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A COMPARATIVE STUDY ON PERFORMANCE OF MM5 AND WRF MODELS IN SIMULATION OF THE TROPICAL CYCLONE RASHMI

M. A. E. Akhter* and M. M. Alam

Department of Physics, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

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ABSTRACT

Tropical cyclone is one of the most devastating and deadly weather phenomena. It is a result of organized intense convective activities over warm tropical oceans. In the recent years, mesoscale models are extensively used for simulation of genesis, intensification and movement of tropical cyclones. During 24-28 October 2008, a tropical cyclonic storm named, Rashmi, was active in the Bay of Bengal part of the Indian Ocean. At 18 UTC on 26 October 2008, the system crossed Bangladesh coast near at lat. 21.8^0 N and long. 89.5^0 E. In the present study, two state-of-the-art mesoscale models, MM5 and WRF-ARW, have been used to evaluate their performances in the simulation of Rashmi. Horizontal resolution of 90 km and 30 km respectively for mother and nested domain were used in both the models. Various meteorological fields' viz. central pressure, winds, precipitation etc. obtained from the simulations are verified against those observed to test their performance. The simulated tracks are also compared with that obtained from JTWC. The results indicate that MM5 model has better forecast skill in terms of intensity prediction but WRF-ARW model has better forecast skill in terms of track prediction of the cyclonic storm.

Keywords: *Tropical cyclone, Mesoscale models, Track, Intensity, Precipitation*.

1. INTRODUCTION

The Bay of Bengal tropical cyclone disaster is the deadliest natural hazard in the Indian sub-continent. It has a significant socio-economic impact on the countries bordering the Bay of Bengal, especially India, Bangladesh and Myanmar. Therefore, it is very important to predict these cyclones with high accuracy to save the valuable lives and wealth. There have been considerable improvements in the field of weather prediction by numerical models. The Pennsylvania State University (PSU)/National Center for Atmospheric Research (NCAR) mesoscale model MM5 has been used in a number of studies for the simulation of tropical cyclones (Zhang *et al*., 2003). Mohanty *et al.* (2003) used MM5 model to simulate the Orissa super cyclone (1999). Again, WRF model has also been used in a number of studies for the simulation of tropical cyclones (Pattanaik *et al.,* 2009; Rama *et al.,* 2007). There are a number of comparative studies on the performance of the mesoscale models for severe weather events triggered by convection. Sousounis *et al.* (2004) made a comparative study on the performance of WRF, MM5, RUC and ETA models for heavy precipitation event and suggested that WRF model has the capability to generate physically realistic fine-scale structure which is not seen in the standard output resolution of other operational forecast models. Forecast skill of WRF model has been found better in the comparison study between WRF and ETA on the surface sensible weather forecast over Western United States (Cheng *et al.,* 2005). On the other hand, better forecast skill of MM5 model has been demonstrated in the comparative study on the performance of MM5 and RAMS models in simulating the Bay of Bengal cyclone (Patra *et al.,* 2000). Again, Pattanayak *et al.* (2008) made a comparative study on the performance of MM5 and WRF models in simulating of tropical cyclones over Indian seas. The intensity of the tropical cyclones Mala, Gunu and Sidr in terms of MSLP and maximum sustainable wind illustrates that MM5 has a tendency to intensify the system, whereas WRF gives reasonably good results, similar to the observations.

In the present study, MM5 and WRF-ARW are used to simulate the tropical cyclone Rashmi formed over Bay of Bengal. The performances of the models have been evaluated and compared with observations and verifying analyses. A brief description of the mesoscale models along with the numerical experiments and data used for the present study are given in section II. The synoptic situation for the above mentioned cyclone used in the present study is described in section III. The results are presented in section IV in order to evaluate the performance of the models and the conclusions are in section V.

2. MODEL DESCRIPTION AND METHODOLOGY

MM5 has been widely used for simulation/prediction of severe weather events such as tropical cyclones, heavy rainfall, thunderstorms etc. MM5 is a nonhydrostatic mesoscale model with pressure perturbation p′ three velocity components (*u, v, w*), temperature *T* and specific humidity *q* as the prognostic variables. Model equations in the terrain following sigma co-ordinate are used in surface flux form and solved on Arakawa B grid. Leapfrog time integration scheme with time splitting technique is used in model integration. With a

* Corresponding author: afraabida@hotmail.com

number of sensitivity tests, it has demonstrated that the combination of Kain–Fritsch cumulus parameterization scheme with MRF PBL, in general, provides better result for simulation of tropical cyclones (Mandal *et al.,* 2004). Table 1(a) summarizes the model configuration and various options used by MM5 in the present study.

Table 1: (a) Brief description of the MM5 model

Dynamics	Non-hydrostatic with 3-D Coriolis force
Mother Domain	0.22^0S - 37.94 ^{0}N, 67.36 ^{0}E-108.64 ^{0}E
Inner Domain	5.36 ^{0}N -28.71 ^{0}N, 81.66 ^{0}E - 99.20 ^{0}E
Resolution	90 and 30 km
Horizontal grid scheme	Arakawa B grid
Time integration scheme	Leap-frog scheme with time splitting technique Lateral boundary condition NCEP / NCAR GFS forecast
Radiation scheme	Dudhia's shortwave/longwave simple cloud
PBL scheme	MRF
Cumulus parameterization scheme	Kain Fritsch
Microphysics	Simple ice

The WRF-ARW modeling system developed by the Mesoscale and Microscale Meteorology (MMM) Division of NCAR is designed to be a flexible, state-of-the-art atmospheric simulation system which is suitable for a broad range of applications such as idealized simulations, parameterization research, data assimilation research, real-time NWP etc. Model equations are in the mass-based terrain following coordinate system and solved on Arakawa-C grid. Runge-Kutta 2nd and 3rd order time integration technique is used for model integration. The new generation of the MRF PBL scheme is introduced here as Yonsei University (YSU) PBL. It has an explicit representation of entrainment at the PBL top, which is derived (Noh *et al.,* 2003) from large eddy simulation. Table 1(b) summarizes the model configuration and various options used by WRF-ARW in the present study.

Table 1: (b) Brief description of the WRF-ARW model

Model	NCAR Mesoscale model WRF
Dynamics	Non-hydrostatic with 3-D Coriolis force
Mother Domain	1.58 ^{0}S – 38.94 ^{0}N, 66.10 ^{0}E-110.02 ^{0}E
Inner Domain	4.19 ^{0}N -28.50 ^{0}N, 81.25 ^{0}E - 99.17 ^{0}E
Resolution	90 and 30 km
No of vertical levels	28
Horizontal grid scheme	Arakawa C grid
Time integration scheme	Runge-Kutta 2nd & 3rdorder time splitting technique
Lateral boundary condition	NCEP / NCAR GFS forecast
Radiation scheme	Dudhia's shortwave /RRTM longwave
PBL scheme	YSU
Cumulus parameterization scheme	Kain Fritsch
Microphysics	Ferrier

To analyze the evolution and structure of TC Rashmi, the MM5 and WRF models were run for 96 hrs with the initial field at 00 UTC of 24 October 2008 and the models simulated data were compared with those obtained from Joint Typhoon Warning Centre (JTWC). The National Center for Environmental Prediction (NCEP) FNL reanalysis data (1º X 1º horizontal resolution) are used to provide the initial and lateral boundary conditions respectively to all the models.

3. SYSTEM DESCRIPTION

A low formed over west central Bay and adjoining area on 24 October 2008 and intensified into a well-marked low over the same area at 0000 UTC of 25 October 2008. At 0600 UTC of the same day the system concentrated into a depression over the same area (positioned near lat 16.5°N and long. 86.5°E) and started to move in a northerly direction initially. At 0300 UTC of 26 October the system intensified into a deep depression over northwest Bay and adjoining west central Bay. After that the system changed its direction of movement and moved north-northeastwards and concentrated into a cyclonic storm 'Rashmi' at 1200 UTC of the same day over northwest Bay and adjoining area (near lat. 20.2°N and long. 88.2°E). By moving rapidly towards the same direction the system started to cross Khulna-Barisal coast of Bangladesh near Patharghata at 2100 UTC of the same day and completed crossing the coast by 0300 UTC of 27 October and lay over south-central part of the country as a land depression. Then the system moved towards the same direction further and became unimportant by giving precipitation. The track of the cyclone ‘Rashmi’ is given in Figure 1. Under its influence heavy rainfall with high winds were recorded over most parts of Bangladesh. The recorded maximum winds were at Hatiya, Patuakhali, Mongla, Barisal 45 kts (83 km/hr) each, Khulna and Dhaka 35 kts (64 km/hr) each, Bhola and Jessore 30 kts (56 km/hr) each. No causalities were reported.

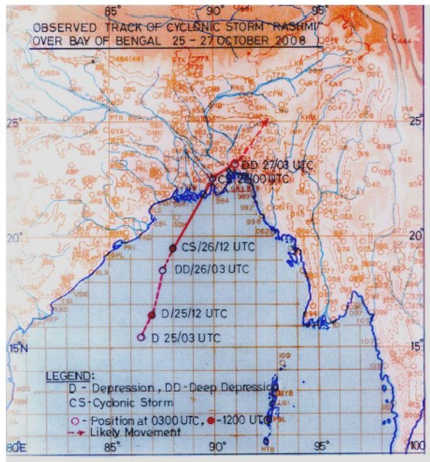

Figure 1: Track of the cyclone ‘Rashmi’ during 24-27 October 2008.

4. RESULTS AND DISCUSSION

To analyze the evolution and structure of TC Rashmi, the MM5 model was run for 96 hrs with the initial field at 00 UTC of 24 October 2008. But after 63 hrs of simulation at 15 UTC of 26 October 2008 for MM5 model and after 75 hrs of simulation at 03 UTC of 27 October 2008 for WRF model system attained at the state of highest intensity. Using MM5 and WRF models, the different meteorological parameters are discussed for the evolution and structure of the TC Rashmi in the following sub-section. MM5 and WRF model simulated data were compared with those obtained from Joint Typhoon Warning Centre (JTWC).

A. Pressure field

Minimum seal level pressure (MSLP) of a TC is of great importance as it helps to measure the intensity of a TC. Figure 2 shows the comparative evolution of observed MSLP and simulated MSLP of MM5 and WRF models for TC Rashmi. It appears from the Figure 2 that MM5 model simulated and observed MSLP gradually drops with time and coincides with each other at 18 UTC of 24 October and 06 UTC of 25 October (i.e. 18 and 30 hours of simulation respectively). After that simulated MSLP decreases and finally reaches to the peak intensity with lowest pressure of 976 hPa just before landfall making an oscillation with higher MSLP 992 hPa and thereafter MSLP increases. The Model simulated MSLP of 976 hPa is obtained at 15 UTC of 26 October where as the observed MSLP of 989 hPa is obtained at 18 UTC of 26 October 2008.

Again, the WRF model simulated and observed MSLP gradually drops with time and attains peak intensity just before the landfall and thereafter MSLP increases. The Model simulated MSLP of 979 hPa is obtained at 03 UTC of 27 October whereas the observed MSLP of 989 hPa is obtained at 18 UTC of 26 October 2008. The model simulated MSLP at the centre of the cyclone after 09 hours from the observed MSLP. It is noted that landfall occurs faster for MM5 model than that for WRF model. The variation of MM5 and WRF models simulated MSLP compared to that of observed with time shows that both the models simulated realistic temporal variation of MSLP.

B. Wind field

Maximum wind speed (MWS) directly devastates the affected area at the time of landfall. Figure 3 shows the temporal variations of MM5 and WRF models simulated MWS and observed winds of TC Rashmi. The model simulated MWS are obtained at the standard meteorological height of 10 m. The MM5 and WRF Models simulated MWSs are higher than the observed values through almost full forecast hours without any exception. The simulated highest MWS are obtained at 15 UTC of 26 October and at 03 UTC of 27 October whereas that for observed MWS is at 18 UTC of 26 October 2008. After that both the simulated winds by MM5 and WRF and observed winds decrease with time gradually.

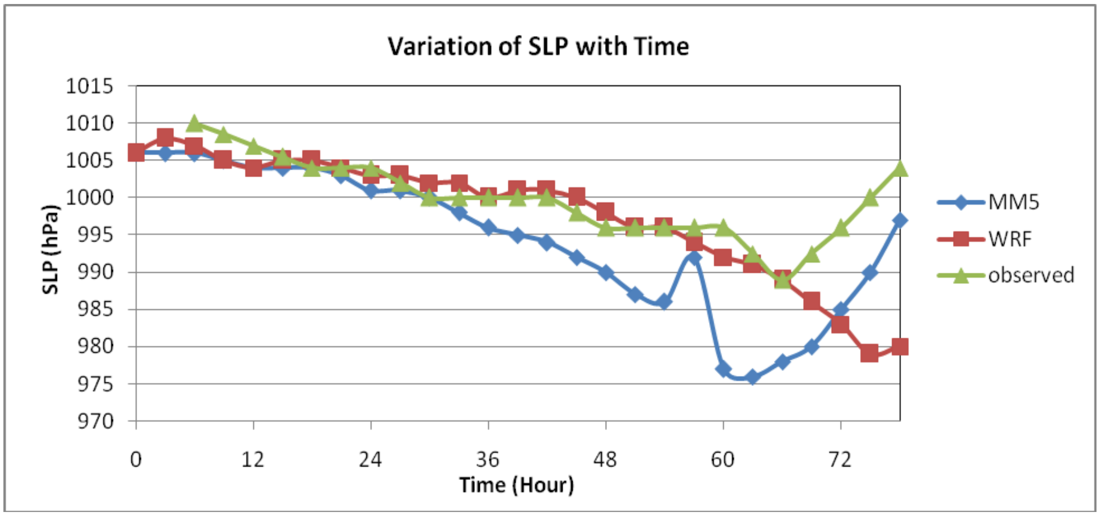

Figure 2: Evolution of MM5 and WRF models simulated minimum central pressure and observed minimum central pressure of the eye of the TC Rashmi with time.

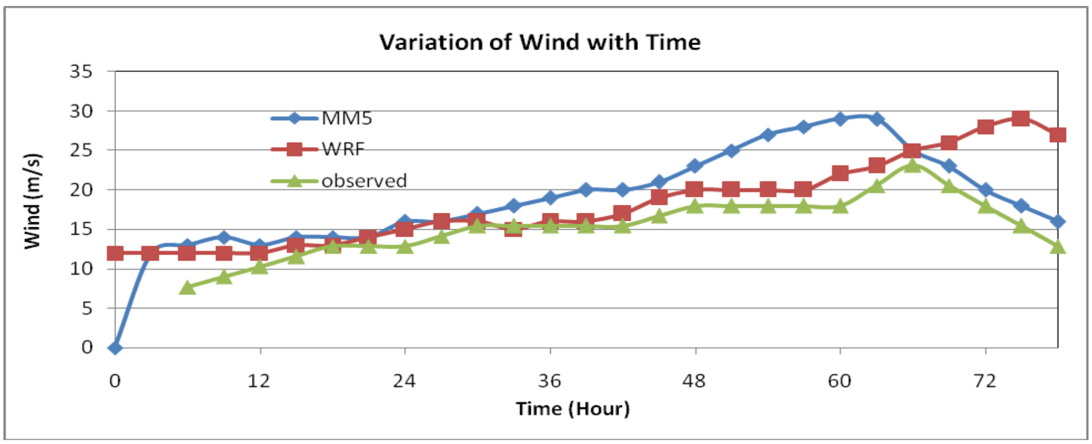

Figure 3: Observed and MM5 and WRF Models simulated wind speed (m/s) with time of TC Rashmi.

C. Rainfall pattern

Figure 4a shows the MM5 and WRF models simulated 24 hrs accumulated rainfall along with rainfall obtained from TRMM data of TC Rashmi valid for the day 24, 25 and 26 October 2008 (i.e. ending at 00 UTC of 25, 26 October and 27 October). The rainfall shows a highly asymmetric character in the horizontal distribution. On 24 October 2008, the rainfall occurs mainly at the sea and a small amount of rain occurs over Bangladesh and its surrounding. MM5 model simulated rainfall spreads on more area than that simulated by WRF model. The simulated rainfall by MM5 and WRF models is comparable to the rainfall obtained from TRMM data with large spatial variability. On 25 October 2008, the rainfall occurs mainly at the sea. MM5 model simulated rainfall is more than that simulated by WRF model over Bangladesh and especially eastern side of Bangladesh. Finally, the simulated rainfall by MM5 and WRF models is comparable with the rainfall obtained from TRMM data with large spatial variability. On 26 October 2008, the rainfall occurs mainly over Bangladesh and its surrounding. MM5 simulated heavy rainfall over whole Bangladesh whereas WRF model simulated heavy rainfall over south western side and sea. So, there is a spatial variability in the rainfall simulated by the two models. Rainfall obtained from TRMM is small in amount compared to the rainfall simulated by the two models. MM5 and WRF model simulated rainfall is comparable to the rainfall obtained from TRMM data with some spatial and temporal variability. Figure 4b shows the model simulated 24 hrs accumulated rainfall of TC

Rashmi for 26 October 2008 (i.e. ending at 00 UTC of 27October 2008). The rainfall shows a highly asymmetric character in the horizontal distribution. Pattern of rainfall simulated by MM5 is similar to the rainfall obtained from TRMM and BMD rain-gauge data. Pattern of rainfall simulated by WRF model is differed than other simulated and observed rainfall. Simulated pattern of rainfall by MM5 protrudes from the north to south for MM5. It turns out that the model used in the present study has overestimated the 24 hrs rainfall of cyclone Rashmi than the rainfall obtained from TRMM and BMD rain-gauge data.

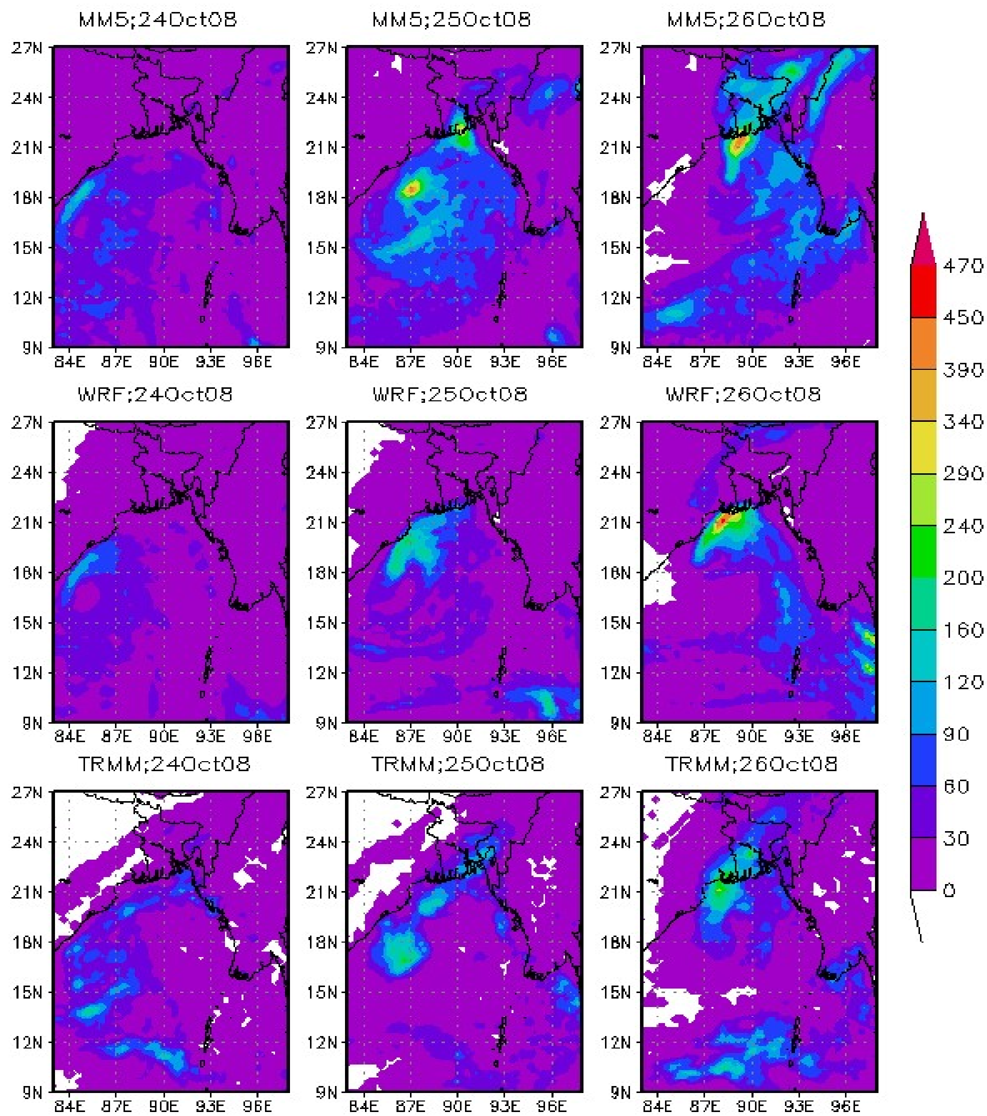

Figure 4a: MM5 and WRF simulated 24 hrs accumulated rainfall (mm) of TC Rashmi along with rainfall obtained from TRMM data valid for 24, 25 and 26 October 2008.

D. Track pattern

MM5 and WRF models simulated track of TC Rashmi along with observed track are plotted in the Figure 5 (a-b). The track forecasts of TC Rashmi for 96, 72, 48 and 24 hrs are based on the initial fields of 00 UTC of 24 October, 00 UTC of 25 October, 00 UTC of 26 October and 12 UTC of 26 October respectively for MM5 model.

It is seen from Figure 5a that the simulated track obtained by running the MM5 model for 96, 72, 48 and 24 hours model run is parallel to observed track but it is deviated to the east side of the observed track. It may be because of initial data error. Figure shows that model is able to generate northward movement of the system very well. It reveals that tracks obtained from 24 and 48 hrs simulation of model are more close to the JTWC best track compared to tracks obtained from 72 and 96 hrs simulation of model. However, there are some errors in the positions with respect to time which shows some ahead in landfall. The track from 48 hours simulation track is better than that of any others simulation. The landfall position for 48 hrs simulation track is much closer to that of observed track than any other simulation. So, by changing initial data in simulation, track becomes close to the observed track.

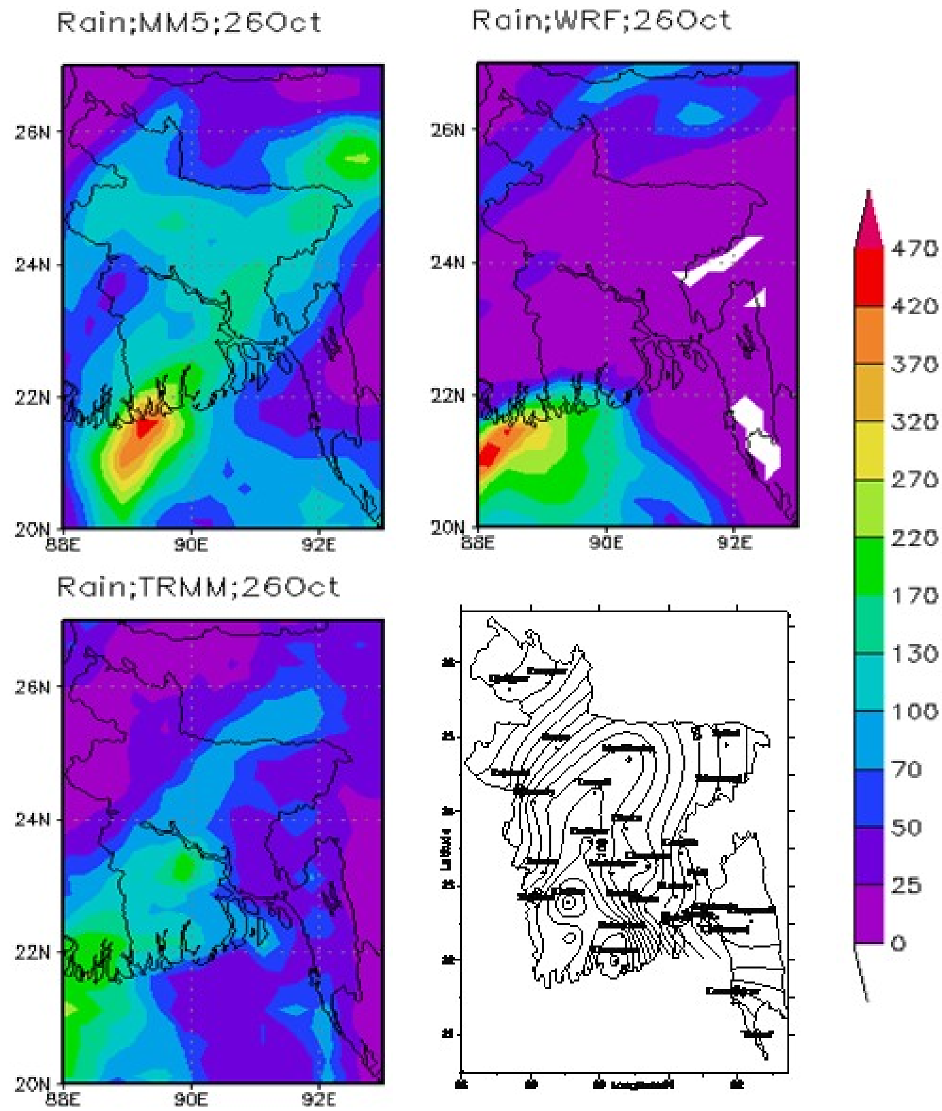

Figure 4b: MM5 and WRF simulated 24 hrs accumulated rainfall (mm) of TC Rashmi along with rainfall obtained from TRMM and BMD rain-gauge data valid for 26 October 2008.

It is seen from Figure 5b that WRF model simulated positions for 96, 72, 48 and 24 hours model run are parallel to observed track but it is deviated east and west side of the observed track. It may be because of initial data error. Figure shows that model was able to generate northward movement of the system very well. It reveals that tracks obtained from 24 and 48 hrs simulation of model are more close to the JTWC best track compared to tracks obtained from 72 and 96 hrs simulation of model. However, there are some errors in the positions with respect to time which shows some ahead in landfall. The track from 48 hours simulation track is better than that of any others simulation. The landfall position for 48 hrs simulation track is much closer to the track obtained from JTWC observed data than any other simulation of model. So, by changing initial data in simulation, track becomes close to the observed track.

It is seen from the Figure 5(a-b) that simulated track obtained from MM5 and WRF model is parallel to observed track. But it is deviated to the eastern side of the observed track using MM5 model and eastern and western side of the observed track using WRF model. It may be because of initial data problem. Again, track obtained from MM5 and WRF model for 48 hrs simulation is the best among other simulations. By changing initial data we can improve this track.

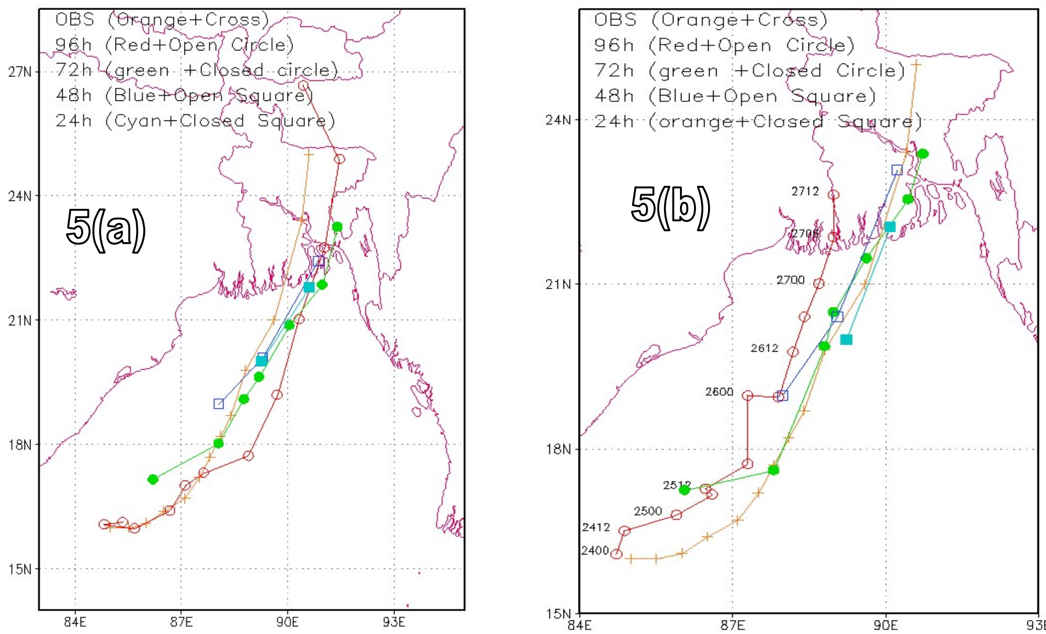

Figure 5: (a) MM5 model simulated and observed track of TC Rashmi, (b) WRF model simulated and observed track of TC Rashmi

5. CONCLUSIONS

From the comparative study on the performance of the mesoscale models, following broad conclusions are derived.

(i) All the models could simulate most of the features of the cyclone Rashmi reasonably accuracy. The WRF-ARW could simulate the intensity in terms of minimum central pressure and maximum sustainable wind with more accuracy. However, MM5 intensify the storm rapidly.

(ii) MM5 and WRF models simulated rainfall is comparable to the rainfall obtained from TRMM data with some spatial and temporal variability. Both the models used in the present study have overestimated the 24 hrs rainfall of cyclone Rashmi than the rainfall obtained from TRMM and BMD rain-gauge data.

(iii) The simulated track obtained from MM5 and WRF model is parallel to observed track. Again, track obtained from 48 hrs simulation is the best among other simulations.

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