



# Bay of Bengal cyclones Mora and Maarutha in regional atmospheric modeling system

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## Abstract

The coastal region of India is exposed to nearly 7% of tropical cyclones occurring in the world. The large basin of Bay of Bengal incites cyclones with varying intensity that is capable enough to cause huge damage to life and money. To understand the underlying mechanism behind these TCs and enhance their forecast accuracy, it is essential to simulate them precisely using different numerical models by applying appropriate micro-physics, Cumulus Convection (CC) and Planetary Boundary Layer (PBL) schemes. The present study uses the Regional Atmospheric Modeling System (RAMS) to simulate TCs Mora and Maarutha in the Bay of Bengal region and associated landfall in Northeast India and Bangladesh. The study is an approach to investigate and analyze winds, precipitation and other dynamical variables associated with the formation of these cyclones by providing initial and boundary conditions from the NCEP-FNL (Final) operational global analysis data (6 hourly temporal and 1.0° spatial resolution). The model output is further nudged towards the observational soundings which are obtained from NCAR-ADP upper air observational dataset. Along with this, an attempt has been made to obtain the optimum configuration of distribution and intensity of a precipitation field to match observations.

**Keywords** RAMS · Tropical cyclone · Landfall · Microphysics and cumulus convection

## Introduction

A Tropical Cyclone (TC) is a low-pressure system rotated by well-known coriolis effect with inwards surface winds which is originated over a tropical ocean (Lighthill 1998). It comprises of strong damaging vertical winds and very high precipitation near the eyewall. A mature TC is a fine example of a Carnot heat engine, except that the engine does no work on its environment; instead, the available work is locally dissipated and a fraction of the dissipated energy is recycled into the engine (Emanuel 2005). It gains its energy principally by heat transfer from the ocean with the large surface heat fluxes in and near the eyewall. As a natural hazard, a TC is one of the major threatening weather-related disasters that can cause loss of lives and considerable economic damages (Emanuel 2005; Bouwer 2011; Mendelsohn

et al. 2012). Therefore, given the nature of cyclone damage, it is imperative to track down a tropical cyclone well ahead to minimize the societal and economic impacts (Islam et al. 2015).

The prediction skill of track and intensity of TCs has been improvised during the last several decades in India. This has been achieved with the help of advanced observational tools, modeling results and their assimilation. The models consist of a set of several dynamical equations concerning conservation of mass, momentum and heat. These equations are solved using different numerical schemes by means of discretization of underlying partial differential equations (PDE). Other atmospheric processes such as evaporation, condensation and rainfall are parameterized and are solved along with other equations. Most of the TC studies have given a large emphasis on improving the skill of models in predicting track and intensity of cyclones. Various studies have shown that predictive skill of TCs is largely dependent upon initial and boundary conditions fed to the model (Mullen et al. 1989; White et al. 1999; Pielke 2006). The accuracy of initial condition is important as a small error in them can give rise to large discrepancies in model results with time. The solutions of regional models always respond

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to the large-scale flow patterns (Majewski 1997); therefore, the necessity of providing suitable boundary conditions was also considered. Apart from lateral boundary, the importance of ocean surface and subsurface condition was also realized in the recent decade as the SST and other ocean parameters were known to control surface fluxes of heat and moisture (Sun et al. 2017; Rai et al. 2019). These are necessary to regulate the intensity of TCs by providing adequate energy and moisture to the overlying atmosphere. Chaudhuri et al. (2019) using the mooring data observed the ocean mixing response during the TC for the salinity and temperature. Jyothi et al. (2019) using the ocean circulation model simulated the tropical cyclone, Phailin (2013) and analyzed the thermal signatures after the passage of cyclone which showed that the East India Coastal Current and cyclonic eddy contribute to the faster advection of cold wake and recovery of sea surface temperature to the pre-storm state. Few other studies related to model coupling observed the periodic feedback among the atmosphere, ocean, and the wave models and showed how the correct representation of momentum and heat fluxes improves the prediction of different tropical cyclones (Prakash and Pant 2017; Dutta et al. 2019; Pant and Prakash 2020; Agrawal et al. 2020). Similarly, the coverage of the land mass and distribution of vegetation is also influential for calculation of fluxes and generating circulation differences over the continents. Badarinath et al. (2012) have shown improvements in track forecast errors while using adequate land vegetation parameterization techniques. The atmospheric factors effecting the TC are listed by other studies that analyzed the role of cumulus convection, vertical mixing in the PBL and cloud microphysics (Kain and Fritsch 1993; Kanada et al. 2012; Zhang et al. 2017) on TC structure. Shen et al. (2017) have similarly shown the role of thermodynamic state and wind nudging on TC genesis and their intensification. They showed that the correct thermodynamic profile can effectively imitate instability in atmospheric and convective equilibrium.

In the present study, we have tried to simulate two TCs Mora and Maarutha which occurred during pre-monsoon season of 2017. For our simulation, we have used a non-hydrostatic mesoscale model Regional Atmospheric Modeling System (RAMS).

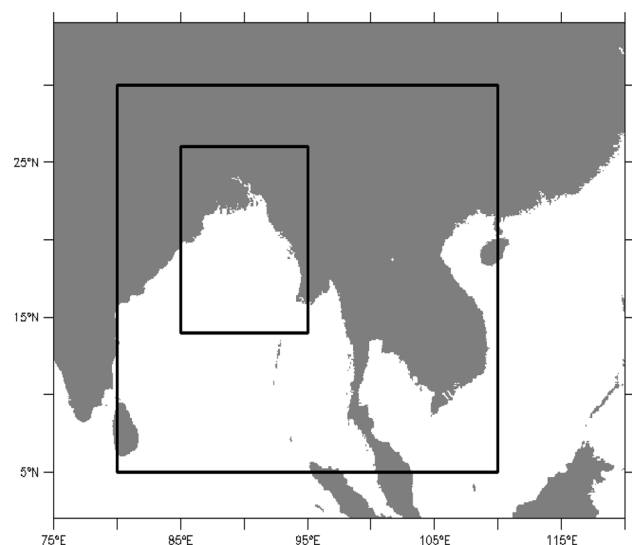
## Experiment set-up and data used

The model used in this study is the non-hydrostatic Regional Atmospheric Modeling System (RAMS; Cotton et al. 2003), that includes the capability of configuring multiple, two-way, nested, Arakawa C structured grid. The model domain was configured using three-dimensional, double-nested, two-way interactive grids with horizontal spacing of 50 km and 25 km. A stretched vertical grid scheme (40 levels)

ranged from the surface to approximately 27 km, starting with 50-m spacing at the surface, stretching out to 1000-m spacing at approximately 11 km above ground level (AGL), and then remaining at a constant 1000-m spacing throughout the remainder of the vertical extent. The initial and lateral boundary conditions were given from the NCEP-FNL 6-hourly reanalysis dataset having 1° horizontal resolutions. Time steps of the 50 s and 25 s were used for grids 1 and 2, respectively. Radiative boundary conditions as described in Klemp and Wilhelmson (1978) were used at the lateral boundaries. For radiation, cumulus parameterization and microphysics, we used Harrington radiation, Modified Kuo and bulk microphysics schemes which have enhanced the RAMS ability to capture TC track and intensity. For comparing the model results, we have used the information of cyclone track and intensity from the report provided by IMD. The observed precipitation data having 25-km horizontal resolution is taken from the Tropical Rainfall Measuring Mission (TRMM) website.

## Results and discussion

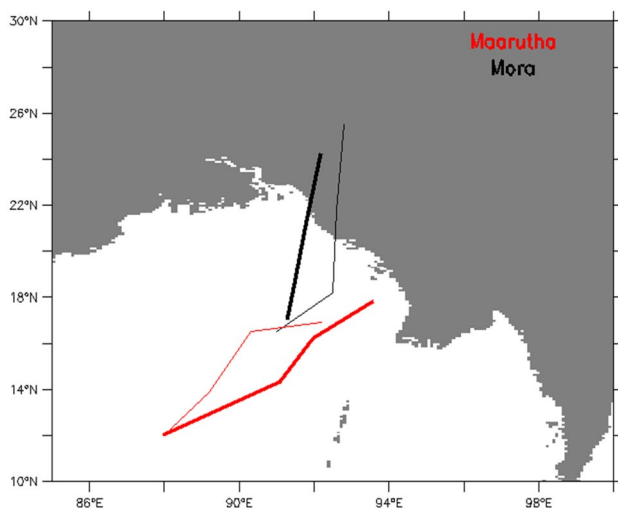
Figure 1 shows inner and outer domains used for the model run over which entire experiment was performed. The outer and inner domains were having spatial dimension of 80 E–110 E; 5 N–30 N and 85 E–95 E; 14 N–26 N, respectively, encompassing the northern Bay of Bengal. The assessment of simulated cyclones and model validation is being performed on the basis of both the domains. RAMS incorporates a two-way nesting approach which provides feedback from inner to outer domain and vice versa. This is expected



**Fig. 1** Model domain. Inner and outer domains used for the model run over which entire experiment was performed

to improve the storm simulation. The prediction of storm track and intensity is really important to save thousands of lives and economy. The storm tracks for both the cyclones are shown in Fig. 2. The dark lines show the track of the cyclone as per the IMD report of cyclones Mora and Maarutha, whereas the thin lines demonstrate the trajectory of the modeled output. For identification of modeled track, we have tried to locate the center of Mean Sea Level Pressure (MSLP) from the model output manually using a code. The figure shows that the simulated tracks of both the cyclones are comparable with the observations. The model is shown to deviate from its observed path during most of the simulation period. It is getting close to the observed path during the last hours of the simulation period. This can happen due to a number of reasons, including the systematic error, cumulus parameterization and model resolutions. We expect more reliable path as the model resolution is improved. The intensity of modeled cyclones was compared considering the lowest MSLP profiles of Bay of Bengal during the progression of storms. The IMD report already mentioned the lowest MSLP values and we have compared it with our model output in Fig. 3. The temporal evolution of MSLP values signifies strength of a cyclone which is clearly shown in this figure for both the cyclones. The examination of this figure shows the cyclone simulation underestimates the lowest mean sea level pressure and the difference decreases with the increment in simulation time. The strength of Mora appears to be stronger than Maarutha as Mora attains comparatively lower MSLP values as compared to Maarutha.

The structure of winds and advection of vorticity is equally important to identify the storm impact. Winds inside TCs are lowest at the center and intensify gradually as we move away from it. The wind intensity attains its maximum



**Fig. 2** Cyclone tracks predicted by RAMS (light) and as observed by IMD (solid)

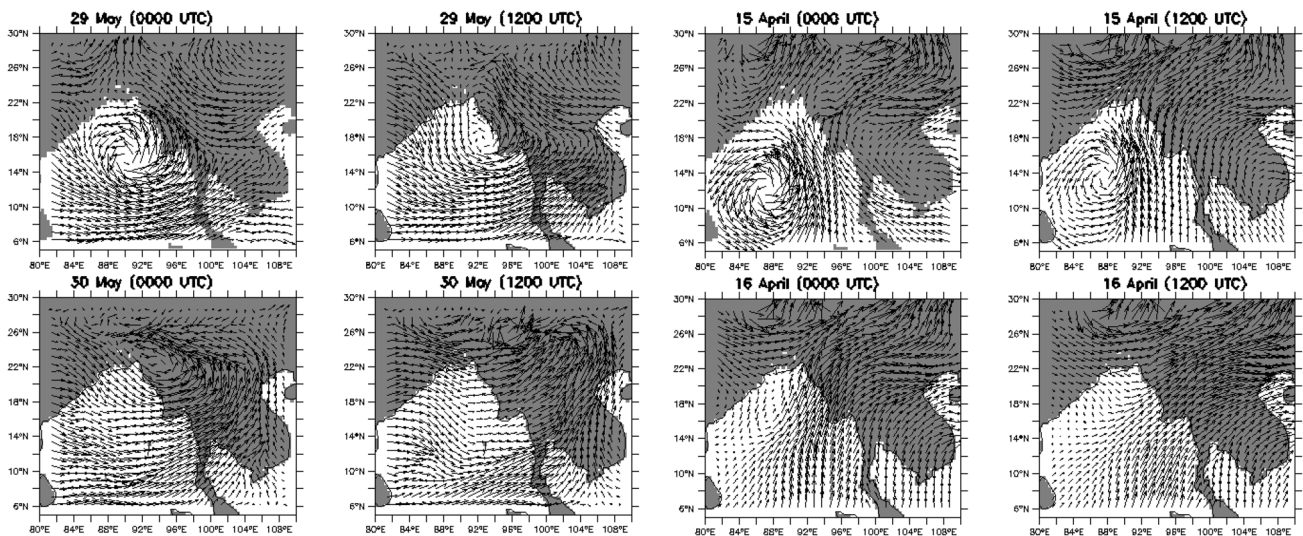
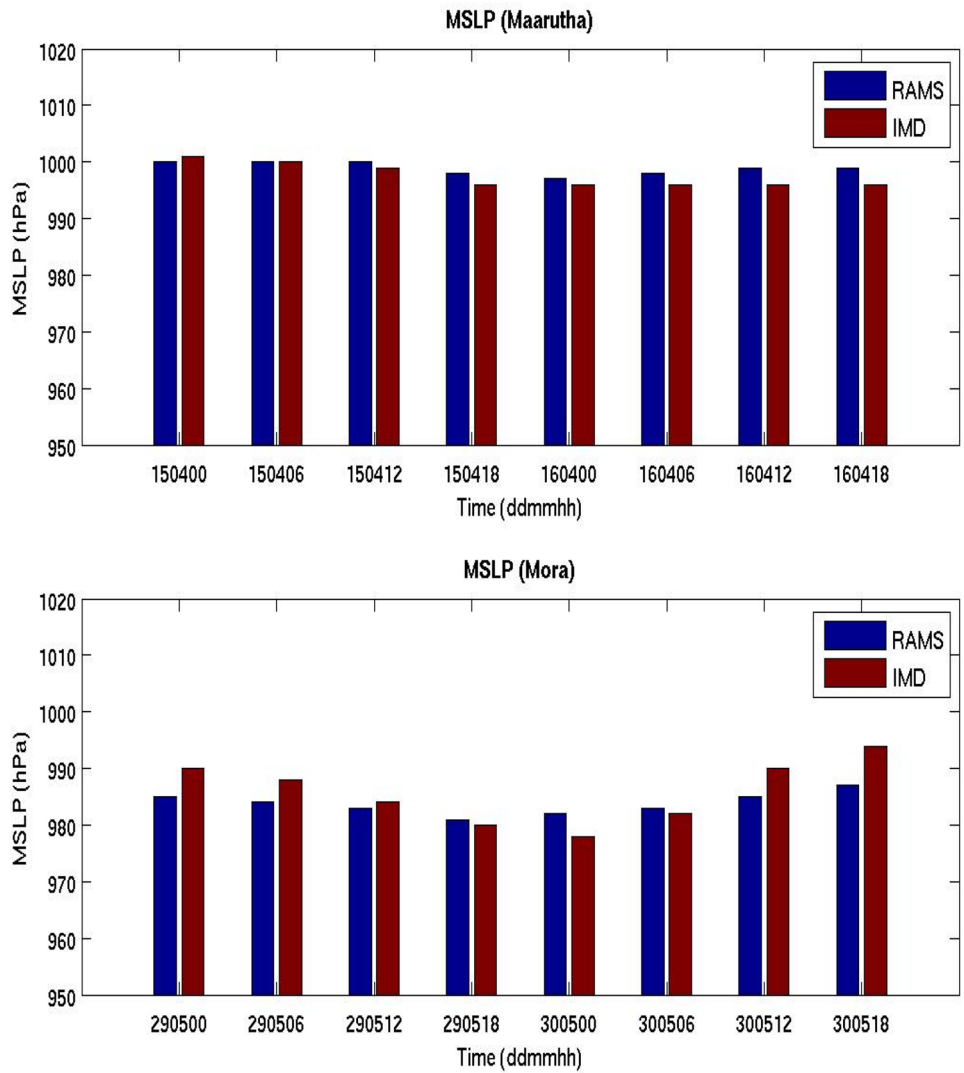
value at the radius of maximum winds (RMW) and further decreases afterwards. Therefore, a region is more prone to destruction caused by a storm if it comes within the range of RMW. The horizontal structure of winds for both the cyclones is shown in Fig. 4 for different time periods as per the intensity of the storm. The vorticity is transported as per the storm trajectory before and after making the landfall. The 850-ha horizontal wind vectors show a realistic picture of vorticity movement when compared with the IMD track record. The storm area is shown to be calm at the center with higher winds around it. The high-intensity storm winds are observed up to 200 km from the storm center during its intensification phase. The winds, however, get weakened as the storm proceeded further towards the coast and made the landfall. This happens as the storm is unable to get enough moisture and fluxes near the coast and dies soon after making the landfall.

The storm impact can be visualized in terms of total accumulated precipitation. The pattern of precipitation is aligned towards the spiral rainbands inside a storm system. Figure 5 shows the precipitation distribution in mm/day as per the TRMM data and model results at two different times for both the cyclones. The analysis of surface precipitation shows that it is slightly underestimated when simulated Maarutha, whereas these are overestimated with Mora. The position of principal rainbands is coinciding with the observation. The model results do not show characteristic circular or spiral bands as compared to the TRMM data values. The difference in rainfall patterns may arise due to coarse resolution and convective parameterization used.

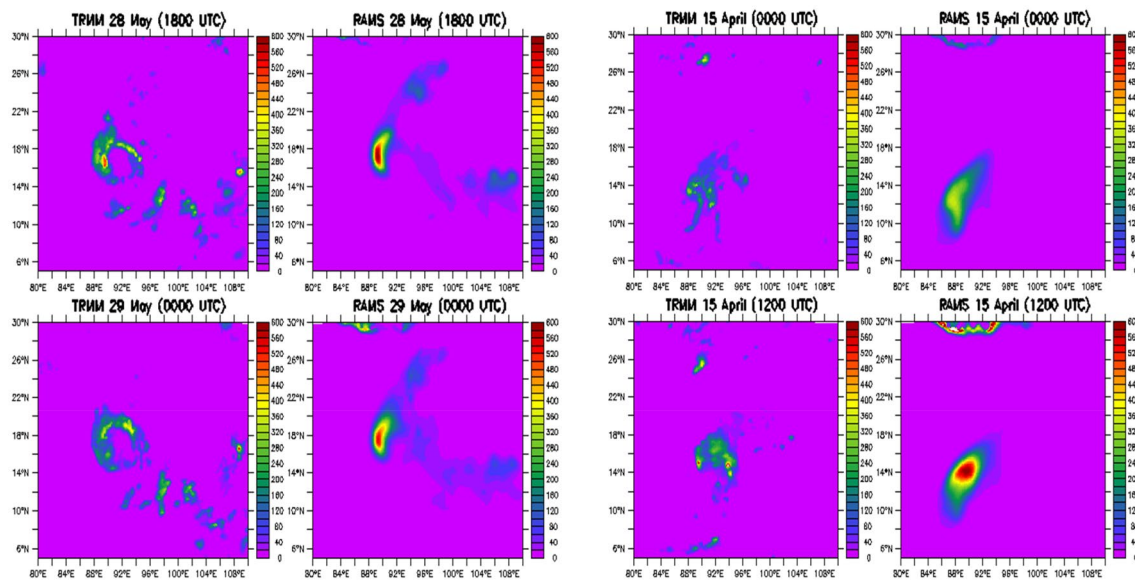
## Conclusion

Tropical Cyclones as natural hazard are always of prime importance for coastal vulnerability. They cause destruction to livelihood and economy of coastal regions by inducing storm surge, strong winds, lightening and precipitation in their path. They are useful for vertical mixing of ocean and advection of nutrients towards the coasts. Therefore, the study of cyclogenesis and its intensification is always of major concern for meteorologists and society. In the present study, we have tried to assess the capability of RAMS in simulating two pre-monsoonal TCs Mora and Maarutha which occurred in Bay of Bengal. RAMS is equipped with advanced numerical schemes and physics pursuits which are necessary to simulate this atmospheric phenomena realistically. The model solutions are obtained at 25-km horizontal resolution. The analysis of model track shows deviations from the observed patterns which have the potential to improvise with increasing resolution of the model. The model winds and pressure at storm center are comparable to

**Fig. 3** Mean Sea Level Pressure (MSLP) recorded by IMD and RAMS: The cyclone simulation underestimates the lowest mean sea level pressure and the difference decreases with the increment in simulation time



**Fig. 4** Horizontal winds at 850 hPa during Mora (left) and Maarutha (right)



**Fig. 5** Precipitation (mm/day) observed by TRMM and RAMS during Mora (left) and Maarutha (right): The precipitation values are underestimated when simulated Maarutha, whereas these are overestimated with Mora

the observed studies. Overall, we see that RAMS has captured these mesoscale events realistically.

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