Predictability of Pre-Monsoon Thunderstorms over Bangladesh Using WRF Model

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Abstract

An investigation of a thunderstorm event has been attempted in this study. The thunderstorm event occurred May 12, 2022, over Dhaka and the surrounding areas. The Advanced Research WRF (WRF-ARW) model version 3.9 has been utilized to simulate the thunderstorm occurrence. In this study, the model is configured with Kessler Scheme for micro-physics, Yonsei University Scheme for PBL Parameterizations, Dudhia Shortwave Scheme and Rapid Radiative Transfer Model (RRTM) Longwave Scheme for atmospheric radiation, and Kain-Fritsch Scheme, Grell-Devenyi (GD) ensemble scheme, and Grell 3D scheme for cumulus physics option per run. After then, the model is built for 48 hours using six hourly Global Forecast System (GFS) data on a single domain with a 15 km horizontal resolution and a 3600 second history interval. The data ranges from 0000 UTC on May 11, 2022, to 0000 UTC on May 13, 2022. Grid Analysis and Display System (GrADS) is used to view one hourly model output. A thorough analysis is conducted on a number of parameters that are significant in the formation and evolution of thunderstorms, including Mean Sea Level Pressure (MSLP), wind patterns at different pressure levels, surface temperature, relative humidity, rainfall amount, vorticity, CAPE, CIN, K Index and Latent Heat (LH). The outcomes of the parameters are compared with the BMD observation.

Keywords: RRTMM, vorticity, CAPE and K Index.

1. Introduction

Bangladesh is a nation plagued by natural calamities. Geographically speaking, it is situated within an area that is known to be vulnerable to many natural catastrophes, such as storms, droughts, floods, etc. Long-term climate change is now occurring in Bangladesh. Bangladesh is experiencing many natural catastrophes every year as a result of climate change, with thunderstorms being one of the most common calamities there. The pre-monsoon months of March, April, and May are the busiest for thunderstorm activity across Bangladesh. During the pre-monsoon season, severe thunderstorms usually develop in eastern and northeastern India and proceed towards the northwest and southeast [1]. They are referred to as "kalbaishakhi" locally [2]. Along with strong winds, copious amounts of rain, and occasionally hail, sleet, or snow, a thunderstorm is typified by lightning and thunder. In every thunderstorm, lightning occurs. Lightning strikes rank as the leading cause of weather-related deaths globally, after hurricanes, flash floods, and tornadoes [3]. Lightning-related injuries raise concerns for public health. More and more individuals are worried about the impact thunderstorms have on the economy and the lives they take. A record number of lightning-related deaths have occurred in Bangladesh in recent years. Thunderstorms have a harmful influence on our economy, the ecological, and agricultural output. Leslie *et al.,* [6] conducted research on the relationship between severe thunderstorms and tornado formation, coming to the conclusion that there is a regular pattern. Reynolds *et al.,* [7] by simulating this process in a lab, attempted to identify the fundamental physical mechanism that leads to thunderstorm electrification. Rotunno *et al.,* [8] looked at the three-dimensional cloud model's supercell-like convection and its rotation, and discovered that the thunderstorm always forms on the right flank of the updraft due to a favorable dynamic vertical pressure gradient that results from storm rotation. Lilly *et al.,* [9] discussed the scientific difficulties and some of the early developments of NWP when attempting to produce numerical predictions for convective storms and storm environments. Michael *et al.,* [10] researched how initiation develops and how to find boundary layers that are crucial for forecasting using data from sensitive Doppler radars. Using isentropic charts, Namias et al. [11] have attempted to forecast the occurrence of thunderstorms. In their study of the diurnal variations of convective activity and rainfall in tropical Asia, Ohsawa *et al.,* [12] used hourly (or 3-hourly) rainfall data from Bangladesh, Malaysia, Vietnam, and Thailand along with hourly equivalent black body temperature (TBB) data from the Japanese Geostationary Meteorological Satellite (GMS-5). There is a strong possibility that the energy and water cycles in tropical Asia are significantly impacted by rainfall and convective activity maxima that take place late at night or early in the morning. Anirban and Chaudhuri conducted research in 2013 on the effects of environmental contaminants and meteorological factors on thunderstorm and lightning activity over an Indian urban metropolis [13] . The value of understanding the aerosol state in forecasting enhanced lightning during storms that create lightning over northern Alabama was

investigated by Anita *et al.* [14]. In July 2001, Orville-Allen *et al.*, [15] looked at ways to enhance lightning strikes from clouds to the ground above Houston, Texas. 2017 saw study on the potential contribution of aerosols to the charge structure of isolated thunderstorms carried out by Gopalakrishnan *et al.,* [16] . The characteristics of thunderstorms seen between 1996 and 2008 are examined in this study. In order to better understand and forecast convective storms that lead to flash floods, C. Price *et al.,* [17] conducted research on the flash project in 2011 using lightning data. This study demonstrates how thunderstorms may be extremely devastating due to their brief but powerful periods of rainfall, which frequently result in flash floods. In 1952, Gupta studied the origins and migration of the Nor'westers in Bengal [18]. In northern India during tropical summer thunderstorms, Guha (2009) investigated the electrical characteristics of lightning. Regional differences in tropical lightning distributions were studied by Boccippio and Goodman in 2000. The possible impacts of past and future climate change on the global frequency of lightning strikes were examined in 1994 by Colin Price and David Rind of NASA Goddard Institute for Space Studies at Columbia University in New York. In 1997, Hodanish and David Sharp calculated Florida's lightning climatology for a ten-year period, from 1986 to 1995. Research on lightning activity as a climate change indicator was done in 1998 by N. Reeve and R. Toumi. 1994 saw the study of the latitudinal variation of lightning occurrence features by Mackerras and Darveniza. Kar-Liou *et al.,* studied the effects of aerosols on the amplification of cloud to ground lightning over major South Korean urban centers. According to study by Diffenbaugh-Scherer *et al.,* in 2013, there are robust increases in severe thunderstorm conditions in response to climate forcing. Although severe thunderstorms are one of the key factors contributing to catastrophic damage in the United States, their response to increased greenhouse forcing has remained a significant source of uncertainty for the assessment of the implications of climate change, according to their study. The computation of the electric field and lightning potential index in numerical weather prediction models was carried out in 2015 by S. O. Dementyeva and others. A 2007 investigation by Colin Price examined the possibility that increased lightning is caused by a drier climate. The study reveals that a section is devoted to extreme weather, which includes flash floods, which are frequently associated with powerful thunderstorms with a lot of lightning [19]. M Rajeevan *et al.,* conducted research on creating a probabilistic model that perfectly predicts lightning strikes over south-east India in April 2012. Based on TRMM LIS data (1998–2005), this study displays the monthly climatology of lightning flashes over India. The study uses TRMM LIS data to create a monthly climatology of lightning strikes over India. It also shows that April and May are the peak months for lightning activity across the southern peninsula. Studies on the climatological aspects of lightning activity over India are scarce. The climatological characteristics of lightning across India have been investigated by Manohar (1999), Tinmaker (2009), and Nath (2009). Using data from TRMM LIS, Ranalkar and Chaudari (2009) investigated the seasonal fluctuation of lightning activity over the Indian subcontinent. Chatterjee et al (2008), Litta and Mohanty (2008), Srivastava et al (2008), Mukhopadhyay (2009), and Rajeevan *et al.*, (2010) have produced numerical models of thunderstorm cases that were seen over India. Binary logistic regression models were developed by Dasgupta and De (2007) to anticipate pre-monsoon convective events over Kolkata, India, in the short term. Using statistical techniques, Ghosh et al. (1999) investigated the important meteorological elements for thunderstorm prediction at Kolkata. Pre-monsoon thunderstorms were predicted using the multivariate approach by Chatterjee et al. (2008). Using a variety of thermodynamic and kinematic characteristics, Bhowmik Roy et al. (2007) investigated the thermodynamics of the atmosphere in connection to the occurrence of convective rainfall across the Indian subcontinent. Their findings demonstrated that deep convection cannot always occur in the presence of a strong thermodynamic environment [20]. As a result, an attempt has been taken to simulate TS events over Dhaka and adjoining regions on 12 May 2022 using WRF-ARW model. Various weather parameters were examined for deep analyses of the event. For validation of the model performance, simulated values of different parameters have been compared with observed value of BMD. These outcomes show that the model's ability to predict thunderstorm occurrences is satisfactory.

2. Experimental Setup, Data used and Methodology

In this study, the WRF model is run on a single domain at 15 km horizontal resolution. The domain is centered (23°N, 90°E) over Bangladesh to represent the regional-scale circulations and to solve the complex flows of this region.

The domain configuration of the model in the present study is depicted in Figure 1. The initial condition of the model simulation is taken as 0000 UTC of 11 May 2022 and lateral boundary condition is taken for 48 hours.

The Global Forecast System (GFS) dataset run by the National Centre for Environmental Prediction (NCEP) with the 1°x1° horizontal and 6 hours temporal resolution were used as the initial and lateral boundary condition in this study. The WRF-ARW model has the availability of a good number of schemes for the examination of different physics such as microphysics, planetary boundary layer (PBL) physics, surface layer physics, radiation physics and cumulus parameterization. The physics and dynamics employed in the model in this study are summarized in Table 1. Three-hourly observed data of MSLP, Temperature, RH and rainfall have been collected from Bangladesh Meteorological Department (BMD) for the validation of model performance.

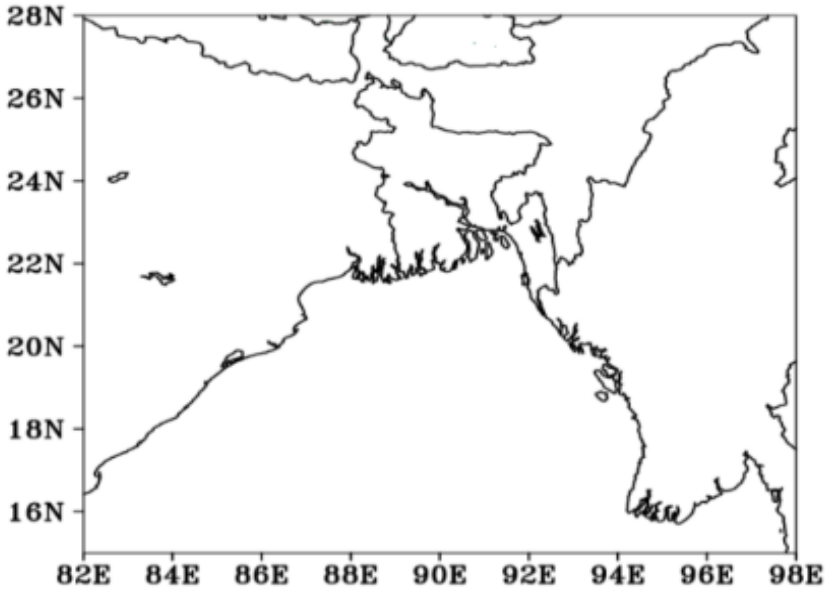

Figure 1: WRF Model domain configuration

Table 1: Overview of the WRF model configuration

Domain and Dynamics	
WRF core -	ARW
Data -	NCEP–GFS
Interval -	6 h
Number of domain -	1
Central point of the domain -	23° N, 90° E
Resolution -	15 km × 15 km
Grid size -	222 × 222 × 38
Covered area -	15.5°– 28.5° N and 82°– 98° E
Map projection -	Mercator
Integration time step -	30 s
Vertical coordinates -	Pressure coordinate
Time integration scheme -	3rd order Runge-Kutta
Spatial differencing scheme -	6th order centered difference
Physics	
Microphysics -	Kessler scheme
PBL Parameterization -	Yonsei University (YSU) scheme
Surface layer physics -	Revised MM5 scheme
Land-surface model -	Unified Noah LSM
Short wave radiation -	Dudhia scheme
Long wave radiation -	RRTM scheme
Cumulus parameterization -	Kain–Fritsch (new Eta) scheme

The WRF-ARW Model has been used for the study of the selected thunderstorm events occurred over Dhaka and adjoining regions, Bangladesh on 12 May 2022. Model was run using six hourly NCEP-GFS datasets from 0000 UTC of 11 May 2022 to 0000 UTC of 13 May 2022 as initial and lateral boundary condition. Hourly outputs of the model were analyzed for investigating the causes and mechanisms for the formation of the thunderstorm event. Various parameters such as: mean sea level pressure, wind speed and direction at 850 hPa, 500 hPa and 200 hPa pressure level, temperature, relative humidity, vertical cross-section of relative humidity, vorticity, vertical wind shear, latent heat, divergence and convergence, MCAPE, rainfall have been investigated. For the validation of the model performance, values of several parameters were compared with the observed value collected from BMD.

3. Results and Discussion

A remarkable number of meteorological parameters, such as mean sea level pressure, temperature, relative humidity, wind pattern, vorticity, latent heat, divergence and convergence, amount of rainfall etc, play an important role for the formation and development of thunderstorms. The thunderstorm event—which happened

over Dhaka and adjoining areas on 12 May 2022 was recorded for the NWP analysis for this article. In this section behavior of parameters that are responsible for the formation of thunderstorm event of 12 May 2022 is discussed.

3.1 Analysis of Mean Sea Level Pressure

WRF model simulated Mean Sea Level Pressure (MSLP) from 0004 UTC to 0009 UTC on 12 May 2022 based on 0000 UTC of 11 May 2022 is depicted in Fig. 2 (a-f). The thunderstorm event occurred at 0838 UTC on 12 May 2022 in Dhaka and the adjoining areas.

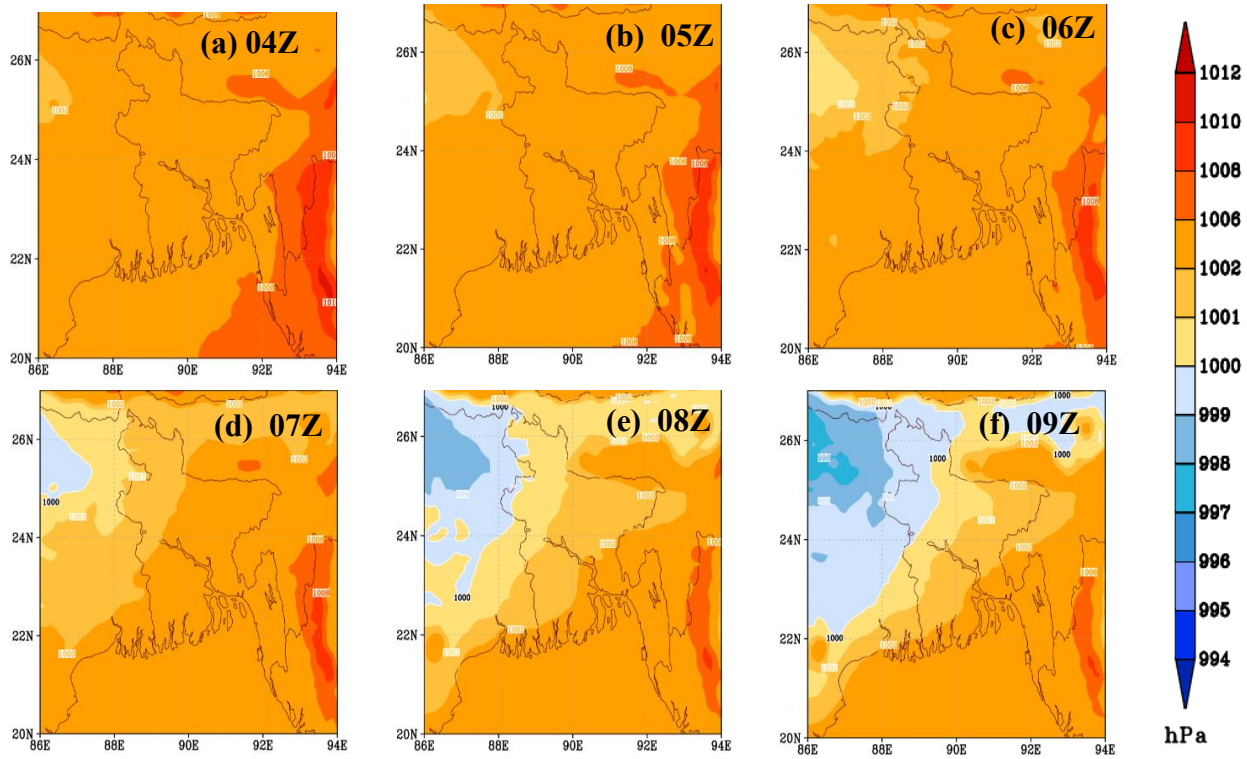

Fig. 2 (a-f): WRF model simulated MSLP from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

The model's prediction indicates that trough of low lies over West Bengal and adjacent area and it extends up to Dhaka and adjoining area in Fig. 2 (a-f). The model reveals that a low (999–1006 hPa) trough is present in several parts of Bangladesh, especially in the northwest. The magnitude of the model MSLP is determined to be between 997 and 1006 hPa over West Bengal to Dhaka. The model's predicted pressure gradient is roughly 9 hPa, or 83.34 kph wind speed, which is in line with the observed gusty 83 kph wind speed.

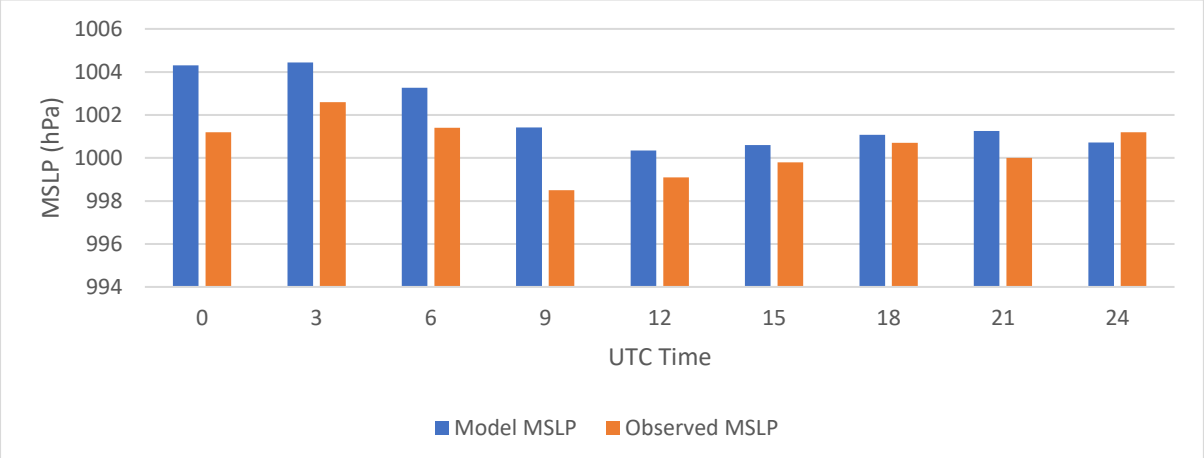

Fig. 3: Comparison between model simulated MSLP with observed data from 0000 UTC of 12 May 2022 to 0000 UTC of 13 May 2022.

3.2 Analysis of Wind Pattern at 500 hPa Level

WRF model simulated wind speed and direction at 500 hPa level from 0004 UTC to 0009 UTC on 12 May 2022 based on 0000 UTC of 11 May 2022 is represented in Fig. 4 (a-f).

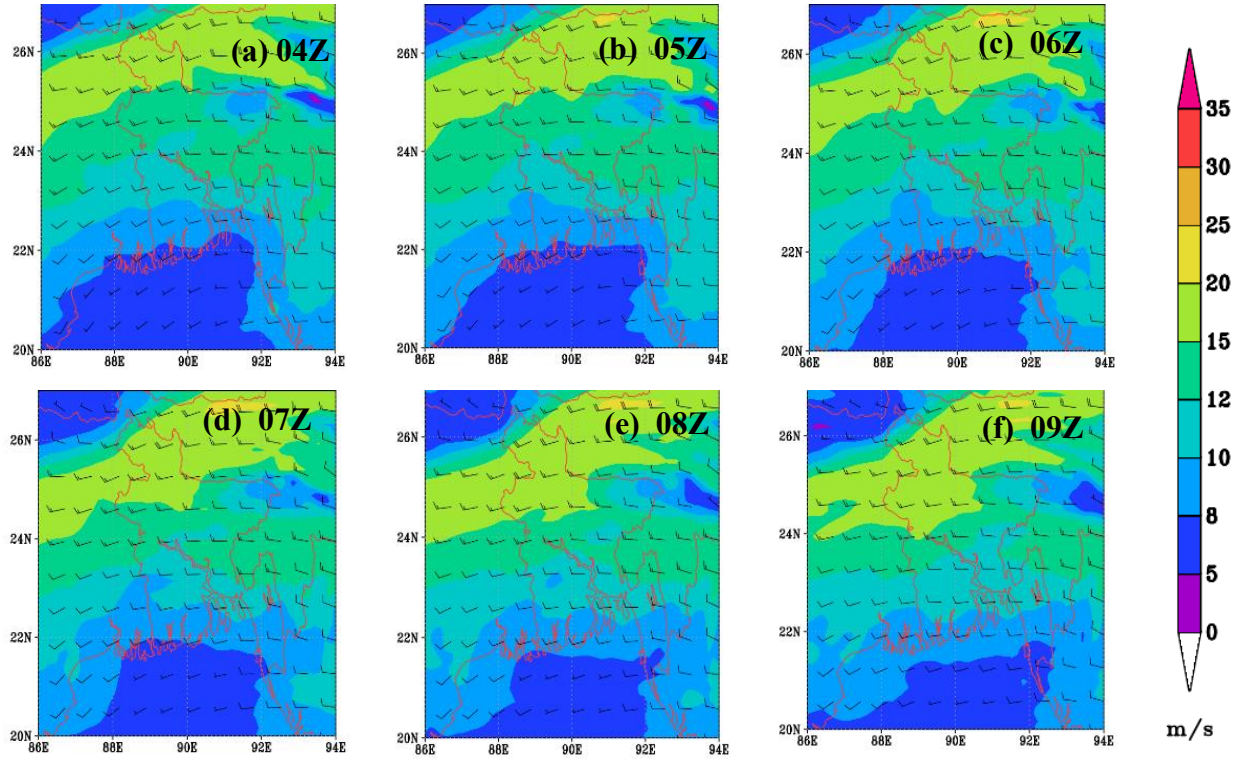

Fig. 4 (a-f): WRF model simulated wind speed and direction at 500 hPa level from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

High levels of moisture are carried by southerly or southwesterly winds. The orderly convergence zone is located in the region of West Bengal and its surroundings. Given its buoyant nature, high moisture content, and delayed condensation, convective clouds have the potential to form. It benefits this convective cloud's ability to develop into a thunderstorm.

3.3 Analysis of Relative Humidity (RH)

WRF model simulated Relative Humidity (RH) from 0004 UTC to 0009 UTC on 12 May 2022 based on 0000 UTC of 11 May 2022 is represented in Fig. 5 (a-f).

The relative humidity (RH) in Bangladesh's west and southwest is measured between 50% and 70%, while over the country and its surrounding territories, including Dhaka, it is measured between 60% and 90%. While the western half of the country is arid and hot, Bangladesh and its surroundings have warm, humid air. Thunder-cell formation occurs at the right side of the dry line. Warm, humid air might therefore mix with hot, dry air, which is the main requirement for thunderstorm formation over Dhaka and the surrounding area.

3.4 K Index Analysis

WRF model simulated K Index value from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022 is depicted in Fig. 7 (a-f).

In West Bengal and the surrounding region, the K Index values are roughly 25–40, and they fluctuate between 25 and 40 across Bangladesh, according to the WRF model. Around 35–40 is the K Index value in Dhaka and the surrounding areas. A K Index value of more than 34 is considered a supporting threshold value. As a result, the K Index value for Dhaka and the surrounding areas indicates that many thunderstorms are expected to form and is a suitable threshold number (Bangladesh Meteorological Department, BMD).

3.5 Rainfall Analysis

WRF model simulated rainfall from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022 is described in Fig. 8 (a-f). Dhaka and the surrounding areas experience significant rainfall during the storms. The Dhaka region receives substantially more rainfall, between 30 and 150 mm, while the rest of the

country has rainfall between 15 and 200 mm, according to the model. This exceptionally heavy rainfall combined with a strong, squall breeze from the south or southwest was perfectly predicted by the WRF model. This significant amount of rainfall is supportive for the formation of thunderstorm.

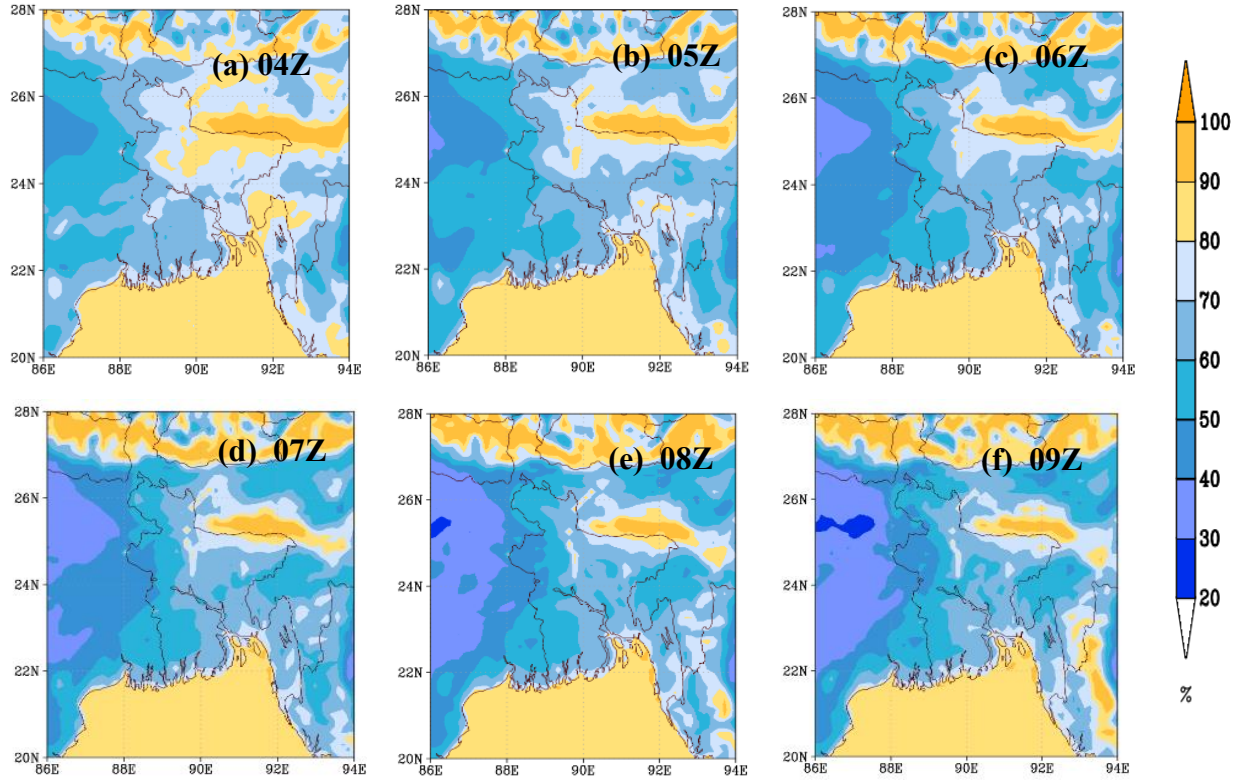

Fig. 5 (a-f): WRF model simulated Relative Humidity from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

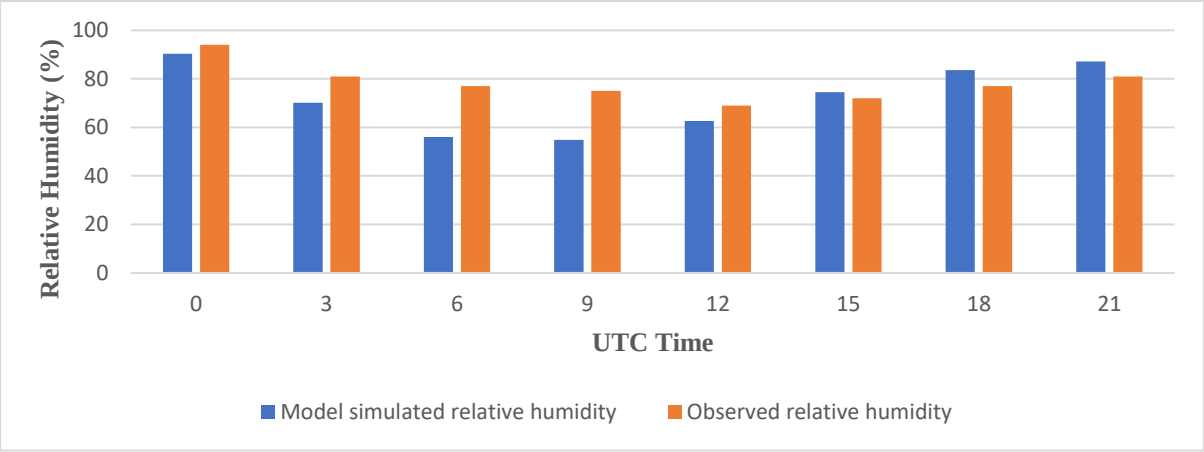

Figure 6: Comparison between model simulated RH with observed data from 0000 UTC of 12 May 2022 to 0000 UTC of 13 May 2022.

3.6 MCAPE Analysis

WRF model simulated MCAPE from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022 is depicted in Fig. 10 (a-f).

MCAPE is examined in this study in order to comprehend thunderstorm occurrences. The MCAPE value over Bangladesh is projected by the WRF-ARW model to be between 1000 and 2000 j/kg, but the MCAPE value in Dhaka and its surrounding areas is between 1500 and 2000 j/kg. The MCAPE Value—which is more than 1500 j/kg—is the primary factor responsible for the formation of thunderstorms over Dhaka and the adjacent areas.

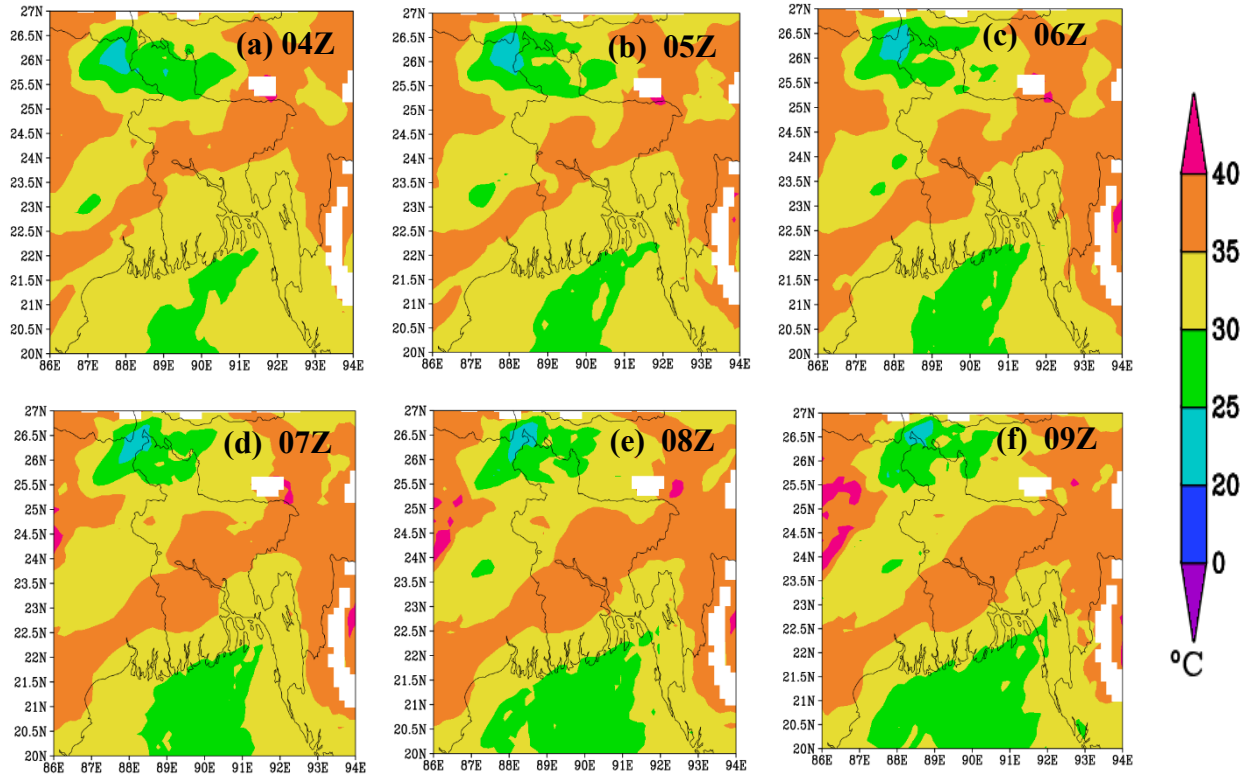

Fig. 7 (a-f): WRF model simulated K Index from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

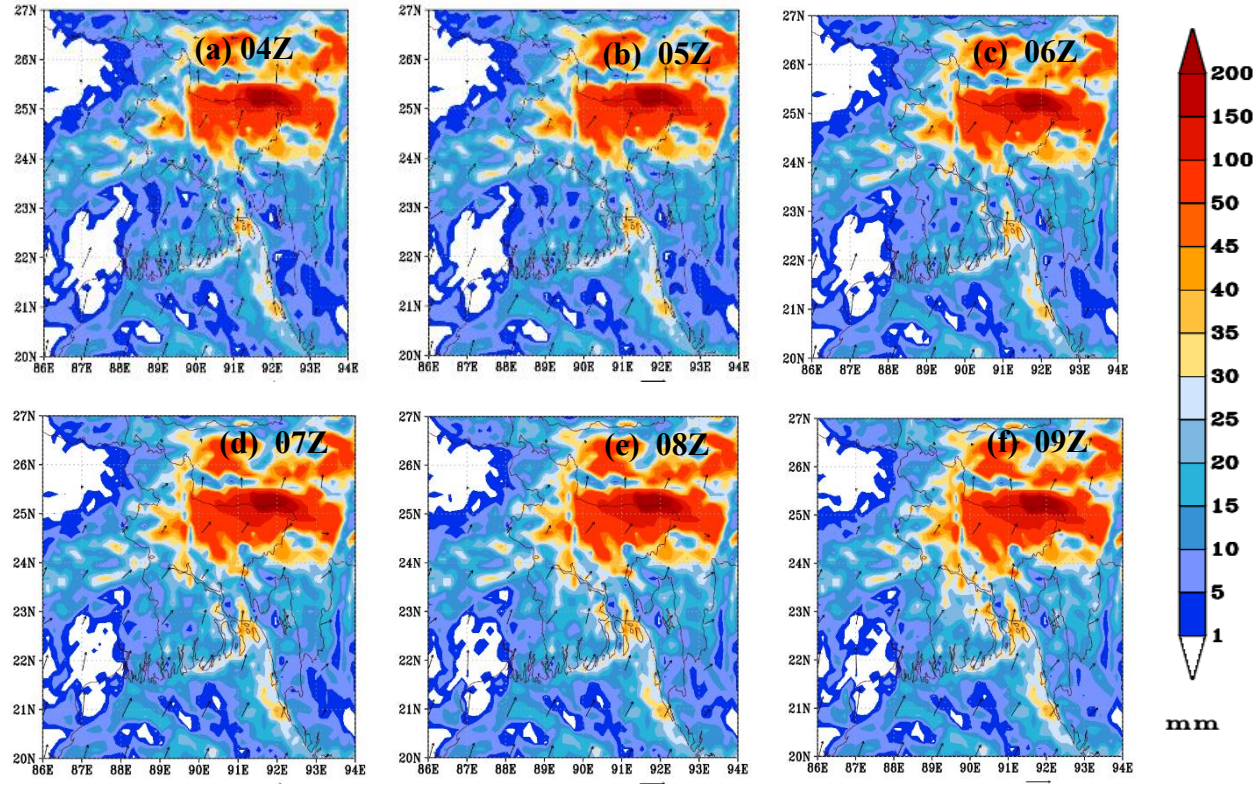

Fig. 8 (a-f): WRF model simulated rainfall from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

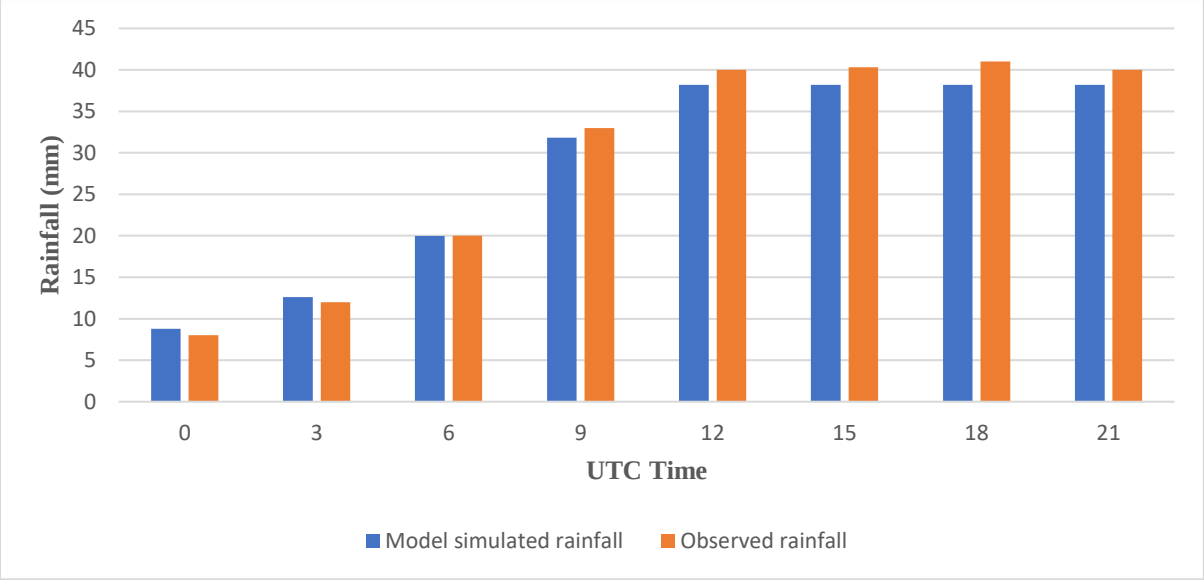

Figure 9: Comparison between model simulated Rainfall with observed data from 0000 UTC of 12 May 2022 to 0000 UTC of 13 May 2022.

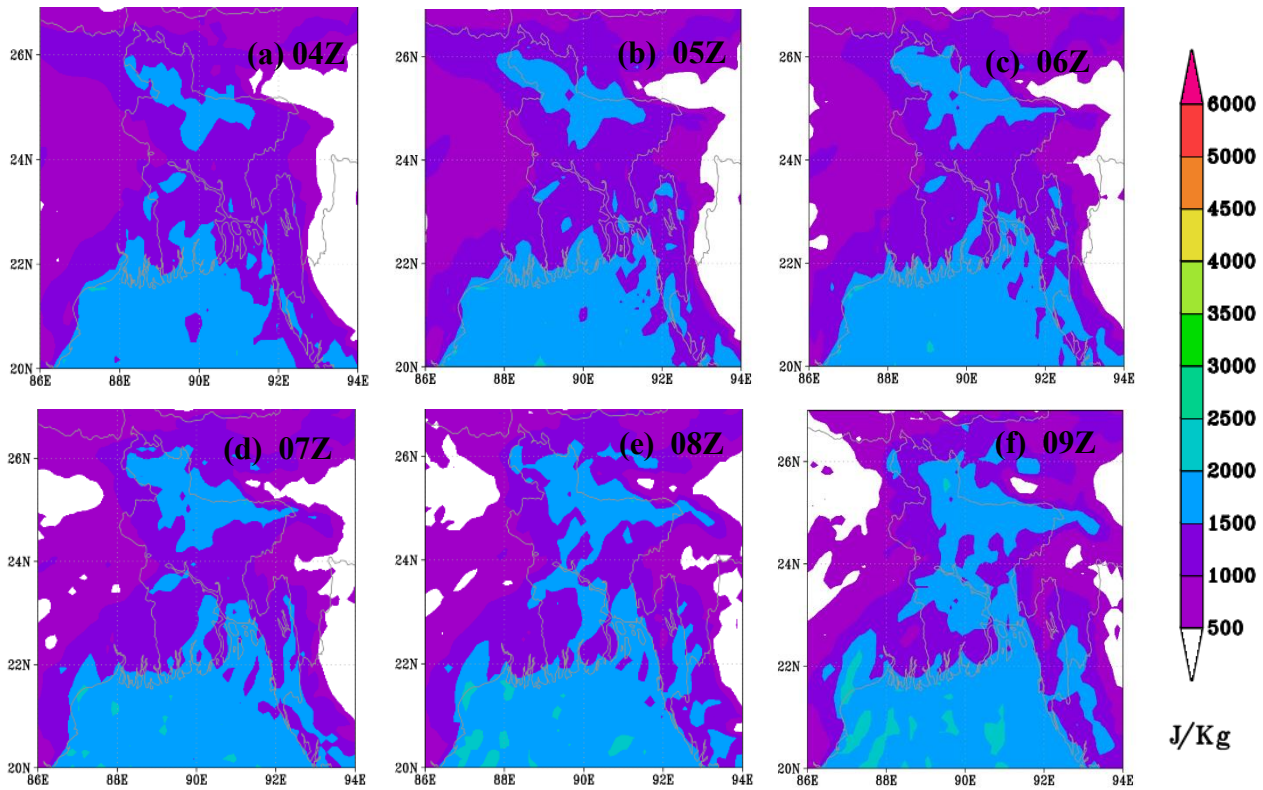

Fig. 10 (a-f): WRF model simulated Latent Heat from 0004 UTC to 0009 UTC on 12 May, 2022 based on 0000 UTC of 11 May, 2022.

4. Conclusion

The thunderstorms that passed across Dhaka and adjacent areas 12 May 2022 was the subject of our investigation. With the aid of the WRF model, we attempted to mimic the event; nonetheless, the model's skill test received the most attention. The Advanced Research WRF (WRF-ARW) model version 3.9 has been utilized to simulate these thunderstorm occurrences. We discovered that the model's performance is satisfactory to forecast the occurrences. There is not much of a difference between the observed value and the model value of the parameters. This suggests that the model does a great job of forecasting the occurrences of thunderstorms. The model's performance is determined to be adequate, while it might be improved with the addition of more parameters. Finally, it can be

concluded that the WRF-ARW model captured these three thunderstorm events fairly well, despite some temporal and spatial error for capturing different characteristics.

5. Acknowledgements

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