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# Simulation of the Tropical Cyclone Aila using Numerical Models

M. A. E. Akhter[1,2*], M. M. Alam[1]
[1]*Department of Physics, Khulna University of Engineering & Technology, Khulna, Bangladesh*
[2]*SAARC Meteorological Research Centre, Dhaka, Bangladesh*

**Abstract**

Tropical cyclone is a result of organized intense convective activities over warm tropical oceans. It is one of the most devastating and deadly weather phenomena. In the recent years, mesoscale models are extensively used for simulation of genesis, intensification and movement of tropical cyclones. During 23-27 May 2009, a severe cyclonic storm named, Aila, was active in the Bay of Bengal part of the Indian Ocean. At 06 UTC on 25 May 2009, the system crossed Bangladesh coast near at lat. $21.5^0$ N and long. $88.0^0$ 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 Aila. 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. Recently, 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 [1]. Mohanty et al. [2] 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 [3, 4]. There are a number of comparative studies on the performance of the mesoscale models for severe weather events triggered by convection. Sousounis et al. [5] 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 [6]. 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 [7]. Again, Pattanayak et al. [8] 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 simulates the intensity of the system fairly, whereas WRF gives reasonably good results, similar to the observations. In the present study, MM5 version 3.7 and WRF-ARW version 3.1 are used to simulate the tropical cyclone Aila 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

* Corresponding author. Mobile: +88-01714 087397
*E-mail: afraabida@hotmail.com (M. A. E. Akhter)*
*For color version visit:http://www.cuet.ac.bd/IJIST/index.html*

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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 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 number of sensitivity tests, it has demonstrated that the combination of Kain–Fritisch cumulus parameterization scheme with MRF PBL, in general, provides better result for simulation of tropical cyclones [9]. Table 1 summarizes the model configuration and various options used by MM5 in the present study.

Table 1 Brief description of the MM5 and WRF models

| parameters | Used for MM5 V 3.7 model | Used for WRF version 3.1 model |
|---|---|---|
| Dynamics | Non-hydrostatic with 3-D Coriolis force | Non-hydrostatic with 3-D Coriolis force |
| Mother Domain | $0.22^0$S - 37.94 $^0$N, 67.36 $^0$E-108.64 $^0$E | $1.58^0$S-$38.94^0$N, 66.10 $^0$E-110.$^0$2 $^0$E |
| Inner Domain | 5.36 $^0$N -28.71 $^0$N, 81.66 $^0$E - 99.20 $^0$E | 4.19 $^0$N -28.50 $^0$N, 81.25 $^0$E - 99.17 $^0$E |
| Resolution | 90 and 30 km | 90 and 30 km |
| Map projection | Mercator | Mercator |
| No of vertical levels | 28 | 28 |
| Horizontal grid scheme | Arakawa B grid | Arakawa C grid |
| Time integration scheme | Leap-frog scheme with time splitting technique | Runge-Kutta 2nd & 3rd order time splitting technique |
| Radiation scheme | Dudhia's shortwave/ longwave simple cloud | Dudhia's shortwave / RRTM longwave |
| PBL scheme | MRF | YSU |
| Cumulus parameterization scheme | Kain Fritsch | Kain Fritsch |
| Microphysics | Simple ice | Ferrier |

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 [10] from large eddy simulation. Table 1 summarizes the model configuration and various options used by WRF-ARW in the present study are partly chosen from the study carried out by Pattanayak et al. [8].

Two models have two different procedures for the configurations of the domain size. Areas of interest of this study are situated within the domain size occupied by both the models. So, little different of domain size is ignored. There is no specific reason for this difference of area. Map projection used in this study is Mercator for both the models.

To analyze the evolution and structure of TC Aila, the MM5 and WRF models were run for 72 hrs with the initial field at 00 UTC of 23 May 2009 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. Model simulated 24 hrs accumulated rainfall are compared with that obtained from Tropical Rainfall Measuring Mission (TRMM) and also with that obtained from Bangladesh meteorological Department (BMD) rain-gauge. TRMM is a gridded rainfall data. These gridded estimates are on a 3-hour temporal resolution and a $0.25^0$ x $0.25^0$ spatial resolution in a global belt extending from $50^0$S to $50^0$N latitude. TRMM data is obtained from http://disc2.nascom.nasa.gov /data/TRMM/ Gridded/3B42RT/. BMD raingauge data is an observed data. It is collected at different meteorological station situated at different place of Bangladesh for every 3 hours and finally accumulated for 24 hours for calculating daily rainfall at BMD head office at Dhaka, Bangladesh. We just collect it from BMD and plot for our purpose.

## 3. System Description

At 06 UTC of 23 May 2009 the system was in the state of depression and was centered near $16.5^0$N, $88^0$E i.e. about 600 km south of Sagar Island. The INSAT imageries of the system at different stages of intensification and landfall are shown in Fig. 1. The depression moved mainly in a northerly direction and intensified into deep depression and at 03 UTC of 24 May was near $18.0^0$N, $88.5^0$E. At 12 UTC of 24 May it was intensified into a cyclonic storm and named as Aila and was centered near $18.5^0$N, 88.50E. It continued to move in a northerly direction and intensified into a severe cyclonic storm at 06 UTC of 25 May and was centered over northwest Bay of Bengal near $21.5^0$N $88.0^0$E close to Sagar Island. The system crossed West Bengal coast close to the east of Sagar Island (lat/lon $21.8^0$N, $88.1^0$E) between 0800 to 0900 UTC as a severe cyclonic storm with wind speed of 100 to 110 kph. The lowest estimated central pressure was about 967 hPa at the time of landfall. After the landfall, the system continued to move in a northerly direction, gradually weakened into a cyclonic storm and at 1500 UTC of 25 May was centered over Gangetic West Bengal, close to Kolkata. While it continued its northerly movement, it further weakened into a deep depression and at 0300 UTC of 26 May it was over Sub-Himalayan west Bengal close to Malda. It weakened into a depression and at 0060 UTC of 26 May was close to Bagdogra. It weakened further and became less marked on 27 May.

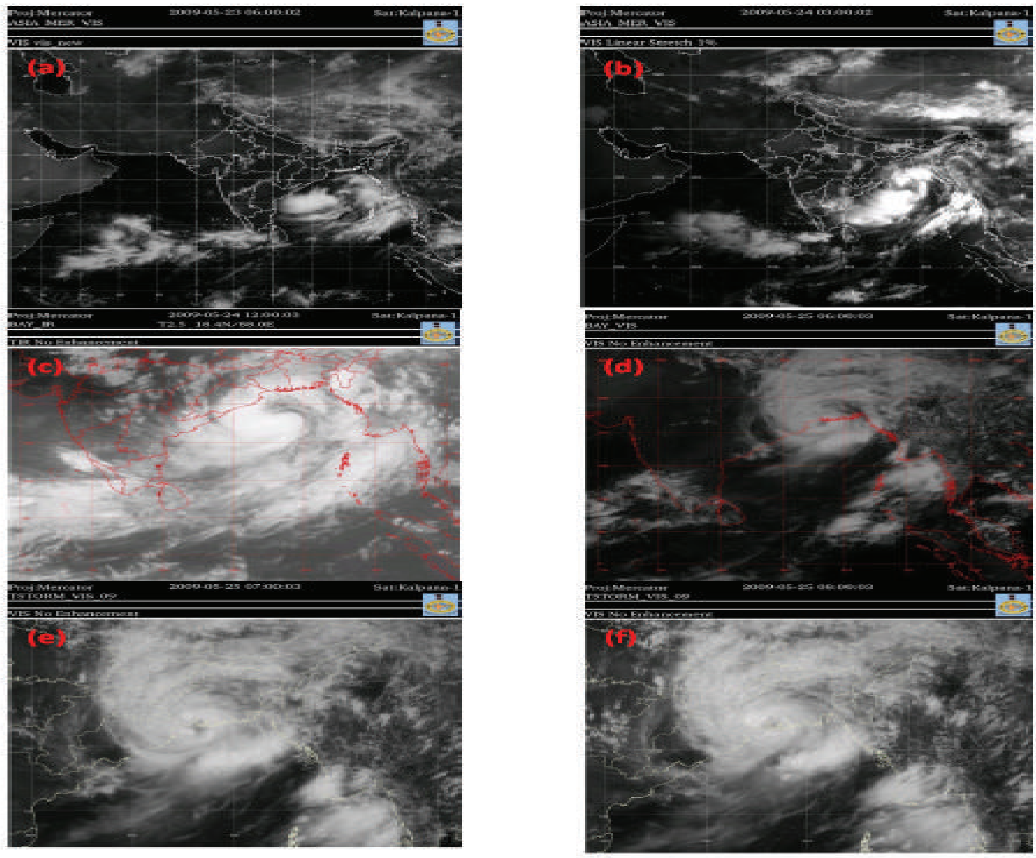


Fig. 1: INSAT (Indian National Satellite System) imageries of the system at different stages of intensification and landfall a) depression, (b) deep depression, (c) cyclonic storm, (d) severe cyclonic storm, (e) prior to landfall and (f) during landfall.

**4. Results and Discussion**

To analyze the evolution and structure of TC Aila the MM5 and WRF models were run for 72 hrs from the initial field at 00 UTC of 23 May 2009. But after 51 highest hrs of simulation of MM5 model at 03 UTC of 25 May 2009 and after 57 hrs of simulation of WRF model at 09 UTC of 25 May 2009 the system attained intensity (minimum pressure).

Using MM5 and WRF models, the different meteorological parameters are discussed for the evolution and structure of the TC Aila in the following sub-section. We compare the MM5 and WRF models simulated data with those obtained from JTWC. Models output are taken for 3 hourly intervals and plotted by Grid Analysis and Display System (GrADS) software.

***Pressure Field***

Minimum sea level pressure (MSLP) of a TC is of great importance as it helps to measure the intensity of a cyclone, Fig. 2 shows the observed and model simulated MSLP of TC Aila. From the figure it is observed that the model simulated and observed MSLP drops gradually with time and attains peak intensity just before the landfall and thereafter MSLP increases. The simulated MSLP using both the models is lower than that of observed. The MM5 and WRF Models simulated and JTWC observed times of highest intensity are 03 UTC, 09 UTC and 06 UTC on 25 May 2009 respectively. The variation of MM5 and WRF models simulated MSLP compare to that of observed with time shows that model simulates realistic temporal variation of MSLP.

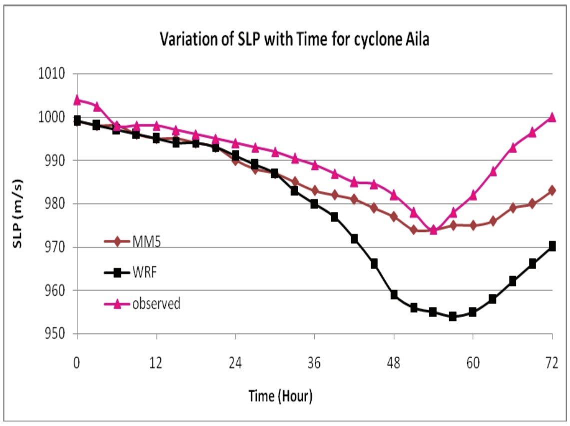


Fig. 2: MM5 model simulated and observed central pressure of TC Aila

***Wind Field***

Maximum wind speed (MWS) directly devastates the affected area at the time of landfall. Fig. 3 shows the time variations of MM5 and WRF models simulated MWSs and observed maximum winds of TC Aila. The models simulated MWSs are obtained at the standard meteorological height of 10 m. Up to 30 hours of forecast, models simulated MWSs are almost same as that of observed. After that MM5 model simulated MWSs are lower than the observed values for full forecast hours except for the moment when the predicted value of MWS is matched with that of the observed value. Again, after 30 hours of simulation, WRF model simulated MWSs are higher than those of the observed values. Finally after 30 hours of simulation, WRF model simulated MWSs are higher than those obtained from MM5 model.

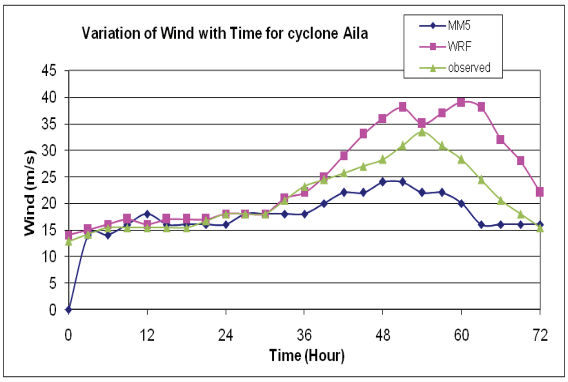


Fig. 3: Observed and MM5 and WRF models simulated wind speed (m/s) of TC Aila

***Rainfall Pattern***

Fig. 4a shows the MM5 and WRF models simulated 24 hrs accumulated rainfall (mm) along with rainfall obtained from TRMM data of TC Aila valid for the days 23, 24, and 25 May 2009 (i.e. ending at 00 UTC of 24, 25and 26 May). The rainfall shows a highly asymmetric character in the horizontal distribution. On 23 May 2009, the rainfall occurs mainly at the sea and a small amount of rain occurs over Bangladesh and its surrounding. MM5 model simulated rainfall is more 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 24 May 2009, the rainfall occurs mainly at the sea. MM5 model simulated rainfall is more than that simulated by WRF model over Bangladesh and especially southern side of Bangladesh. Interestingly, there is no rain in some area of Bangladesh simulated by WRF model. Rainfall simulated by WRF model is more than MM5 model at sea portion. Finally, the simulated rainfall by MM5 and WRF models is comparable to the rainfall obtained from TRMM data with large spatial variability. On 25 May 2009, the rainfall occurs mainly over Bangladesh and its surrounding. MM5 simulated heavy rainfall over middle and south and north sides whereas WRF model simulated heavy rainfall southwestern side. 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.

Fig. 4b shows the MM5 and WRF models simulated 24 hrs accumulated rainfall of TC Aila along with rainfall obtained from BMD rain-gauge and TRMM data valid for the day 25 May 2009 (i.e. ending at 00 UTC of 26 May). Rainfall obtained from WRF model is more than that obtained from MM5. Simulated rainfall matched more with rainfall obtained from rain-gauge data than the rainfall obtained from TRMM data. 24 hrs accumulated rainfall of TC Aila obtained from MM5 and WRF models are comparable with that obtained from TRMM and BMD rain-gauge data with spatial and temporal variability. The rainfall shows a highly asymmetric character in the horizontal distribution. It shows more rainfall (simulated by MM5) over north-eastern Bangladesh on 25 May 2009. It turns out that the model used in the present study is overestimated the 24 hrs rainfall of cyclone Aila valid for day 25 May 2009. It is noted that TRMM underestimates the pre-monsoon rainfall in this region.

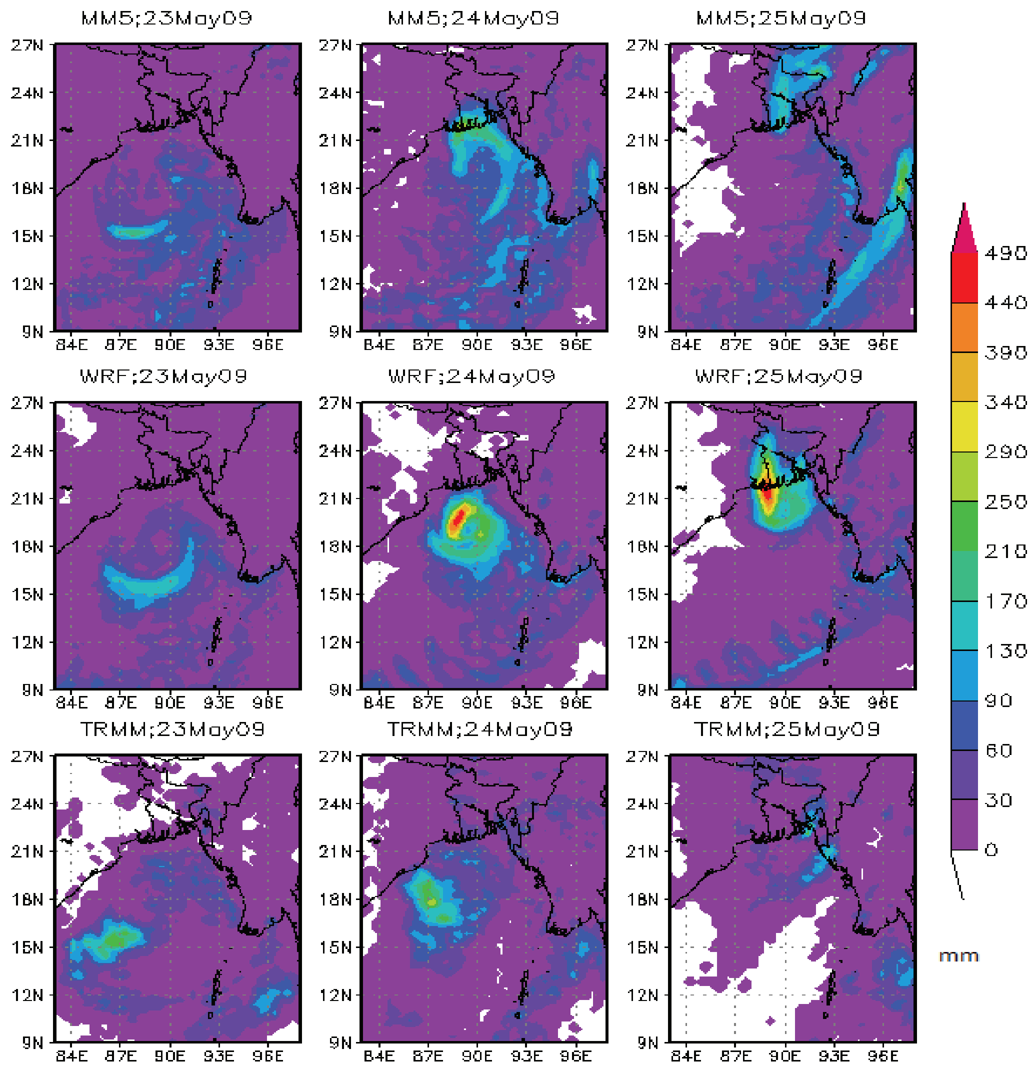


Fig. 4a: Accumulated rainfall (mm) of TC Aila for the days 23, 24 and 25 May 2009 simulated by MM5 and WRF Models along with that obtained from TRMM data.

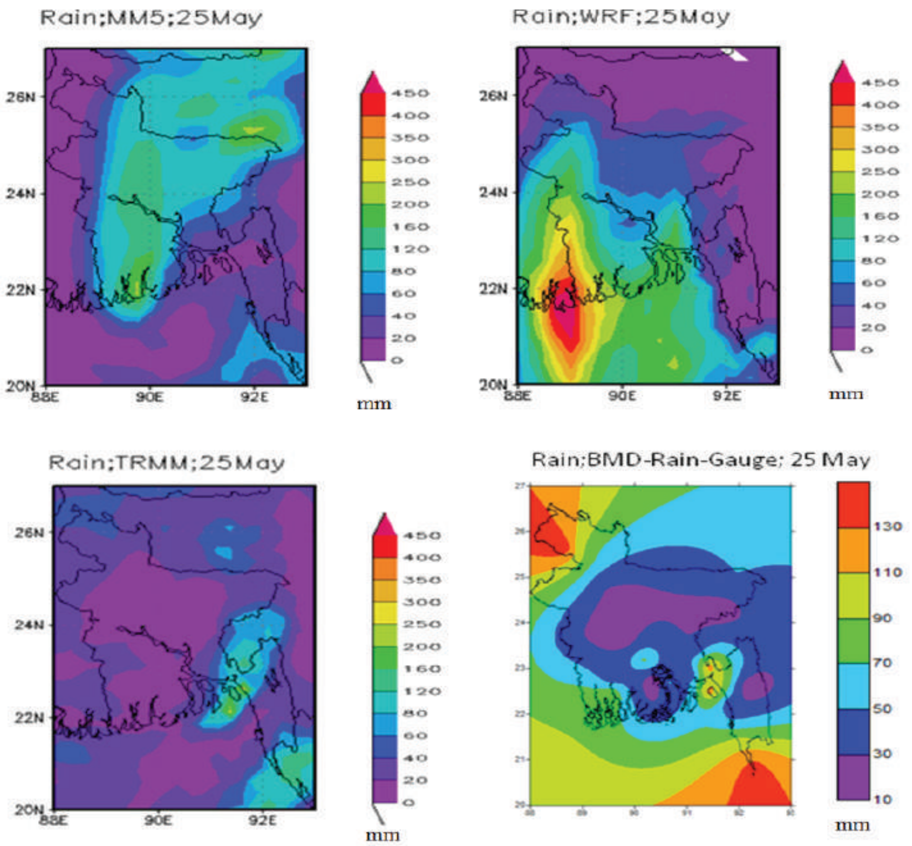


Fig. 4b: MM5 and WRF models simulated 24 hrs accumulated rainfall (mm) of TC Aila along with rainfall obtained from TRMM and BMD rain-gauge data valid for 25 May 2009.

***Track Pattern and landfall time and position***

MM5 and WRF models simulated track of TC Aila along with observed track are plotted in the Fig. 5a and Fig. 5b respectively. The track forecasts of TC Aila for 96, 72 48 and 24 hrs are based on the initial fields of 00 UTC of 22 May , 00 UTC of 23 May, 00 UTC of 24 May 12 UTC of 24 May respectively for MM5 model. Again, the track forecasts of TC Aila for 96, 72 48 and 24 hrs are based on the initial fields of 18 UTC of 22 May , 00 UTC of 23 May, 00 UTC of 24 May 12 UTC of 24 May respectively for WRF model. For 96 hour run, WRF model was unable to run using initial condition of 00 /06/12 UTC of 22 May. It may be due to NCEP data adjustment problem for WRF model. Although, it was fine for MM5 model. Finally, WRF model was run using initial condition of 18 UTC of 22 May. For 24 hours run, initial condition of 12 UTC of 24 May was used, for both the models, instead of 00 UTC of 25 May because actual landfall time (0830 UTC of 25 May) is very close to 00UTC of 25 May.

It is seen from Fig. 5a that MM5 model simulated track for 96, 72, 48 and 24 hours model run are parallel to observed track but it is deviated east side of the observed track. It may be because of initial data error. Figure shows that model was able to generate northwest, north and northeast 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 24 hours simulation track is better than that of any others simulation. The landfall position for 24 hrs simulation track is much closer to any other simulation. So, by changing initial time for lateral boundary condition data in simulated, i.e. by decreasing forecast time, simulated track becomes close to the observed track.

It is seen from Fig. 5b that WRF model simulated track for 96, 72, 48 and 24 hours model run are parallel to observed track but it is deviated east side of the observed track. It may be because of initial data error. Figure shows that model was able to generate northwest, north and northeast 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 lag in landfall. The track from 48 hours simulation track is better than that of any other simulation. The landfall position for 48 hrs simulation track is much closer to any other simulation. So, by changing initial data in simulated, track becomes close to the observed track.

The landfall times and positions are tabulated in Table 2. Position error for 24, 48, 72 and 96 hours forecast are 247, 240, 86 and 81 km respectively for MM5 and those are 320, 223, 28 and 81 km respectively for WRF model. Performances for both the models are comparable. Landfall time error is less in WRF model compare to MM5 model.

It is seen from the figure that simulated track obtained from MM5 and WRF model is parallel to observed track but it is deviated in the eastern side of the observed track. It is because of initial data problem. Again, from the figure (Fig. 5a and Fig. 5b) and Table 2 track obtained from MM5 model for 24 hrs simulation is the best among other simulation whereas track obtained from WRF model for 48 hrs simulation is the best among other simulation.

| Cyclone | Forecast Hours | obs/ models | initial condition date/Time (UTC) | landfall time date/Time (UTC) | landfall position | | Error | |
|---|---|---|---|---|---|---|---|---|
| | | | | | lat°N | lon°E | Distance (km) | Time (hours) |
| Aila | | Obs | ------ | 25/0830 | 21.80 | 88.30 | | |
| | 96 | MM5 | 22/0000 | 24/2330 | 22.00 | 90.52 | 247e | 10E |
| | 72 | | 23/0000 | 25/0600 | 22.00 | 90.45 | 240e | 2.50E |
| | 48 | | 24/0000 | 250300 | 21.60 | 89.05 | 86e | 5.5E |
| | 24 | | 24/1200 | 25/0715 | 21.60 | 89.00 | 81e | 0.45E |
| | | | | | | | | |
| | 96 | WRF | 22/1800 | 25/0630 | 20.00 | 90.55 | 320e | 2E |
| | 72 | | 23/0000 | 25/0645 | 21.65 | 90.30 | 223e | 1.75E |
| | 48 | | 24/0000 | 25/0600 | 21.65 | 88.50 | 28e | 2.5E |
| | 24 | | 24/1200 | 25/0915 | 21.60 | 89.00 | 81e | 2.25D |

e indicates forecast landfall position east to the actual position, Dindicates forecast landfall time is delayed compared to actual time and Eindicates forecast landfall time is earlier to actual landfall time. 25/0830 means 0830 UTC of 25 May 2009

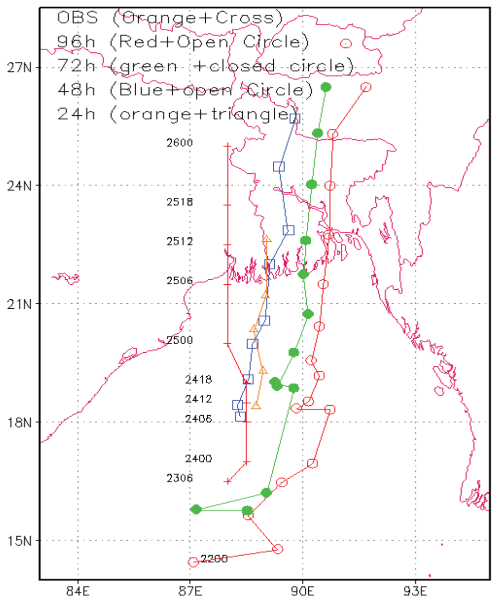


Fig. 5a: MM5 model simulated track and observed track of cyclone Aila

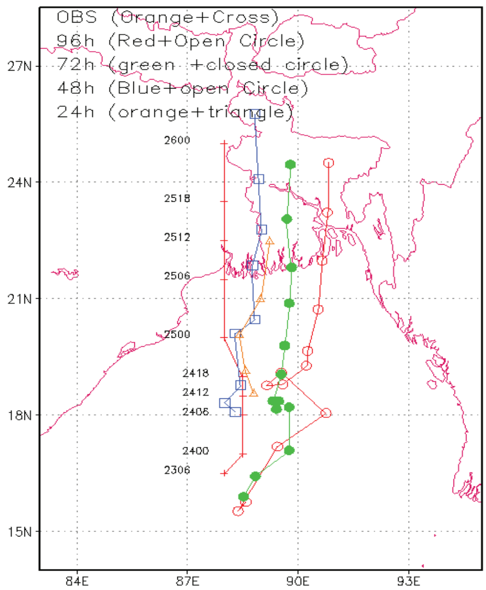


Fig. 5b: WRF model simulated track and observed track of cyclone Aila

## 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 Aila reasonably accuracy. Both the MM5 and WRF-ARW models could simulate the intensity in terms of minimum central pressure and maximum sustainable wind in the same development manner as the observed. However, the magnitudes are more or less than those of observed.

(ii) MM5 and WRF models simulated rainfall is comparable to the rainfall obtained from TRMM data with some spatial and temporal variability. WRF model have overestimated the 24 hrs rainfall of cyclone Aila than the rainfall obtained from TRMM and BMD rain-gauge data in most of the days. But MM5 model have overestimated the 24 hrs rainfall of cyclone Aila than the rainfall obtained BMD rain-gauge data and it is comparable to rainfall obtained from TRMM data.

(iii) The simulated track obtained from MM5 and WRF model is parallel to observed track. Again, track obtained from MM5 model for 24 hrs simulation is the best among other simulation whereas track obtained from WRF model for 48 hrs simulation is the best among other simulation.

**References:**

[1] D. -L. Zhang and X. Wang, Adv. Atmos. Sci., 20, 711 (2003).

[2] U. C. Mohanty, M. Mandal and S. Raman, Natural Hazards, 31, 373 (2003).

[3] D. R. Pattanaik and Y. V. R. Rao, J. Earth Syst. Sci. 118, 309 (2009).

[4] Y. V. R. Rao, H.R. Hatwar, K. S. Ahmed and Y. Sudhakar, Pure appl. geophys. 164, 1593 (2007).

[5] P. J. Sousounis, T. A. Hutchinson, S. F. Marshall, Amer. Meteor. Soc., 2004, J24.6.

[6] W. Y. Y. Cheng and W. J. Steenburgh, Weather and Forecasting, 20, 812 (2005).

[7] K. P. Patra, M. S. Santhanam, K.V.J. Potty, M. Tewari and P. L. S. Rao, Current Science, 79, 70 (2000).

[8] S. Pattanayak and U. C. Mohanty, Current Science, 95, 923 (2008).

[9] M. Mandal, U. C. Mohanty, and S. Raman, Natural Hazards, 31, 391 (2004).

[10] Y. Noh, W. -G. Cheon, and S. -Y. Hongs, Bound. -Layer Meteor., 107, 401 (2003).