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IMPACT OF CHOOSEN MICROPHYSICS ON TROPICAL CYCLONE PREDICTION: A CASE STUDY

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ABSTRACT

In this paper, results of the experiments to simulate the severe cyclonic storm Aila with different microphysical parameterization with the aim to evaluate their sensitivity using the non hydrostatic mesoscale model MM5 v3.7 is presented. Several sets of numerical experiments are performed with 90 km and 30 km horizontal resolution. The dimension of the coarse domain, which is mother domain, is taken as 34x41 and that for the nested one is as 49x52. The convection schemes Grell with MRF planetary boundary layer (PBL) parameterization schemes is used. Model simulated track and sea level pressure are compared with those observed. The simulated minimum central pressure were found 966, 967, 976, 967, 974 and 974 hPa when warm rain (WR), simple ice (SI), mixed phase-Reisner1 (MR1), Goddard microphysics (MG), Reisner graupel-Reisner 2 (MR2) and Schultz microphysics (MS) respectively were incorporated and that for observed one was 968 hPa. The results indicate that the microphysical parameterization option have their own impact on the simulation of Aila.

Keywords: *Cumulus convective scheme, Microphysics, Planetary boundary layer and Tropical cyclone intensification.*

1. INTRODUCTION

Tropical cyclones are known over the whole globe for their devastation in the tropical regions particularly as they make landfall mainly due to high winds, torrential rains and the associated storm surge. There are averages of five tropical cyclones annually over the Bay of Bengal, which represents 5.85% of the global frequency (Bhaskar Rao *et al.,* 2001). To improve forecasts of these storm systems, it is important to acquire a better understanding of their internal dynamics.

Tropical cyclones form over warm ocean regions and intensify under favorable atmospheric conditions. Warm oceans provide the energy supply to the atmosphere in the form of latent heat and sensible heat, and favorable atmospheric thermodynamics associated with low level dynamical convergence contribute to the intensification of a surface low into a cyclonic storm. The degree of intensification and the movement of a tropical cyclone depend on the prevailing atmospheric conditions, but in order to enable public officials to implement mitigation measures effectively, predictions with a lead time of 24–72 h is desirable.

As the tropical cyclones form and develop over remote oceanic regions, observational exploration of the active region of cyclone development is not possible and, consequently, predictive power is limited. Satellite observations provide useful information for locating a storm region and its intensity. Dvorak (1975) developed a technique to interpret the satellite cloud pictures to determine the different stages of a developing cyclone. The forecasting centers issue the weather prediction bulletins of the brewing storms using synoptic analyses of the conventional observations, satellite cloud pictures and numerical model output. However, current conventional synoptic forecasting methods have a major limitation in the form of subjectivity, whereas current numerical models are subject to the limitation of a paucity of observations. These problems are being met with the development of numerical models and data assimilation techniques; consequently, modeling techniques are becoming common for weather prediction and, specifically, for tropical cyclone studies.

The use of numerical models for tropical cyclone studies started in the early 1970s when axi-symmetric models were used to gain an understanding of the physical and dynamical mechanisms of tropical cyclone development (Yamasaki, 1968; Ooyama, 1969; Rosenthal, 1971; Anthes, 1977; Bhaskar Rao and Ashok, 1999, 2001). These studies led to an understanding of the importance of boundary layer and convective processes in tropical cyclone development. For tropical cyclone prediction, three-dimensional asymmetric models are being used by many meteorological organizations (Iwasaki *et al.,* 1987; Mathur, 1991; Puri *et al.,* 1992; Chen *et al.,* 1995; Kurihara *et al.,* 1995). For the Indian region, the India Meteorological Department issues forecasts of tropical cyclones over the North Indian Ocean using high-resolution limited-area models together with an assimilation of synthetic observations (Prasad *et al.,* 1997; Prasad and Rama Rao, 2003).

The NCAR- MM5 is a high-resolution mesoscale model that has been used for tropical cyclone simulation and sensitivity studies. Liu *et al.* (1997) simulated the intensity, inner-core structure and track of a hurricane with this model with three nested domains and a 6-km resolution for the inner-most domain. Braun and Tao (2000)

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reported that Burk-Thompson and Bulk Aerodynamic schemes of the planetary boundary layer (PBL) produced stronger cyclones than the MRF scheme. Davis and Bosart (2001) simulated hurricane Diana and concluded that model physics plays a more important role during the transformation from marginal storm to hurricane intensity than from mesoscale vortex to marginal storm. Wang (2002) examined the sensitivity of tropical cyclone development to explicit moisture schemes and reported that tropical cyclone intensification is not sensible to cloud microphysics. Braun (2002) simulated the asymmetrical structure of the eye and eyewall of hurricane Bob (1991) with a fine resolution of 1.3 km of the inner-most domain. Mohanty *et al.* (2004) simulated the Orissa super cyclone with a single domain at a resolution of 30 km, and their study indicates that MM5 could predict intensification up to 48 h but underestimated it thereafter. Rao and Bhaskar Rao (2003) also reported a good simulation of the Orissa cyclone but underestimated the intensity using the combinations of Grell cumulus, MRF PBL and Simple-Ice microphysics schemes as the physical processes. Yang and Cheng (2005) studied the sensitivity of Typhoon Toraji to different parameterization schemes and reported that the Grell convection scheme and Goddard Microphysics explicit moisture schemes gave the best track, whereas the warm rain scheme gave the lowest central surface pressure.

In this study NCAR MM5 is used to simulate the severe cyclonic storm Aila that hit the Bangladesh coast on 25 May 2009. MM5 uses many physical processes like radiation, surface layer processes, planetary boundary layer processes and precipitation (this includes cumulus parameterization and resolvable–scale microphysics). Detail description of the model is documented in Grell *et al.* (1994). In this study we used 6 different microphysics options named warm rain (WR), simple ice (SI), mixed phase-Reisner1 (MR1), Goddard microphysics (MG), Reisner graupel-Reisner 2 (MR2) and Schultz microphysics (MS) to test the sensitivity of microphysics to simulate the severe cyclonic storm Aila that hit the Bangladesh coast on 25 May 2009. Our special interest was to observe the effect on intensity and track using 6 different microphysics options.

2. DESCRIPTION OF MM5 MODEL

NCAR MM5 is a non-hydrostatic primitive equation model developed by Pennsylvania State University (PSU)/National Center for Atmospheric Research (NCAR) that was adapted for the present study. A detailed description of the NCAR MM5 is provided by Grell *et al.* (1994). This model has the inherent versatility to choose the domain region of interest, the horizontal resolution, the interactive nested domains and also has various options for choosing parameterization schemes for convection, PBL, explicit moisture, radiation and soil processes. Terrestrial and isobaric meteorological data are horizontally interpolated from a latitude-longitude mesh to a variable high-resolution domain on either a Mercator, Lambert conformal, or polar stereographic projection. Since the interpolation does not provide mesoscale detail, the interpolated data may be enhanced with observations from the standard network of surface and rawinsonde stations using either a successive-scan Cressman technique or multi-quadric scheme. Sigma surfaces near the ground closely follow the terrain, and the higher-level sigma surfaces tend to approximate isobaric surfaces. Since MM5 is a regional model, it requires an initial condition as well as lateral boundary condition to run. To produce lateral boundary condition for a model run, one needs gridded data to cover the entire time period that the model is integrated. It is a 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 surface flux form and solved on Arakawa B grid. Leapfrog time integration scheme with time splitting technique is used in model integration.

Table 1: Domain design of the model

Fifth generation Penn State/NCAR Mesoscale Model (MM5) Version 3.7

Dynamics	Non-hydrostatic with three-dimensional Coriolis force
Main prognostic variables	u, v, w, T, p' and q
Map projection	Lambert conformal mapping
Central point of the domain	20° N, 88° E
Horizontal grid distance	90 km and 30 km
Number of vertical levels	23 half sigma levels
Horizontal grid system	Arakawa B grid
Time integration scheme	Leapfrog scheme with time-splitting technique
Radiation parameterization scheme	Cloud
PBL parameterization scheme	MRF
Cumulus parameterization schemes	Grell
Microphysics	WR, SI, MR1, MG, MR1 and MS
Soil model	5-layer soil model

For our present study, we have used two step domains. The mother domain is taken between 6.85 - 33.61^0 N, 69.27-106.57^0 E and the nested one between 13.57 -26.27^0 N, 84.61-99.34^0 E. The dimension of the coarse domain, which is the mother domain, is taken as 34 x 41 and that for the nested one as 49 x 52, thus the grid distances for coarse and nested domain became as 90 km and 30 km respectively. Microphysics sensitivity experiments were conducted to simulate the developmental stages of the severe cyclonic storm Aila. The details of the options used in this study are given in Table 1. For all of these experiments, the model was integrated for 96 h, starting from 0000 UTC on 23 May 2009. 23 sigma levels in the vertical with the top at 100 hPa is used. 6 hourly data with 1x1 degree resolutions from the National Centre for Environment Prediction (NCEP) are used as atmospheric initial and lateral boundary conditions data.

Table 2: Observed track position and other parameters for Severe Cyclonic Storm "Aila" over the Bay of Bengal during 23-26 may, 2009

Date	Time (UTC	Centre lat^0 N/ long ^{0} E	Estimated			Grade
			Centre Pressure (hPa)	Maximum Sustained Surface Wind	Pressure drop at the Centre (hPa)	
23-05-2009	0600	16.5/88.0	998	25	3	D
	1200	16.5/88.0	994	25	3	D
	1800	17.0/88.5	996	25	4	D
24-05-2009	0000	17.0/88.5	996	25	4	D
	0300	18.0/88.5	992	30	4	DD
	0600	18.0/88.5	988	30	5	DD
	0900	18.0/88.5	986	35	5	DD
	1200	18.5/88.5	986	35	6	CS
	1500	19.0/88.5	986	35	8	CS
	1800	19.0/88.5	986	35	8	CS
	2100	20.0/88.0	984	40	8	CS
25-05-2009	0000	20.0/88.0	980	40	10	CS
	0300	20.5/88.0	978	50	12	CS
	0600	21.5/88.0	974	55	15	SCS
	The system crosses West Bengal coast close to Sagar Island between 0800 and 0900 UTC and lay centred over Gangetic West Bengal close to Diamond Horbour					
	0900	22.0/88.0	968	60	20	SCS
	1200	22.5/88.0	970	50	16	SCS
	1500	23.0/88.0	978	45	14	CS
	1800	23.5/88.0	980	40	12	CS
	2100	24.0/88.0	981	35	10	CS
26-05-2009	0000	25.0/88.0	982	30	08	CS
	0300	25.5/88.0	988	25	06	DD
	0600	27.0/88.5	992	20	04	D
	0900	The system weakened into a well marked low pressure area over Sub-Himalayan West Bengal and neighbourhood				

3. DESCRIPTION OF THE SYSTEM

The system is concentrated into a depression and lay centered at 06 UTC of 23th May near lat. 16.5^0 N/long 88.0^0 E about 600kms south of Sagar island. The best track of the system is shown in Fig. 2. The observed parameters of the system are shown in the Table-2. The depression moved mainly in a northerly direction and intensified into deep depression and lay centered at 03 UTC of 24th near 18.0^0 N/long. 88.5^0E. It further intensified into a cyclonic storm Aila at 12 UTC of 24th may and lay centered near 18.5^0 N/long. 88.5^0E. It continued to move in northerly direction and intensified into a severe cyclonic storm at 06 UTC of 25th May and lay centered over northwest Bay of Bengal near 21.5^0 N and 88.0^0E close to Sagar Island of India.

4. RESULTS AND DISCUSSION

We have assessed the results obtained from several numerical experiments carried out using MM5 to simulate the severe cyclonic storm 'Aila' and presented the model-derived characteristics of the development (intensification) and structure of this cyclone to test the sensitivity or role of the microphysical processes. To test sensitivity of microphysics schemes, MM5 physics options which are used, other than microphysics, includes: i) MRF for Planetary Boundary Layer, ii) Grell for cumulus parameterization iii) Cloud Radiation Schemes for radiation calculation and iv) 5- Layer Soil model to predict soil temperature. Six microphysics options are used for six independent runs. The microphysics options are Warm Rain (WR), Simple Ice (SI), Mixed Phase –Reisner (MR1), Mixed phase with Graupel – Goddard (MG), Mixed phase with Graupel – Reisner (MR2) and Mixed phase with Graupel – Schultz (MS). All these options have been applied for both the domains. The model is run for 96 hours from 00 UTC of 23 May to 00 UTC of 27 May 2009 and their outputs are compared with those reported by Indian Meteorological Department (IMD). Outputs of all six options have been produced at three hours interval and processed using Grid Analysis and Display System (GrADS). Using GrADS the model predicted mean sea-level pressure (SLP) is drawn just before the crossing time as suggested by the model.

The model-derived central sea level pressure (CSLP) and maximum wind are shown in Figure 1a and 1b. The WR, SI and MG schemes is seen to have produced similar results, with CSLP of 966, 966 and 965 hPa, while MR1, MR2 and MS schemes is seen with CSLP of 976, 973 and 972 hPa. The observed minimum CSLP were 968 hPa according to IMD. The minimum CSLP using WR, SI, MR1, MG, MR2 and MS are obtained after 48h, 51h, 48h, 51h, 51h and 54h respectively from 00UTC of 23 May, 2009. The observed minimum CSLP are obtained after 57h (09UTC of 25 May, 2009) from 00UTC of 23 May, 2009 i.e. model simulated minimum CSLP are obtained earlier than that of observed. It should be note that sustenance of minimum CSLP (maximum attained intensity) around 968 hPa or lower lasted for 6h, 9h, and 15h with the scheme WR, SI and MG respectively, whereas MRI, MR2 and MS schemes through reached to minimum CSLP as 976, 973 and 972 hPa, but CSLP start to raise quickly.

Correspondingly, the model simulated maximum wind speed attained was about 31 m s^{-1}, 31 m s^{-1}, 28 m s^{-1}, 34 m s^{-1}, 29 m s^{-1} and 32 m s^{-1}, with the WR, SI, MR1, MG, MR2 and MS scheme respectively, whereas observed one is 30.864 m s^{-1}. So, the model simulated maximum wind speeds with all schemes are same or close to the observed one

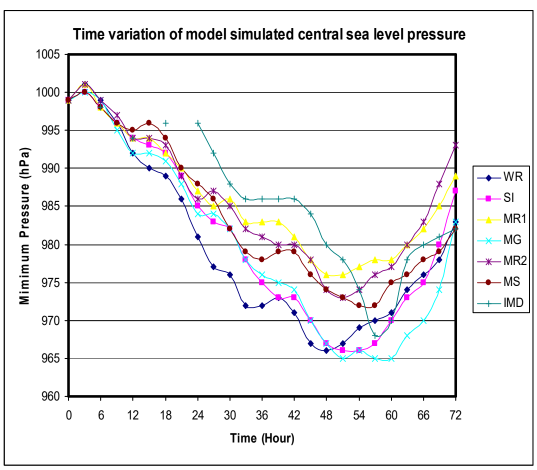

Figure 1a: Comparison among simulated pressure using different microphysics and observed pressure

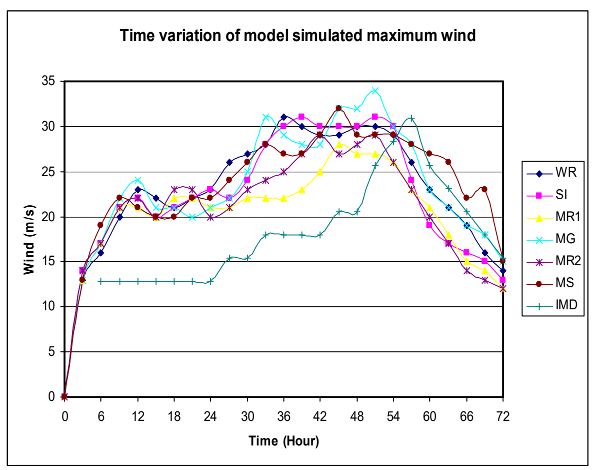

Figure 1b: Comparison among simulated wind using different microphysics and observed wind

The model-simulated track positions for these experiments with different microphysics are shown in Figure 2. It shows that the track is almost similar for all of the schemes, with a deviation to the right of that of the observation. The landfall positions with time for all schemes are tabulated in the Table -3. Four model simulated tracks using WR, SI, MG and MR2 schemes coincide just before the landfall position. Model simulated track using MR1 scheme also coincides after landfall but track using MS scheme does not coincide at all and its track move paralleled to others tracks (Figure 2). All the schemes produced little bit different track with almost the same error, which indicates that the microphysics options have no significant impact on the movement of the tropical cyclones at a resolution of 30 km.

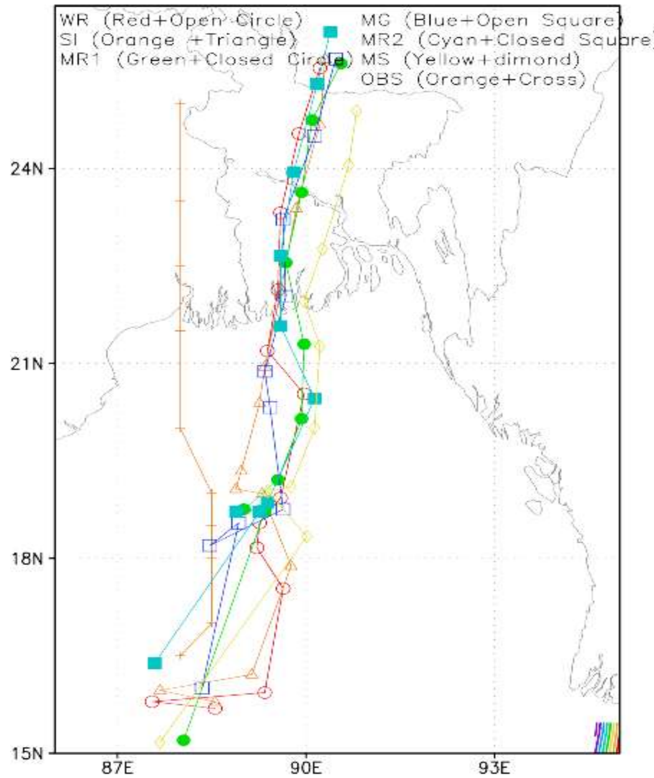

Figure 2: Comparison among simulated track using different microphysics and observed track

Table 3: Model simulated and observed Landfall time and position, and pressure and time just before landfall

	Landfall Time	Landfall Position		Pressure and time just before landfall	
		Lat	Lon	Pressure	Time
WR	2009.5.25_03:53	21.74	89.51	967	2009.5.25_03
SI	2009.5.25_04:30	21.71	89.51	966	2009.5.25_03
MR1	2009.5.25_02:15	21.78	89.85	976	2009.5.25_00
MG	2009.5.25_04:45	21.71	89.64	965	2009.5.25_03
MR2	2009.5.25_02:00	21.85	89.64	974	2009.5.25_00
MS	2009:5.25_04:23	21.75	90.06	973	2009.5.25_03
Observed	2009.5.25_08	21.5	88.0	968	2009.5.25_08

5. CONCLUSION

In this study, NCAR MM5 model was used to study the sensitivity/ role of the physical processes in the simulation of the severe cyclonic storm Aila. From the simulations the following results come forward:

i. Pressure drops are different for different microphysics options.
ii. Duration at the minimum CSLP is different for different microphysics options.
iii. At the formation stage tracks are different for different microphysics options.
iv. Landfall times are different for different microphysics options.

Hence we may conclude that the microphysical parameterization option have their own impact on the simulation of Aila.

The present study has investigated only one cyclone, and more cases should be examined to supplement these results. We propose that it would be desirable to make sensitivity experiments with all possible combinations of the schemes of the physical processes.

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