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Real-Time Track Prediction of Vardah and Roanu Tropical Cyclones over the Bay of Bengal region using the ARW Model

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ABSTRACT:
The real-time track prediction of tropical cyclones (TCs) over the Bay of Bengal (BOB) region at 9-km resolution is evaluated on the basis of initial conditions using the advanced mesoscale Weather Research and Forecasting (ARW) model. In the present study Vardah and Roanu two cyclonic storms (CS) developed in the BOB region in the year 2016, were considered for the real time track prediction. The Vardah tropical cyclone forecast simulation carried out for 102 hr, 78 hr and 54 hr and for the Roanu cyclone forecast simulations were carried out for 98 hr, 72 hr and 48 hr. Two nested domains are considered for WRF model simulation. The horizontal resolution of domain-1, and domain-2, are 27 km, and 9 km respectively. The simulated track and intensity of tropical cyclones were compared with the real-time data provided by the Indian Meteorological Department (IMD). Throughout the WRF model Simulations microphysics (mp) parameterization scheme is fixed to Thompson graupel 2 moment scheme, the convective cumulus physics (cu) option is fixed to Grell-3D ensemble scheme and Planetary boundary layer scheme is fixed to updated Yonsei University scheme. The ARW model is more accurate in cyclone track prediction when model initialized at the high intensity stage of the tropical cyclone [1].
KEYWORDS: Tropical Cyclone, WRF Model, Track Error, Track Forecast, parameterizations, microphysics, cumulus physics

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I. INTRODUCTION:

TC track forecasting is a critical component for disaster warnings and mitigation efforts. The tropical cyclone track forecast errors over the NIO are high relative to those over the Pacific and Atlantic Oceans [2]. Vardah the most intense Tropical Cyclone and Roanu weak Tropical Cyclone developed over the BOB region during the year 2016. The Vardah cyclone developed from a low-pressure system that formed near the Malay Peninsula in the Bay of Bengal on 6th December and intensified into a 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 north Tamil Nadu coast near Chennai (13.13o N and 80.3o E) during 0930-1130 hrs UTC with a wind speed of 110 kmph gusting to 125 kmph. At the time of landfall on 12th the estimated central pressure was 976 hPa and the estimated maximum sustained surface wind speed was about 70 Knots. Vardah TC Simulations were initiated on 09th December 2016, 0000 UTC with lateral boundary condition and were carried up to 13th December 2016, 0600 UTC [10]. The Roanu cyclone developed over southwest Bay of Bengal of Sri Lanka coast on 14th May 2016. It further moved northwestwards and lay over Sri Lanka in the morning of 16th. The system continued to move along the east coast of India while moving northeastwards and intensified with maximum sustained wind speed reaching 40 knots at 0600 UTC of 19th and to 45 knots at 1800 UTC of 20th May. The cyclone maintained its intensity of 45 knots and crossed the Bangladesh coast near latitude 22.60N and longitude 91.60E. After the landfall, the cyclone started weakening due to the land interactions. The Roanu TC Simulations were initiated on 18th May 2016, 0000 UTC with lateral boundary condition and were carried up to 23th May 2016, 0000 UTC [11].

II. DATA AND METHODOLOGY

The Advanced Research WRF (ARW) v 3.9.1.1 mesoscale model developed by NCAR used in the tropical cyclone simulations. The MODIS based terrain topographical data have been used for domain-1 and domain-2 in the WRF Preprocessing system (WPS). The NCEP GFS 0.25 Degree Analysis and Forecast Grids data is used as the initial conditions to WRF. These NCEP GFS 0.25 Degree Analysis and Forecast Grids data are on 0.25-degree by 0.25-degree grids prepared operationally for forecasting up to 16 days. The forecast data download url https://rda.ucar.edu/datasets/ds084.1/index.html#sfol-wl-/data/ds084.1. The mp, cu and pbl schemes used in the present simulation to investigate the track of the tropical cyclones [3] were listed in Table 1 and WRF Model dynamics and domain details are listed in Table-2. The HPC Cluster facility available at Center of Excellence details are given in Table 3.

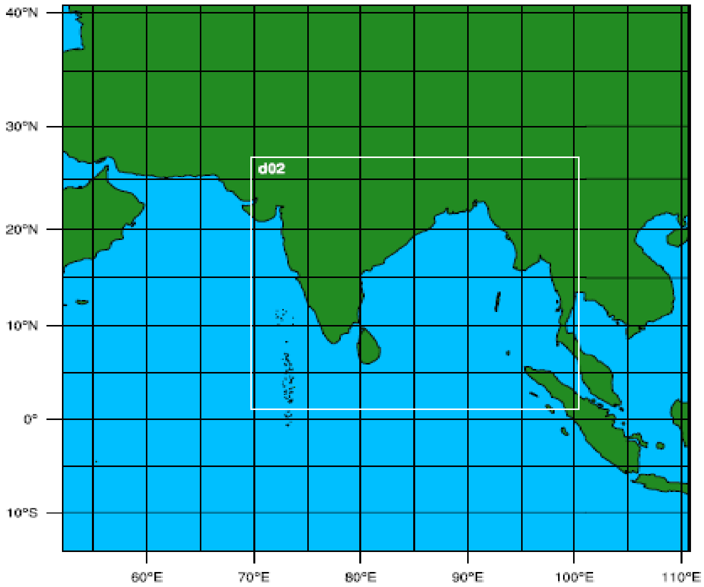


Fig. 1. WPS Domain Configuration

Table 1. List of model micro physics,cumulus and Planetery Boundary layer parameterization schemes.

scheme	Acronyms
Thompson graupel scheme 2 moment (mp option=8)	THOM2
Yonsei University (pbl option=1)	YSU
Grell-3D ensemble (cu option=5)	G3D

Table 2. 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	81.4°E, 15°N
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

Table 3. HPC Cluster facility Specifications

HPC Cluster Specifications	
Master nodes	Fujitsu PRIMERGY RX200 S8 Servers (02)
Compute Nodes	Fujitsu PRIMERGY RX200 S8 (08)
Compute Nodes (MIC nodes)	Fujitsu PRIMERGY CX400 S2 (02)
Communication with all internal cluster	D Link 24 port Gigabit ports with the manageable Ethernet switch
Fast Interconnects	Mellanox 18 port switch (01)
I/O display	KVM 16port switch (01)
Fujitsu DX 60 Storage	40 TB

III. RESULTS AND DISCUSSIONS

The Initial state, representation of the physical processes and 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 and Roanu cyclones. The USGS (United States Geological Survey) 2m resolution terrain topographical data have been used for both domain1 and domain2 in the WRF pre-processing system (WPS) [5] [6]. In the entire tropical cyclones simulation experiments the planetary boundary layer, microphysics and cumulus physics is fixed to YSU, THOM2 and Grell-3D ensemble schemes respectively [7] [9]. The wrf model forecast track and the IMD observed Cyclone tracks were compared and the haversine formula is used to compute the cyclone track error. In Fig. 5 the wrf model forecast track error for different initial were presented.

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

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

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

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

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

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

3. 1 Vardah Cyclone Track Simulation

Vardah TC Simulations were initiated on 09th, 10th and 11th December 2016, 0000 UTC with lateral boundary conditions were carried up to 13th December 2016, 0600 UTC. The model forecast run for 102hr, 78 hr and 54 hr and the simulated track of Vardah cyclone with different initial conditions were plotted in Fig. 2. The track errors and the RMSE of Track errors were plotted in Fig.3. The Sea Level Pressure and Maximum Sustained Wind Speed were plotted in Fig.5 and Fig.6.

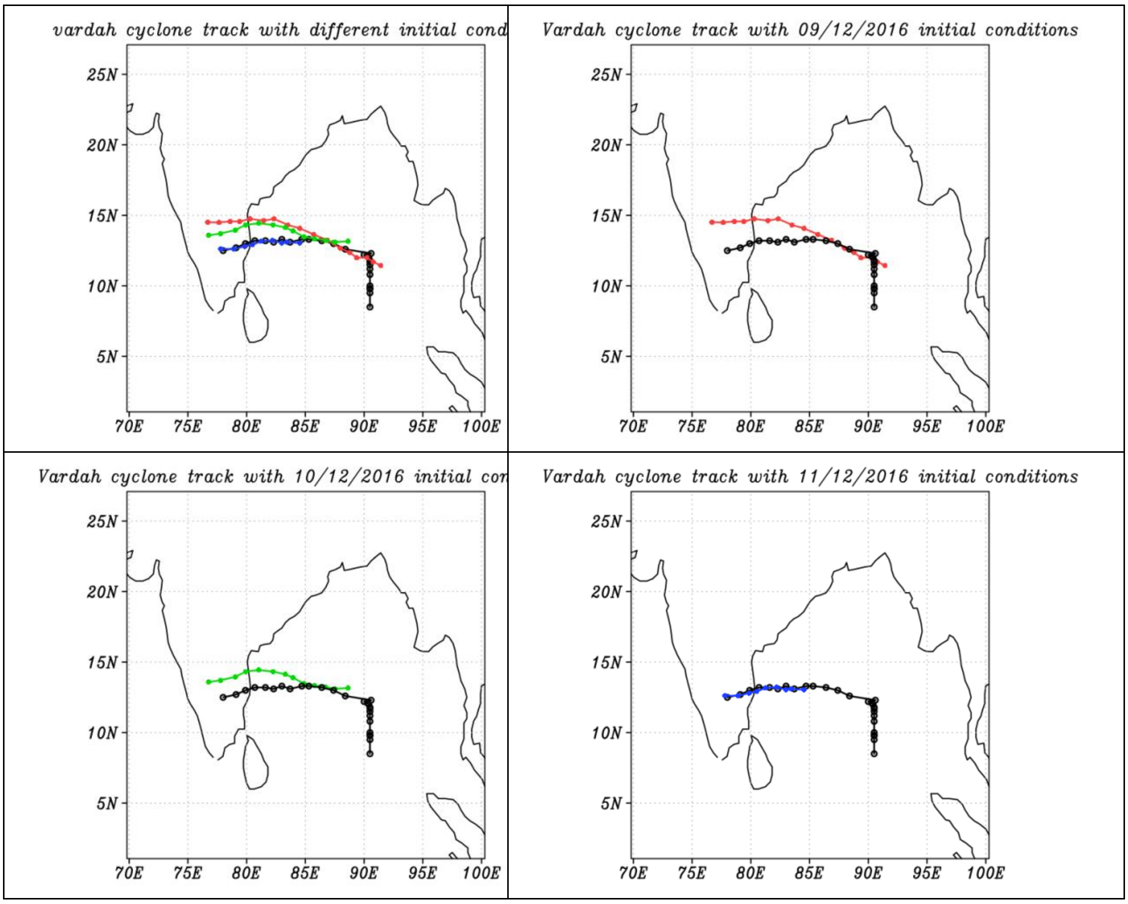


Fig.2 Vardah Cyclone forecast track for different initial conditions

The RMSE of Tracks in Fig.3 indicates that the WRF forecast simulations with 11/12/2016 initial conditions produces the relatively small track error compared to other initial conditions. The RMSE of track error is maximum 160.1 km for 09/12/2016 initial conditions and minimum 30.2 km for 11/12/2016 initial conditions.

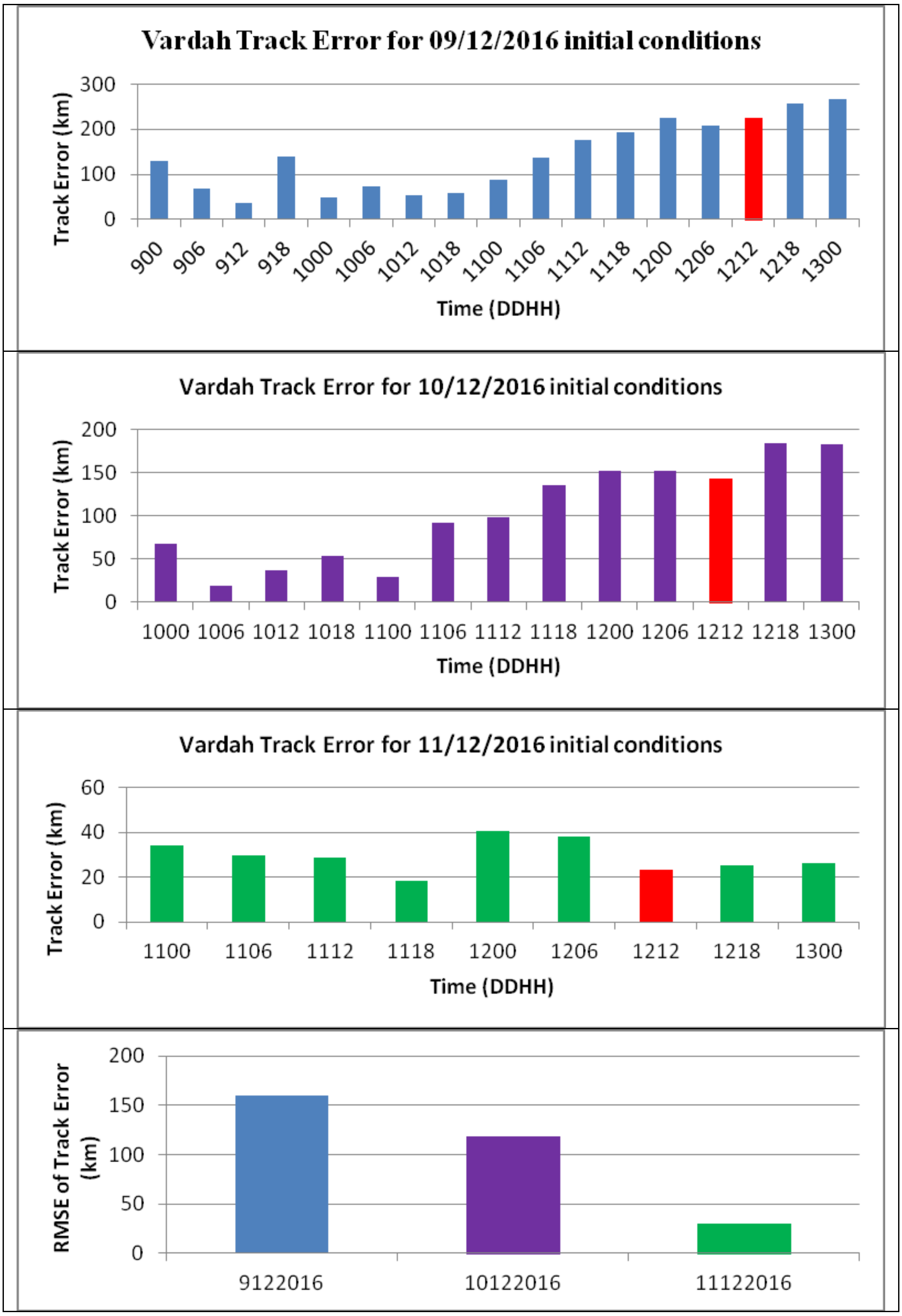


Fig.3 Vardah Cyclone forecast track errors and the RMSE of Track errors

Time variation of model-simulated central sea level pressure (CSLP) with IMD observations for Vardah TC in hPa is plotted in Fig. 4. The 09th December, 2016 initial condition underestimates the CSLP and 10th and 11th December, 2016 initial condition overestimates the CSLP of Vardah cyclone.

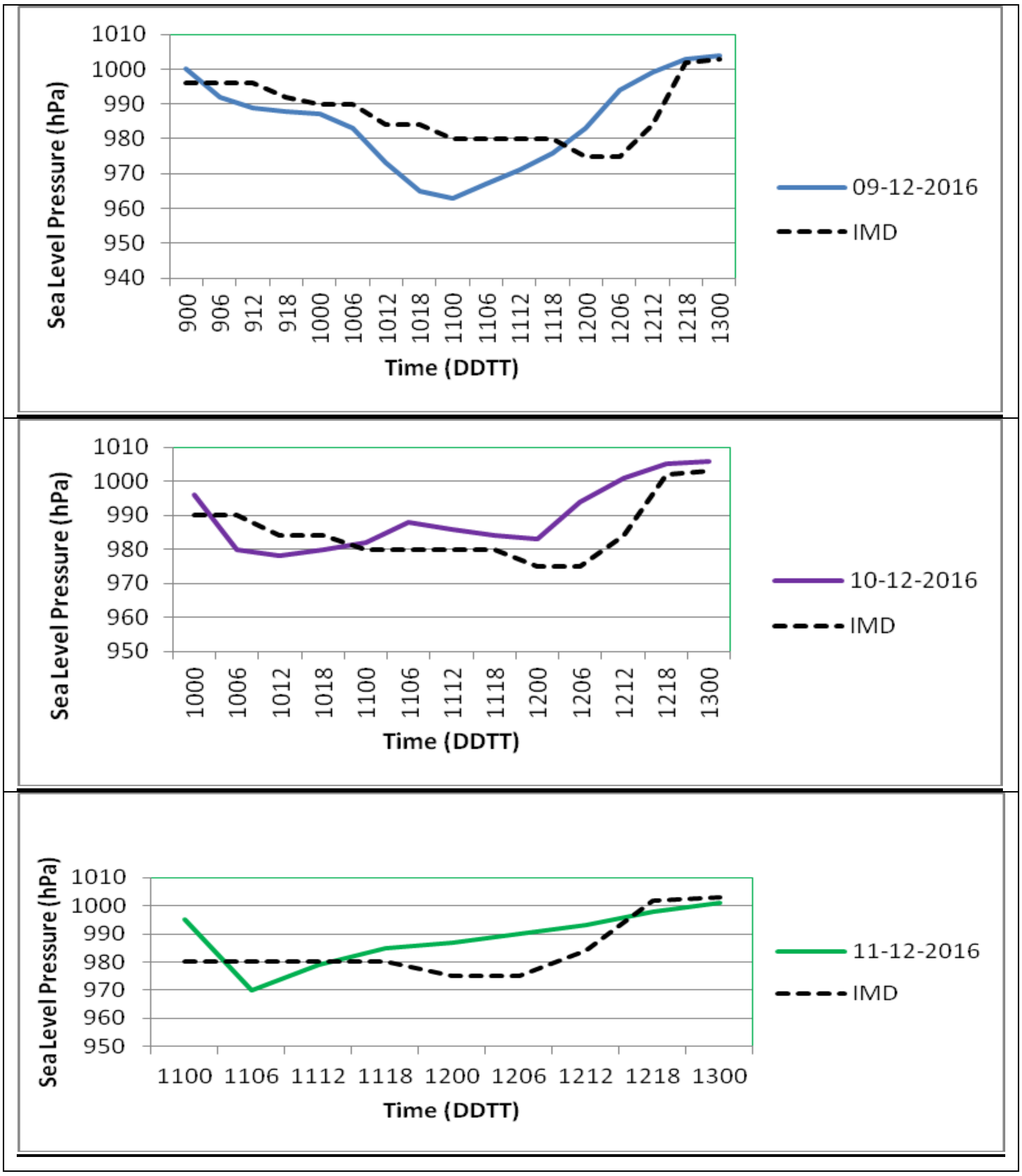


Fig. 4 Time variation of model CSLP with IMD in (hPa)

Fig.5 shows the 10-m Maximum Sustained Wind speed compared with IMD observations. All the simulations under estimated the MSW. 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 simulations.

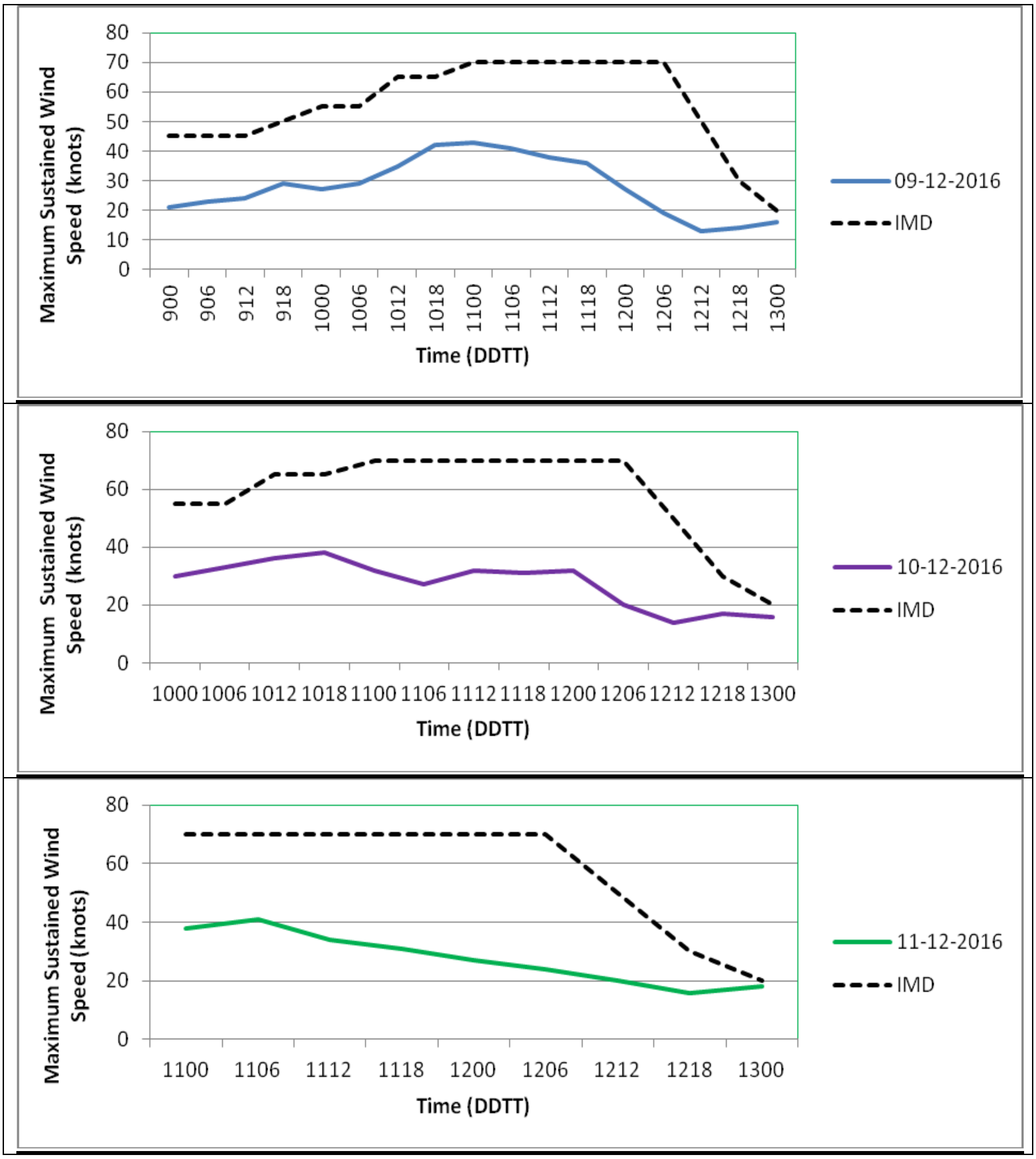


Fig. 5 Time variation of model surface wind with IMD in (knots) for Vardah Cyclone

3. 2 Roanu Cyclone Track Simulation

Roanu TC Simulations were initiated on 18th, 19th and 20th May 2016, 0000 UTC with lateral boundary conditions were carried up to 23th May 2016, 0000 UTC. The model forecast run for 96 hr, 72 hr and 48 hr and the simulated track of Roanu cyclone with different initial conditions were plotted in Fig. 6. The track errors and the RMSE of Track errors were plotted in Fig.7. The Sea Level Pressure and Maximum Sustained Wind Speed were plotted in Fig.8 and Fig.9.

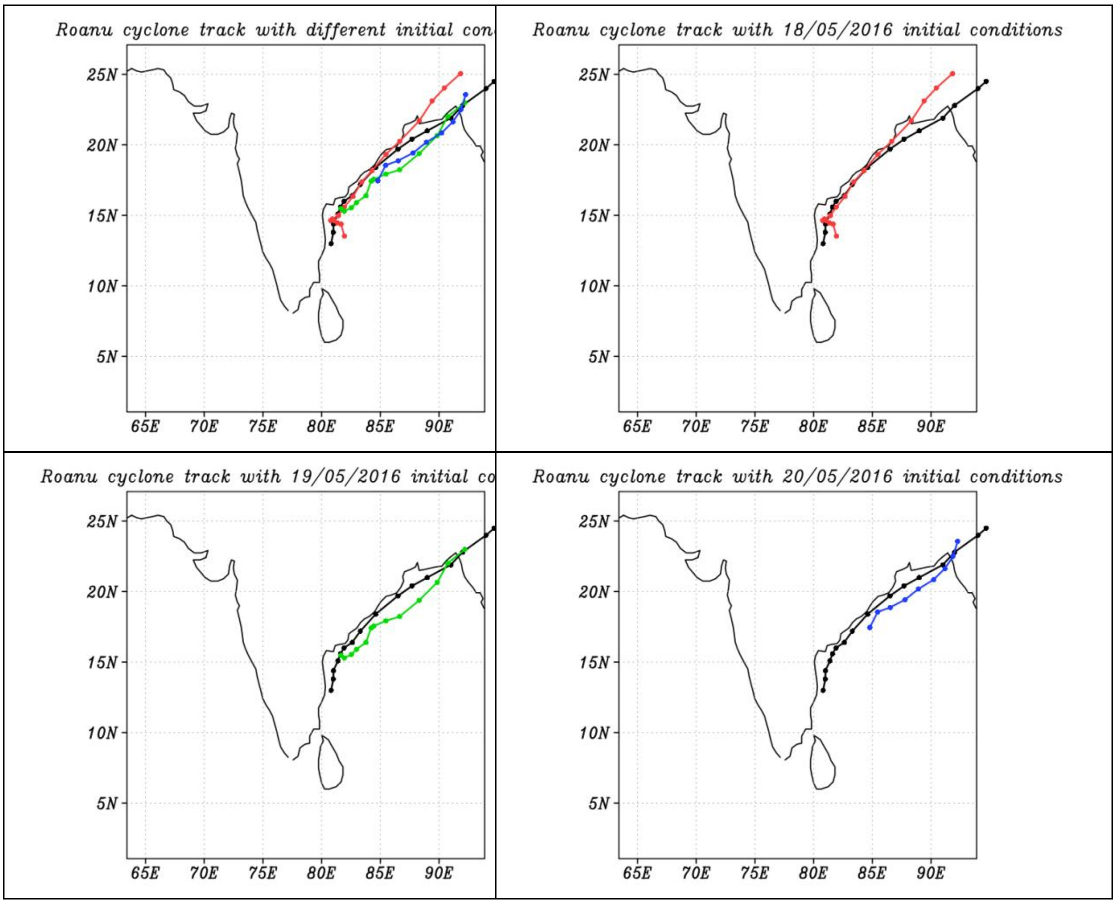
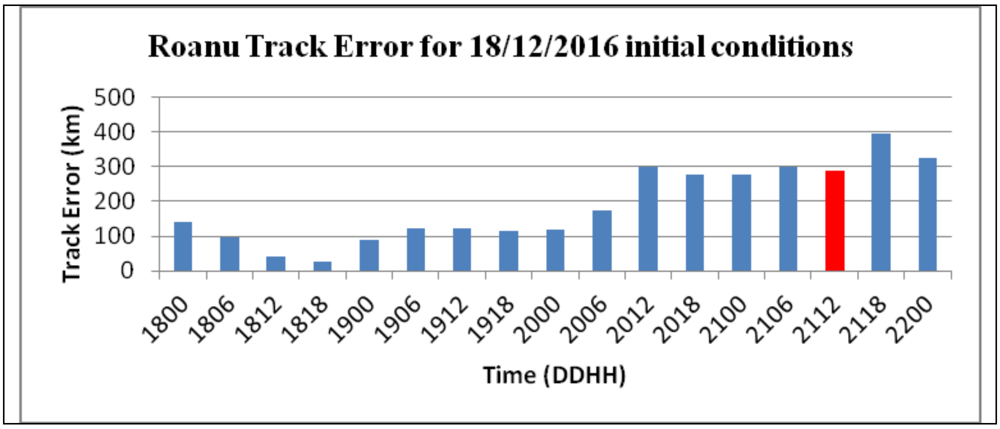


Fig.6 Roanu Cyclone forecast track for different initial conditions

The RMSE of Tracks in Fig.7 indicates that the WRF forecast simulations with 20/05/2016 initial conditions produces the relatively small track error compared to other initial conditions. The RMSE of track error is maximum 189.9 km for 18/05/2016 initial conditions and minimum 126.6 km for 20/05/2016 initial conditions.



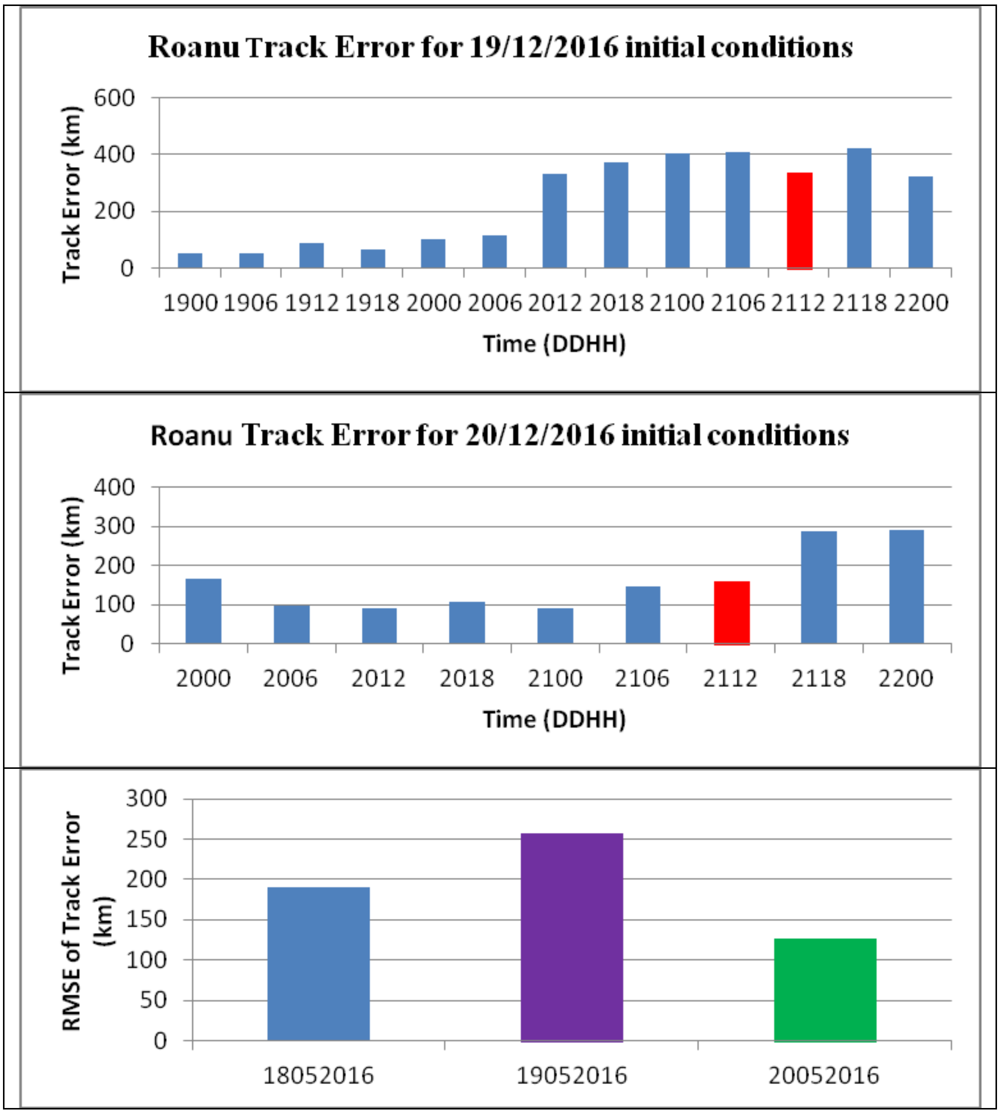
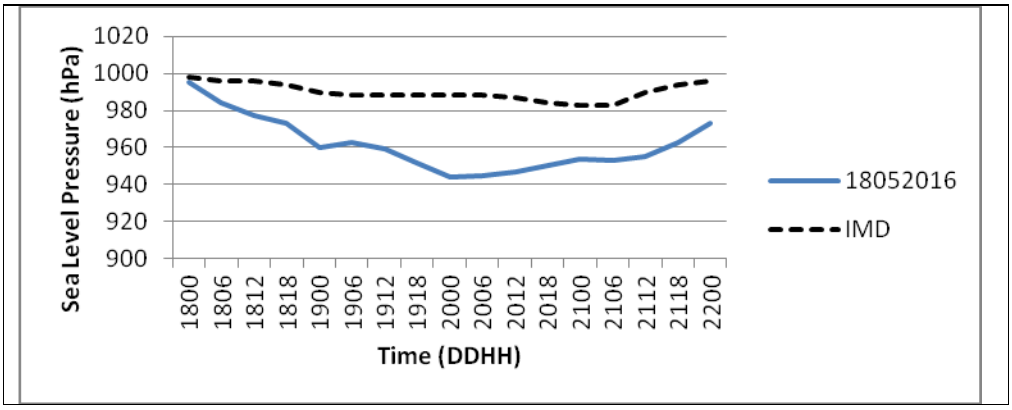


Fig.7 Roanu Cyclone forecast track errors and the RMSE of Track errors

Time variation of model-simulated central sea level pressure (CSLP) with IMD observations for Roanu TC in hPa is plotted in Fig. 8. All the three simulations underestimate the CSLP of Roanu cyclone.



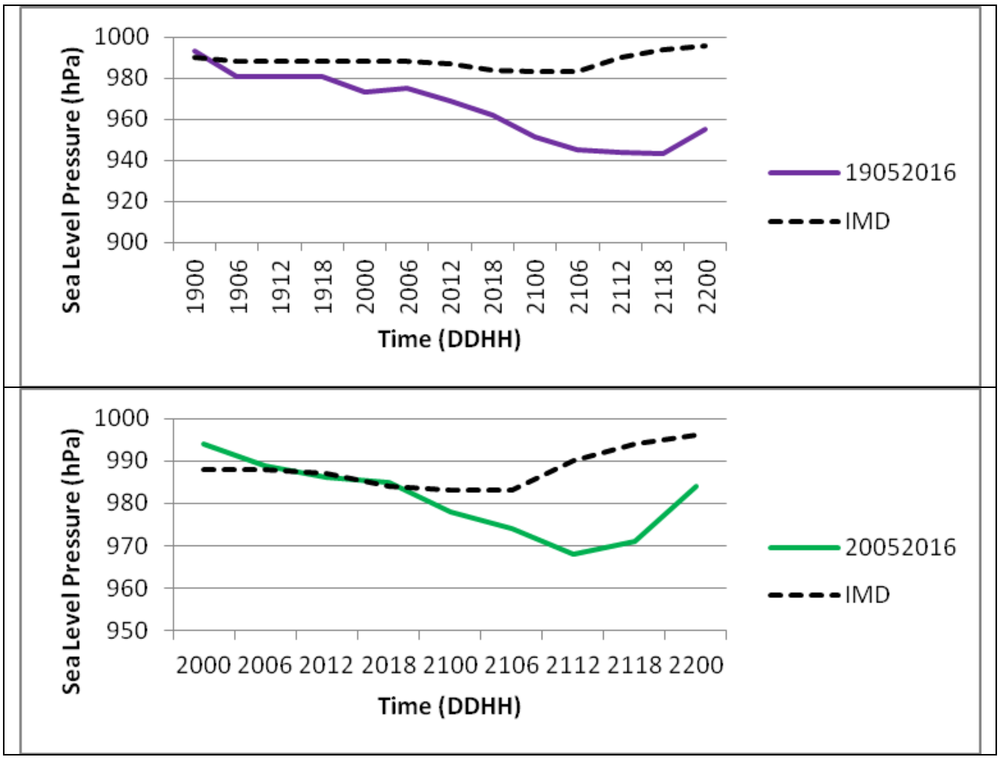
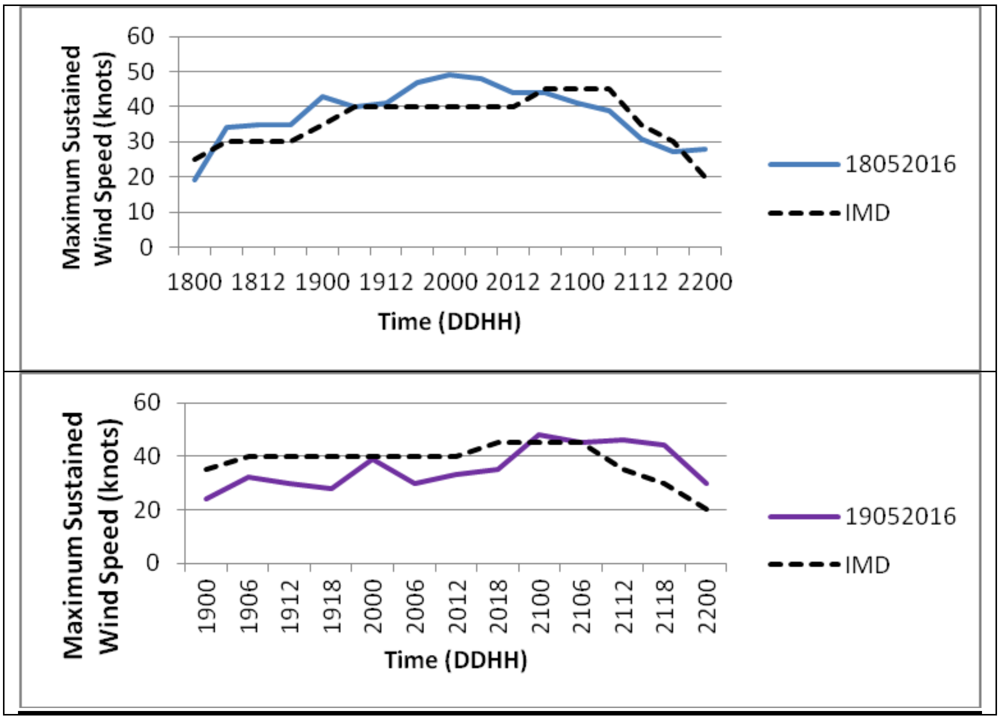


Fig. 8 Time variation of model CSLP with IMD in (hPa)

Fig.9 shows the 10-m Maximum Sustained Wind speed compared with IMD observations. The 18th May, 2016 initial condition overestimates the MSW speed up to the landfall and later underestimated the MSW speed. The 19th December, 2016 initial condition underestimated the MSW speed of Roanu cyclone until the landfall and later overestimated. The 20th December, 2016 initial condition underestimated the MSW speed of Roanu cyclone. When the tropical cyclone attains the Severe Cyclone Strom intensity level the Maximum Sustained Wind speed of 45 knots only 19th December, 2016 initial condition is estimated 48 knots.



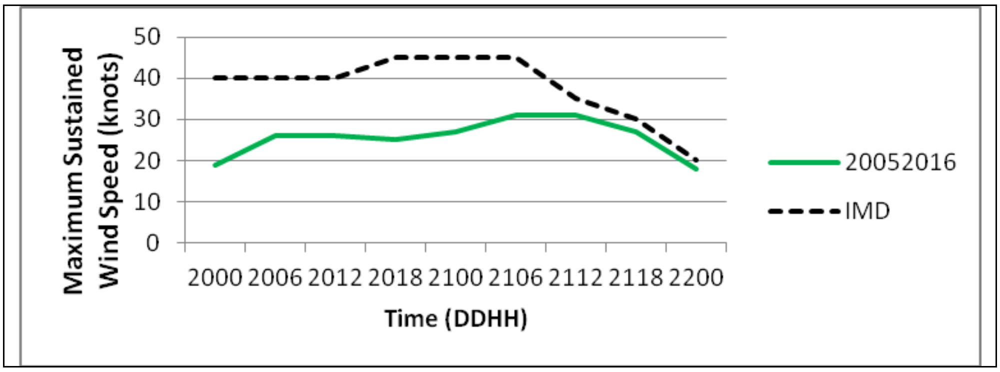


Fig. 9 Time variation of model surface wind with IMD in (knots) for Roanu Cyclone

IV. CONCLUSIONS

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 and Roanu TC simulations 11th December, 2016 and 20th May, 2016 initial conditions gives out the best track results which closely matches with the IMD track. The track error for this simulation is the minimum. For Vardah cyclone all simulations under estimated the MSW. For Roanu cyclone all simulations under estimated the CSLP. When the tropical cyclone attains the Severe Cyclone Strom intensity level ARW model track prediction skill is improved. The ARW model is more accurate in cyclone track prediction when model initialized at the high intensity stage of the tropical cyclone.

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