International Journal of Oceans and Oceanography
ISSN 0973-2667 Volume 10, Number 1 (2016), pp. 49-59

http://www.ripublication.com

Impact of Microphysics Schemes in the Simulation of Cyclone Hudhud using WRF-ARW model

Dhana Lakshmi Douluri[1]* and K. Annapurnaiah[2]

[1]Department of Meteorology & Oceanography,*
Andhra University, Visakhaptnam-500003, India.
E-mail: dl.ayyalasomayajula@gmail.com

[2]Indian National Centre for Ocean Information Services,
Pragathi Nagar, Hyderabad-500090, India.
E-mail: anup@incois.gov.in

Abstract

A Very Severe Cyclonic Strom (VSCS) "Hudhud" crossed Andhra coast near Visakhapatnam on 12th October 2014 and caused significant damage to property due to both wind and surge. In the present study, an attempt is made to simulate and test the capability of the state of art Advanced Research Weather Research and Forecasting (WRF-ARW) model in capturing the wind intensity and track of cyclone accurately. The simulation has been carried out using three domains with a horizontal resolution of 27 km for domain 1, 9 km for domain 2 and 3 km for domain 3. Multiple simulations using initial conditions (NCEP FNL) at an interval of 6 hours, same cumulus parameterization and time integration schemes but with different microphysics schemes are carried out. The main source of energy for tropical cyclone is the latent hear release (convective heating) in clouds, which depend on microphysical processes and the released dynamical properties. The objective of the present study is to find out the best microphysics for accurate simulation of intensity and track of tropical cyclone at high model domain resolution towards storm surge studies. The best performance was found for the model integrated for 48 hours starting from 10th October 2014 to 12th October 2014. Simulated features include (track, maximum sustained wind, sea level pressure and rainfall) were compared with IMD best track data and it was observed that simulations with WRF LIN microphysics scheme compare well with observations. Other synoptic features of rainfall was also simulated and discussed in relation to model performance. Overall this study gives emphasis on the studies towards sensitivity analysis of microphysics parameterization using WRF simulations at high model grid resolution (3 km) to imply towards storm surge applications in Bay of Bengal.

Keywords: Bay of Bengal, Tropical cyclone, Mesoscale model, Microphysics, Maximum sustained wind speed, Sea Level Pressure, Rainfall

Introduction

The Hudhud cyclone was the very severe cyclonic storm occurred over the Bay of Bengal during 07-14th October 2014. It developed over low-pressure area near Tenasserim coast and adjoining North Andaman Sea in the morning of 6th October 2014. It emerged into Southeast Bay of Bengal and continued to move west-northwestwards intensifying into a severe cyclonic storm in the morning of 09th October and into a very severe cyclonic storm in the afternoon of 10th October. It crossed north Andhra Pradesh coast over Visakhapatnam (VSP) between 1200 and 1300 hrs IST (0630 – 0730 UTC) of 12th October. IMD reported the maximum sustained wind speed of 180 kmph at the time of landfall. The lowest estimated central pressure was 950 hPa from 0000 UTC of 12th to 0600 UTC of 12th October. The maximum estimated wind speed was 185 kmph. The system moved in a west northwestward direction over the sea area and then northwestward at the time of landfall. The lowest observed pressure of 950.3 hPa was reported by Visakhapatnam station at 0700 UTC (at the time of landfall) of 12th October and the maximum sustained wind speed of 130 kmph at 0500 UTC. The damage was quite severe and the VSCS, Hudhud mainly affected North Andhra Pradesh and adjoining south Odisha. In Andhra Pradesh, 46 people lost their lives, and 43 were injured. About 41,269 houses were damaged. Thousands of animals including poultry/duck perished. 2.3 lakh Hectares of land was submerged (Medha and Sunitha, 2015). The IMD post cyclonic survey (IMD report 2014) reported maximum of storm surge of 1.4 meters above the astronomical tide at Visakhapatnam at the landfall.Thus, it is pertinent to further examine the detailed synoptic features of the cyclone with different physics and dynamical schemes using Advanced Research Weather Research and Forecasting (ARW-WRF, hereafter WRF) Mesoscale model developed at National Center for Atmospheric Research (NCAR) because of its superior performance in generating fine-scale atmospheric structures as well as its better forecast skill (Otkin et al. 2005; Pattanayak and Mohanty 2008).

Prediction of TC track and intensity is very essential to give prior warning to people with a view to mitigate loss of life and property. Lately, Mesoscale weather models and computing facilities available have increased prediction skill considerably. Even so, numerical weather prediction (NWP) models get their initial (IC) and boundary (BC) conditions from a low-resolution global forecast system (GFS) and are interpolated into the model domain of interest, and thereafter the basic conservation and momentum equations with specified physics parameterization schemes and time step are solved. The uncertainties in the ICs, physics parameterization schemes and limitations in numerical techniques like truncation and discretization errors and round-off errors from the computation are the major causes of reduced forecast skill in NWP models. While numerical and round-off errors can be reduced only to certain extent, it is possible to reduce the uncertainty in the physics schemes and the ICs through the sensitivity studies and data assimilation techniques.

The NWP models have different physics parameterization schemes to represent the atmospheric processes, but these schemes have been developed by different groups with different assumptions and are region specific. Sensitivity studies are a rational way to determine the best set of physics parameterization schemes for a specific region and reduce the uncertainties in subgrid-scale process.

Several studies (Srinivas et al., 2007; Deshpande et al., 2010; Osuri et al., 2012a; Raju et al., 2011, Rao and Prasad, 2007; and Chandrasekar and Balaji, 2012, 2015) have done extensive analysis towards simulation of cyclones using NWP models. They have implemented all the available combination of schemes of CU, PBL and MP parameterization. Srinivas et al., (2013) have conducted sensitivity studies with extensive numerical experiments with combinations of CU, PBL, MP and LS parameterizations on over 21 cyclones in the BoB region with the best set of physics schemes arrived from their study and observed that best set of schemes overestimated the intensity of cyclone with the mean error ranging from 1 to 22 m/s corresponding to 24- and 72-h simulations and have higher mean track errors. Overall, the above studies conclude that (1) the best schemes obtained for the track over predict the intensity of the cyclone; (2) the results differ, when the grid size and number of nesting are changed. According to them, the performance of physics schemes depends on the grid resolutions and number of nesting and the best schemes arrived from any sensitivity study will give the best results only when the same model configuration used. Furthermore, they indicated that the CU, PBL and MP parameterizations play a crucial role in TC simulations.

From the above studies, it is clear different sets of physics parameterization schemes are used for simulating TCs even within the region of BOB and the performance of these physics schemes mainly depends on the grid resolution and the number of nesting. So, in this study we try to determine the optimum physics schemes for the region of BOB for the specific grid resolution through sensitivity studies. Very little information exists on how the parameterization schemes for a given grid resolutions would impact the storm surge prediction. This study will provide initial results to imply for application in storm surge studies. The main objective of this study is to arrive at the optimum set of schemes for the BoB region to increase forecast skill towards storm surge forecast.

WRF-ARW model description

The present work is to understand the evolution of tropical cyclone Hudhud 8-14th October 2014 using WRF-ARW towards the better prediction of wind and pressure fields that are important in storm surge studies. A brief description of the model used for the study is given below.

The Weather Research and Forecast (WRF ARW Version 3.7) model (Skamarock et al. 2008) is used in this study for its accurate numerics, higher order mass conservation characteristics and advanced physics. The model consists of fully compressible non-hydrostatic equations and the prognostic variables include the three-dimensional wind, perturbation quantities of pressure, potential temperature, geo-potential, surface pressure, turbulent kinetic energy and scalars (water vapor mixing ratio, cloud water, etc.). The model vertical coordinate is terrain following hydrostatic pressure and the horizontal grid is Arakawa C-grid staggering. A third-order Runge–Kutta time integration is used in the model. The model has several options for spatial discretization, diffusion, nesting, and lateral boundary conditions. The model can be initialized with available large-scale analyses meteorological data sets and also includes advanced data assimilation procedures. A number of options are also available in the model for representing the sub grid-scale physical processes for convection, explicit microphysics, atmospheric radiation, boundary layer turbulence, and surface temperature/moisture treatment.

The model is configured with two two-way interactive nested domains (outer-domain: 27 km resolution, (148 × 148), and inner domain: 9 km resolution, (346 × 346) and 3 km resolution (730 x 730) grids in west-east and north-south directions, respectively) and 36 vertical levels. The physics used in the model includes Yonsei University (Hong et al.2006) nonlocal diffusion scheme for PBL processes, Kain-Fritisch (KF-Eta) (Kain, 2004) mass flux scheme for cumulus convection and 6 microphysics schemes are used. (Honget al. 2004) for explicit moisture processes, Noah land surface scheme for soil processes, Rapid Radiation Transfer model (RRTM) for long wave radiation (Mlawer et al. 1997) and Dudhia (1989) scheme for shortwave. The overview of the model used in the study is given in Table 1. The schemes used to study the impact of microphysics parameterization are listed in Table 2.

Table 1: Microphysics parameterization schemes

Microphysics (MP)	
1.	Kessler scheme (KS)
2.	Lin et al. scheme (LIN)
3.	WRF Single Moment 3 class simple ice scheme (WSM3)
4.	Ferrier (new Eta) microphysics (FERRIER)
5.	WRF Single Moment 6 class Graupel scheme (WSM6)
6.	Thompson scheme (THOMP)

Table 2: Model dynamics and domain details

Dynamics	
Equation	Non-hydrostatic
Time integration scheme	Third-order Runge–Kutta scheme
Horizontal grid type	Arakawa-C grid
Domain	
Map projection	Mercator
Central point of the domain	86 E, 12 N
No of domains	3
No of vertical layers	36 Sigma levels
Horizontal grid distance	27 km in domain 1, 9 km in domain 2,and 3 km in domain 3
Time step	150 s

ARW-WRF Model Domain and Dynamic Options

The WRF has been used for simulating the TCs. The physics schemes and dynamic options are detailed in the model technical note (Skamarock et al., 2008), and the governing equations and the numerical technique used in the models are described in Skamarock and Klemp (2008). Table 2 lists the number of nesting, grid resolutions and dynamic options used in this study.

Data for WRF model:

The United States Geological Survey (USGS) 3000 resolution topographical data have been used in the WRF preprocessing system (WPS). Providing the initial and boundary conditions from the National Centre for Environmental Prediction (NCEP) FiNaL Analysis (FNL; $1^0 \times 1^0$) data considered for model simulations. The time varying lateral boundary conditions are derived at every 6 h interval from the NCEP-FNL forecast fields. The IMD observed track and wind would be taken to be the truth for validating the simulated tracks.

Sensitivity studies for the Hudhud were carried out in order to determine the best microphysics parameterization scheme for the track and intensity prediction. Simulations were carried out for the three model grid resolutions 27, 9 and 3 km respectively. Results from the high model grid resolution (3 km) have been used for the analysis. In all the experiments, the Kain-Fritsch (KF) cumulus parameterization scheme, Yonsei-University (YSU) planetary boundary layer (PBL) scheme were kept fixed (Osuri et al., 2012). The model output and the IMD observed track compared concurrently. The track error (in km) is computed for the whole track and the results during the landfall are given, since the features during the landfall are significant for storm surge studies. The best scheme has been chosen on the basis of the propagation of the simulated track along with the analysis of intensity in terms of 10-m Maximum sustained wind (MSW) and central sea level pressure (CSLP) has been conducted.

Results and Discussion

Track:

The microphysics parameterization schemes explicitly handle water vapour, cloud and precipitation processes and also the microphysical processes of melting of snow, graupel and cloud ice hydrometers, suppression of falling rain by evaporation. In this study, 6 different microphysics parameterization schemes available in WRF v 3.7 model have been considered along with KF cumulus parameterization, and YSU PBL scheme. The propagation of tracks is shown Fig. 1.

The track errors at different initial conditions are given in fig. 2. It can be observed that the track error increased for 72 and 96 hours. It shows that the low level wind convergence and vorticity are captured well for 24 and 48 hours initial conditions. Where as for 72 and 96 hours conditions the deviation is large. Overall 48 hours initial condition simulations showed less track error displacement during landfall. Lin et al., scheme showed the best performance with 20.47 km and the second best performance was shown by WSM-6 scheme with 31.66 km. All other schemes showed higher displacement errors ranging from 60-80 km during landfall.

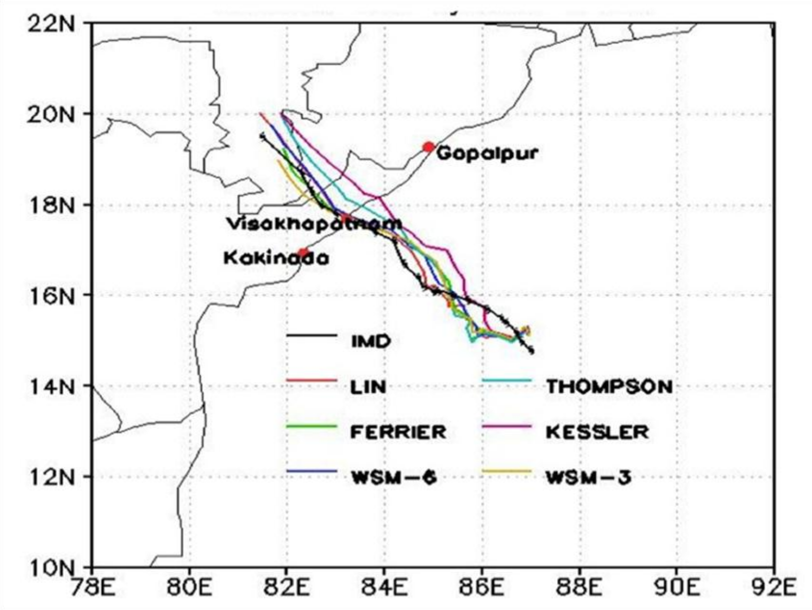

Figure 1: Simulated tracks of Hudhud by different microphysics parameterization schemes

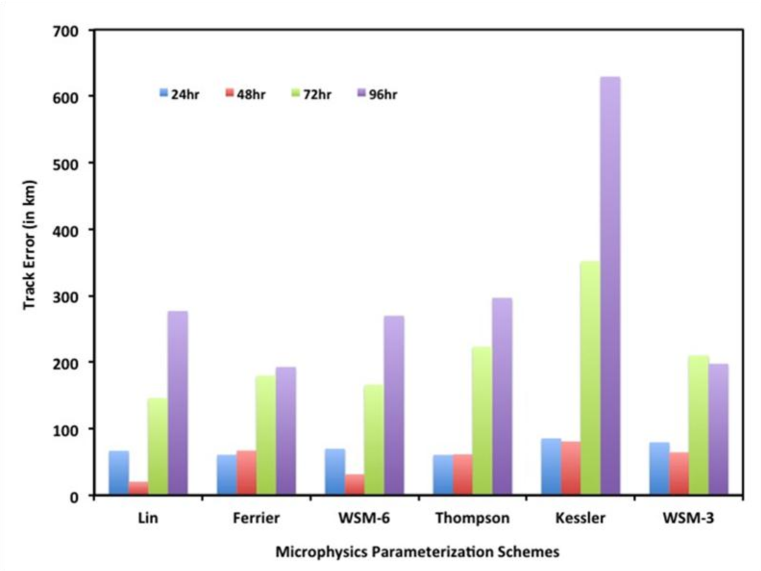

Figure 2: Track error (at 24, 48, 72 and 96 hours) during landfall time

The results for central sea level pressure, maximum sustained wind speed and 24-hour accumulated rainfall are given for 48- hour initial condition at 3 km horizontal resolution grid. At other coarse grid resolutions 9 and 27 km are not presented here. Central sea level pressure, maximum sustained wind speed, minimum track error and better prediction of 24- hour accumulated rainfall during the landfall are the necessary requirement for the better prediction of storm surge forecast. Since the motivation of the study is to test the best microphysics parameterization scheme at high resolution for storm surge prediction.

The temporal variability of track error for 48 hours initial condition compared against IMD best track data is shown in fig. 3. It can be observed that Lin scheme showed consistent increase and decrease at various phases of depression in accordance with IMD data. It showed lowest track error compared with all other schemes during landfall, which is well required for better storm surge forecasts.

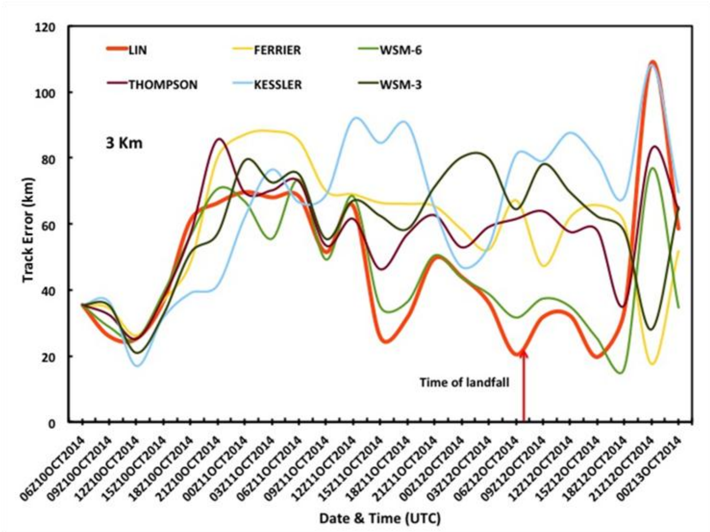

Figure 3: Track error for 48 hr initial conditions compared with IMD best track data (in km)

Central sea level pressure:

The central sea level pressure is depicted in Fig. 4. WSM-3 scheme showed nearer value to the IMD observation, but Lin scheme along with Thompson scheme have shown lowest pressure during landfall. Lin scheme has shown the lowest of all the schemes. Lowest sea level pressure is the primary requirement as input to the storm surge models. All the models underestimated the pressure compared with IMD data, except WSM-3 scheme.The initial position of the storm is well simulated by all the schemes. Lin scheme predicts the values of 929.34 hPa at 06 UTC on 12th October in comparison to IMD best track value of 950 hPa. WSM-3 predicted nearest value of 948 hPa at 06 UTC. The central sea level pressure for all the other schemes varied from 928 to 933 hPa for the Hudhud cyclone.

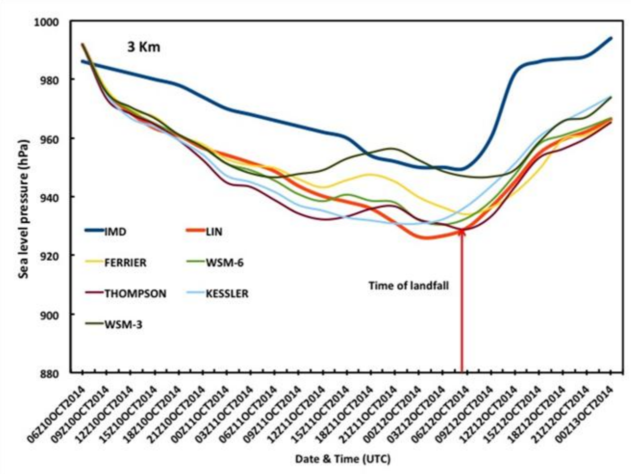

Figure 4: Temporal variability of model simulated sea level pressure with IMD best track data

Maximum sustained wind speed:

Fig. 5. Depicts the 10-m MSW speed along with IMD best track data. From the 06 UTC 10th October all the schemes overestimated the wind speed still 09 UTC 11th October. From 12 UTC 11th October onwards the LIN scheme showed better comparison with the IMD best track data. During landfall at 06 UTC on 12th October WSM-6, Kessler schemes showed nearest values. Lin scheme showed over all better performance with 51.98 m/s against 51.44 m/s of IMD value. The corresponding values of wind speeds for other schemes varied from 47.42 to 54.14 m/s. Thompson speed overestimated the value in comparison to IMD observation.

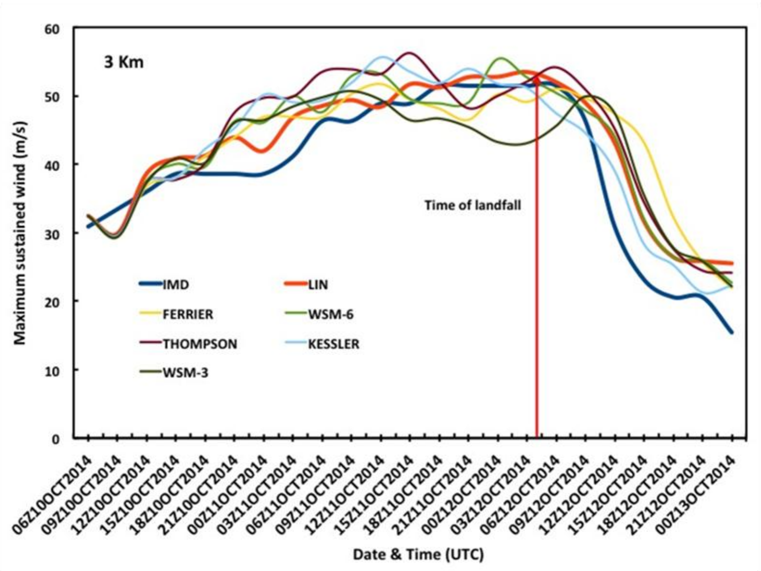

Figure 5: Temporal variability of model simulated maximum sustained wind speed with IMD best track data

Precipitation:
Figure 6 shows the 24-hr accumulated rainfall by different schemes along with TRMM observation. Precipitation is an important parameter to be simulated accurately by the model. For the Hudhud (on 0000 UTC of 12th October 2014), the close inspection of the rain band structures during landfall shows the intensification of rain bands over the land. Combined with high winds, intensified rain bands with cause severe damage and would be responsible for enhancement of storm surges. Though the cases WRF simulated rainfall overestimated the values in comparison to TRMM, the features of the rain bands were well captured. For Hudhud cyclone, TRMM observation varies from 13 to 18 cm. WRF simulations for different microphysics parameterization schemes vary from 35-45 cm. Still the sensitivity of simulations needs to be investigated with PBL and Cumulus parameterizations for other cyclonic conditons.

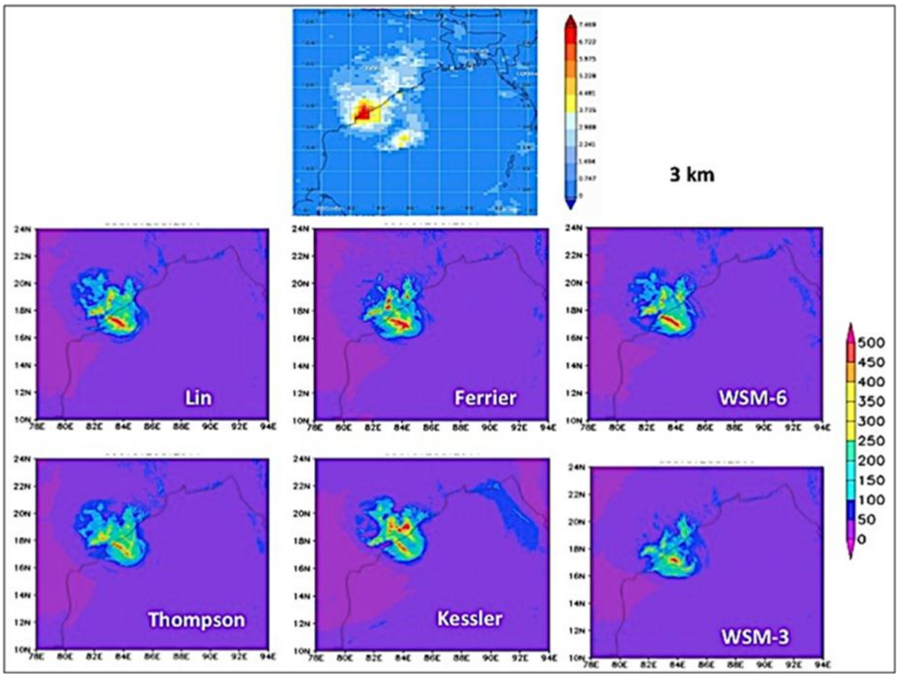

Figure 6: 24- hour accumulated rainfall by different schemes along with TRMM observations during landfall

Conclusions

The 48-hour forecast of the track error was found to be least for the Lin et al., scheme. The WSM-6 scheme predicts the CSLP nearer to IMD. But Lin scheme predicted the lowest values of CSLP. The intensity in terms of MSW speed simulated by Lin scheme matches well with the observations while other microphysics schemes show nearer values and overestimate the values. Rainfall, is an important parameter, is well captured by all the schemes, though the values are overestimated, the features of the rain band structures are well captured and represented. However, the suitability of Lin and other schemes for the storm surge forecast for the tropical cyclonic conditions may be examined by conducting more case studies. The damage caused to the coastal structures, life and property can be minimized by accurate prediction of cyclonic storms adopting best performing schemes/models to predict track and intensity for storm surge modeling.

Acknowledgments

Authors wish to thank the Director, Indian National Centre for Ocean Information Services, Ministry of Earth Sciences, Govt. of India, Hyderabad, for motivation and encouragement.

References

[1] Osuri, K.K., Mohanty, U.C., Routray, A., Kulkarni, M.A., Mohapatra, M., 2012. Customization of WRF-ARW model with physical parameterization schemes for the simulation of tropical cyclones over North Indian Ocean. Natural Hazards 63:1337–1359.

[2] Srinivas C, Venkatesan R, Bhaskar Rao D and Hari Prasad D 2007 Numerical simulation of Andhra severe cyclone(2003): Model sensitivity to the boundary layer and convectionparameterization; Pure Appl. Geophys. 164(8–9)1465–1487.

[3] Deshpande M, Pattnaik S and Salvekar P 2010 Impactof physical parameterization schemes on numerical simulation of super cyclone Gonu; Natural Hazards 55(2)211–231.

[4] Rao D and Prasad D 2007 Sensitivity of tropical cycloneintensification to boundary layer and convective processes;Natural Hazards 41(3) 429–445.

[5] Chandrasekar R, Balaji C., 2015,"Impact of physics parameterization and 3DVAR data assimilation on prediction of tropical cyclones in the Bay of Bengal region," Nat Hazards :1-25; DOI 10.1007/s11069015-1966-5

[6] Srinivas CV, Bhaskar Rao DV, Yesubabu V, Baskaran R, Venkatraman B (2013) Tropical cyclone predictionsover the Bay of Bengal using the high-resolution Advanced Research Weather Research andForecasting (ARW) model. Q J R Meteorol Soc 139(676):1810–1825

[7] Skamarock W, Klemp J (2008) A time-split nonhydrostatic atmospheric model for weather research andforecasting applications. J Comput Phys 227(7):3465–3485

[8] Hong, S. Y.,Y. Noh, and J. Dudhia, 2006,"A new vertical diffusionpackage with explicit treatment of entrainment processes," Mon. Weather. Rev., 134, pp. 2318–2341.

[9] Kain, J. S., 2004,"The Kain–Fritsch convective parameterization:An update" J. Appl. Meteor., 43, pp. 170–181.

[10] Hong, S. Y., J. Dudhia, and S. Chen,2004,"A revised approach toice microphysical processes for the bulk parameterization ofclouds and precipitation," Mon. Weather. Rev., 132, pp. 103–120.

[11] Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A.Clough, 1997,"Radiative transfer for inhomogeneous atmosphere:RRTM, a validated correlated-k model for the longwave," J. Geophys. Res., 102 (D14), 16, pp. 663–16 682.

[12] Dudhia, J., 1989,"Numerical study of convection observed duringthe winter monsoon experiment using a mesoscale two dimensional model," J. Atmos. Sci., 46, pp. 3077–3107.

[13] Medha K., and Sunitha Devi S, 2015,"Cyclones and depressions over the north Indian Ocean during 2014," MAUSAM, 66 (3),pp. 337-354.