

## Ocean - atmosphere interaction during Thane cyclone: a numerical study using WRF

K. K. Vinod<sup>1</sup>, M. Soumya<sup>2</sup>, P. Tkalich<sup>1</sup> & P. Vethamony<sup>2\*</sup>

<sup>1</sup>Tropical Marine Science Institute, National University of Singapore

<sup>2</sup>CSIR-National Institute of Oceanography, Dona Paula, Goa, India

\*[Email: mony@nio.org]

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Cyclone 'Thane' developed over the southeast Bay of Bengal (BoB) at 88.5° E, 8.5° N during 25 – 31 December 2011. Simulations have been carried out using Weather Research and Forecasting (WRF) model to generate fine resolution winds that prevailed over the BoB during this extreme weather event. Global Final analysis data from the National Centres for Environmental Prediction (NCEP) having a spatial resolution of 1° and a temporal resolution of 6 h have been used to provide the initial and boundary conditions. The model results (spatial resolution of 12km and temporal resolution of 1 h) have been validated with track data and vertical observations. Maximum sustained wind speed during Thane cyclone was 15m/s, and made landfall over Tamil Nadu coast. This study investigates the factors which reinforce cyclone genesis, its propagation and atmospheric parameters that prevailed while the cyclone was passing through the coastal region. We have also studied the variations in sea level along the west coast of India during the passage of Cyclone Thane in the Bay of Bengal and east coast of India.

[**Keywords:** Cyclone Thane, WRF model, atmospheric parameters]

### Introduction

Cyclone is a natural disaster, which generates serious threats to the coastal environment by strong winds and wind induced storm surges. Tropical oceans are hearts for cyclones (10°S to 15°N)<sup>1</sup>. Globally, about 80% of all the tropical cyclones form near to or within the Intertropical Convergence zone (ITCZ)<sup>2</sup>. In this region, unstable flow is generated by latent heat release in deep cumulus convection. ITCZ generates cyclonic potential vorticity anomaly, which reverses the meridional potential vorticity gradient on its poleward side and it satisfies the necessary condition for the combined barotropic and baroclinic instabilities<sup>3</sup> in lower troposphere. In northern Indian Ocean, the cyclone generation occurs mainly between April and December<sup>4</sup>. Several cyclonic response studies were carried out over northern Indian Ocean by<sup>2, 5-14</sup>.

A very severe cyclonic storm 'Thane' developed over the Bay of Bengal, crossed the Tamil Nadu coast, close to south of Cuddalore between 0100 and 0200 UTC of 30 December, 2011 with a wind speed of 35m/s. After the land fall, the system rapidly weakened into a severe cyclonic storm over north Tamil Nadu and into a deep depression over north interior Tamil Nadu. On

31 December 2011, it weakened into a low pressure area over north Kerala. Storm surge of about 1m height inundated the low lying coastal areas of Tamil Nadu at the time of landfall of cyclone<sup>15</sup>. In order to estimate the surge heights and its impact on coastal areas, it is important to determine the cyclone parameters. The objective of present study is to look into the role of various ocean atmosphere parameters and their spatial distribution. In the present study, we examine various cyclone genesis parameters and impact of cyclone on sea surface elevation.

### Materials and Methods

Numerical simulations were carried out to generate the atmospheric parameters over the BoB using the Weather Research and Forecasting (WRF) model<sup>16</sup>. It is based on fully compressible, non-hydrostatic Euler equations, third order Runge-Kutta (RK3) integration scheme and Arakawa C grid. Vertical mixing and diffusion was done by Asymmetric Convective Model with non-local upward mixing and local downward mixing (ACM2) scheme<sup>17</sup> and surface physics by Pleim-Xiu scheme.

The global Final analysis data from the National Centre for Environmental Prediction (NCEP)

having a spatial resolution of 1° and a temporal resolution of 6 h have been used to provide the initial and boundary conditions to the model. Terrain data has been taken from the US Geological Survey (USGS) which has a resolution of 0.9km. The model domain extends from 75.23° E to 89.75° E and 3.18°N to 15.60° N (Fig. 2) with a spatial resolution of 12km and the simulations were carried out from 23 Dec 2011 to 1 Jan 2012. A total of 27 sigma levels were applied in the vertical levels from surface to 100 hPa.

The observational data obtained from the Joint Typhoon Warning Centre (JTWC) best track and Indian Meteorological Department (IMD) during the cyclone was used for model validation. Upper-air sounding observations for the Bangalore region were obtained from the website <http://weather.uwyo.edu/upperair/sounding.html> and used for the validation of simulated atmospheric parameters at different vertical levels (Fig. 4).

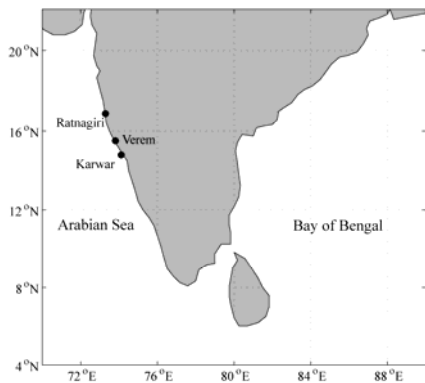


Fig. 1. Locations showing the AWS and Sea level observations along the coast of India

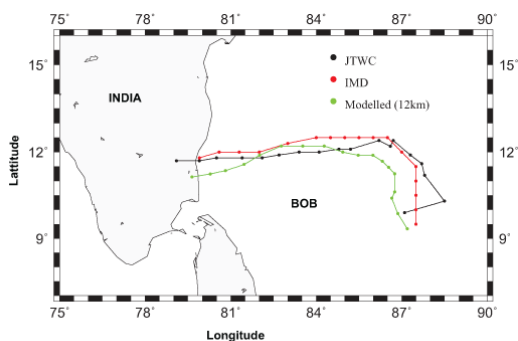


Fig. 2. Comparison of Cyclone Thane track between observed (JTWC, black line), (IMD, red line) and computed (WRF, green line).

**Results and Discussions**

*Model validation*

Fig. 2 shows the simulated cyclone track of Thane cyclone with the observed track data available at every 6h from the JTWC and IMD. The simulated track was consistent with both JTWC and IMD tracks. The simulated wind speed is compared with the JTWC best track data and IMD observation during the cyclone period (Fig. 3). For the vertical validation, station selected is Bangalore observatory (77.58°E, 12.96°N) at 00h on 27 Dec 2011. The vertical wind speed and direction and air temperature match well with the observations (Fig. 4).

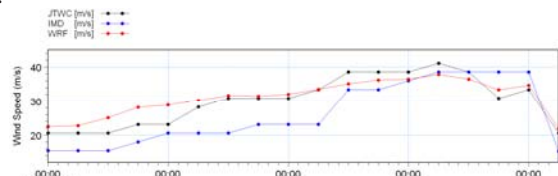


Fig.3. Comparison of JTWC observations, IMD observations and WRF simulated results of wind speed during the Thane cyclone.

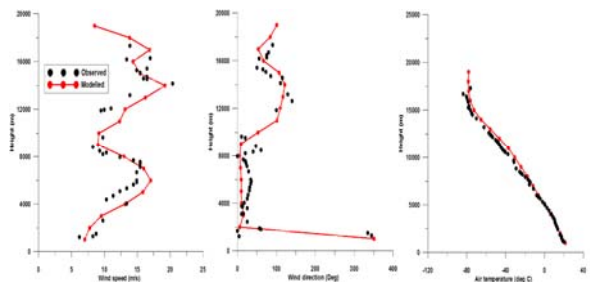


Fig. 4. Comparison of simulated wind speed and direction and air temperature with sounding data at 77.58° E and 12.96° N.

*Cyclone genesis parameters*

The primary energy source driving tropical cyclones is the latent heat release due to condensation of water vapour<sup>18</sup> and transfer of sensible heat from the warm ocean heats the air in contact with it, generates buoyancy and upward motion at the surface which play an important role in the initial stages of formation of the cyclone<sup>19</sup>. The latent heat flux (LHF) and sensible heat flux (SHF) exchanges between Ocean-atmosphere system plays an important role in the development and evolution of cyclone<sup>20,21</sup>. The fluxes are strongly sensitive to surface and planetary boundary layer parameterization<sup>22</sup>, and are maximum at areas having maximum wind speed.; i.e. during cyclones, the values of latent and sensible heat fluxes are the maximum at the eye walls (Fig. 5a&b) where strong convective

activities take place, and is decreasing inwards and outwards radially. The impact of storm intensity depends mainly on the diameter of the cyclone.

For the present study we considered atmospheric parameters such as Latent heat, sensible heat, surface friction velocity, Sea level pressure, Vertical wind shear, Mid Tropospheric Relative Humidity (500mb) and Relative vorticity on 29 Dec. 2011 at 6am. ACM2 scheme with the grid resolution of 12km is used. From the Fig. 5 (a) it is clear that the latent heat is minimum at the cyclonic centre and increases upto  $\sim 1500 \text{ W/m}^2$ ; the same time the sensible heat varies upto  $240 \text{ W/m}^2$  (Fig. 5b) and is confined to the southeast of eye; i.e., the intensity of cyclone depends on the latent heat from the ocean. The surface friction velocity associated with the turbulence mixing increases during extreme events<sup>20</sup>. Fig. 5c shows the simulation output of the surface friction velocity ( $U^*$ ). Surface friction velocity is very weak within the eye of the typhoon, indicating that this area is calm and the turbulence is weak and its high values are confined largely to the eye wall. Normally, the friction velocity values vary from zero to 0.4 m/s and having maximum at complex topography.

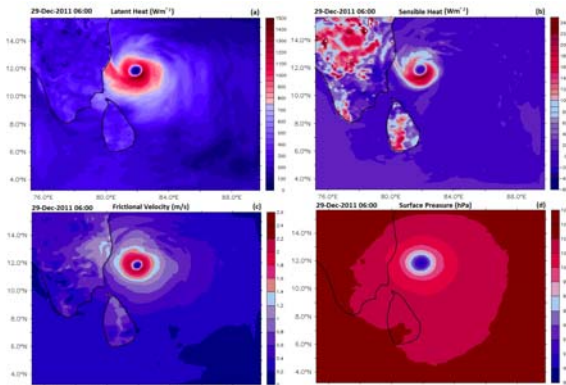


Fig. 5. Simulated (a) latent heat (b) sensible heat (c) surface friction velocity and (d) sea level pressure during cyclone Thane on 29 Dec 2011 at 06 h.

The VWS formed due to lateral forcing of surrounding atmosphere, creates a controlled deep convection, this advects heat from condensation to the upper tropospheric levels and that increases the ventilation, responsible for tilt in upper and lower potential vorticity and mid-level flow warming in vortex. The tilt is the fast adjustment between asymmetric and asymmetric diabatic heating. Cyclones are more likely to form in regions with low vertical wind shear (VWS)<sup>2</sup>, which inhibit intensification. The VWS is calculated as the difference in zonal component of the wind between the pressure levels 850mb and 200mb according to

$$\text{VWS} = U_{850} - U_{200}$$

For the present study the VWS is calculated from the simulated winds at 850mb and 200mb. The zonal shear is highly correlated with magnitude of the total shear at the low latitudes. A low vertical zonal wind shear of 40m/s was observed on 29 Dec 2011 06h of the cyclone, as shown in Fig. 6(a). Since we are calculating only shear in speed, lower layer wind speed is more than that of upper layer, but not too much difference was noticed. Mid tropospheric Relative humidity (500mb) plays an important role in the development of deep convection, and is high over the region of cyclogenesis. Fig. 6(b) shows 85-100% of MTRH during the cyclone on 29 Dec 2011 06h, and a minimum at the eye. As a whole, the largest value of mid-level moisture was at the eye wall and its surroundings. The moisture gradient is along the eye wall and follows the cyclonic path.

According to Gray<sup>2</sup>, the region of positive relative vorticity shows the chance of tropical cyclogenesis and it increases with larger vorticity. Relative vorticity is a measure of rotation of the environmental flow which characterizes the kinematics of the fluid, and is calculated as the curl of the velocity vector. A positive value means anticlockwise and negative implies clockwise rotation; its value is directly associated with the quantity of velocity shear. The presence of a northward (southward) relative vorticity gradient in the environmental flow increases (reduces) kinetic energy to the symmetric vortex and gyres<sup>23</sup> and the vortex moves faster in the case of a positive relative vorticity. Relative vorticity is calculated using the dynamical equation:

$$\text{RV} = (dV/dx) - (dU/dy)$$

where,  $U = U_{850} - U_{200}$ ; and  $V = V_{850} - V_{200}$

The relative vorticity calculated from the simulated wind data, a low relative vorticity value of 0.0002m/s (not shown) before the cyclone formation. Since the wind is strong, higher relative vorticity is needed to veer the environmental flow in anticlockwise. From Fig. 5(c) shows the RV at 27 December 2001 before the land fall. It is clear that higher relative vorticity ( $0.002\text{s}^{-1}$ ) is produced at the vortex and it controls the cyclone. Higher value of relative vorticity has a greater tendency to curl more the air flow. The RV during the cyclone from 23/12/2011 to 1/1/2012 was shown in Fig. 6(d).

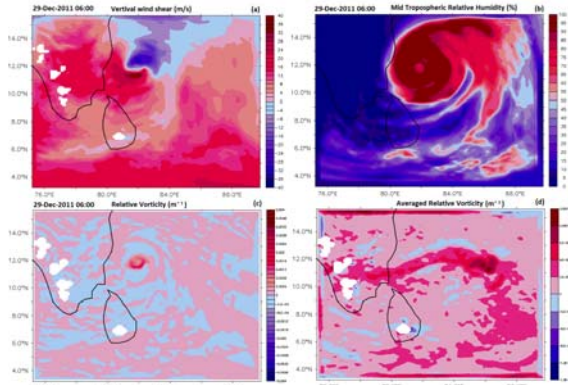


Fig. 6. simulated (a) Vertical wind shear (b) Mid Tropospheric Relative Humidity (500mb) (c) Relative vorticity and (d) Averaged Relative vorticity.

*Sea level variation during Thane cyclone*

For the present study we analyzed the available data of sea level residual and wind speed over three locations on the west coast of Indian Peninsula (Fig. 1). From the observation it is noted a strong negative surge along the Observation locations were noted, negative surge of 22cm over Ratnagiri, 20cm over Verem (Goa) and 18cm over Karwar, but from the wind data we can confirm that the blowing over the locations were not strong enough to generate both the positive and negative surges (Fig. 7). From this we can confirm the existence of remote force from BoB to Arabian Sea.

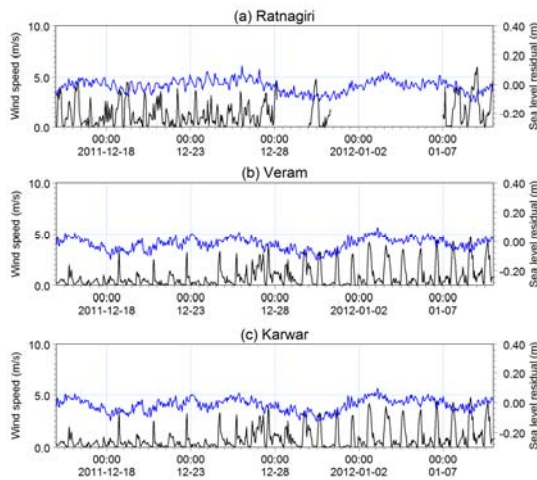


Fig. 7. Observed wind speed and sea level residual along the west coast of India

**Conclusions**

Atmospheric circulation and surge during Thane cyclone have been analyzed using measurements and numerical simulations. The atmospheric characteristics are well simulated by the WRF model, and the results of horizontal and vertical atmospheric structures have been analyzed to study

their changes during extreme event. Sea level along the northern part of west coast of India shows a negative surge of ~20cm confirming the existence of remote forcing from BoB to AS during Thane.

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