International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Thunderstorm Event Simulation over the Balasore (Odisha) Using WRF-ARW Model

Mahesh Sharma

School of Earth Ocean and Climate Science, Indian Institute of Technology Bhubaneswar, Odisha, India
e mail : 20cl06011@iitbbs.ac.in

ABSTRACT

The vast majority of extreme weather occurrences are convective in origin. The Advance Research dynamic core of the Weather Research and Forecasting Model was used to simulate the thunderstorm event that happened over Balasore District, Odisha near the Bay of Bengal on 07 August 2021, which resulted in 5 deaths (WRF-ARW). The WRF model was run using 3 hourly NCEP-GFS datasets from 0000UTC of 07 August to 0000UTC of 08 August 2021 as initial and boundary conditions, with a domain of 500 m horizontal resolution. The model's performance has been evaluated using hourly outputs. With certain spatial and temporal biases in the data, the WRF model captured the analyzed thunderstorm event on 07 August 2021 very well. However, during 0900 UTC, the model simulated 24-hour rainfall over the Balasore district increased significantly. Mesoscale models are required for accurate and precise forecasting of high-impact weather phenomena. A thunderstorm event that happened on 07 August 2021 at Balasore, Odisha (21.50°N, 86.90°E) was attempted to be simulated in this study. The National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction (NOAA/NCEP) devised and developed this model. The findings of these investigations demonstrate that the 500 m resolution WRF-ARW has superior thunderstorm modeling capacity. As a result, high-resolution models have the potential to give severe thunderstorm forecasters with unique and reliable data.

Key words – WRF-ARW Model, Thunderstorm, Simulation, Rainfall, Wind, Specific Humidity

INTRODUCTION

A thunderstorm is a violent and brief meteorological disturbance that is almost usually accompanied by lightning, thunder, dense clouds, heavy rain or hail, and strong, gusty winds. Thunderstorms form when warm and wet air layers rise in a massive, fast updraft to cooler parts of the atmosphere. The moisture trapped in the updraft condenses to form towering cumulonimbus clouds, which eventually produce precipitation. The cooled air sinks earthward in columns, slamming into the ground with intense downdrafts and horizontal winds.

Thunderstorms occur more frequently in many parts of India during the pre-monsoon months (March-May), when the atmosphere is particularly unstable due to high temperatures at lower levels. During April, the eastern and northeastern areas of the country, namely Gangetic West Bengal, Jharkhand, Odisha, Bihar, Assam, and parts of other northeastern states, are severely afflicted by violent thunderstorms, colloquially known as 'Kal-baishakhi' or 'Nor'westers.'.Nor'westers are mesoscale convective systems that can form within the seasonal, low-level trough's large-scale envelope across West Bengal, Bihar, and Jharkhand, with a probable embedded low pressure region. These violent thunderstorms, which include thunder, squall lines, lightning, heavy rain, and hail, cause considerable crop loss, property damage, and even death. The number of people killed or injured in this region as a result of lightning related with thunderstorms is among the highest in the world. After colliding with the earth's surface, the intense wind produced by a thunderstorm downdraft expands out laterally and is known as a downburst, which poses a serious threat to aviation. During severe thunderstorms, the biggest number of aircraft accidents are documented. Nor'westers are responsible for 72 percent of tornadoes in India. These thunderstorms have a huge socioeconomic impact in the eastern and northeastern parts of the country. The synoptic situation and localized thermodynamic conditions of the atmosphere are largely responsible for the formation, intensification, and dissemination of severe thunderstorms. The creation and severity of severe rain are influenced by microphysical and electrical properties. Because of their tiny spatial and temporal extent, as well as the intrinsic nonlinearity of their dynamics and physics, thunderstorm forecasting is one of the most difficult challenges in weather prediction. In the modeling of convective clouds and mesoscale convective processes, numerical modeling has made significant progress.

Mesoscale models were created with the ability to change horizontal and vertical resolutions, nest domains, and select relevant settings for various physical parameterization approaches. These models are frequently used in a wide range of applications, including thunder storm forecasting, by appropriately selecting several key parameters. For several decades, stability indices have been a cornerstone in the forecasting of convection, and they are occasionally used in the academic literature as well. Several writers have investigated the effectiveness of various stability indices for thunderstorm prediction. Warm air advection in the lower levels and cold air advection in the upper levels (usually associated with deep troughs in the upper tropospheric westerlies) will boost conditional instabilities in the atmosphere, favoring the outbreak of violent thunderstorms. Srinivasan et al. have provided a thorough explanation of the causes of violent thunderstorms in India, as well as various case examples. The current study used the WRF–

ARW model, which was built and developed by the (NOAA/NCEP) National Oceanic and Atmospheric Administration/National Centers for Environment Prediction, to replicate the thunderstorm event that occurred on 07 August 2021 at Balasore, Odisha (21.50°N, 86.90°E).

MODEL DESCRIPTION

This section gives a quick overview of the WRF-ARW model, as well as the data and technique used to simulate and analyze the selected thunderstorm event.

Model Introduction

The WRF Model is a cutting-edge mesoscale NWP system that can be used for operational forecasting as well as atmospheric research. It has a software design that allows for computing parallelism and system flexibility, as well as several dynamical cores and a 3-Dimensional Variational (3DVar) data assimilation system. (W. C. Skamarock and colleagues, 2008). WRF is well suited to a wide range of applications at ranges ranging from a few meters to thousands of kilometers. Research and operational NWP, data assimilation and parameterized-physics research, downscaling climate simulations, driving air quality models, atmosphere-ocean interaction, and idealized simulations are all examples of WRF applications (i.e., boundary-layer eddies, convection, baroclinic waves). The Advanced Research WRF (ARW) solver (formerly known as the Eulerian mass or "em") created primarily at NCAR, and the Nonhydrostatic Mesoscale Model (NMM) solver developed at NCEP, are the two main dynamics solvers in the WRF system. The ARW system combines the ARW dynamics solver with other WRF system components to provide a simulation. During the current research, the WRF-ARW (Version 4.1) was used.

Model Experimental Setup

The WRF model is run on a single domain at 0.5 km horizontal resolution. The domain size is taken 150x104 km. The domain is centered (21.5°N, 86.9°E) over Balasore, Odisha to represent the regional-scale circulations and to check model prediction using GFS. The domain of WRF model for the NWP (Numerical Weather Prediction) study with the topography in background. There are 31 vertical layers. The model is run using the Kain-Fritsch (new Eta) scheme for cumulus parameterization (J. S. Kain, 2004), Yonsei University (YSU) scheme for the boundary layer parameterization(Y. S. Hong*etal.*, 2006), WSM 6 class graupel schemes for microphysics (Y. S. Hong, and J. Lim, 2006) and Rapid Radiative Transfer Model (RRTM) for longwave (E. J. Mlawer *etal.*, 1997) and Dudhia for short wave radiation scheme (J. Dudhia, 1989) for the selected case. The initial condition of the model simulation is taken as 0000 UTC of 07 August 2021 and lateral boundary condition is taken for 24 hours with 3 hours intervals.

Data Used

The NCEP RDA GFS data for initial condition 07/08/2021/00 and in boundary condition 24 hour forecast data of 3 hour interval i.e. f00, f03, f06, f09, f12, f15, f18, f21, f24.NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive data of National Centre for Environmental Prediction (NCEP) with the 0.25°×0.25° horizontal and 3-h temporal resolution were used as the initial and lateral boundary condition.

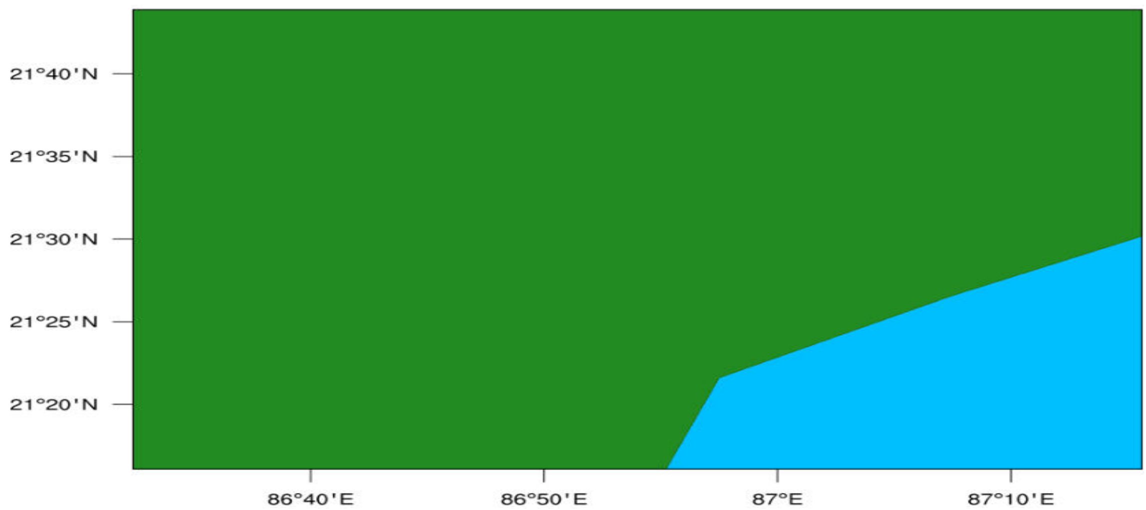


Figure 1. WRF Model domain for NWP study

Methodology

The WRF-ARW Model developed by NCARNCEP, USA has been used for the study of the selected thunderstorm occurred over Balasore, Odisha on 07 August 2021. Model was run using 3 hourly NCEP-GFS datasets from 0000UTC of 07 August to 0000UTC of 08 August 2021 as initial and boundary condition. The model outputs help to investigate the causes and mechanisms for the formation of the thunderstorm event. Hourly outputs have been analyzed to compare and/or assess the model performance. The mean sea level pressure; low level and upper level wind flow; horizontal and vertical profile of moisture flux; low level vertical wind shear of the u component of wind; convective available potential energy, convective inhibition energy, outgoing long wave radiation and rainfall etc fields have been investigated. The thunderstorm become mature stage and passed through the northeast region (i.e., Balasore) of the Odisha at about 0900 UTC as per GPM observation. Thus all model parameters are prepared for the 0900UTC (during mature time of thunderstorm event) of 07 August, 2021. Model simulated total convective (Cumulus scheme) and non-convective (Grid scale) precipitation at surface level has been considered as rainfall throughout the study. Observed daily rainfall data of GPM (Global Precipitation Measurment) IMERG (Integrated Multi-satellitE Retrievals for GPM)has been used to validate / compare the model simulated rainfall. Both temporal and spatial comparison methods have been used to compare the model simulated rainfall with the observed rainfall.

RESULT AND DISCUSSION

Low Level Winds

The distribution of low level (850 hPa) wind flow (ms-1) valid at 0900 UTC of 07 August 2021 is presented in Fig. 2. At 0900 UTC on August 7, 2021, a strong southwesterly/southerly low level jet (LLJ) bringing moisture from the Bay of Bengal into Balasore is the most conspicuous feature. These low-level winds converged over Odisha's narrow strip from a vast area of the Bay of Bengal, allowing moisture intrusion and the development of severe convective activity in the Balasore District.

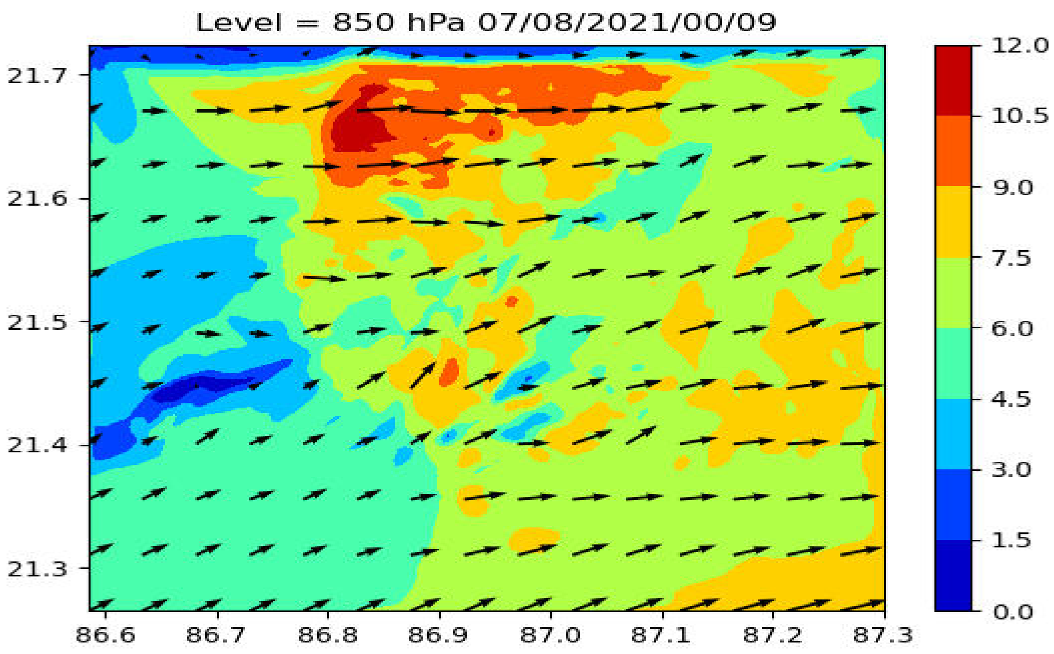


Figure 2. Distribution of low level (850 hPa) wind flow (m/s) valid at 0900 UTC of 07 August 2021

Upper Level Winds

The distribution of upper level (250hPa) wind flow (ms-1) valid at 0900 UTC of 07 August 2021 representing the subtropical jet stream over the region is shown in Fig.3. A jet stream in the order of 22.5m/s may be seen over top region of Balasore at 0900 UTC of 07 August, 2021, marking a strong vertical wind shear in the environment. The existence of subtropical jet stream at upper level provides a mechanism for strong vertical wind shear, thus favoring development of severe convection. The speed of subtropical jet stream (22.5 m/s) has been found to contribute to the severity of the thunderstorms.

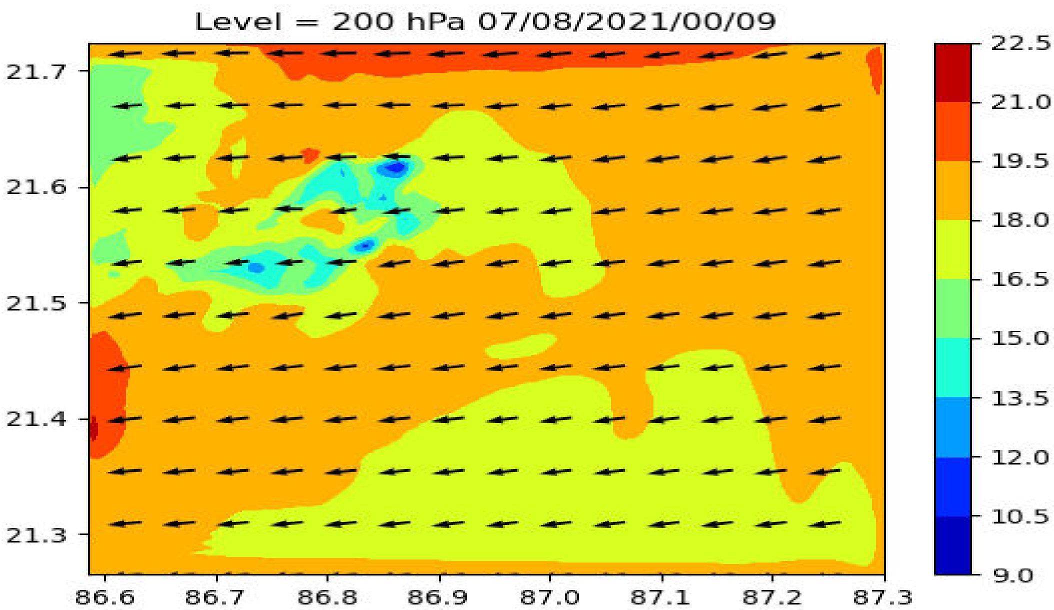


Figure 3. Distribution of upper level (200 hPa) wind flow (m/s) valid at 0900 UTC of 07 August 2021

Specific Humidity at 2m / Moisture

The distribution of low level 2m specific humidity valid at 0800 UTC and 0900 UTC (1-hr before and current event over Balasore) of 07 August 2021 is presented in Fig.4(a)&(b). It is found that the contents of moisture of the order of 0.027kg/kg over most of the northern parts of Balasore, Odisha and 0.025 over rest of the part of Balasore at 0800 UTC of 07 August, 2021. The circulation of southerly/southwesterly LLJ transports required moisture from the Bay of Bengal to the plains of Odisha and the adjoining states of India.

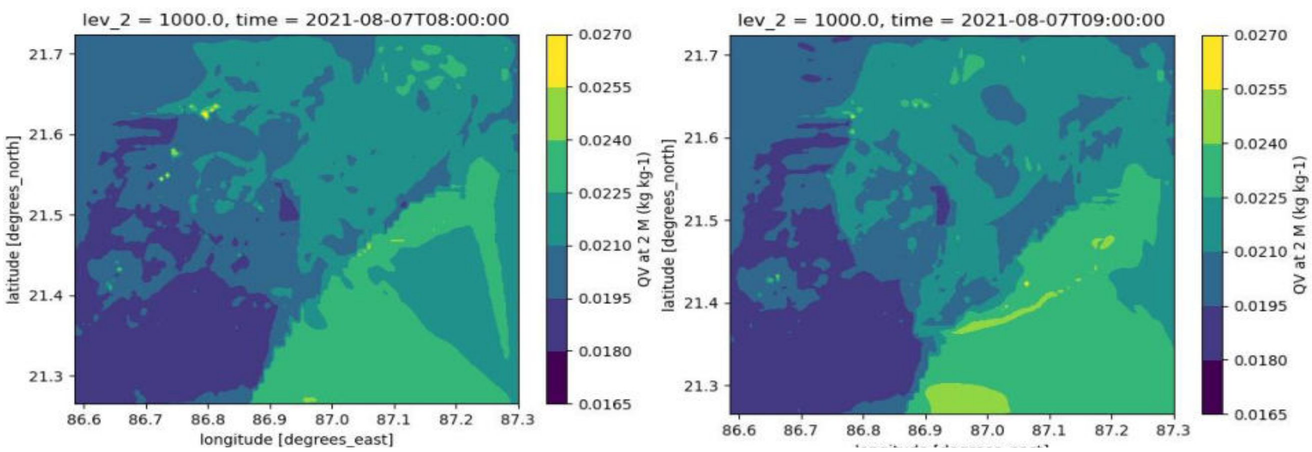
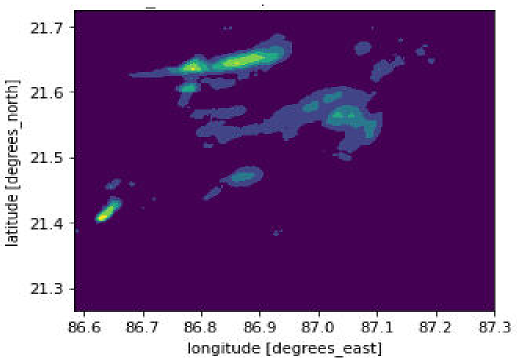


Figure 4.(a) Distribution of specific humidity at 2m valid at 0800 UTC (1-hr before the event) of 07 August 2021.
Figure 4.(b) Distribution of specific humidity at 2m valid at 0900 UTC (at the time of event) of 07 August 2021.

Rainfall Analysis

The 24-h accumulated model simulated and observed rainfall valid for 0900 UTC of 07 August 2021 is shown in Fig. 5(a-b). It is found that the model captured the location of the rainfall as compared with GPM IMERG observations in reasonably well. The 24-h accumulated rainfall pattern is almost same in model simulation (a) and GPM observation (b). However, the intensity of model simulated rainfall is slightly lower and the area coverage of model simulated rainfall is slightly broader than that of GPM observation. The network of the observation stations over Balasore is not too dense enough to measure this highly localized thunderstorm event. There are very few observatory over the northeast part of Odisha where model simulated highest rainfall [Fig.5(b)] and the thunderstorm occurred on 07 August, 2021. The highest observed rainfall is about 49 mm at Balasore of Odisha, whereas model simulated rainfall is about ~48 mm which is almost same as observed rainfall. It is found that the WRF-ARW model accurately estimated the thunderstorm event rainfall over Balasore. Fig 5(c) is showing Simulated Time Series plot for Precipitation for 24 hrs in mm for 7 August 2021 over Balasore District. And Fig 5(d) is showing the GPM Precipitation Observation Time Series plot for 24 hrs in mm for 7 August 2021 over

Balasore District for validation. So, we can observe from this simulated time series plot that time series plot is more accurately matching with the GPM observed data time series plot. Thus the WRF-ARW model simulated rainfall seems to be realistic though there are spatial and temporal biases in the simulated rainfall pattern.



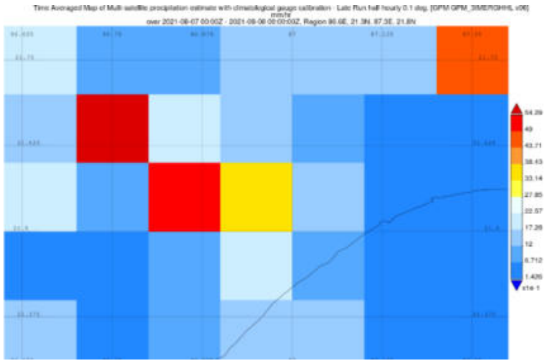
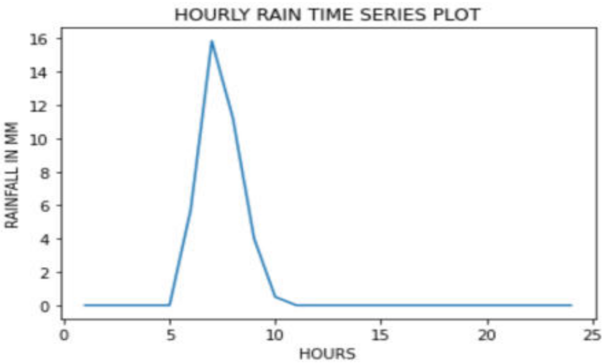


Fig 5. (a) Simulated Accumulated Precipitation for 24 hrs in mm for 7 August 2021 over Balasore District. Fig 5. (b) GPM Precipitation Observation for 24 hrs in mm for 7 August 2021 over Balasore District.



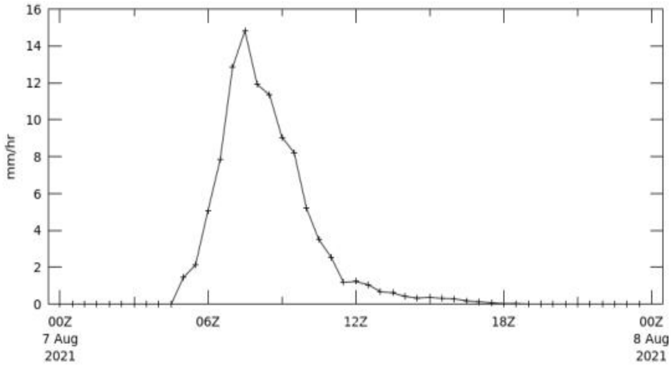


Fig 5. (c) Simulated Time Series plot for Precipitation for 24 hrs in mm.Fig 5.(d)GPM Precipitation Observation Time Series plot for 24 hrs in mm for 7 August 2021 over Balasore District.

Temperature at 2m

Temperature at 2m from the surface at 0900 UTC of 07 August, 2021is around 303 K in the Northern region of Balasore where the thunderstorm has occurred and temperature has reduced due to the rainfall at that location as compared to the surrounding region.

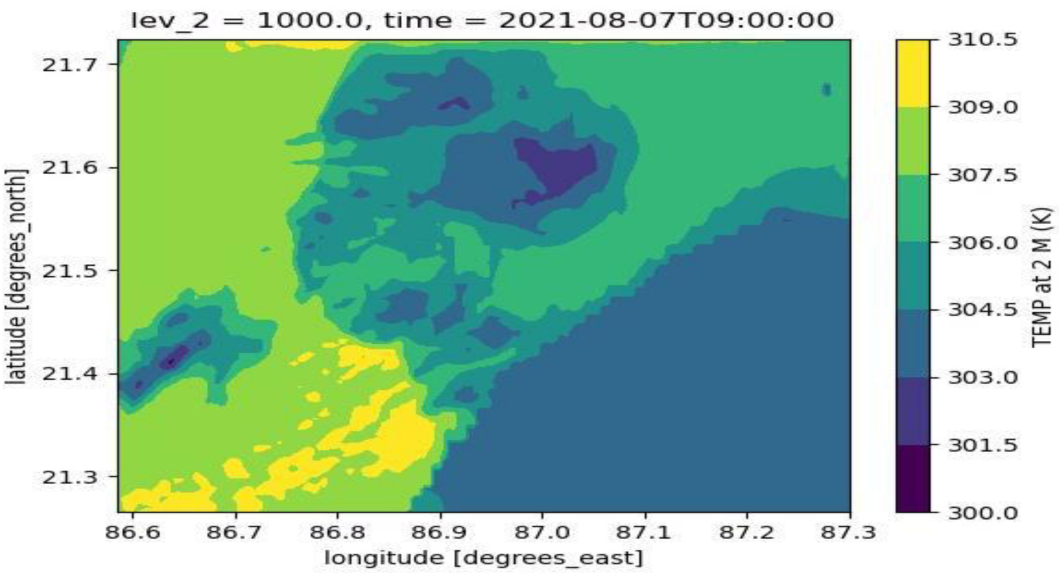


Fig 6. Temperature distribution at 2m from the surface at 0900 UTC of 07 August 2021.

CONCLUSIONS

On the basis of the current study, the following conclusions can be extracted:

1. The WRF model captured the studied thunderstorm event on 07 August 2021 in reasonably well though there are some spatial and temporal biases in the model simulation. The distribution of low level (850 hPa) wind flow shows that a strong southwesterly/southerly low level jet (LLJ) of the order of ~12 m/s whichconverged over the narrow belt of Odisha from large area of the Bay of Bengal, helps for moisture incursion and to develop severe convective activity over Bangladesh.
2. A subtropical jet stream at upper level 200 hPa wind flow in the order of 22 m/s may be seen over Balasore at 0900 UTC of 07 August, 2021, marking a very strong vertical wind shear in the environment. The existence of subtropical jet stream at upper level provides a mechanism for strong vertical wind shear, thus favouring development of severe convection.
3. A strong southerly/southwesterly low level jet (~12 ms -1) transporting moisture of the order of specific humidity 0.027 kg/kg from vast area of the Bay of Bengal towards the narrow zone (eastern and northern part) of Odisha which vertically reached up to the top of the troposphere.
4. Temperature at 2m from the surface at 0900 UTC is around 303 K in the Northern region of Balasore where the thunderstorm has occurred and temperature has reduced due to the rainfall as compared to surrounding region.
5. The WRF model has captured the location and structure of the rainfall over northeast part of Odisha i.e. Balasore and its neighborhoods in reasonably well. And the model simulated 24-h rainfall over the Balasore estimated the same amount of rainfall as compared to that of GPM data Observation.
6. Finally, it is concluded that the WRF-ARW model version 4.1 may be adopted in study of research and prediction of the thunderstorms over Balasore, Odisha, but it needs to do more case study.

ACKNOWLEDGEMENTS

The authors are thankful to NCAR-RDA, MMM for providing the WRF model source code, and necessary support to run and executive the model. The authors are also thankful to NCEP for providing the GFS datas and IC &LBC data to run the model. Thanks to the Director, IMD and Prof. U.C. Mohanty for providing the necessary data and constant support during this study.

REFERENCES

1. A. J. Litta and U. C. Mohanty, Simulation of a severe thunderstorm event during the field experiment of STORM programme 2006, using WRF–NMM model, *Current Science*Vol. 95, No. 2 (25 July 2008), pp. 204-215.
2. E. J. Mlawer, S. J. Taubman, P. D. Brown, M. J. Iacono and S. A. Clough, 1997, “Radiative transfer for inhomogeneous atmospheres: *RRTM, a validated correlated-k model for the long wave*”, J. Geophys. Res.,102D, 16663–16682
3. J. Dudhia, 1989, “Numerical study of convection observed during the Winter Monsoon Experiment using a mesoscale two dimensional model”, J. Atmos. Sci.,46, 3077–3107 17. J. R. Holton, 2004, “*An introduction to dynamic meteorology*”, Fourth Edition, International Geophysics Series, Volume 88, Chapter 9, 296-31
4. J. S. Kain, 2004, “The Kain–Fritsch Convective Parameterization: *An Update”, J. Appl. Meteor*., 43, 170–181
5. J. R. Holton, 2004, “An introduction to dynamic meteorology”, Fourth Edition, *International Geophysics Series*, Volume 88, Chapter 9, 296-313.
6. K. Prasad, 2006, “Environment and synoptic conditions associated with Nor’westers and Tornadoes in Bangladesh: An appraisal based on Numerical Weather Prediction (NWP) guidance products”, SAARC Meteorological Research Centre (SMRC), *SMRC Scientific Report*, 14, 87 pp.
7. M. N. Ahasan, M. N Islam, and N. Ferdousi, 2010, “A diagnostic study on synoptic and environmental conditions associated with Nor’westers in and around Bangladesh using MM5 model”, *Proceedings of the SAARC Seminar on Nor’westers and Tornadoes over the SAARC Region and their Forecasting & Preparedness*, 20-21 August, 2008, Dhaka, Bangladesh, 143-156
8. S. Das, 2009, “Composite characteristics of Nor’Westers observed by TRMM & simulated by WRF Model, SAARC Meteorological Research Centre (SMRC), *SMRC Scientific Report*, 25, 47 pp
9. S. Das, 2010, “Climatology of Thunderstorms over the SAARC Region”, SAARC Meteorological Simulation of a Thunderstorm Event Over Bangladesh Using WRF-ARW Model 131 *Journal of Mechanical Engineering*, Vol. ME 44, No. 2, December 2014 Transaction of the Mechanical Engineering Division, The Institute of Engineers, Bangladesh Research Centre (SMRC).SMRC Scientific Report, 35, 73 pp.
10. W. C. Skamarock , J. B. Klemp, J, Dudhia, D. O. Gill, D. M. Barker, M. G. Duda, X. Y. Huang, W. Wang, and J. G. Powers, 2008, “*A Description of the Advanced Research WRF Version 3*”, Mesoscale and Microscale Meteorology Division, National Center for Atmospheric Research, Boulder, Colorado, USA, NCAR TECHNICAL NOTE, NCAR/TN–475+STR, June 2008, 113 pp.
11. Y. S. Hong, J. Y. Noh and J. Dudhia, 2006, “A new vertical diffusion package with an explicit treatment of entrainment process”, Mon. Wea. Rev.,134, 2318–2341
12. Y. S. Hong, and J. Lim, 2006, “The WRF SingleMoment 6-Class Microphysics Scheme (WSM6)”, *J. Korean Meteor*. Soc., 42,129-151