Study of track and intensity of two tropical cyclones using Advance Weather Research and Forecasting Model

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Abstract

Tropical cyclones rank among the most destructive natural disaster in the world. Every year people of coastal areas are encountered with these natural calamities. Accurate and timely forecast of track and intensity of tropical cyclones may reduce loss of lives and properties significantly. In this study, an attempt has been made to study track and intensity of two tropical cyclones i.e., Amphan a super cyclone and Bulbul a very severe cyclone using Weather Research and Forecasting (WRF) model. The model is configured with two two-way interactive nested domains with horizontal resolution of 27kms and 9kms to simulate cyclone Amphan and Bulbul. Outputs from 9kms domain are analyzed to reproduce track and intensity. Results are compared with best track data available from RSMC (New Delhi). It is found that track and intensity of Bulbul is predicted reasonably well compared to Amphan. These outcomes are very significant to understand as well as forecast of track and intensity of tropical cyclones.

Keywords: Tropical cyclone, WRF model, Track, Intensity.

1. Introduction

Tropical Cyclones (TCs) are warm core vortex where wind blows counter clock wise in the northern hemisphere and clock wise in southern hemisphere. When wind speed surpasses 34kts it is called as tropical cyclone in the Indian Ocean. TCs are also known to as 'Hurricanes' over Atlantic Ocean, 'Typhoons' over Pacific Ocean, 'Willy-Willy' over Australian Seas. TC genesis is prominently seasonal with key maximum in the post monsoon season (October - November) and secondary maximum in the pre-monsoon season (April - May) over the Bay of Bengal (BoB). Indian sub-continent has an elongated shoreline with the dense population. As a result, the damage of the cyclones are more prominent along the coastal regions of India-Bangladesh. The precise and timely prediction of the track and intensity of TCs with sufficient lead time can save the loss of lives and properties.

The strength of a TC is measured by horizontal wind speed and the pressure drop. Wind speed that measures the strength of TCs are the tangential components of horizontal wind which is known as primary circulation. TCs are the most destructive natural calamities with huge potential of damage of lives and properties. The destruction is mostly owing to heavy rainfall, strong winds and associated storm surges [1]. Every year the people of tropical regions meet with these natural calamities. Thus, early warnings with impacts are very crucial to reduce the damage due to the TCs [2].

Forecasting of TCs track, intensity and landfall position are very crucial for disaster management. The accuracy of track forecast has improved significantly over the past decades owing to improvements in numerical prediction models [3]. Nevertheless, still significant errors in track forecast, more than 1,000 km beyond 72 hours exist and stop further improvement of the annual-mean error [4]. TC motion is mostly controlled by steering (i.e., horizontal advection of relative vorticity), the beta effect (meridional advection of the Coriolis parameter), and their nonlinear interaction [5].

The Weather Research and Forecasting (WRF) model has been extensively used for the simulation of various hazardous weather phenomena, e.g. heavy rainfall, tropical cyclone, storm surge etc and real time numerical weather prediction (NWP) globally [6,7]. Weather agencies of various nations give forecasts of TCs operationally. The high-resolution non-hydrostatic mesoscale atmospheric models are being used for research and operational forecasting of several mesoscale atmospheric phenomena. Various studies were conducted to evaluate the skill of WRF model for TCs track and intensity forecasts in near real-time over the NIO basin [8,9,10,11,12,13]. The present study focuses on two tropical cyclones one is pre monsoon e.g. Amphan and another is post monsoon e.g. Bulbul were simulated with the help of Advanced Research version of the Weather Research and Forecasting (WRF-ARW) model to evaluate track and intensity. This study would help to improve the understanding the behavior of track and intensity of TCs forecast.

2. Data and methodology

The United States Geological Survey (USGS) 10`resolution terrain topographical data have been used in the WRF preprocessing system (WPS) [14]. The National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS)/Final analysis (FNL) 0.25° resolution Global Tropospheric Analyses and Forecast Grids data were used as initial and boundary conditions. This data is available from 2015-07-08 onward. The lateral boundary conditions are available at 3hours intervals. RSMC, New Delhi observed/estimated data were used to compare the model simulated track and intensity.

The non-hydrostatic compressible WRF model with hydrostatic option was developed by national Centre for Atmospheric Research (NCAR) is used in the study. It has features like a fully compressible, Eulerian non-hydrostatic control equation set, a topography following, hydrostatic pressure vertical coordinate system with the constant pressure surface at the top level of the model. The staggered grid, like Arakawa-C grid, used in the model and a third order Runge-Kutta time integration scheme used for both horizontal and vertical directions. The WRF model integrates several procedures like MP, CP, PBL, surface layer, land surface, long wave and short wave radiations with multiple options for each process [15]. A brief summary of the model configurations is presented in table 1.

The model selected for the study is a non-hydrostatic version of the Weather Research and Forecasting (WRF-ARW) model (V4.2), which is configured with a two-way two interactive nested grid domain with horizontal resolution of 27kms and 9kms. The results from 9kms domain were considered for analyses. The model lateral boundary conditions are updated every 6 hours interval. The model was initialized with five different initial conditions (e.g., 120 hours, 96 hours, 72 hours, 48 hours and 24 hours lead time). The observed tracks of selected TCs making landfall over India (West Bengal)-Bangladesh coast are shown in Figure 1.

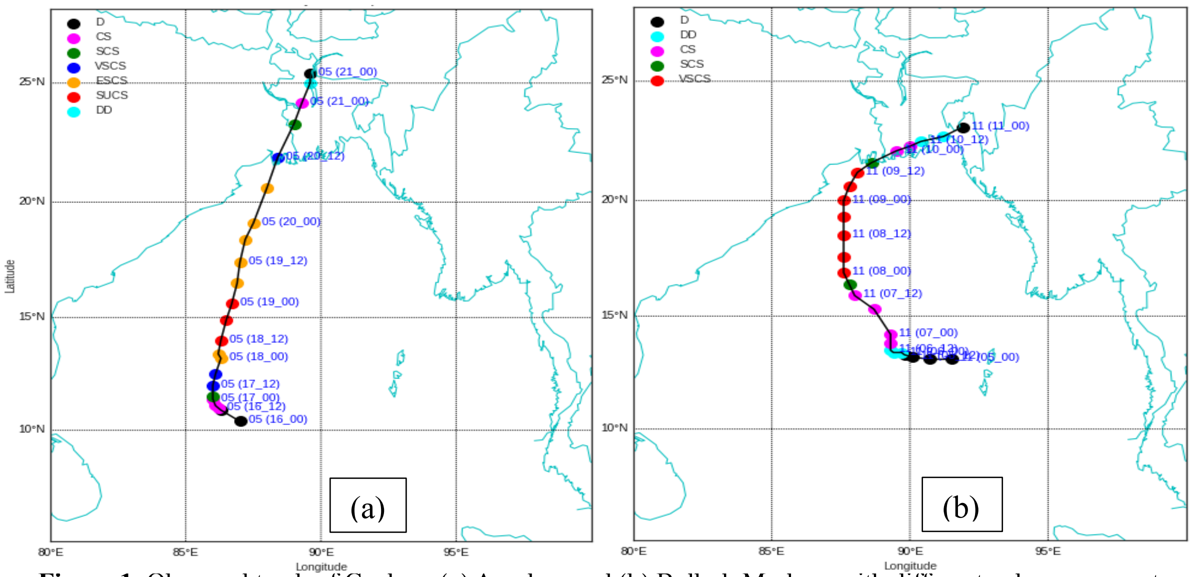

Figure 1. Observed track of Cyclone (a) Amphan and (b) Bulbul. Markers with different colors represents various intensity stage.

Table 1: Brief description of WRF model configuration

Model	WRF V4.2
No. of Domain	2
Map Projection	Mercator
Resolution	27 km, 9 km
Time step	35s
Central point of the domain	17.5^0 N, 87.5^0E
No. Of grid points	152, 265(WE); 144, 298(NS)
No. Of Vertical levels	42Sigma Levels
Horizontal Grid	Arakawa C Grid
Time Integration	Runge-Kutta second and third order time
Radiation Scheme	Dudhia's short wave/RRTM long wave
PBL Scheme	YSU scheme
Convection	Kain-Fritsch (new Eta) scheme
Micro Physics	WSM3-class simple ice scheme

3. Results and Discussions

The model simulated composite tracks with all initial conditions of TC Amphan and Bulbul along with RSMC (New Delhi) best track is presented in figure 2. The model has replicated re-curvature nature of tracks with all initial conditions which is consistent with RSMC best track. There is a spread to the east of best track as well as landfall positions with all initial conditions except 24hrs initial condition for Amphan in figure 2(a) which is very close to the RSMC best track. Tracks as well as landfall positions with all initial conditions are very consistent with RSMC best track excluding 120hrs initial condition for Bulbul in figure 2(b). Model showed right-side deviation from the best track for lead times 72 hours or more for Amphan and for Bulbul lead times is 96 hours or more. Again for shorter lead times, deviation is decreased significantly for both cases. Whole analyses of track forecast suggest that WRF is capable to reproduce track prediction with some spatial deviation. Finally, it is clear that tracks as well as landfall positions is simulated well in Bulbul compared to Amphan.

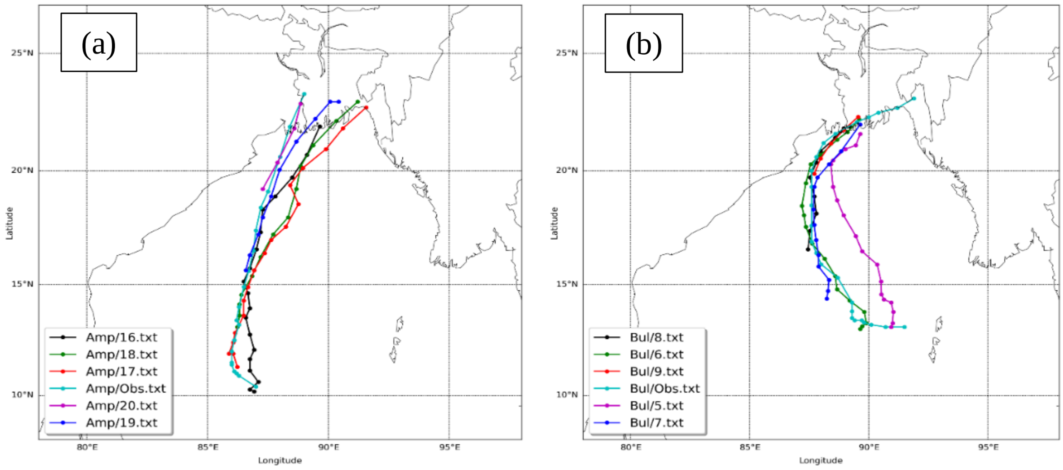

Figure 2: Composite tracks with all initial conditions of (a) Amphan and (b) Bulbul

Table 2: Forecast Landfall position and time error of Amphan

Lead Time	Initial Time	Landfall Point		Landfall Time		Error	
		F/C	Actual	F/C	Actual	Kms	Hours
24	20/00utc	21.83/88.59	21.9/88.4	20/12utc	20/1200utc	21	0
48	19/00utc	21.85/89.06	21.9/88.4	20/15utc	20/1200utc	68	3
72	18/00utc	22.15/90.33	21.9/88.4	20/18utc	20/1200utc	200	6
96	17/00utc	21.83/90.60	21.9/88.4	21/00utc	20/1200utc	227	12
120	16/00utc	21.91/89.64	21.9/88.4	20/12utc	20/1200utc	128	0

Table 3: Forecast Landfall position and time error of Bulbul

Lead Time	Initial Time	Landfall Point		Landfall Time		Error	
		F/C	Actual	F/C	Actual	Kms	Hours
24	09/00utc	21.6/88.8	21.55/88.5	09/18utc	09/18utc	32	0
48	08/00utc	21.42/88.59	21.55/88.5	09/18utc	09/18utc	17	0
72	07/00utc	21.99/89.64	21.55/88.5	10/00utc	09/18utc	128	6
96	06/00utc	21.67/89.11	21.55/88.5	10/00utc	09/18utc	65	6
120	05/00utc	21.59/89.64	21.55/88.5	10/00utc	09/18utc	118	6

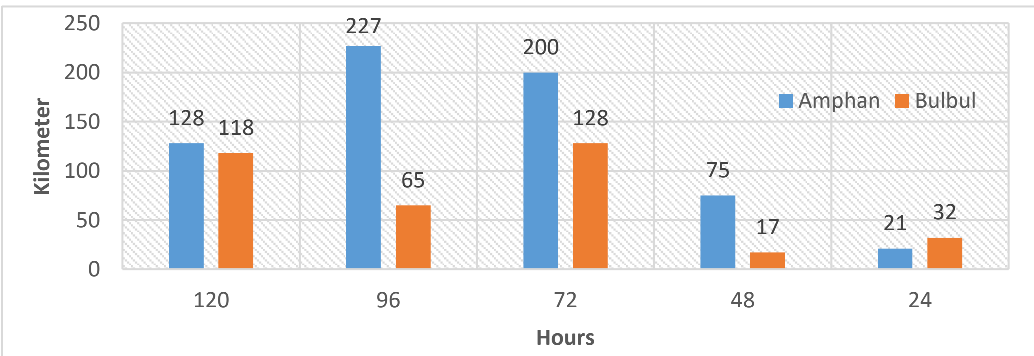

Figure 3: Comparison of landfall position error of Amphan and Bulbul with different initial conditions.

Figure 3 shows the 24, 48, 72, 96 and 120 hours landfall position errors of TC Amphan and Bulbul. Overall Bulbul landfall position errors quite less compared to Amphan except 24 hours lead time. Such track errors are expected due to the inherent errors of the WRF model. Forecast landfall positions errors are presented in table 2 and 3 for TC Amphan and Bulbul respectively. Landfall position errors for 120 hours are insignificant for both cases with respect to lead time. Again 96 and 72 hours errors are impressive for Bulbul but it is significant for Amphan. Finally, 48 and 24 hours errors are negligible except for Amphan (75kms) with lead time 48 hours. Except 120 hours lead time, there is a decreasing trend of landfall position errors for Amphan as lead time decreases. There is no such trend for Bulbul though Bulbul errors are insignificant except 72 hours lead time. Once more errors in 120 hours lead time is inspiring compared to 72 hours, since uncertainty decreases as lead time decreases. Overall Bulbul errors are less compared to Amphan.

Table 4: Intensity forecast error during landfall time of Amphan

Lead Time	Initial Time	Minimum Central Pressure		Maximum Wind Speed		Error	
		F/C	Actual	F/C	Actual	SLP	Wind Speed
24	20/00utc	969	968	60	80	1	-20
48	19/00utc	974	968	59	80	6	-21
72	18/00utc	977	968	51	80	9	-29
96	17/00utc	979	968	56	80	11	-24
120	16/00utc	972	968	27	80	4	-53

Table 5: Intensity forecast error during landfall time of Bulbul

Lead Time	Initial Time	Minimum Central Pressure		Maximum Wind Speed		Error	
		F/C	Actual	F/C	Actual	SLP	Wind Speed
24	09/00utc	984	986	62	60	-2	2
48	08/00utc	988	986	48	60	2	-12
72	07/00utc	993	986	48	60	7	-12
96	06/00utc	998	986	40	60	12	-20
120	05/00utc	997	986	44	60	11	-16

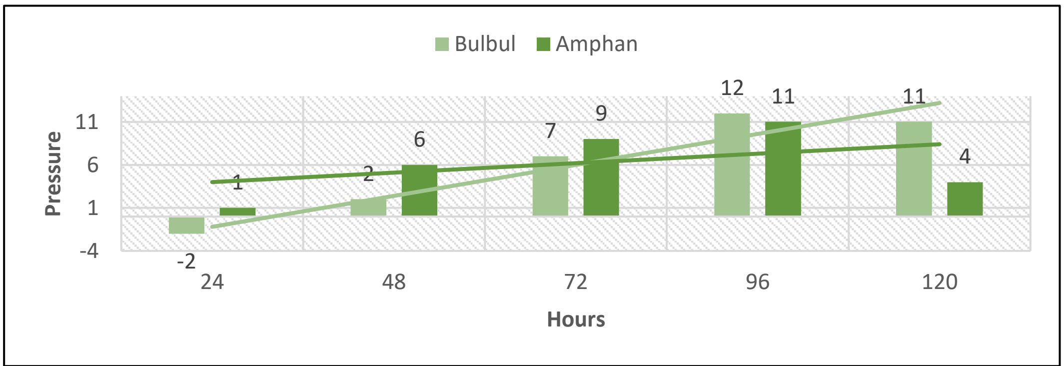

Figure 4: Comparison of minimum central pressure errors during landfall time of Amphan and Bulbul with different initial conditions.

Figure 4 displays the 24, 48, 72, 96 and 120 hours intensity errors in terms of Minimum Central Pressure (MCP). Intensity errors in terms MCP is significant with lead times 72 hours or more for Bulbul. MCP errors is 2hPa with lead times 24 and 48 hours is very impressive in case of Bulbul. Intensity forecast errors during landfall time in terms of MCP are presented in table 4 and 5 for Amphan and Bulbul respectively. Again intensity errors in terms MCP is significant for Amphan except 24 and 120 hours lead times. MCP error is only 1hPa with lead time 24 hours in case of Amphan. As lead time decreases, errors in MCP also decreases for both cases. WRF performance is better for Amphan compared to Bulbul in case of lead times 96 hours or higher. Again lead times 72 hours or lower, WRF performance is better for Bulbul compared to Amphan. Overall intensity in terms MCP is overestimated for all initial conditions by the model except for Bulbul in case of 24 hours lead times (underestimated by 2hPa).

Figure 5 shows the 24, 48, 72, 96 and 120 hours intensity errors in terms of maximum surface wind speed in kts. Overall intensity in terms maximum surface wind speed is underestimated for all initial conditions by the model except for Bulbul in case of 24 hours initial condition (overestimated by 2kts). Intensity forecast errors during landfall time in terms of maximum wind speed are presented in table 4 and 5 for Amphan and Bulbul respectively. Intensity errors is significant for all initial conditions in case of Amphan. Intensity errors are very impressive for Bulbul in all initial conditions except 96 hours forecast (under- estimated by 20kts). Nevertheless there is a decreasing trend of errors as lead time decreasing for both cases and in case of Bulbul it is significant.

Figure 6 shows the 24, 48, 72, 96 and 120 hours landfall time errors. Landfall time errors are very consistent with all initial conditions except 96 hours forecast in case of Amphan which is delayed by 12 hours. In case of 24 hours forecast landfall time as well as actual landfall time happen together and for all other forecast hours it is only delayed by 6 hours in both cases. Forecast landfall times errors are presented in table 2 and 3 for TC Amphan and Bulbul respectively. It is found that landfall time as well as actual landfall time coincide for forecast hours 24 and 48 hours in case of Bulbul which is very crucial for disaster management authority.

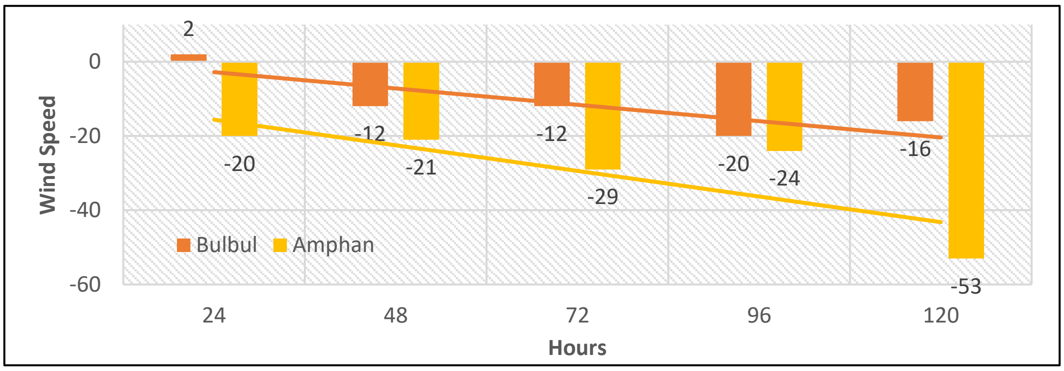

Figure 5: Comparison of maximum surface wind speed (kts) error during landfall time of Amphan and Bulbul with different initial conditions.

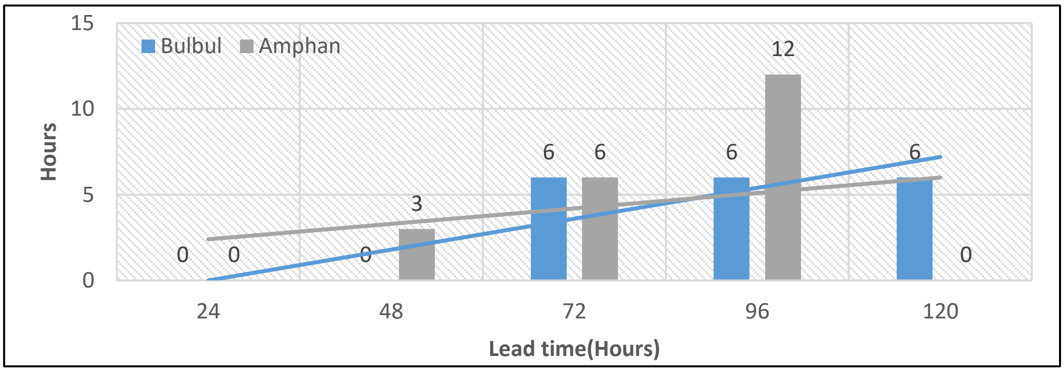

Figure 6: Comparison of landfall time error of Amphan and Bulbul with different initial conditions.

4. Conclusion

In this study, the track and intensity along with landfall position of two TCs from different seasons (i.e., pre-monsoon and post monsoon) have been investigated with WRF-ARW model using two-way interactive nested domain with the NCEP/GDAS final analysis (FNL) 0.25^0 resolution data as the initial and boundary conditions. Investigations of the maximum surface wind and the minimum central pressure errors during landfall time is exhibited differences in model performance for two cases. It is clearly seen that overall tracks were reasonably well in Bulbul compared to Amphan for all forecast times. There is a large spread of landfall positions to the right of the actual landfall position for Amphan. In case of Bulbul the spread is small but to the right of the actual landfall position. However, the model is capable to reproduce the recurvature nature of the TCs. Again 24 hours model prediction is very impressive for both cases. As lead time increases model forecast performance decreases. Landfall positions errors with 24, 48, 72, 96 and 120 hours lead time are 21, 68, 200, 227 and 128 kms in case of Amphan and 32, 17, 128, 65 and 118kms for Bulbul.

Intensity forecast errors in terms of MCP is overestimated for all initial conditions by the model except for Bulbul in case of 24 hours forecast. Model performance is better for Amphan compared to Bulbul in case of 96 and 120 hours lead times. Again for lead times 24, 48 and 72 hours model performance is better for Bulbul compared to Amphan. As lead time decreases, errors in MCP also decreases for both cases. Intensity forecast errors in terms of maximum wind speed is underestimated for all initial conditions by the model except for Bulbul in case of 24 hours forecast. Nevertheless there is a decreasing trend of errors as lead time reduces for both cases and in case of Bulbul it is significant. It is also found that landfall forecast time quite impressive compared to actual landfall time for all initial conditions (except 96hours forecast for Amphan) which are very crucial for disaster management authority.

Finally, the performance of the WRF model is exposed against accessible observed/estimated data from RSMC. It is found that WRF model has improved prediction capabilities in terms of track and intensity.

Acknowledgements

The authors are acknowledged to RSMC (New Delhi) for providing observed track, intensity and wind speed data for justification of model simulated results. The authors also sincerely thank to NCEP for providing their final analyses data for this study.

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