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The Sensitivity of Tropical cyclone Hudhud Simulations to physics Parameterization Schemes using the advanced mesoscale Weather Research and Forecasting (WRF) model

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Abstract: **-- The Tropical Cyclone Hudhud caused extensive damage and loss of life in eastern India and Nepal during October 2014. 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. The cyclone reached its peak intensity with a minimum central pressure of 950 mbar and reached the maximum sustained wind speed of 180 km/h. The cyclone crossed the Andhrapradesh coast near Visakhapatnam on October 12. In this present study The sensitivity of numerical simulations of tropical cyclone HUDHUD to physics parameterizations is carried out with a view to determine the best set of physics options for prediction of cyclones originating in the north Indian Ocean. The latent heat release in the clouds is the main source of energy for cyclone and the convective heating is mainly dependent on the cloud dynamical properties and microphysical processes. 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 track and intensity of simulated cyclone are compared with best track estimates provided by the Joint Typhoon Warning Centre (JTWC) data. Simulations are performed over the heavy rainfall days 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:-- **- Hudhud, WRF Model, physics parameterizations, Cyclone track, Track error**

I. INTRODUCTION

The Very Severe Cyclonic Storm HUDHUD developed from a low pressure area over North Andaman Sea in the morning of 6th October 2014 and turned into a depression in the morning of the 7th October over the north Andaman Sea. It intensified into a Cyclone Strom in the morning of 8th October and further intensified into a Very Severe Cyclonic Storm (VSCS) in the afternoon of 10th October. It continued to intensify while moving north-west direction and reached maximum intensity with a maximum sustained wind speed (MSW) of 185 kmph over the West Central Bay of Bengal off Andhra Pradesh coast in the early morning of 12th October 2014. It crossed north Andhra Pradesh coast over Visakhapatnam (VSK) 17.7°N 83.3°E between 0630 and 0730 UTC of 12th October. At the time of landfall on 12th the estimated central pressure was 950 hPa with pressure drop of 54 hPa (IMD 2014) and the estimated maximum sustained surface wind speed was about 100 Knots. It caused very heavy to extremely heavy rainfall over North Andhra Pradesh and South Odisha Maximum 24 hour cumulative rainfall of 38 cm ending at 0300 UTC of 13October was reported from Gantyada (dist Vizianagaram) in Andhra Pradesh. Maximum storm surge of 1.4 meters above the astronomical tide has been reported by the tide gauge at Visakhapatnam. The numerical weather prediction (NWP) and dynamical statistical models provided good guidance with respect to its 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. It is considered to be very important to examine the synoptic features of cyclone 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).

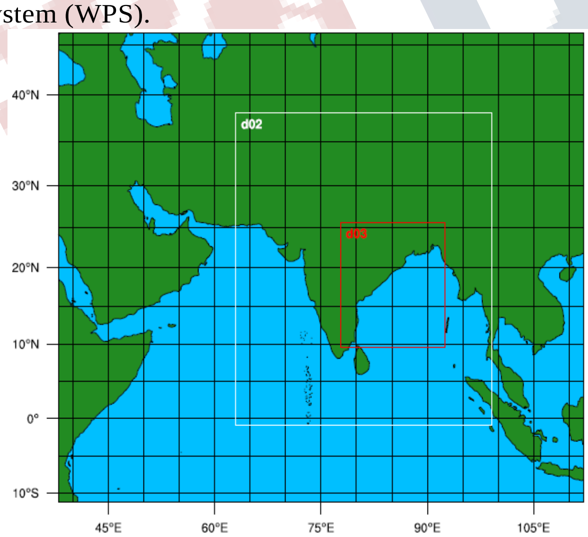

Fig.1 WPS domain configuration used in simulation

The Initial and boundary conditions are obtained from the UCAR & NCAR Research Data Archive http://rda.ucar.edu/datasets/ds083.2/index.html#sfl-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.

Tabel 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

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

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Tabel 2 : WRF Model dynamics and domain details

Dynamics	
Equation Non	hydrostatic
Time integration scheme	Third-order Runge-Kutta scheme
Horizontal grid type	Arakawa-C grid
Domain	
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
Planetary Boundary Layer (PBL)	Yonsei University Scheme (YSU)

III. RESULTS AND DISCUSSIONS

The Simulations for the Hudhud 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 Fig.3 The simulated track of Laila cyclone with different MP and CP parameterization schemes are plotted in the Fig.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 Hudhud TC for different CP and MP is plotted in Fig.8

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

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

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

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

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

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. HUDHUD SIMULATIONS

Hudhud 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 Hudhud cyclone with different MP schemes and CP parameterization Grell-3D ensemble scheme (cu=5) are plotted in the Fig.2.

The Hudhud cyclone with different CP and MP parameterization Thompson graupel scheme 2 moment (mp=8) are plotted in the Fig.3. The Hudhud cyclone with different MP schemes and no CP parameterization scheme (cu=0) are plotted in the Fig.4. The Hudhud cyclone with different MP schemes and CP parameterization Kain-Fritsch(new Eta) scheme (cu=1) are plotted in the Fig.5.

Hudhud cyclone with different MP schemes and CP parameterization Betts-Miller-Janjic scheme (cu=2) are plotted in the Fig.6. The Hudhud cyclone with different MP schemes and CP parameterization Grell-Devenyi ensemble scheme (cu=3) are plotted in the Fig.7.

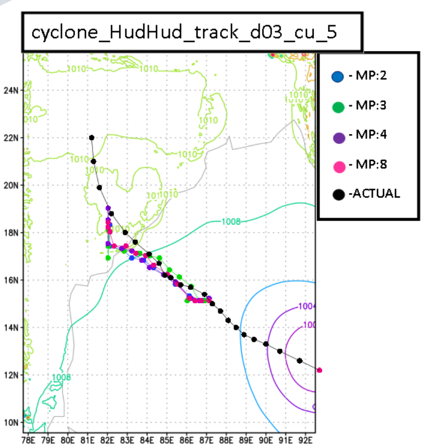

Fig.2 Hudhud track simulations with different MP schemes and fixed CP to Grell-3D ensemble scheme (cu=5)

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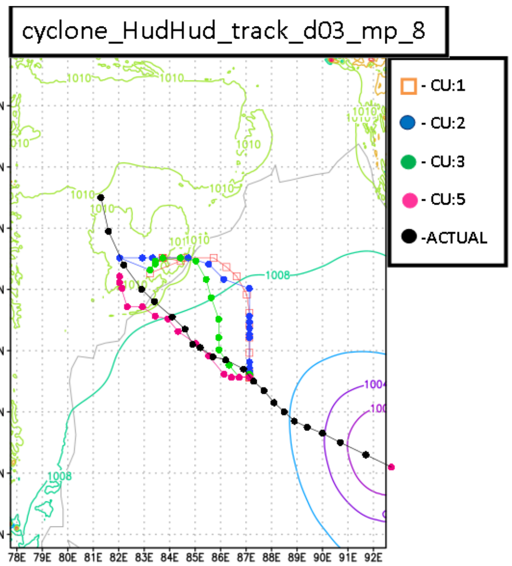

Fig.3 Hudhud track simulations with different CP schemes & fixed MP to Thompson graupel scheme 2 moment (mp=8)

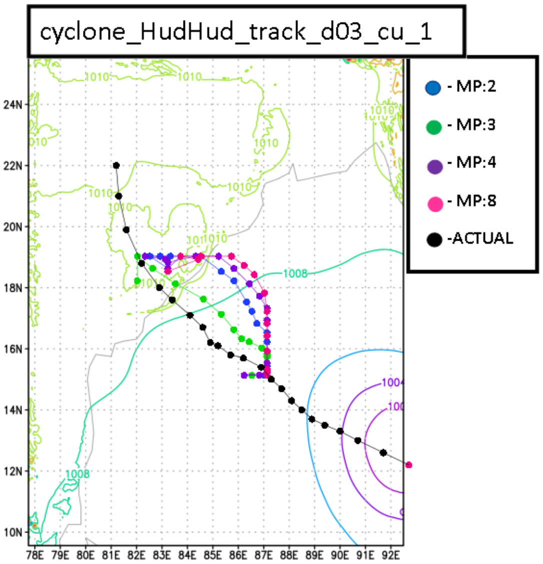

Fig.5 Hudhud track simulations with different MP schemes and fixed CP to Kain-Fritsch(new Eta) scheme (cu=1))

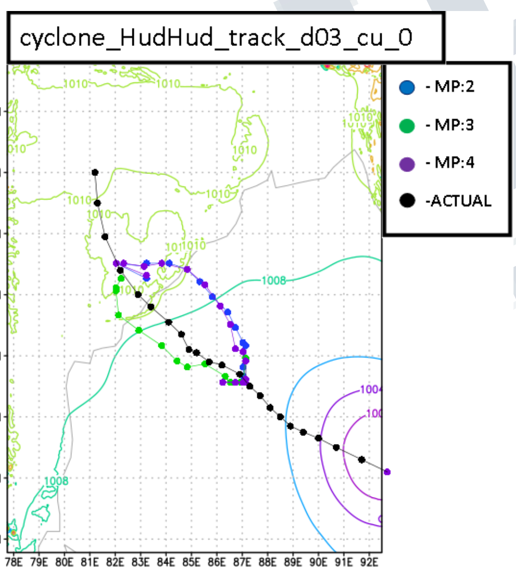

Fig.4 Hudhud track simulations with different MP schemes and without CP scheme (cu=0)

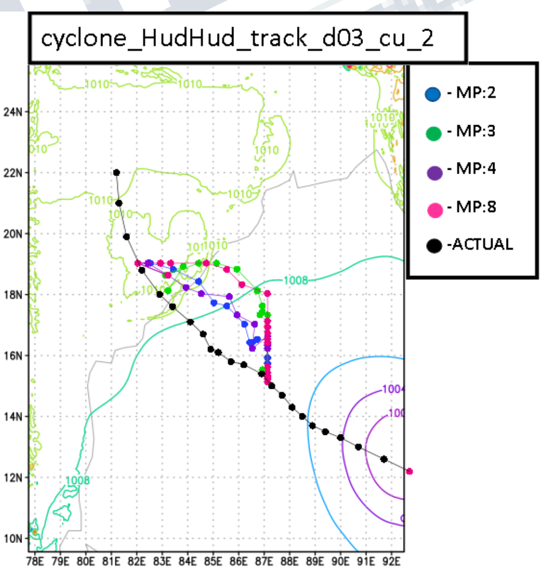

Fig.6 Hudhud track simulations with different MP schemes and fixed CP to Betts-Miller-Janjic scheme (cu=2)

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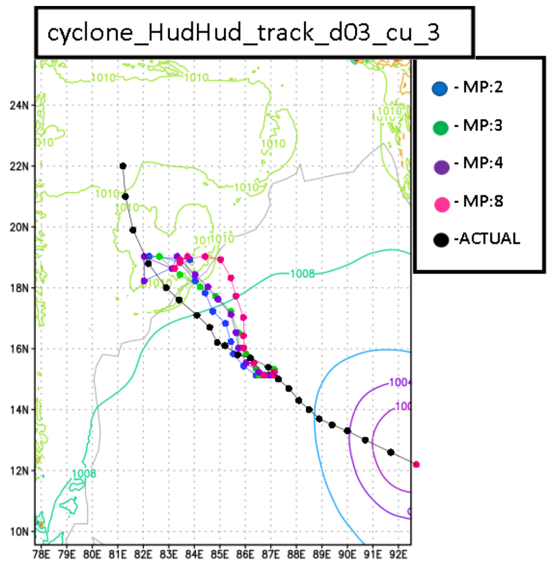

Fig.7 Hudhud track simulations with different MP schemes and fixed CP to Grell-Devenyi ensemble scheme (cu=3)

The track error of Hudhud TC simulations for different mp schemes and cp parameterization Grell-3D ensemble scheme (cu=5) are plotted in the Fig.8

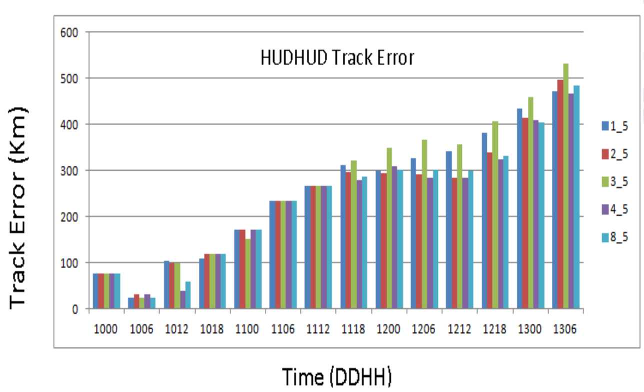

Fig.8 Track error for Hudhud TC simulations

Time variation of model simulated central sea level pressure (CSLP) with JTWC observations for Hudhud TC in hPa is plotted in Fig.9

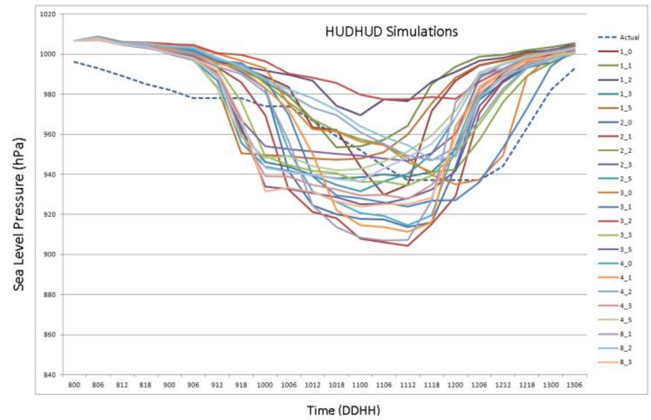

Fig.9 Time variation of model CSLP with JTWC in (hPa)

V. CONCLUSIONS

In this paper, Hudhud cyclone is simulated over the coast of Bay of Bengal and presented the best possible combination of microphysics and cumulus physics. For Hudhud TC simulations THOM2 microphysics scheme in combination G3D 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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