UTC of (a-b) 16 June 2011 and (c-d) 17 June 2011.

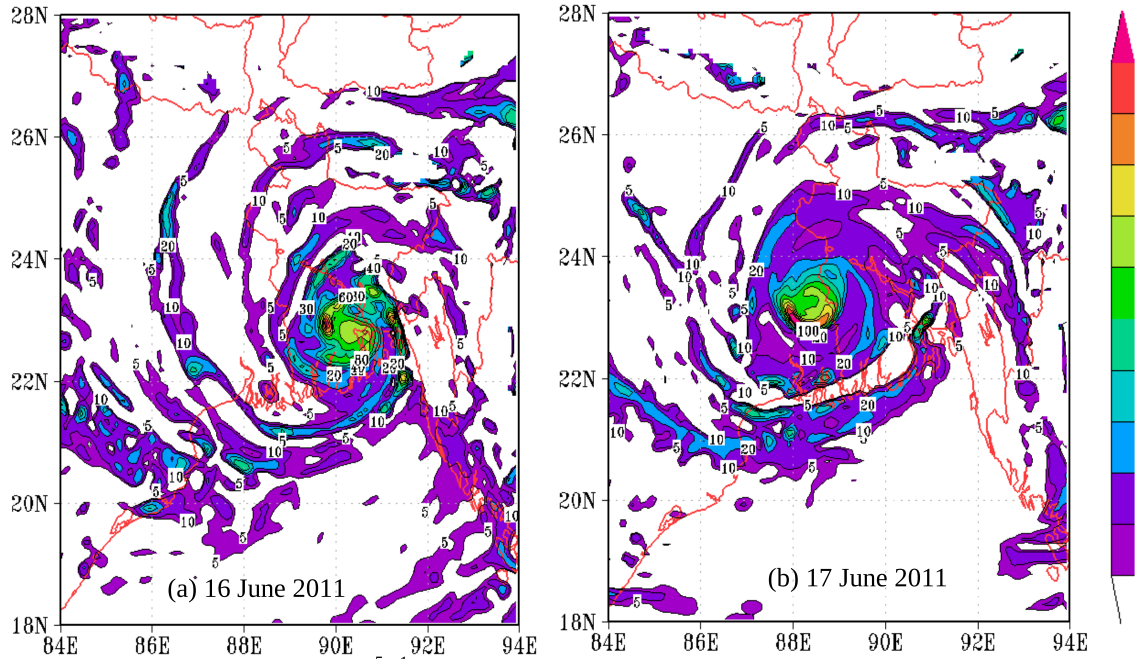

Figure 4. The relative vorticity ($10^{-5}s^{-1}$) distribution at 850 hPa level effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011.

5.3 Relative Vorticity

The model simulated relative vorticity ($\times10^{-5}$ s^{-1}) distribution effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011 at 850 hPa level are displayed in Fig. 4. The model simulated vorticity is found as the order of (20-80) $\times10^{-5}$ s^{-1} above the south-southwestern area of the country at 850 hPa level effective for 1800 UTC of 16 June 2011. From Fig. 4(b) the model simulated vorticity is found is of the order of (5-20) $\times10^{-5}$ s^{-1} above the southern state and is of the order of (30-50) $\times10^{-5}$ s^{-1} over the southwestern region of the country at 850 hPa level effective for 1800 UTC of 17 June 2011. From the Fig. 4, it was strongly detected the positive quantity of vorticity, which indicates that a strong cyclonic circulation as well as the convective activity zone is present over that region at 850 hPa level effective for 1800 UTC of 16-17 June 2011.

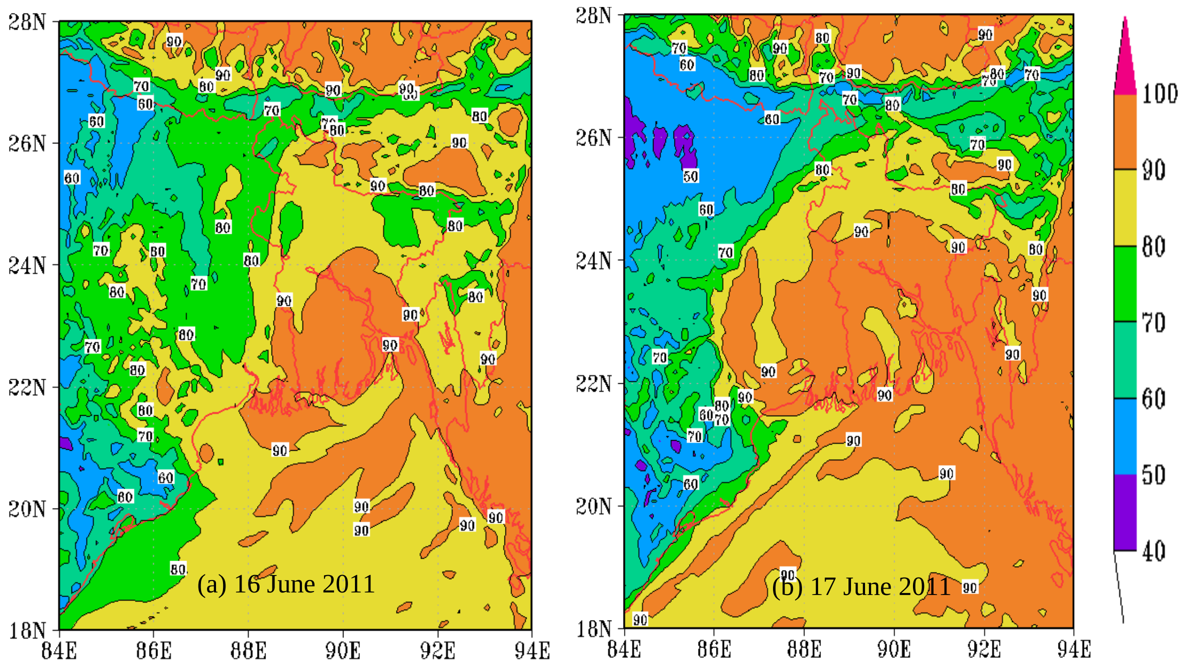

Figure 5. The relative humidity distribution at 850 hPa level valid for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011.

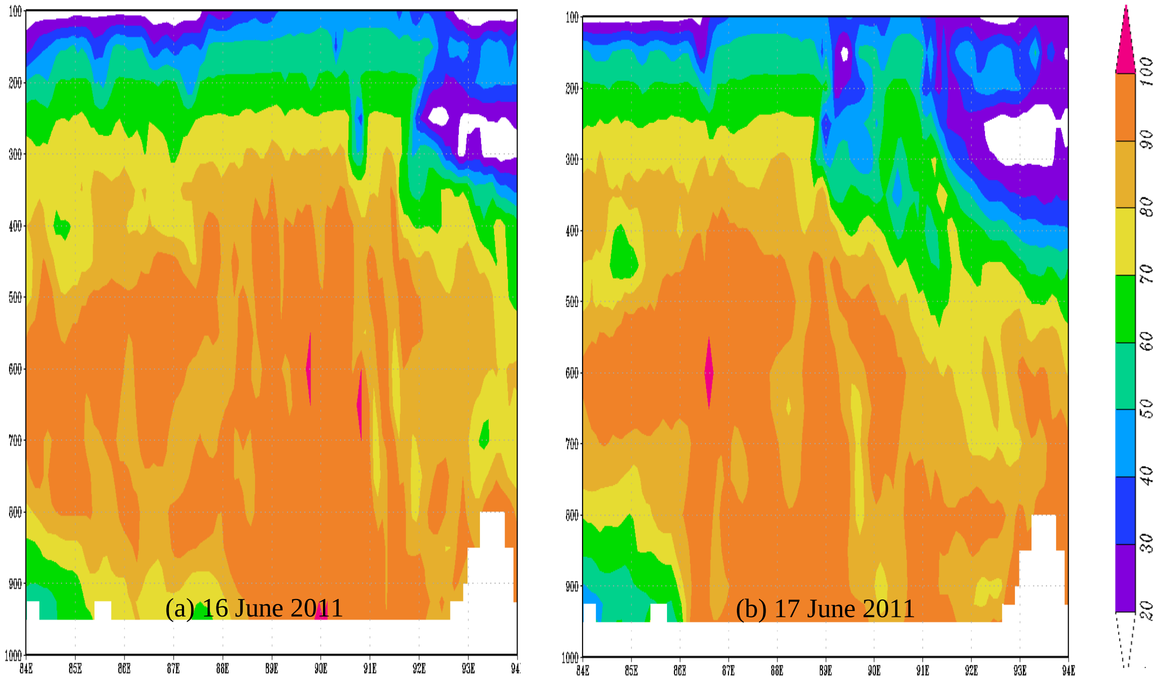

Figure 6. The vertical cross-section of relative humidity along the 22.5^0 N (position of M. Court) valid for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011.

5.4 Relative Humidity (RH)

The Relative Humidity (RH) distribution at 850 hPa level effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011 are presented in Fig. 5. The presence of huge amount of water vapor in the air is the indication of RH. The highest amount of RH indicates that the air is more saturated with water vapor and cannot hold any more, creating the possibility of rain. From Fig. 5(a) it is observed that from the Bay of Bengal a huge amount of water vapor about 90-100% is carried out with the southwesterly flow towards the central, southeastern and adjoining area of the country. The RH is of the order of 80-90% over the northern region and is 60-80% over the rest of the country at 1800 UTC of 16 June 2011. From Fig. 5(b) it is found that, about 90-100% of water vapor from the Bay of Bengal arrives to the central, east, southeast region and adjacent area of the country with the resilient southwesterly flow. The RH is about 80-90% over the northern, northeast region and is about 70-80% over the rest of the country at 1800 UTC of 17 June 2011. The vertical cross-section of RH along the 22.5^0 N (Location of M. Court) effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011 are presented in Fig. 6. It is strongly observed that the RH is vertically exist up to 400 hPa level with the order of 90-100% but up to the 200 hPa level the RH is only about 60-70%. So the existence of the very large amount of moisture or RH a strong convective activity is observed over the region of Madaripur, Barisal, Bhola, Khepupara, Patuakhali, Teknaf, Cox's Bazar, Hatiya, M. Court and Sandwip.

5.5 Vertical Wind Shear

The dissimilation in wind speed and direction from one position to another is defined as the wind shear. The difference in wind speed and direction from one altitude to another above the same point on the earth is known as the vertical wind shear [17]. In this research we define vertical wind shear as the difference between the mean wind vectors of the 200 and 850 hPa levels. The model simulated vertical wind shear (ms^{-1}) of the u-component of wind between 200 and 850 hPa level (u_{200}- u_{850}) valid for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011 are presented in Fig. 7. Shuyi *et al.*, [18] suggested that the vertical wind shear is the leading feature for the irrelevance rainfall when shear is greater than 5 ms^{-1}. It is observed from Fig. 7(a) that, the eastern, central, and southeastern region of the country experiences a strong vertical wind shear is about 10-15 ms^{-1}. The Fig. 7(b) also showed that the eastern, western and northwestern region also experiences an efficient vertical wind shear is approximately 10-20 ms^{-1}. So due to the presence of the strong vertical wind shear over these regions i.e., Madaripur, Barisal, Bhola, Khepupara, Patuakhali, Teknaf, Cox's Bazar, Hatiya, M. Court and Sandwip a huge amount of precipitation occurs.

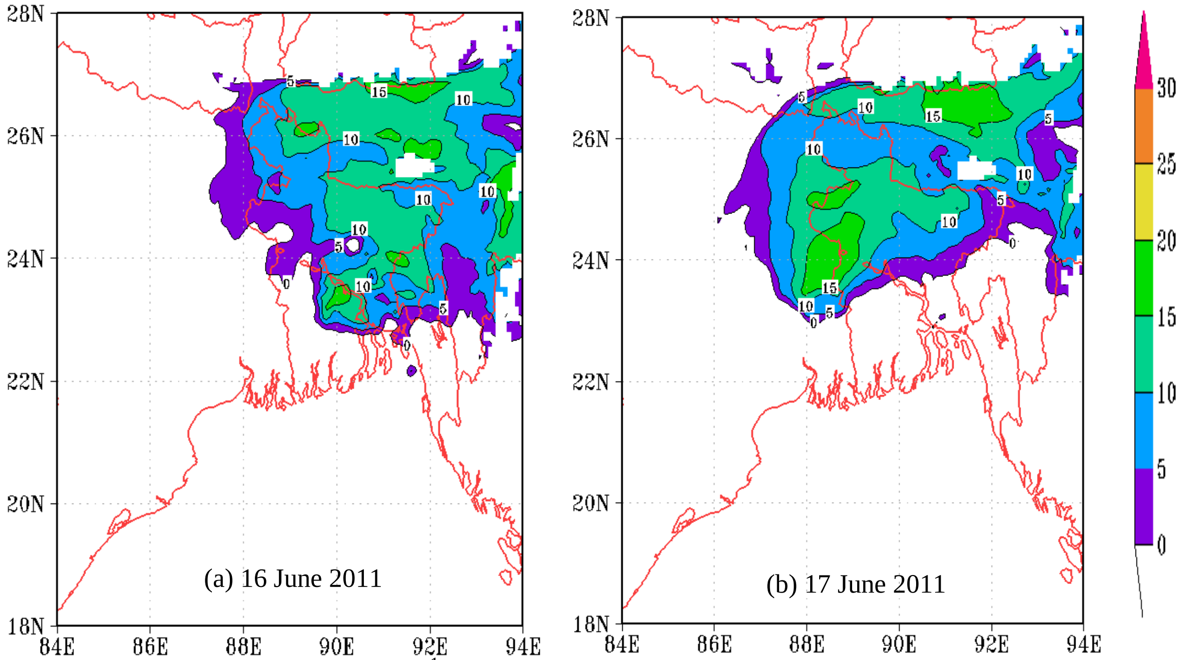

Figure 7. The vertical wind shear (ms-[1]) distribution of the u-component of wind between 200 and 850 hPa level (u_{200}- u_{850}) effective for 1800 UTC of (a) 16 June 2011 and (b) 17 June 2011**.**

5.6 Rainfall Distribution

The 24-h cumulated (a) BMD observed and (b) Model simulated rainfall distribution on 17 June 2011 are displayed in the Fig. 8. Here we introduce the BMD observed rainfall data to make a comparison with the model simulated rainfall data. According to the observation of BMD rain gauge station the area of Madaripur, Barisal, Bhola, Khepupara, Patuakhali, Teknaf, Cox's Bazar, Hatiya, M. Court and Sandwip appears a huge amount of rainfall is about 69, 64, 48, 52, 65, 86, 64, 70, 51 and 59 mm respectively. The model simulates the rainfall over these region is about 89, 71, 111, 132, 144, 188, 209, 172, 69 and 97 mm respectively. A comparison of BMD observed and Model simulated rainfall is shown in Table 2. Also a comparison diagram shown in Fig. 9. From Table 2 and Fig. 9 it is clearly seen that, the BMD observed rainfall over these region and their adjoining area is always over estimated by the model simulated value. It is highly appreciable that, though the model over estimates the value of BMD observed data but detect the position, station or spatial variation almost accurately as BMD expected. But the model simulated rainfall is almost similar to the BMD observed rainfall over Madaripur, Barisal, and M. Court region. The BMD rain gauge and Model both are shows the lowest value of rainfall near the central part of the country. According to the Figure 8 it was detected that, the BMD observed and model simulated rainfall is very low over northern, eastern, northwestern and northeastern region and rest of the area of the country, which indicates that no convective activity was found over these regions. From the analysis of sea level pressure, wind flow distribution, relative vorticity, relative humidity and vertical wind shear it is found that, a strong convective activity was appeared over the south-southeastern area of the country, which is also true for the BMD observed and model simulated rainfall distribution over that region. WRF model is capable to find the position where the rainfall is occurs.

Table 2. Table for the comparison of BMD observed and model simulated rainfall of 17 June 2011.

Position	BMD rainfall (mm)	MODEL rainfall (mm)	Position	BMD rainfall (mm)	MODEL rainfall (mm)
Madaripur	69	89	Teknaf	86	188
Barisal	64	71	Cox's Bazar	64	209
Bhola	48	111	Hatiya	70	172
Khepupara	52	132	M. Court	51	69
Patuakhali	65	144	Sandwip	59	97

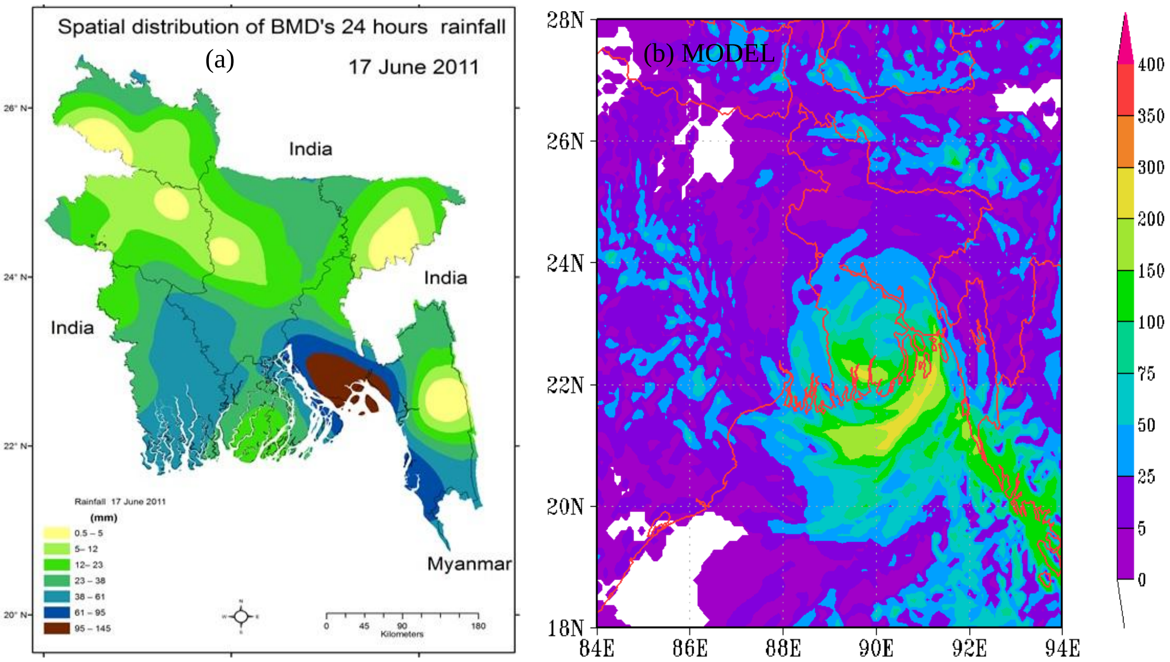

Figure 8. The 24-h cumulated (a) BMD observed and (b) Model simulated rainfall distribution respectively on 17 June 2011.

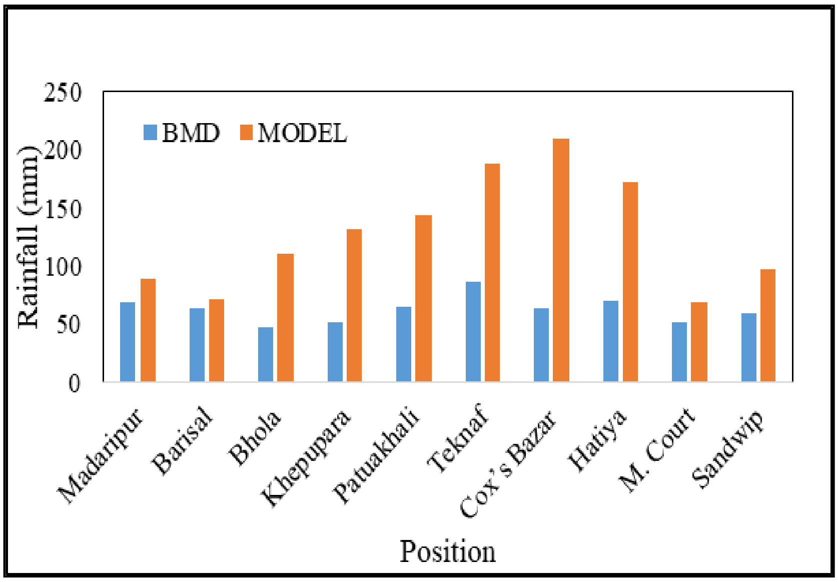

Figure 9. Comparision of the BMD observed and Model simulated rainfall on 17 June 2011.

VI. Conclusions

The central pressure of the depression is almost 980-981 hPa and the depression stays for a long term over the southwestern region. A cyclonic circulation with the wind speed of 10-30 ms^{-1} is observed over the southwestern region up to the 500 hPa level. The relative vorticity is found positive over the south southwestern region that indicates the high convective activity is present over that region. The huge quantity of moistness from the Bay of Bengal with the southwesterly flow reaches towards the south, southeastern and northern region of the country and the RH is of the order of 90-100%, which intensify the convective activity. This RH is extended up to 400 hPa level. Also a strong vertical wind shear of 10-20 ms^{-1} is present over that regions. Due to the presence of the above sufficient favorable condition for convective activity the area of Barisal, Bhola, Madaripur, Teknaf, Cox's Bazar, Hatiya, Khepupara, M. Court, Sandwip and Patuakhali experiences a huge amount of rainfall i.e., 71, 111, 89, 188, 209, 172, 132, 69, 97 and 144 mm respectively over that regions. These model simulated rainfall was compared with the BMD observed rainfall and found that the BMD observed data is overestimated by the model simulated data but the model is proficient to find the exact location where the rainfall event occurs or not.

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