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PREDICTION OF TRACK AND INTENSITY OF THE VERY SEVERE CYCLONIC STORM THANE USING DIFFERENT INITIAL CONDITIONS IN WRF-ARW MODEL

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ABSTRACT

High resolution Advanced Research & Forecasting (WRF –ARW) model version 3.2.1 is used to investigate the very severe cyclonic storm Thane. The model domain is between of 1.20^0-25.64^0 N, 69.36^0-94.70^0 E, with a horizontal resolution of 9 km. The horizontal grid dimension is 350 x 250. Kain-Fritisch's cumulus parameterization scheme has been used with Yonsei University (YSU) planetary boundary layer (PBL). Model is run with the four different initial data of GFS from 00 UTC of 26 to 29 December, 2011 using time steps 30 seconds. The track of the cyclone is well produced by most of the run and the landfall position and time of the cyclone is produced better using the initial condition of 00 UTC of 29 December, 2011 than the others.

Keywords: *Tropical cyclone; Thane; WRF. Cumulus Parameterization Scheme*

1. INTRODUCTION

Tropical cyclones (TCs), due to strong winds, torrential rainfall and storm surges, are one of the most dangerous natural calamities throughout the globe. Every year, they cause considerable loss of life and do immense damage to property. India and Bangladesh have a coastline of more than 8000 km, which is prone to very severe cyclone formed in the Arabian Sea and Bay of Bengal. These occur during the pre-monsoon (April–May), early monsoon (June), late and post-monsoon (September– November) seasons. Tropical cyclones, originating in both the Bay of Bengal and Arabian Sea, often attain in the velocities of more than 160 km/h and are notorious for causing intense rain and storm surges as they cross the coast of India, Bangladesh and other coasts. Strong winds, heavy and torrential rains, and the cumulative effect of storm surges and astronomical tides are the three major elements of tropical cyclone disaster. The Bay of Bengal is also the basin where TCs do the most damage due to the combined effects of meteorological forcing, high astronomical tide, shallow bathymetry, funneling shape of the Bay and lack of communications. The need for sea surface temperature (SST) greater than 26.5 ^{0}C and a deep lower level moist layer and absence of strong vertical shear for development from a tropical low to a cyclonic storm and further intensification has been referred to in many studies (Gray, 1992). More than 200,000 people perished in the Bhola cyclone of 1970 in Bangladesh.

Predictions of tropical cyclones have improved steadily over the last three decades, mostly due to a combination of better observations, especially the satellite and radar, improvement in dynamical models and improved understanding of physical processes and mechanisms that govern the motion of tropical cyclones. The current emphasis of international tropical cyclone research is to achieve greater accuracy of tropical cyclone track and intensity prediction, especially in the short range (48–72 h in advance), by maximizing the use of non-conventional data, meso-scale analysis, and the physical parameterization in nonhydrostatic environment at higher model resolution. In India, development of objective techniques for forecasting track of TCs began in 1972 (Sikka and Suryanarayana, 1972) by using a computer oriented half persistence and half climatology technique. There is a study (Singh and Saha, 1978) related to forecasting movement of TCs by adopting a primitive equation barotropic model. Some authors have used multi-level primitive equation models with parameterization of physical processes (Mohanty and Akhilesh, 1997; Gupta and Bansal, 1997). Quasi-Lagrangian Model (QLM) has also been implemented in IMD for operational track forecast up to 72 h in the year 2000AD. QLM (Prasad and Rao, 2003) have been evaluated in 2003 and its performance is found to be even better. The effect of different initial conditions on the track and intensity of tropical cyclone are done using MM5 and WRF models (Pattanayak and Mohanty 2008).

In this study, the high resolution Advanced Research WRF (ARW) meso-scale model adopted from NCAR is

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used to simulate the track and intensity of the severe cyclonic storm ‘Thane’ that crossed north Tamil Nadu and Puduchery coast between Puduchery and Cuddalore within 1-2 UTC of 30th December, 2011 with a wind speed of 120-140 kmph. The objective of the present study is to evaluate the performance of the model towards simulation of track and intensity of the severe cyclonic storm on different initial conditions as the input.

2. MODEL DESCRIPTION AND INITIAL CONDITIONS

The NCAR version 3.1 of Advanced Research WRF (ARW) model has been used. Detail description of the model is documented by William *et. al.* (2009). For the diagnostic study the GFS data at $1^0\times1^0$ grid is used from 00 UTC of December 26 to 00 UTC of December 31, 2011.

The cumulus convection used in this case is modified Kain-Fritisch scheme (Kain, 2004). The cloud microphysics scheme is WRF Single-Moment (WSM) 3-class simple ice scheme, which is a simple efficient scheme with ice and snow processes suitable for mesoscale grid sizes (Hong *et al.,* 1998 ; Hong *et al.,* 2004). It replaces NCEP 3 scheme. The long-wave radiation parameterization is the Rapid Radiative Transfer Model (RRTM) scheme, which is an accurate scheme using look-up tables for efficiency accounts for multiple bands, trace gases, and microphysics species (Mlawer *et al.,* 1997). The short-wave radiation scheme is used as per the Dudhia scheme, which allows simple downward integration for efficient cloud and clear-sky absorption and scattering (Dudhi, 1989). The Planetary Boundary Layer (PBL) parameterization is the Yonsei University Scheme (YSU) (Hong *et al.*, 2006), which is the next generation of MRF–PBL. An overview of the model used in this study is provided in Table 1.

3. DESCRIPTION OF THE SYSTEM

A depression formed over southeast Bay of Bengal in the evening of 25th December, 2011 and lay centred about 1000 km southeast of Chennai. It gradually moved north-northwestwards and intensified into a deep depression in the early morning of 26th December, 2011 and into a cyclonic storm ‘THANE’ at midnight of the same day. It then moved west-northwestwards and intensified into a severe cyclonic storm in the afternoon and into a very severe cyclonic storm in the evening of 28th December, 2011. It then moved west-southwestwards and crossed north Tamil Nadu & Puducherry coast between Cuddalore and Puducherry within 0030 and 0130 hrs UTC of 30th December, 2011 with a wind speed of 120-140 kmph.

Table 1: Domain design of the model

Nonhydrostatic	Dynamics
Model domain	1.2^0–25.64^0N, 69.4^0–94.7^0E
Horizontal grid distance	9 km
Integration time step	30 s
Map projection	Mercator
Horizontal grid system	Arakawa-C grid
Vertical co-ordinate	Sigma co-ordinates 28 levels
Time integration scheme	Third-order Runge–Kutta scheme
Spatial Differencing scheme	Second to Sixth order schemes
Radiation parameterizations	RRTM, Dudhia scheme
Surface layer parameterizations	Monin–Obukhov scheme, thermal diffusion scheme
Cumulus parameterization	Kain- Fritisch schemes
PBL parameterization	YSU scheme
Microphysics	WSM 3 simple ice scheme
Land surface	Unified Noah Land surface Model

After landfall, the system rapidly weakened into a severe cyclonic storm over north coastal Tamil Nadu at 0230 hrs UTC of 30 and into a deep depression around noon and into a depression in the same evening over the north interior Tamil Nadu. It weakened further and lay as a well marked low pressure area over north Kerala and neighbourhood in early morning of 31 December 2011. The best track and associated parameters are shown in Table 2.

4. RESULTS AND DISCUSSION

The results obtained from several numerical experiments carried out using WRF model to simulate the severe cyclonic storm 'Thane' have been assessed and presented the model-derived track and intensity of this cyclone to test the sensitivity or role of the different initial conditions.

The model is run using initial condition from 00 UTC of 26, 27, 28 and 29 December, 2011 up to 00 UTC of 31 December, 2011 and their outputs are compared with those reported by Indian Meteorological Department (IMD). Outputs of all four options have been produced at three hours interval and processed using Grid Analysis and Display System (GrADS). Using GrADS the model predicted minimum central sea-level pressure (CSLP), maximum wind, pressure drop and track are analyzed.

Table 2: Best track and associated parameters according to IMD forecast

Date	Time (UTC)	Centre lat. N/long. E	C.I NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind(Kt)	Estimated Pressure drop at the Centre(hPa)	Grade
25.12.2011	1200	8.5/88.5	1.5	1000	25	3	D
	1800	9.0/88.0	1.5	1000	25	3	D
26.12.2011	0000	9.5/87.5	2.0	998	30	4	DD
	0600	10.0./87.5	2.0	998	30	4	DD
	1200	10.5/87.5	2.0	998	30	5	DD
	1800	11.0/87.5	2.5	996	35	7	CS
27.12.2011	0000	11.5/87.5	2.5	994	40	8	CS
	0600	12.0/87.0	2.5	994	40	8	CS
	1200	12.5/86.5	2.5	992	40	10	CS
	1800	12.5/86.0	3.0	990	45	12	CS
28.12.2011	0000	12.5/85.5	3.0	990	45	12	CS
	0600	12.5/85.0	3.0	988	45	14	CS
	0900	12.5/85.0	3.5	986	55	16	SCS
	1200	12.5/84.5	4.0	982	65	20	VSCS
	1500	12.5/84.0	4.0	980	65	22	VSCS
	1800	12.5/84.0	4.0	978	65	24	VSCS
	2100	12.5/83.5	4.0	976	65	26	VSCS
29.12.2011	0000	12.3/83.0	4.0	974	70	28	VSCS
	0600	12.0/82.0	4.5	972	75	30	VSCS
	0900	12.0/81.7	4.5	972	75	30	VSCS
	1200	12.0/81.3	4.5	972	75	30	VSCS
	1800	12.0/80.6	4.5	972	75	30	VSCS
30.12.2011	0000	11.8/79.9	4.5	972	75	30	VSCS
	0300	11.8/79.5	--	986	55	16	SCS
	0600	11.8/79.0	--	998	30	5	DD
	1200	11.8/78.2	--	1000	25	3	D
31.12.2011	0000	The system weakened into a well marked low pressure area over north Kerala and neighbourhood.					

D : Depression
DD : Deep Depression
CS : Cyclonic Storm
SCS : Severe Cyclonic Storm
VSCS : Very Severe Cyclonic Storm

The model-derived minimum central sea level pressure (CSLP) and maximum wind are shown in Figure 1a and 1b. All the entire run using different initial condition 00 UTC of 26, 27, 28 and 29 December, 2011 are seen to have produced similar results, with Minimum CSLP of 984, 984, 987 and 990. The observed minimum CSLP were 972 hPa according to IMD. The minimum CSLP using different initial condition 00 UTC of 26, 27, 28 and 29 December, 2011 are obtained at 12 UTC of December 28, 12 UTC of December 28, 21 UTC of December 28 and 09 UTC of December 29, 2011 respectively. Again, the observed minimum CSLP are obtained at 06 UTC of

29 December, 2011. So, all the model simulated minimum CSLP (three cases out of four cases) are obtained earlier than that of observed except the model simulated minimum CSLP with initial condition 00 UTC of 27 December, 2011. It may be because of initial data error. It should be noted that simulated minimum CSLPs (maximum attained intensity) are always lower than that of observed. After landfall, observed CSLP rise faster than those of simulated.

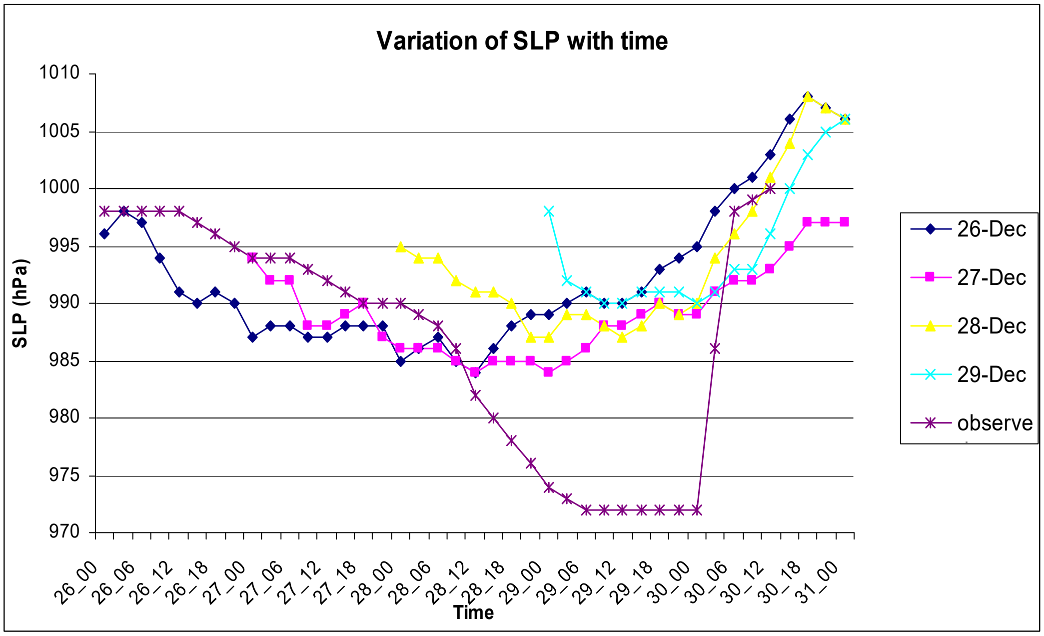

Figure 1a: Comparison of simulated pressures using different initial conditions and observed pressure

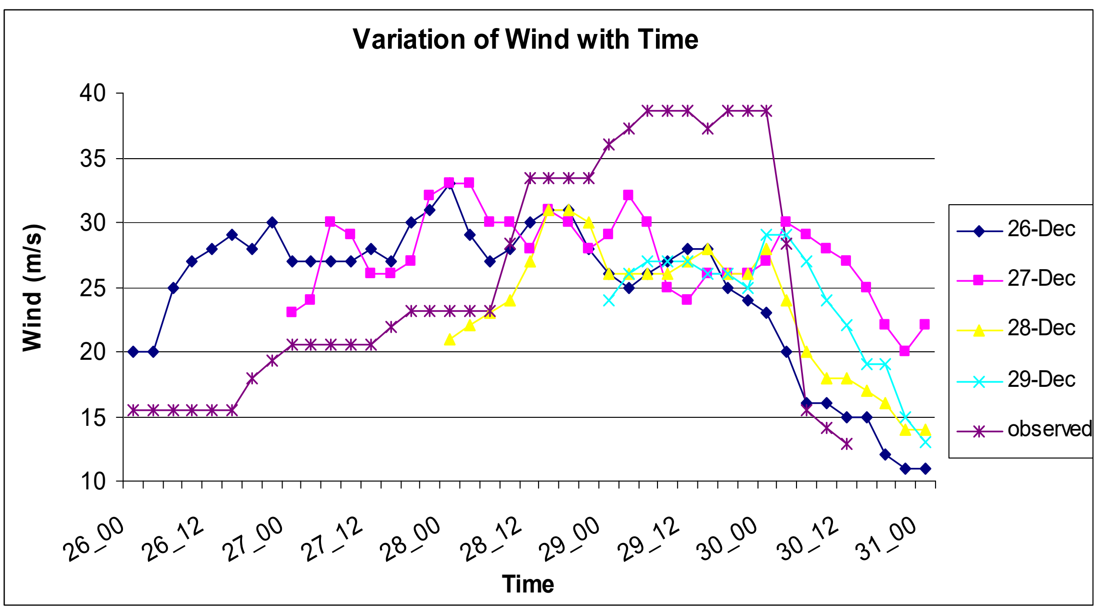

Figure 1b: Comparison of simulated (using different initial conditions) and observed maximum wind

Correspondingly, the model simulated maximum wind speed attained was about 31, 33, 28 and 29 m s^{-1} with the initial conditions 00 UTC of 26, 27, 28 and 29 December, 2011 respectively, whereas observed one is 39 m s^{-1}. So, the model simulated maximum wind speeds with all initial conditions are lower but close to the observed value. The model-simulated derived maximum winds with different initial conditions are shown in Figure 1c. The value of the derived maximum winds obtained with the different initial conditions 00 UTC of 26, 27, 28 and 29

December, 2011 are 79, 79, 76 and 72 Knot respectively. Where as the observed maximum wind is 75 Knot. So, derived maximum winds with different initial conditions are closed to the observed one.

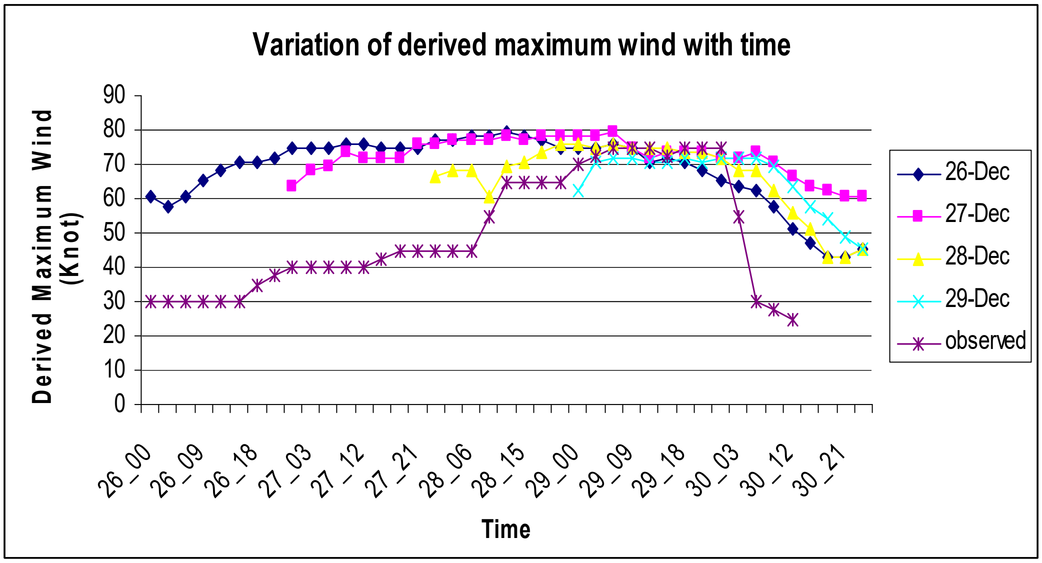

Figure 1c: Comparison of derived (using different initial conditions) and observed maximum wind

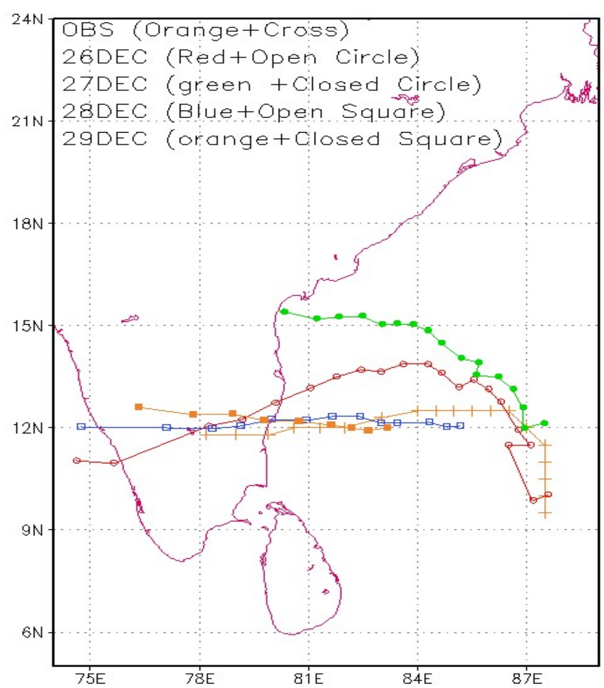

Figure 2: Comparison of simulated tracks using different initial conditions with observed track

The model-simulated track positions for these experiments with different initial conditions are shown in Figure 2. It shows that the track is almost similar for all of the initial conditions at 00 UTC of 26, 27, 28 and 29 December, 2011, with a deviation to the right of that of the observation i.e. deviation is mainly in the position of latitude. The landfall positions with time for all initial conditions are tabulated in the Table 3. Two model-simulated tracks using initial conditions at 00 UTC of 28 and 29 December, 2011 are much close to that of observed one. Between these two tracks, track using initial condition at 00 UTC of 29 December, 2011 is much better than any other.

Track using initial condition at 00 UTC of 26 December, 2011 comes close to the observed near to the landfall but track using initial condition at 00 UTC of 27 December, 2011 goes far from the observed one (Figure 2). It may be for the initial data error. From the figure 2 and Table 3, it is clear that the landfall position and time are better predicted using initial condition at 00 UTC of 29 December, 2011. So, the WRF model simulates the landfall position and time up to 96 hours ahead the landfall time.

Table 3: Model simulated and observed Landfall time and position, and pressure and time just before landfall

Initial condition	Landfall Time	Landfall Position		Pressure and time just before landfall	
		Lat	Lon	Pressure	Time
26 December, 2011	2011.12.29_23:00	12.80	80.27	994	2011.12.29_21
27 December, 2011	2011.12.31_00:55	15.46	80.21	997	2011.12.31_00
28 December, 2011	2011.12.29_23:45	12.26	80.04	989	2011.12.29_21
30 December, 2011	2011.12.30_04:36	12.22	79.99	991	2011.12.30_03
Observed	2011.12.30_01:30	11.80	79.80	972	2011.12.30_00

5. CONCLUSION

In this study, NCAR WRF model is used to study the sensitivity/ role on the initial conditions for the simulation of the track and intensity of the severe cyclonic storm Thane. From the simulations the following results can be summarized:

i. Minimum CSLP are different with different initial conditions.
ii. The magnitude derived maximum winds with different initial conditions are close to each other with observed maximum wind.
iii. Landfall positions and times are different with different initial condition but close to observation except for one simulation.
iv. WRF model is able to predict the landfall position up to 96 hours ahead the landfall.

It may be concluded that the initial conditions option have their own impact on the simulation of Thane. The present study has investigated only for one cyclone, and more cases should be examined to supplement these results.

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