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Tropical cyclone Phailin Track Simulation using the advanced mesoscale Weather Research and Forecasting (WRF) model

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Abstract- *The Severe Cyclonic Storm Phailin caused extensive damage and loss of life in Odissa, India, during October 2013. The cyclone developed from a low pressure system that formed under the influence of an upper-air cyclonic circulation in the Andaman Sea and intensified into a Severe Cyclonic Storm and crossed Odisha coast near Gopalpur on 12 October, 2013. High surge (~2.3m) generated by the cyclone washed away some of the coastal structures constructed at the Gopalpur port besides causing coastal erosion. Wind damage was quite extensive around 50km radius of the cyclone track. The model domain consists of one coarse and two nested domains. The resolution of the coarse domain is 45 km while the two nested domains have resolutions of 15 and 5 km, respectively. The results from the inner most domain have been considered for analyzing and comparing the results. Model simulation outputs are compared with corresponding observation data. The model was run for 72 hrs starting from 10 October, 2013 to 13 October 2013. The track and intensity of simulated cyclone are compared with best track estimates provided by the Joint Typhoon Warning Centre (JTWC) data. Simulations are performed using four convective cumulus parameterization schemes, namely, BMJ (Betts-Miller-Janjic), GD (Grell-Devenyi), G3D (improved Grell-Denenyi) and KF (Kain-Fritsch) in combination with different microphysics parameterization schemes, namely, Kessler Scheme, Lin et al. Scheme, WSM-3 scheme, WSM-5 scheme and Thompson Schemes. The main purpose of the present study is to find the best suitable combination of microphysics, cumulus and PBL schemes for the simulation of accurate track of severe tropical cyclones over Bay of Bengal. The cumulus, planetary boundary layer (PBL) and microphysics (MP) parameterization schemes have more impact on the track and intensity prediction skill than the other parameterizations employed in the mesoscale model.*

Keywords- *Phailin, WRF Model, physics parameterizations, Cyclone track, Track error*

I. INTRODUCTION

The Severe Cyclonic Storm Phailin was the most intense tropical cyclone to make landfall in India. The system was first noticed as a tropical depression on October 4, 2013 within the Gulf of Thailand. Over the next few days, it moved westwards within an area of low to moderate vertical wind shear, before as it passed over the Malay Peninsula, it moved out of the Western Pacific Basin on October 6 and moved into the Andaman Sea during the next day and moved west-northwest into an improving environment for further development before the system was named Phailin on October 9, after it had developed into a cyclonic storm and passed over the Andaman and Nicobar Islands into the Bay of Bengal. On October 10, Phailin intensified rapidly and became a very severe cyclonic storm, equivalent to a category 1 hurricane on the Saffir-Simpson hurricane wind scale (SSHWS). On October 11, the system became equivalent to a category 5 hurricane on the SSHWS before it started to weaken during the next day as it approached the Indian state Odisha. It made landfall later that day, near Gopalpur in Odisha coast at around 2130 IST (1600 UTC). It subsequently weakened over land as a result of frictional forces. The numerical weather prediction and dynamical models provides good guidance with respect to cyclone genesis, track and intensity. The India Meteorological Department (IMD) and the Joint Typhoon Warning Centre (JTWC), USA predicted the genesis, intensity, track, point and time of landfall 5 days in advance. The synoptic features of cyclone phailin was studied with different microphysics schemes using Advanced Research Weather Research and Forecasting (ARW-WRF, hereafter WRF) mesoscale model developed at National Center for Atmospheric Research (NCAR) because of its superior performance in generating fine-scale atmospheric structures as well as its better forecast skill (Otkin et al. 2005; Pattanayak and Mohanty 2008).

II. DATA AND METHODOLOGY

Numerical Weather Prediction (NWP) model used in cyclone simulation is the Advanced Research WRF (ARW) v 3.6.1 mesoscale model developed by NCAR. NWP is a method of weather forecasting that uses governing equations, different numerical methods, parameterization schemes, different domains and Initial and boundary conditions. The MODIS based terrain topographical data have been used for domain1, domain2 and domain3 in the WRF Preprocessing system (WPS).

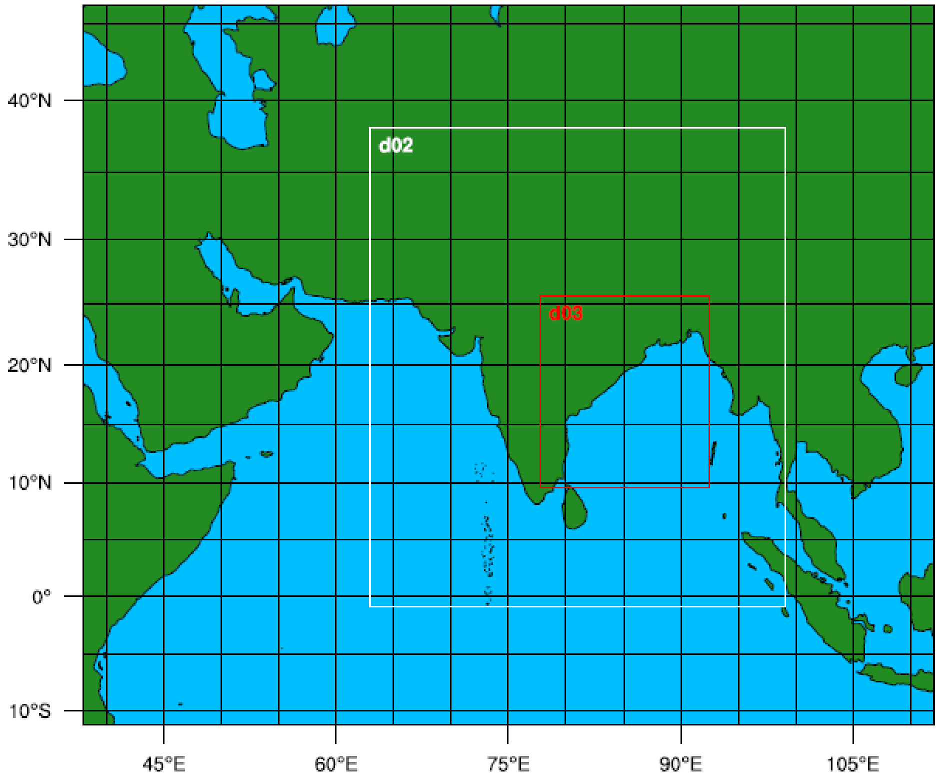

Figure 1. WPS domain configuration used in simulation

The Initial and boundary conditions are obtained from the UCAR & NCAR Research Data Archive http://rda.ucar.edu/datasets/ds083.2/index.html#sfol-wl-/data/ds083.2?g=2. These NCEP FNL (Final) Operational Global Analysis data are on 1-degree by 1-degree grids prepared operationally every six hours. For all the three TC simulations the model output is generated for every six hours were taken into consideration for track position.

Table 1. List of MP and CP used in WRF simulations

Model* Microphysics(mp) *parameterization schemes		
1	Kessler scheme (mp option=1)	KS
2	Lin *et al.* scheme (mp option=2)	*LIN*
3	WRF Single Moment 3-class simple ice scheme(mp option=3)	WSM3
4	WRF Single Moment 5-class scheme (mp option=4)	WSM5
5	Thompson graupel scheme 2 moment (mp option=8)	THOM2
Model* Cumulus-physics (cp) *parameterization schemes		
1	Kain-Fritsch(new Eta) scheme (cu Option=1)	KF
2	Betts-Miller-Janjic scheme (cu Option=2)	BMJ
3	Grell-Devenyi ensemble scheme (cu option=3)	GD
4	Grell-3D ensemble scheme (cu option=5)	G3D
Planetary Boundary Layer (PBL)		
1	Yonsei University Scheme (bl_pbl Option=1)	YSU

The WPS domain configuration is generated using NCL (NCAR Command Language). The CP and MP parameterization schemes used in the present simulation to investigate the track of the tropical cyclones were listed in Table-1 and WRF Model dynamics and domain details are listed in Table.2

Table 2. WRF Model dynamics and domain details

WRF Model Dynamics	
Equation	Non-hydrostatic
Time integration scheme	Third-order Runge-Kutta scheme
Horizontal grid type	Arakawa-C grid
WRF Model Domain details	
Map projection	Mercator projection
Central point of the domain	75°E, 20°N
No. of domains	3
No. of vertical layers	27
Horizontal grid distance	45 km , 15 km & 5 km for domain 1, 2 & 3 respectively
Time step	180 sec, 30 sec & 10 sec for domain 1, 2 &3 respectively
No. of grid points	173 (EW), 148 (SN) in domain 1
	253 (EW), 295 (SN) in domain 2
	310 (EW), 355 (SN) in domain 3

III. RESULTS AND DISCUSSIONS

The Simulations for the Phailin cyclone were carried out in order to determine the best MP adn CP parameterization scheme for track prediction. Results from domain-3, have been used for the analysis. In all the simulations Yonsei-University (YSU) planetary boundary layer (PBL) scheme is kept fixed.
The simulated track of Phailin cyclone with different MP and CP parameterization schemes are plotted in the Figure 3.
The simulated track of Laila cyclone with different MP and CP parameterization schemes are plotted in the Figure 4.
Grid Analysis and Display System (GrADS) was used for visualization of the wrf output.
The wrf model output and the JTWC observed track were compared concurrently. Track error is calculated using Haver-Sine formula. The track error for Phailin TC for different CP and MP is plotted in Figure 5.

$$a = sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi * \cos\varphi * sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (1)$$

$$c = 2 * \tan^{-1}\left(\frac{\sqrt{a}}{\sqrt{(1-a)}}\right) \quad (2)$$

$$D = R * c \quad (3)$$

$$\Delta\varphi = \varphi_{JTWC} - \varphi_{wrf} \quad (4)$$

$$\Delta\lambda = \lambda_{JTWC} - \lambda_{wrf} \quad (5)$$

Where D is Track error, φ is latitude, λ is longitude, R is earth's radius (mean radius = 6,371km) and the angles are in radians.

IV. PHAILIN SIMULATIONS

Phailin TC Simulations were initiated on 8th October 2014, 0000 UTC with lateral boundary condition and were carried up to 13 October 2014, 1200 UTC. The model was run up to 132hr and the simulated track of the Phailin cyclone with different MP schemes and no CP parameterization scheme (cu=0) are plotted in the Figure 2. The Phailin cyclone with different MP schemes and Kain-Fritsch (new Eta) CP parameterization scheme (cu=1) are plotted in the Figure 3.

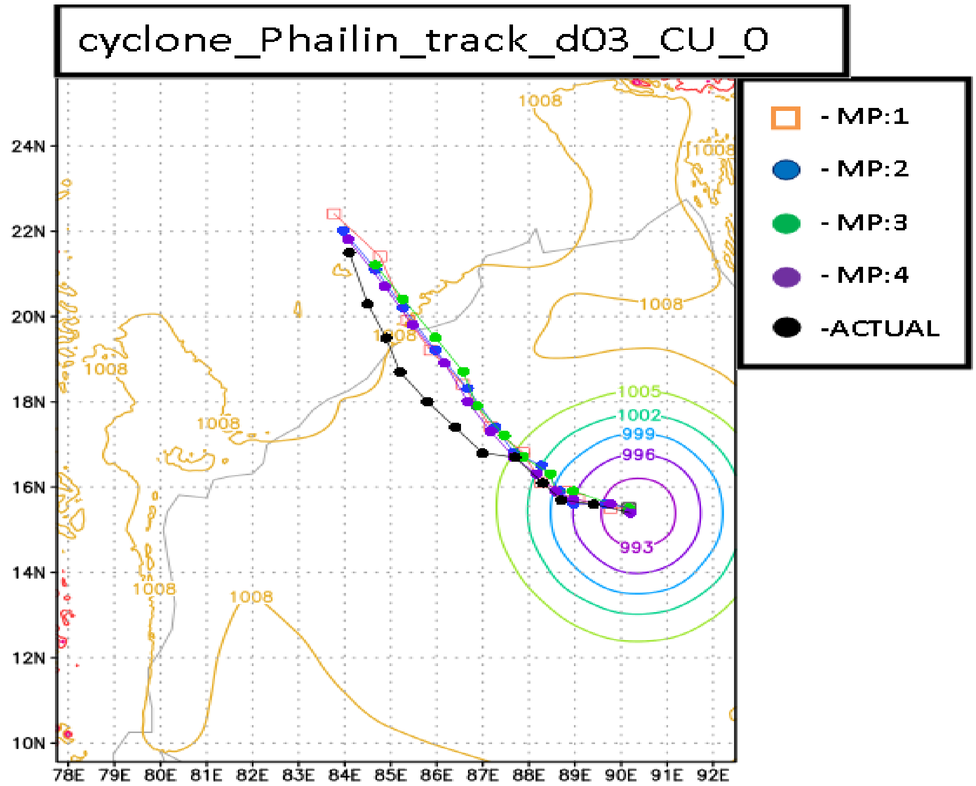

Figure 2. Phailin track simulations with different MP schemes and without CP scheme (cu=0)

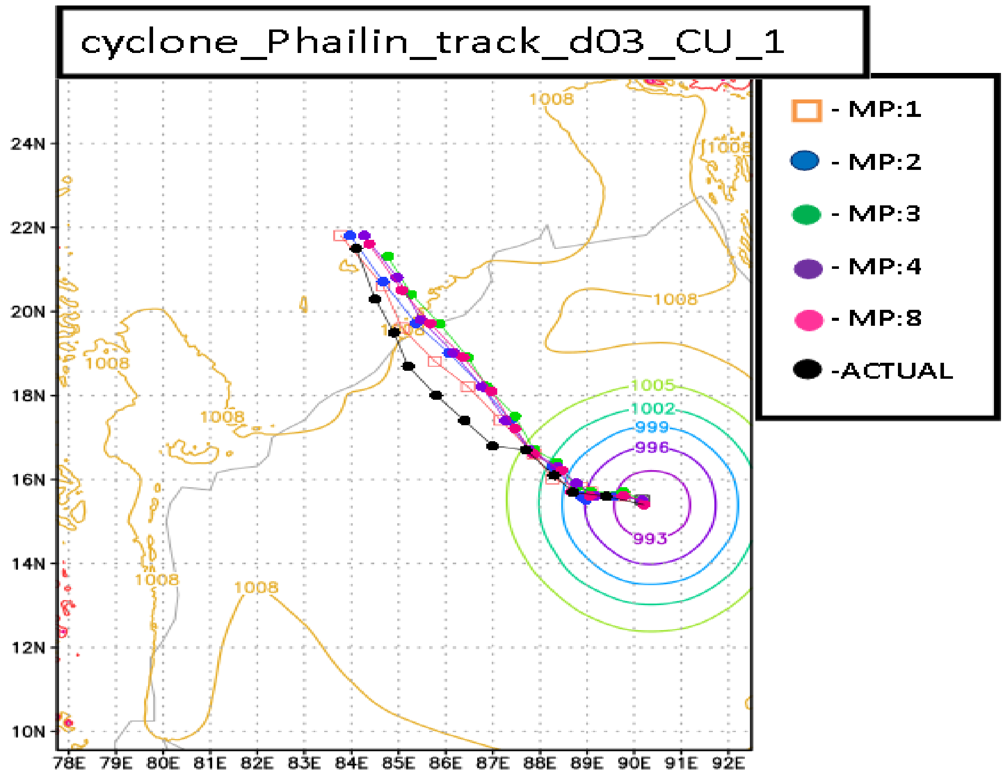

Figure 3. Phailin track simulations with different MP schemes and fixed Kain-Fritsch(new Eta) scheme CP (cu=1))

The track error of Phailin TC simulations for different mp schemes and cp parameterization scheme are plotted in the Figure 4.

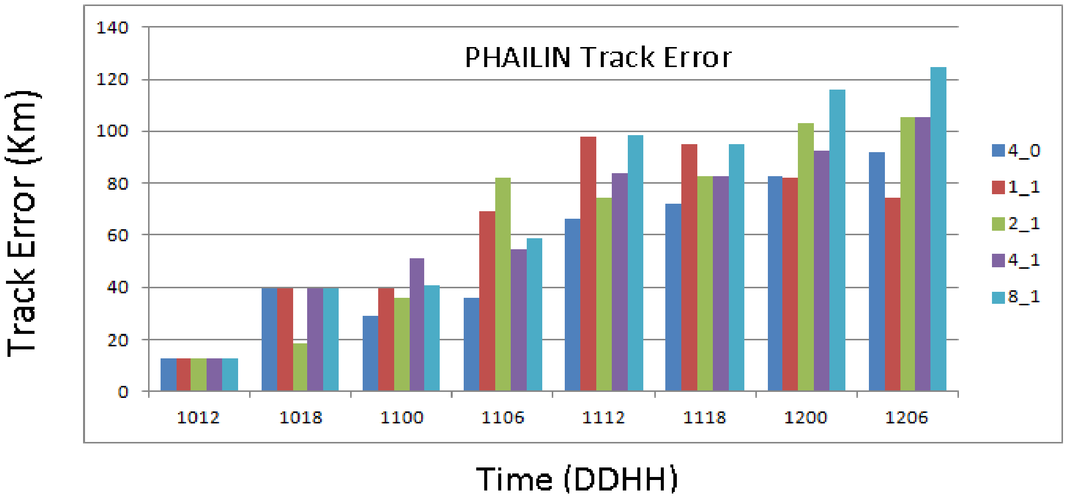

Figure 4. Track error of Phailin TC simulations

Time variation of model simulated central sea level pressure (CSLP) with JTWC observations for Phailin TC in hPa is plotted in Figure 5.

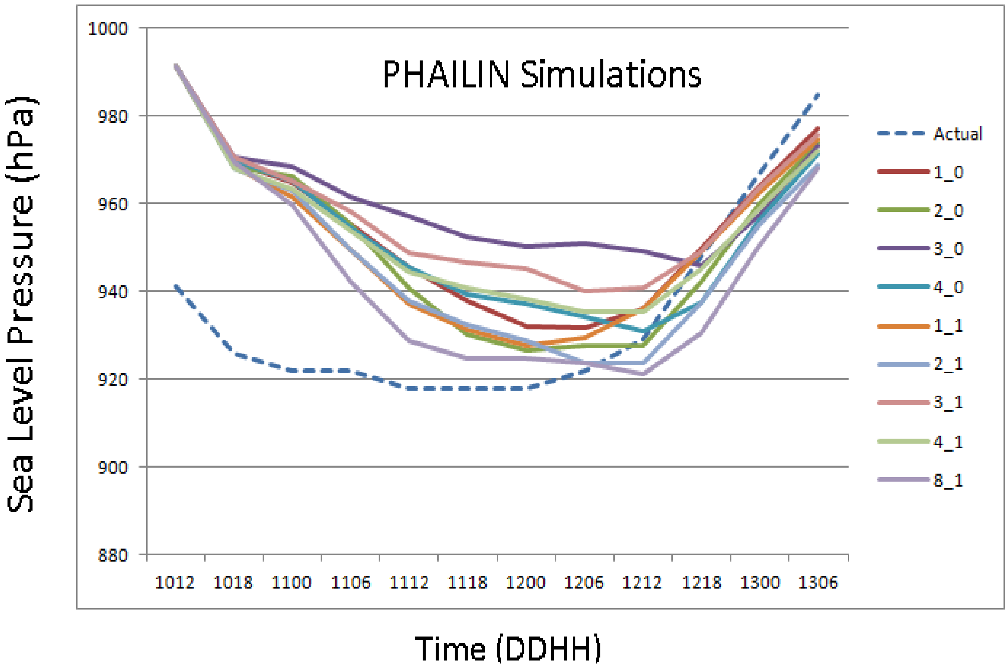

Figure 5. Time variation of model CSLP with JTWC in (hPa)

V. CONCLUSIONS

In this paper, Phailin cyclone is simulated over the coast of Bay of Bengal and presented the best possible combination of microphysics and cumulus physics. For Phailin TC simulations Kessler scheme (mp option=1) microphysics scheme in combination Kain-Fritsch (new Eta) scheme (cu Option=1) cumulus scheme gives out the best results which closely matches with the JTWC track. The track error for this combination is minimum of all the other combinations.

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