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Research paper

Impact of microphysics parameterization schemes in simulation of vardah cyclone using the advanced mesoscale weather research and forecasting model

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Abstract

The very severe Tropical Cyclone Vardah caused huge damage to property and life in south India during December 2016. The sensitivity of numerical simulations of the very severe tropical cyclone Vardah to different physics parameterization schemes is carried out to determine the best microphysics and cumulus physics parameterization schemes. The WRF Numerical weather prediction model configured with two nested domains. The horizontal resolution of domain-1is 27 km and domain-2 is 9 km. The tropical cyclone Vardah simulated track results were compared with the best track data given by the Indian Meteorological Department (IMD). WRF model Simulations were carried out using different microphysics (mp) parameterization schemes by fixing convective cumulus physics (cu) option to Grell-3D ensemble scheme and boundary layer option to updated Yonsei University scheme. The Vardah Cyclone track well simulated using WRF Single Moment-3 (WSM3) microphysics scheme in combination with G3D cumulus physics scheme. The cumulus physics and microphysics parameterization schemes influence the cyclone track prediction skill.

Keywords: *Vardah; ARW Model; Physics Parameterizations; Cyclone Track; Track Error*

1. Introduction

The Bay of Bengal region experiences two tropical-cyclone seasons, mainly during the post-monsoon (October–December) season and less frequently during the pre-monsoon (April–June) season. Because of development, and growing population damage from land falling tropical cyclones increase every year. TC track forecasting is a very important factor for mitigation efforts and disaster warnings [1]. The tropical cyclone track forecast errors over the Bay of Bengal region are relatively high compared to Pacific and Atlantic Oceans [3][4]. The Vardah Cyclone was the very severe Tropical Cyclone in the year 2016 over the Bay of Bengal region. The cyclone developed from a low-pressure system that formed near the Malay Peninsula on 6 December and intensified further into a very Severe Cyclonic Storm on 8th December. The cyclone crossed the Tamil Nadu coast near Chennai between 1500 and 1700 IST on 12th December crossed the Tamilnadu coast near Chennai (13.13o N and 80.3o E) during 0930-1130 hrs UTC with a wind speed of 110 kmph to 125 kmph. The estimated central pressure was 976 hPa observed at the time of landfall on 12th December, 2016 and the estimated wind speed was about 70 Knots. It is considered very important to examine the synoptic features of cyclone Vardah with different physics parameterization schemes using the advanced mesoscale WRF model [9].

2. Data and methodology

The Vardah Tropical Cyclone is simulated using ARW Weather Research and Forecasting model. The MODIS data (topographical terrain) used for the two nested domains in the WRF Preprocessing system (WPS). The NCEP GFS data is used as the boundary condition and initial conditions to WRF model. These NCEP GFS operational Global Analysis data are on 0.25-degree by 0.25-degree grids operationally prepared every six hours [8]. The list of microphysics, cumulus physics and pbl parameterizations considered in the present study to predict the Vardah cyclone track listed in Table-1 and Table-2. The WRF Model domain details and dynamics were listed in Table-3.

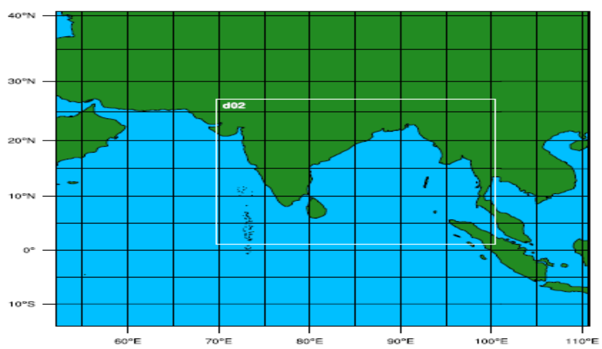

Fig. 1: WPS Domain Configuration.

Table 1: List of Microphysics Schemes

Scheme Acronyms	
Kessler (option=1)	KS
Lin et al. option=2)	LIN
WRF Single Moment 3-class simple ice (option=3)	WSM3
WRF Single Moment 5-class scheme (option=4)	WSM5
Ferrier (new Eta) (option =5)	FERRIER
WRF single moment 6-class (option =6)	WSM6
Thompson graupel 2 moment (option=8)	THOM2
Goddard GCE (option =7)	GODDARD
WRF double moment 5-class (option =14)	WDM5
WRF double moment 6-class (option =16)	WDM6

Table 2: Model Cumulus and Planetery Boundary Layer Parameterization Schemes

scheme	Acronyms
Yonsei University (pbl option=1)	YSU
Grell-3D ensemble (cu option=5)	G3D

Table 3: WRF Model Domain Details and Model Dynamics

Model dynamics details	
Model Equation	Non-hydrostatic
Time integration scheme	Third-order Runge-Kutta scheme
Grid type (Horizontal)	Arakawa-C grid
Model Domain details	
Map projection	Mercator projection
Central point of the domain	81.4oE, 15oN
No. of domains	2
No. of vertical layers	51 eta_levels
Horizontal grid distance	27 km(domain1) and 9 km(domain2)
Time step	90 sec(domain1) and 30 sec(domain2)
Number of grid points	210 (WE), 210 (SN) in domain1 328 (WE), 292 (SN) in domain2

3. Results and discussions

The Initial state, representation of the physical processes and planetary boundary layer conditions in the ARW model decide the accuracy of numerical prediction of tropical cyclones. Results from domain-2, is considered for the study of Vardah cyclone. In the entire Vardah tropical cyclone simulation experiments the planetary boundary layer and cumulus physics is fixed to YSU and Grell-3D ensemble schemes respectively [9]. The wrf model simulated track and the IMD observed Vardah Cyclone track were compared and the haversine formula is used to compute the cyclone track error. In Fig. 5 the wrf model predicted track error for different microphysics parameterization schemes were presented.

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

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

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

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

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

Where D is Track error, φ is latitude, λ is longitude.

3.1. Cyclone track simulation

Vardah TC Simulations were initiated on 07th December 2016, 0000 UTC with lateral boundary condition and were carried up to 13th December 2016, 0000 UTC. The USGS (United States Geological Survey) 2m resolution topographical terrain data used for both domain1 and domain2 in the WRF pre-processing system (WPS)[6]. The model run up to 144hr and the simulated Vardah cyclone track for different microphysics parameterization schemes were plotted in Fig. 2. The Root Mean Square Error (RMSE) of Simulated Tracks were computed and the results were plotted in Fig.4. Based on the RMSE the WSM3 microphysics scheme in combination with G3D cumulus physics scheme produces the minimum track error compared to other mp and cu parameterization schemes. The RMSE track error is 404.648 km maximum for Kessler scheme.

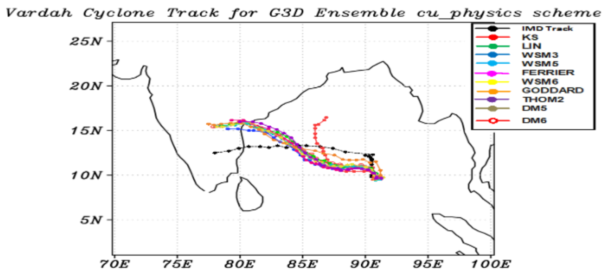

Fig. 2: Vardah Cyclone Track for G3D Ensemble Cumulus Physics Scheme.

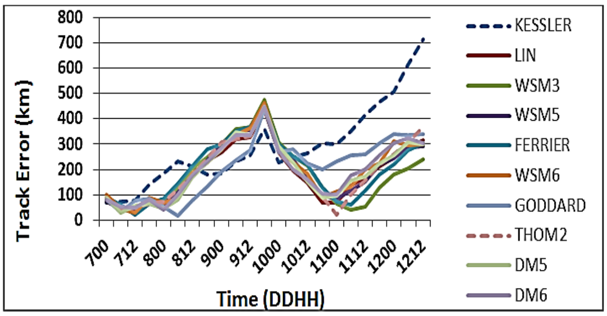

Fig. 3: Track Error for Grell-3D Cumulus Physics Scheme Compared with IMD.

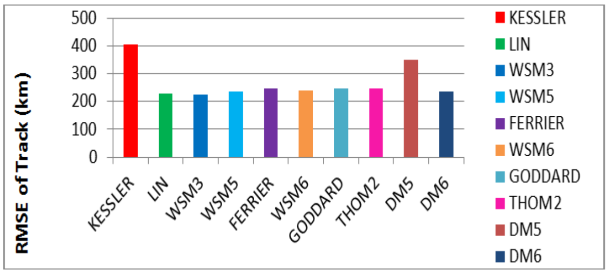

Fig. 4: RMSE of Track for G3D Cumulus Physics Scheme Compared with IMD.

3.2. Central sea level pressure

Time variation of model-simulated central sea level pressure (CSLP) with IMD observations for Vardah TC in hPa is plotted in Fig. 8. All the schemes predict the same CSLP at 0000 UTC on 07 December and continue up to 0006 UTC on 07 December. All the schemes well simulated the initial track position of the storm [7]. Only the THOM2 with G3D scheme predicts the CSLP of 974 hPa from 0000 UTC on 12 December to 0012 UTC on 12 December which is same as the observed value and the others underestimates the CSLP of Vardah cyclone.

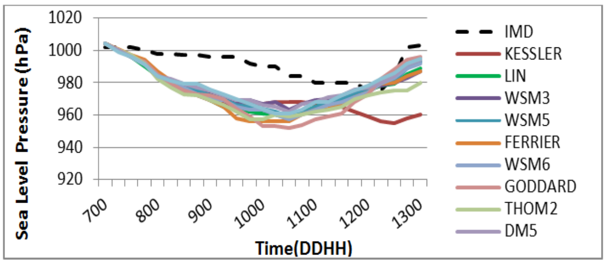

Fig. 5: Time Variation of Model CSLP with IMD in (Hpa) for G3D Scheme.

3.3. Maximum sustained wind

Fig.6 shows the 10-m Maximum Sustained Wind speed compared with IMD observations. At 0000 UTC on 07 December all the schemes under estimated the MSW speed of 23 knots and the actual IMD observation MSW speed is 25 knots. When the tropical cyclone attains the Very Severe Cyclone Strom intensity level the Maximum Sustained Wind speed of 70 knots is under estimated by all the schemes. After the landfall all the schemes over estimated the MSW speed [2], [5].

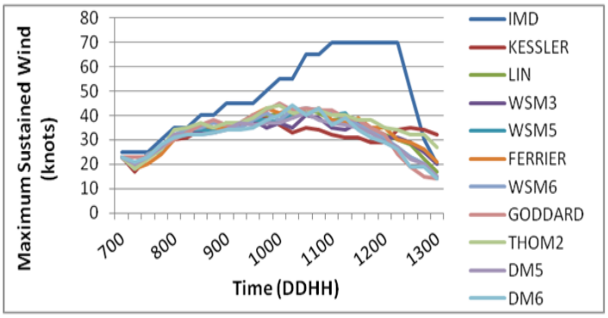

Fig. 6: Time Variation of Model Surface Wind with IMD for G3D Scheme.

3.4. Precipitation

Fig.7 shows the 24-hour accumulated precipitation on 12th December, 2016 by different microphysics parameterization schemes along with Satellite observation (TRMM). Before the landfall (on 10th and 11th December) rainfall is confined mainly over the ocean. On 12th December, 2016 heavy rainfall upto 19 cm recorded at a few places over Chennai, Thiruvallur districts of Tamil Nadu and Nellore, Prakasam districts of Andhra Pradesh [10].

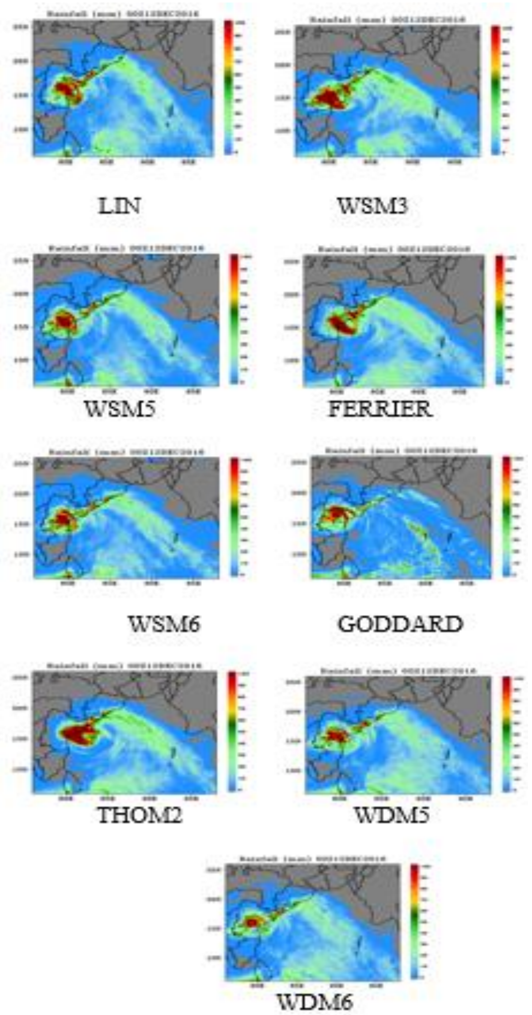

Fig. 7: 24-Hour Accumulated Rainfall for Diferrent Schemes on 12 December 2016.

4. Conclusion

The sensitivity analyses of model performances have mainly focused on model physics, and initial conditions. The analysis associated with inner domain-2 is considered. For Vardah TC simulations WSM3 microphysics scheme in combination G3D cumulus scheme gives out the best results which closely matches with the IMD track and intensity. The track error for this combination is the minimum of all the other combinations

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