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PREDICTABILITY OF OROGRAPHIC RAINFALL FEATURES OVER SYLHET USING NWP MODEL

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ABSTRACT

Topography and orography are two physical factors which produce high impact rainfall over the North-eastern part of Bangladesh. To predict the orographic rainfall of 29 March 2017 over Sylhet, Bangladesh an attempt has been performed using Weather Research and Forecasting (WRF) model. The model has been run in a single domain of 10 km horizontal resolution for 48-h and 72-h using six hourly global final datasets from 0000 UTC of each initial day of the event as initial and lateral boundary conditions with NSSL 2-moment microphysics scheme, Kain–Fritsch cumulous scheme and Yonsei University Planetary Boundary Layer (PBL) scheme. The model outputs such as sea level pressure, wind flow, vorticity, wind shear, humidity, Convective Available Potential Energy (CAPE), Convective Inhibition, Lifted Index, K-index, Total Total Index and rainfall have been analyzed. The model predicted weather parameters were visualized by Grid Analysis and Display System (GrADS) and Geographic Information System (GIS) software and validated with observed data of Bangladesh Meteorological Department (BMD), Tropical Rainfall Measuring Mission (TRMM) and European Centre for Medium-Range Weather Forecasts (ECMRWF) data. The analysis determines that the CAPE of magnitude 800-1000 JKg^{-1}, positive vorticity of $(6\text{-}10)\times10^{-5}s^{-1}$ and relative humidity of 80-100% up to 500-400 hPa levels are accountable for the happening of the orographic extreme rainfall and other parameters are compatible with the observed or theoretical values. This study indicates that the model with an appropriate model set up is capable to predict the orographic precipitation realistically well and can be used for upcoming events.

Keywords: *WRF-ARW; Vorticity; CAPE; CIN; LI; TT.*

1. INTRODUCTION

Tropical Bangladesh is situated in the north-eastern part of South Asia. The great Himalayas stand at some distance to the north, while in the south lays the Bay of Bengal (BoB). West Bengal borders on the west and in the east lies the hilly and forested regions of India and Myanmar. These pretty topographical settings of low lying plain of about 1,47,570 square kilometers has been crisscrossed by many rivers and streams. The elevation of delta area is not more than 150 m above sea level and most of it belongs to 1-2 m above sea level. Flood water covers most of the land surface during the rainy season and damages crops and decrease national economy. The Orographic Rainfall (OR) mainly occurs in the northeastern hilly regions of Bangladesh (Faruq *et al.,* 2019). When moist air is lifted and moves over a mountain range, orographic effect is produced. As the air rises and cools, orographic convective clouds form and serve as the source of rainfall, most of which falls upwind of the mountain ridge. Some also fall a short distance downwind of the ridge and sometimes called spillover. On the lee side of the mountain range, rainfall is usually low, and the area is assumed to be in a rain sleuth. The influence of mountains upon rain is often profound, generating some of the Earth's dampest places. Orographic effects on rainfall are also responsible for some of the planet's sharpest climatic transitions. The classic example is the so called 'rain shadow'; for a mountain range oriented perpendicular to the prevailing winds, rainfall is greatly enhanced on the windward side and suppressed in the lee. However, the full range of orographic influences is much broader than this. Rainfall can be heightened in the lee, over the crest, or well upwind of a mountain. Almost all orographic influences on rainfall occur due to rising and descending atmospheric motions forced by topography. These motions can be forced mechanically, as air affecting on a mountain is lifted over it, or thermally, as heated mountain slopes prompt buoyancy-driven rotations. Rising motion causes the air to expand and cool, which is significant since the amount of water that may exist as vapor in air is an approximately exponential function of temperature. Thus, if cooling is adequate, air saturates and the water vapor condenses into cloud droplets or forms cloud ice-crystals. These droplets and crystals develop by various processes until they become large enough to fall as rain drop. It is important to emphasize that moist ascent over topography alone is typically inadequate to make rainfall. These orographic effects generally modify rainfall during pre-existing storms (Browning *et al.,* 1974; Smith *et al.,* 2006). Globally, the Advanced Research WRF (ARW) model is being usually used for the mockup of a variability of weather events, such as heavy rainfall (Niyogi *et al.*, 2006; Routray *et al.*, 2010; Dodla and Ratna, 2010; Osuri *et al.,* 2012) and TCs (Osuri *et al.,* 2012; Pattanaik *et al*., 2009; Davis *et al.,* 2008).

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So, an effort has been made to forecast the high impact rainfall of 119 mm recorded over Sylhet, Bangladesh on 29 March 2017 by WRF model and an endeavor is also taken to find out the meteorological features of that event.

2. Experimental Setup, Data Used and Methodology

The Advanced Research WRF model, developed at the National Center for Atmospheric Research (NCAR), is one of the two different dynamical hubs of the WRF model. The other core version, the Non-hydrostatic Mesoscale Model (NMM), was developed at the Environmental Modeling Center of the National Centers for Environmental Prediction (NCEP). The Numerical Weather Prediction (NWP) model used in this study is the ARW model of version 3.9.1. The WRF model provides a flexible and portable open-source community model for both atmospheric research and operational forecasting (Skamarock *et al.,* 2008). It is a limited-area, non-hydrostatic basic equation model with multiple options for numerous parameterization schemes for different physical methods.

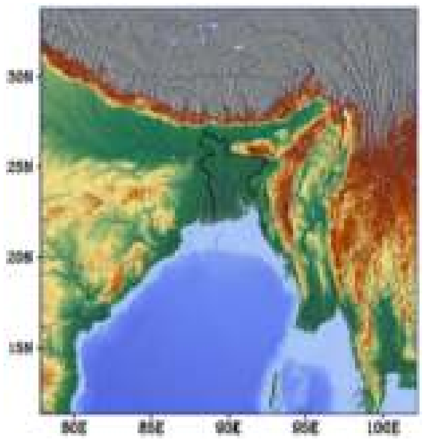


Figure 1: Domain for the NWP study

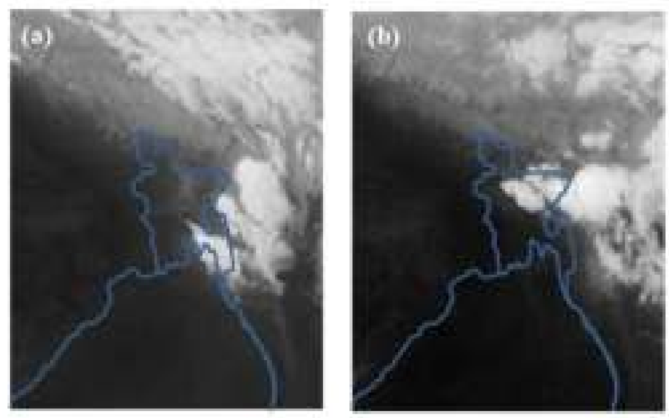


Figure 2: Kalpana-1-TIR imageat (a) 1415 UTC and (b) 2115 UTC of 29 March 2017.

Table 1: WRF Model and Domain Configurations

Dynamics	Non-hydrostatic
WRF Version	3.9.1
Number of domains	1
Central points of the domain	23^0 N and 90^0E
Horizontal grid distance	10 km
Number of grid points	251×251
Run time	72 and 48 hours
Time step	25
Map projection	Mercator
Vertical levels	38
Horizontal grid distribution	Arakawa C-grid
Time integration	3rd order Runge-Kutta
Spatial differencing scheme	6th order centered differencing
Initial conditions	Final (FNL: 1° × 1°)
Lateral boundary condition	Specified options for real-data
Top boundary condition	Gravity wave absorbing
Bottom boundary condition	Physical or free-slip
Diffusion and Damping	Simple Diffusion
Microphysics	NSSL 2-moment Scheme
Cumulus physics	Kain-Fritsch (KF) Scheme
Land surface parameterization	5 Layer Thermal diffusion scheme
PBL parameterization	Yonsei University (YSU) Scheme
Radiation scheme	RRTM for long wave and Dudhia for short wave
Surface layer	Monin-Obukhov similarity theory scheme

The 1° resolution FNL data covering the entire globe every 6-h were taken as the initial and lateral boundary conditions. 30 arc sec United States Geological Survey (USGS) data GTOPO30 were used as topography and 25 categories USGS data were taken as vegetation/land use (Modis and Hi-Def Lakes) coverage. The observed rainfall data of BMD were used to compare or authenticate the model simulated rainfall. The simulation was done on a single domain of 10 km horizontal resolution and the domain (251×251 grid points with 38 unequally spaced sigma levels) of the NWP study is shown in Figure 1. The details of the model and domain configuration are listed in Table 1.

3. RESULT AND DISCUSSIONS

At first the multi-cell thunderstorm was not developed over Sylhet and adjoining area at 1415 UTC of 29 March 2017 and is not captured by Kalpana-1-TIR shown in Figure 2(a). At 2115 UTC of 29 March 2017, the multi-cell thunderstorm is developed over Sylhet and adjoining area which is merged afterwards and captured by Kalpana-1-TIR satellite and shown in Figure 2(b). Different Meteorological parameters are analyzed to describe orographic rainfall over Sylhet and adjoining area.

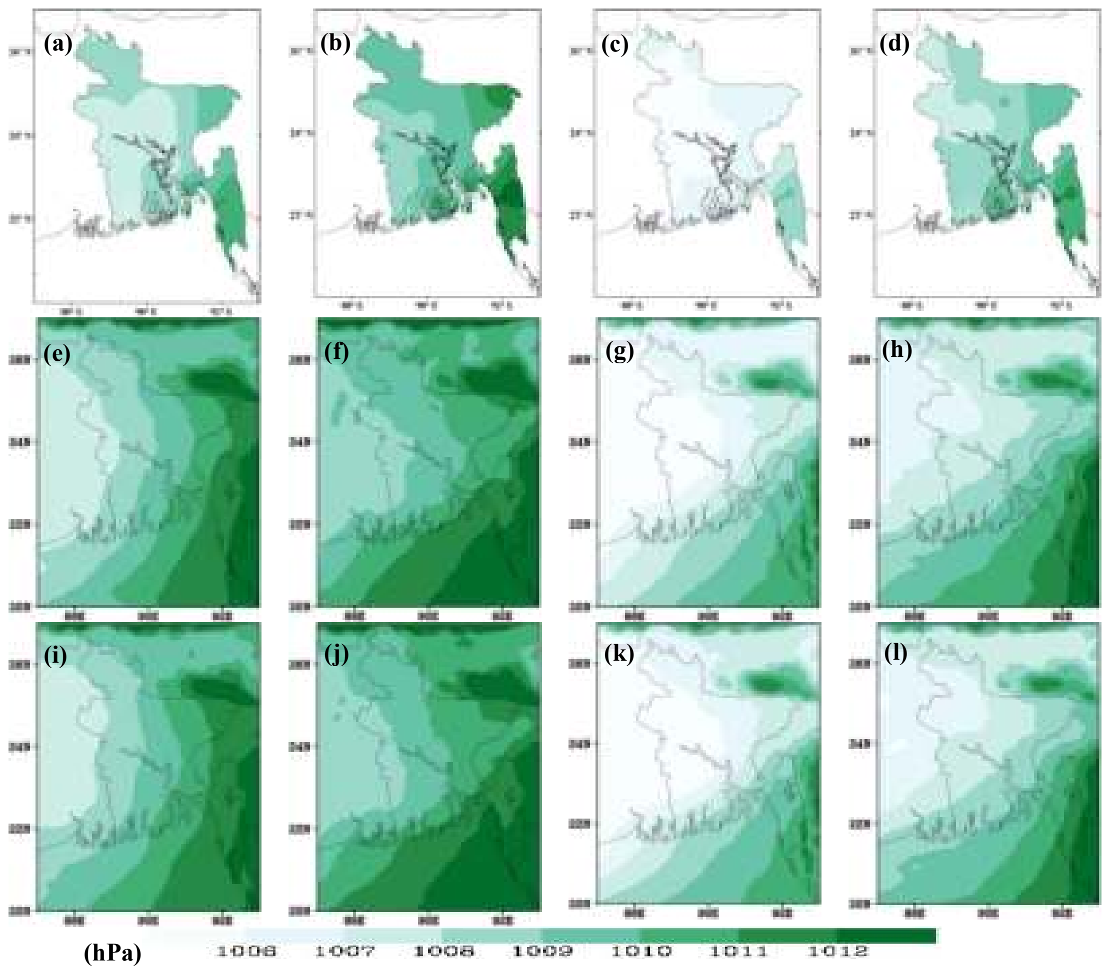


Figure 3: Observed MSLP on 0000, 0600, 1200 & 1800 UTC of (a-d) 29 March 2017; Predicted MSLP on 0000, 0600, 1200 and 1800 UTC of 29 March based on the initial condition of 0000 UTC of (e-h) 27 March and (i-l) 28 March 2017, respectively.

3.1 Sea Level Pressure

The analysis of MSLP on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 compared with observed MSLP on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 which is presented in Figures 3(a-l). The model has simulated 3-4 isobaric lines with two hPa differences penetrated towards Bangladesh from BoB and a trough of low extends up to NE part of Bangladesh from West Bengal and adjoining area is shown in Figures 3(e-l). The convergence zone lies along the trough. The model has also simulated the high-pressure area over Meghalaya and a pressure gradient force in the Southeastern part of Bangladesh which is consistent to the observation. So, this high probability of moisture incursion towards NE part of Bangladesh from the BoB is the source of energy to accelerate the buoyancy processes in wind side of the hills over Sylhet and neighborhood and it is the supportive condition for the formation of orographic clouds and afterwards convective rainfall over Sylhet and adjoining area.

3.2 Wind at 10m Height, 850 and 500 hPa Levels

The model simulated wind flow at 10-meter height on 0000, 0600, 1200 and 1800 UTC of 29 March based on 0000 UTC of 27 and 28 March is compared with BMD's observed wind flow at 10-meter height on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 which is shown in Figures 4(a-l). The model simulated wind flow at 850 and 500 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 shown in Figures 5(a-h) and Figures 6(a-h), respectively.

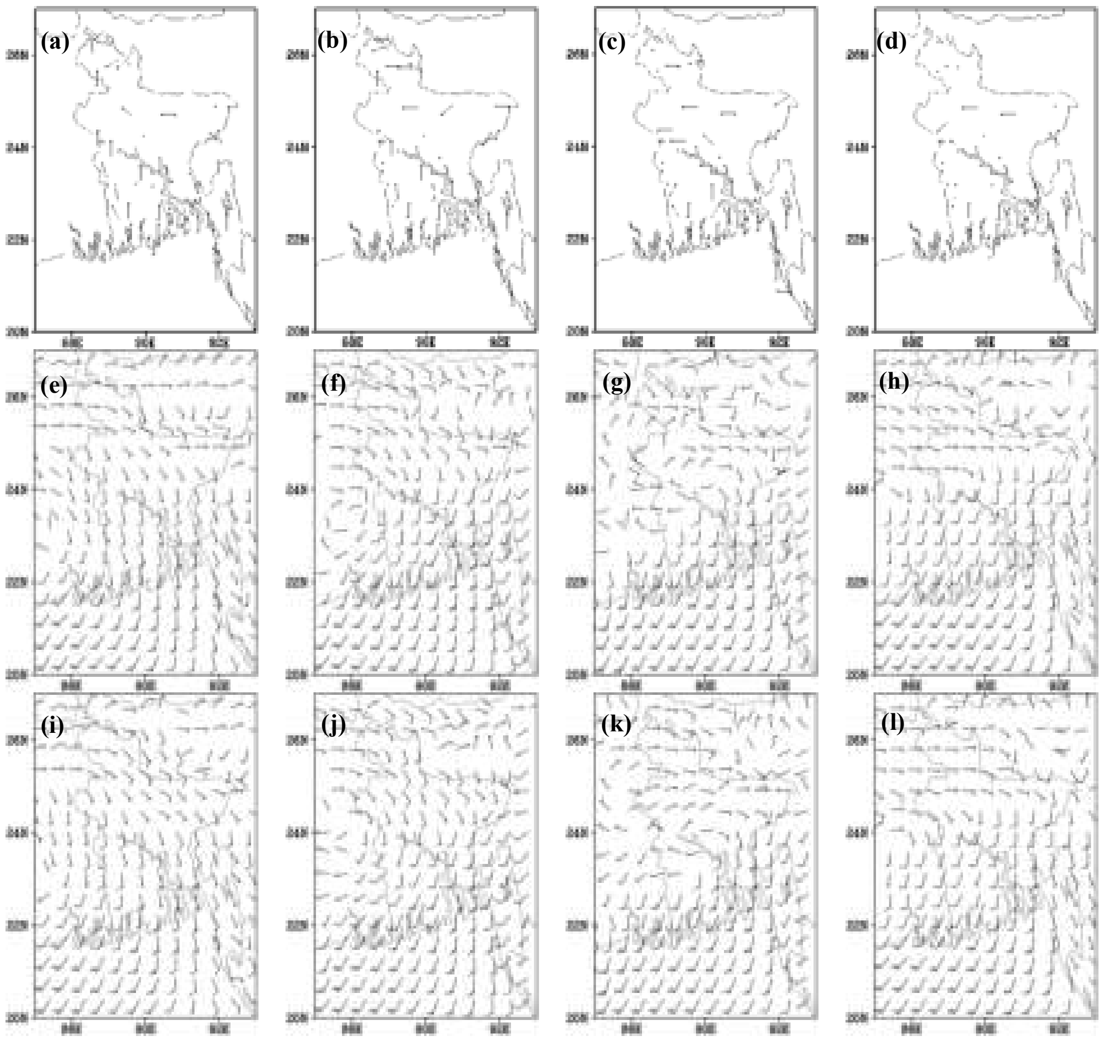


Figure 4: Observed wind flow at 10-meter height on 0000, 0600, 1200 & 1800 UTC of (a-d) 29 March 2017; Predicted wind flow at 10-meter height on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (e-h) 27 March and (i-l) 28 March 2017, respectively.

From the 10-meter height wind analysis, it is found that South-southwesterly wind is blowing from the BoB towards Sylhet through central part of Bangladesh and changes its direction and started to blow from east to west direction which is matched to the observed easterly wind flow of Sylhet and same scenario is found at 850 hPa wind flow. This wind brings high amount of moisture towards Bangladesh and due to the orographic effect in the NE part of Bangladesh, this high moisture uplifted and enhanced shallow or deep convection. This uplifted wind mixes with the model predicted wind at 500 hPa level blowing from the West/Northwest and it is very dry and cold. Owing to the mixing of this cold wind and the uplifting moist wind, cloud formation occurs over Sylhet and adjoining area and is responsible for orographic rainfall.

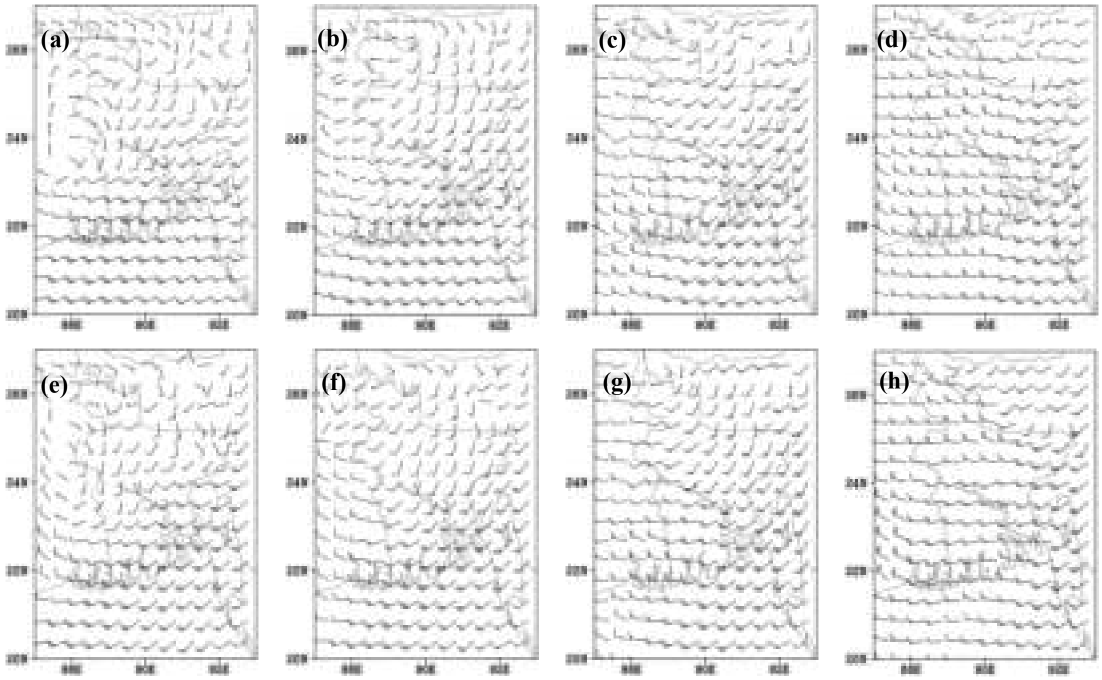


Figure 5: Predicted wind flow at 850 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

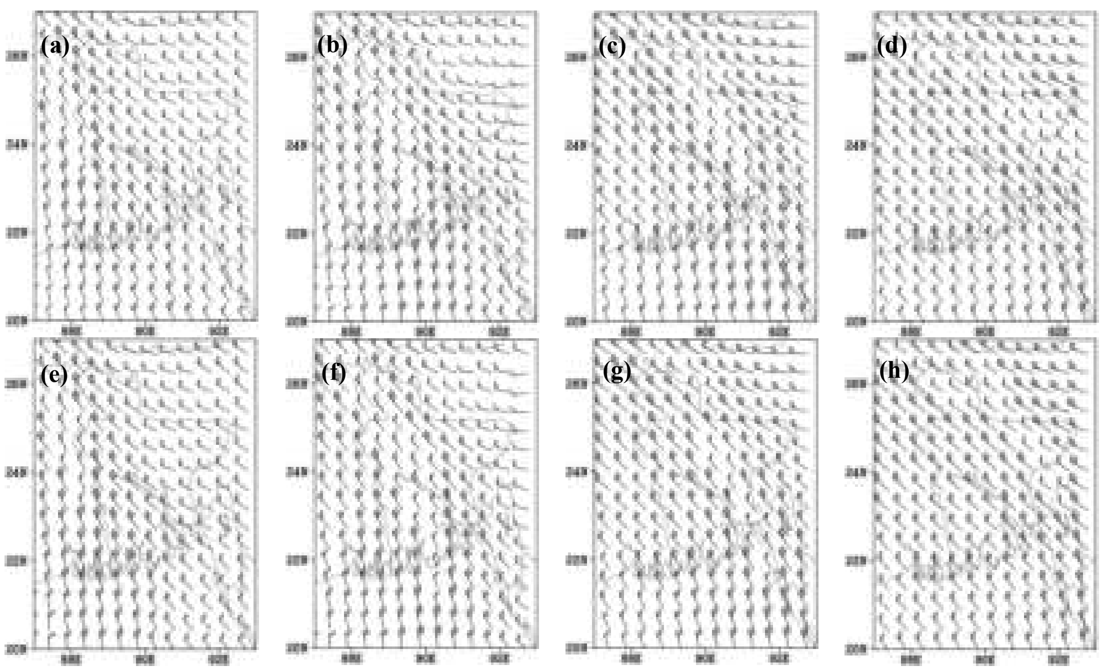


Figure 6: Predicted wind flow at 500 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

3.3 Relative Vorticity at 850 and 500 hPa Levels

The model simulated relative vorticity at 850 and 500 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 is displayed in Figures 7(a-h) and Figures 8(a-h) respectively. Vorticity is the first critical factor in the determination of *thunderstorm* type and potential storm severity. Positive vorticity is related to updraft and negative vorticity is correlated to downdraft.

The model simulated vorticity at 850 hPa level over Sylhet and adjoining area (marked by the circle) is found positive of magnitude (6-10)$\times10^{-5}$ s^{-1} and negative of magnitude (8-10) $\times10^{-5}$ s^{-1} on 0000, 0600, 1200 and 1800 UTC of 29 March 2017, respectively. This positive and negative vorticity is supportive for occurring of deep convective clouds and afterwards heavy rainfall. On the other hand, the vorticity at 500 hPa level over Sylhet and adjoining area is dominated by positive vorticity which is the indication of priority of further updrafts and supportive for deep convection.

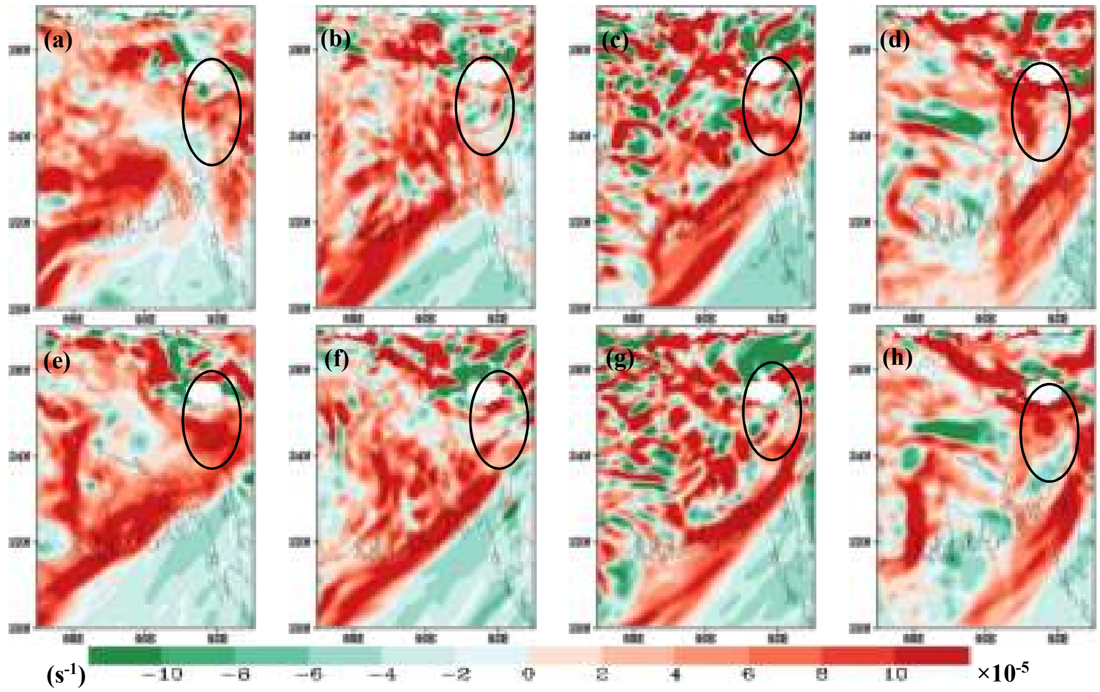


Figure 7: Predicted relative vorticity at 850 hPa on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

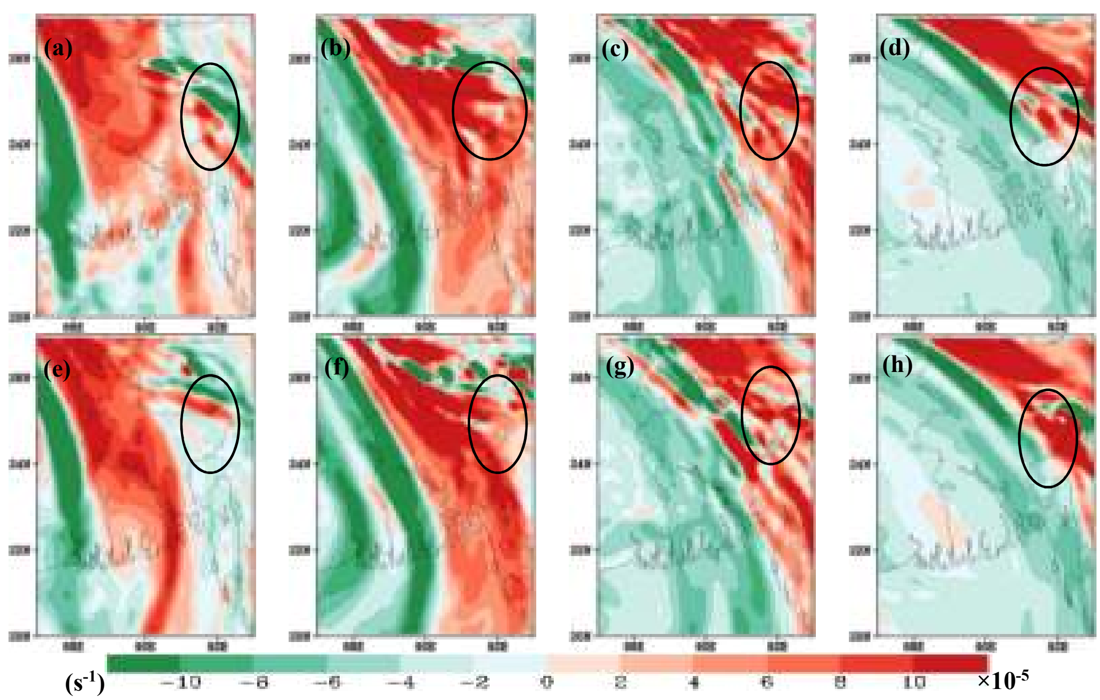


Figure 8: Predicted relative vorticity at 500 hPa on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

3.4 Vertical Wind Shear

Vertical wind shear is the second critical factor in the determination of thunderstorm type and potential storm severity. Wind shear plays a fundamental role in determining the internal dynamics of a thunderstorm, along with the organization of a group of thunderstorms.

Both speed and directional wind shear are important when considering thunderstorms (atmos.uiuc.edu, 2010). The model regenerated wind shear between 500 and 850 hPa level ($u_{500} - u_{850}$) on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 is depicted in Figures 9(a-h). Higher positive value of vertical wind shear is related to thunderstorm intensification and lower wind shear is supportive for tropical cyclone strengthening. The model simulated wind shear of the order of (0-20) knots is related to updraft and lower value of vertical wind shear of the order of (0-5) knots governs downdraft over Sylhet and adjoining area (marked by the circle).

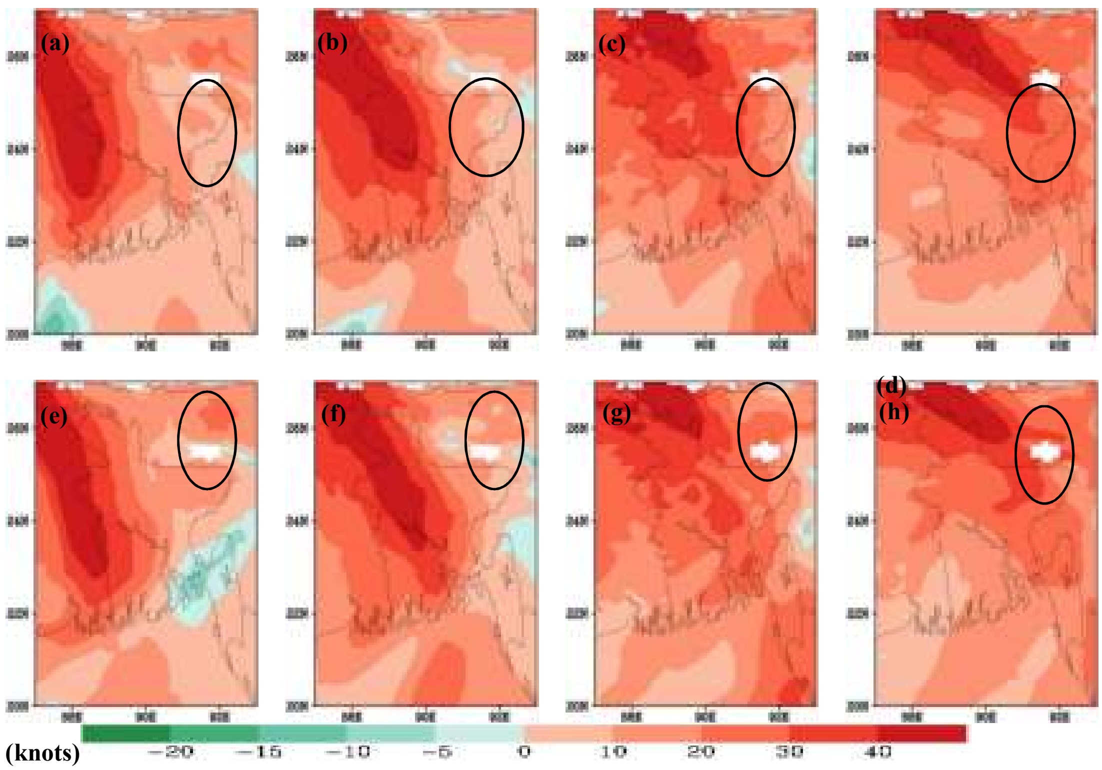


Figure 9: Predicted vertical wind shear between 500 and 850 hPa on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

3.5 Relative Humidity at 2m Height and its Vertical Cross-Section

The model simulated RH at 2m height on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 is compared with observed RH at 2m height on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 shown in Figures 10(a-l). The model generated RH is about 75-95% over Sylhet and adjoining area which is consistent to the observation. The abundant moisture percentage is responsible for buoyancy of air and finally cloud formation. It is also mentionable that RH is more than 95% at the wind side of hilly region of Sylhet and adjoining area which trigger precipitation processes over those regions. The heavy rainfall is shown in Figures 16(a-e) occurred at the right side of the dry line drawn in the picture (border of dry and cold air with moist and warm air) and the prerequisite is moisture abundance.

The model simulated vertical cross-section of RH on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 for latitude 24.9°N is shown in Figures 11(a-h) and for longitude 91.9°E is shown in Figures 12(a-h) respectively. The model simulated latitudinal cross-section of RH along 24.9°N indicates that 60-80% of moisture is extended up to 600 hPa level along 87-90 °E and 60-100% of moisture is extended up to 400 hPa level along 91-93 °E, whereas the longitudinal cross-section of RH along 91.9°E indicates that 60-80% of moisture is extended up to 400 hPa level.

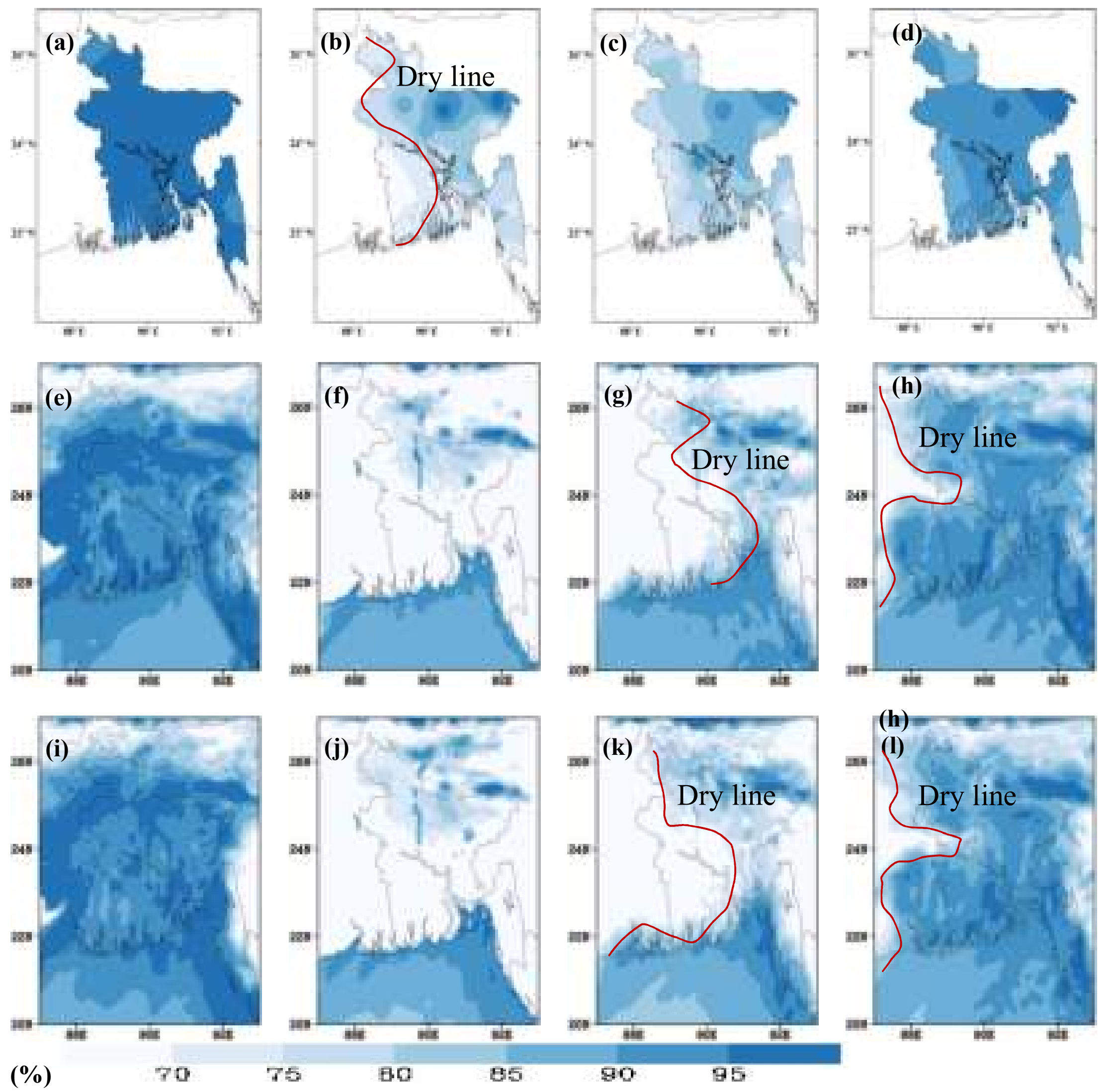


Figure 10: Observed RH at 2m height on 0000, 0600, 1200 & 1800 UTC of (a-d) 29 March 2017; Predicted RH at 2m height on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (e-h) 27 March and (i-l) 28 March 2017, respectively.

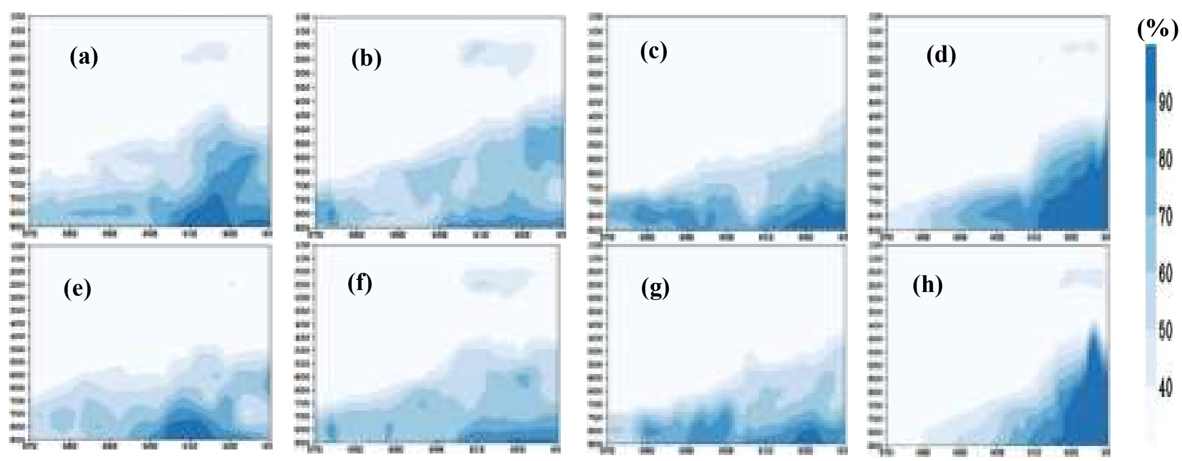


Figure 11: Predicted latitudinal (24.9°N) cross-section at Sylhet of RH on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

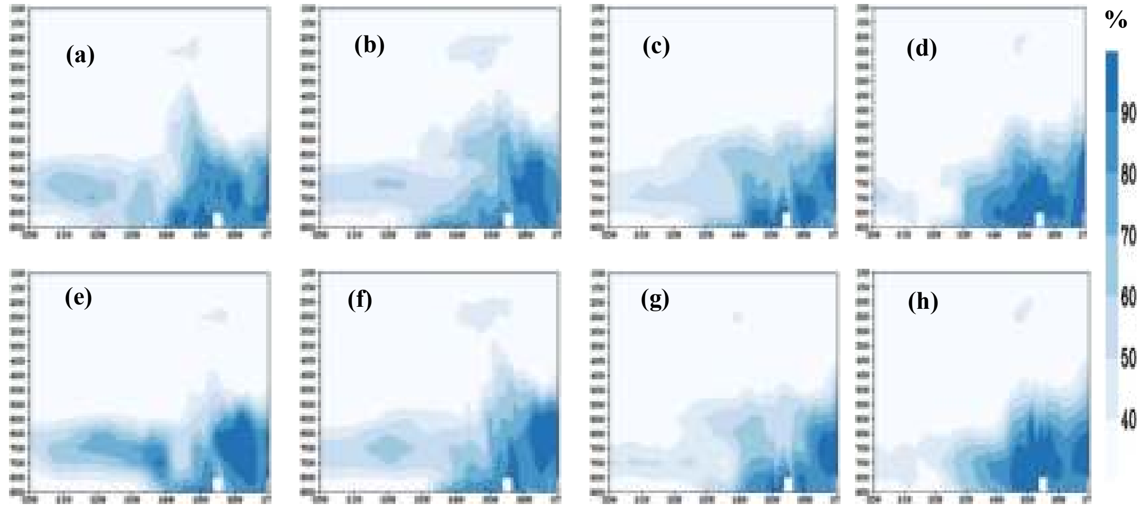


Figure 12: Predicted longitudinal (91.9°E) cross-section of RH on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

3.6 CAPE at 850 hPa Level

The model simulated CAPE at 850 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of 27 and 28 March 2017 is shown in Figures 13(a-h). The model simulated CAPE is found 400 – 800 JKg^{-1} over Sylhet and adjoining area at 0000 and 0600 UTC at developing stage of the system. Afterwards the CAPE is increasing to 1000 JKg^{-1} or more over the study region. The value of CAPE is 1000 JKg^{-1} or more is liable for moderate unstable [UK Ag Weather Center] condition of the atmosphere which enhanced heavy to very heavy rainfall. The amount of 24h rainfall over Sylhet was recorded, 119 mm (BMD) which is consistent to the model simulated CAPE value.

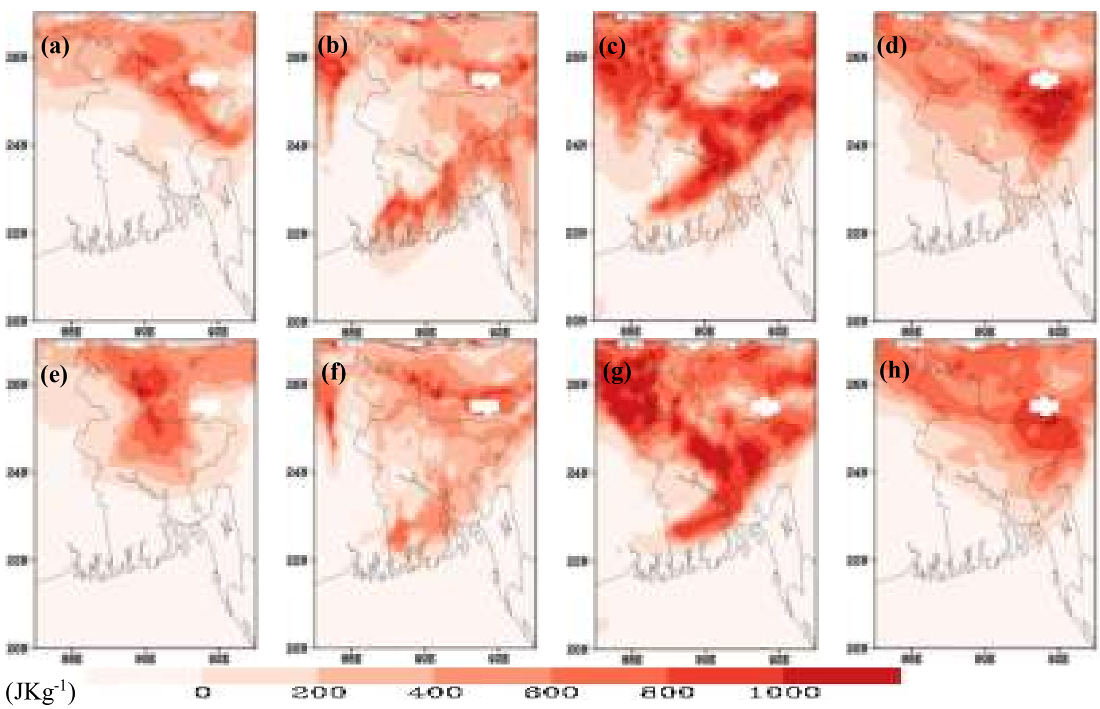


Figure 13: Predicted CAPE at 850 hPa on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively

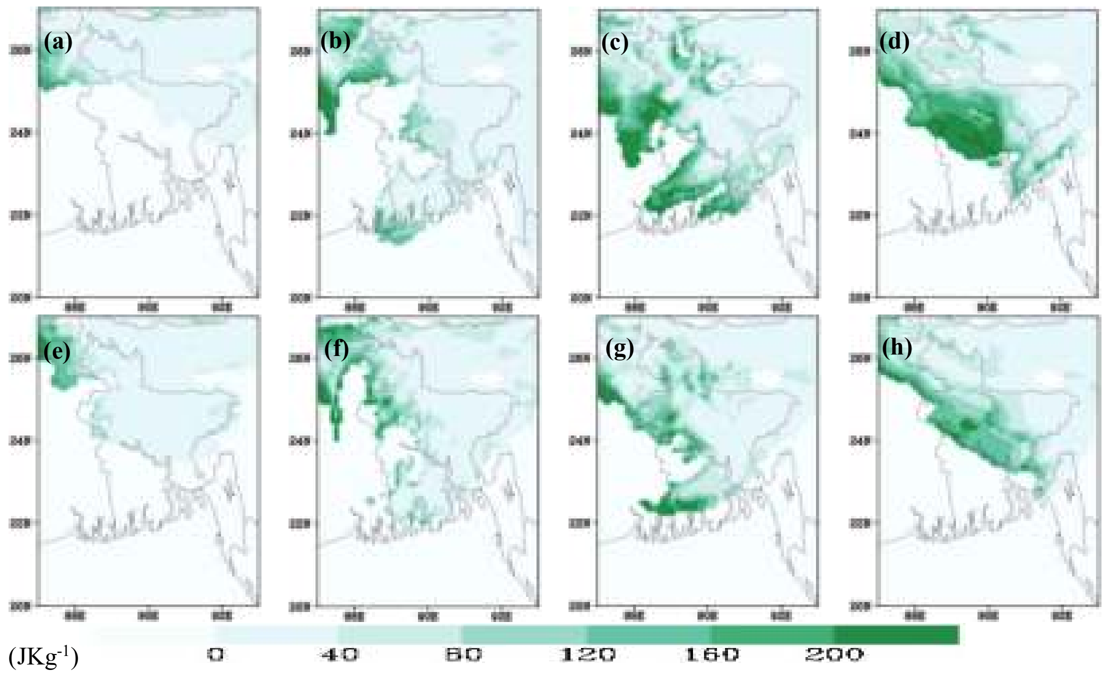


Figure 14: Predicted CIN at 850 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on the initial condition of 0000 UTC of (a-d) 27 March and (e-h) 28 March 2017, respectively.

3.7 CIN at 850 hPa Level

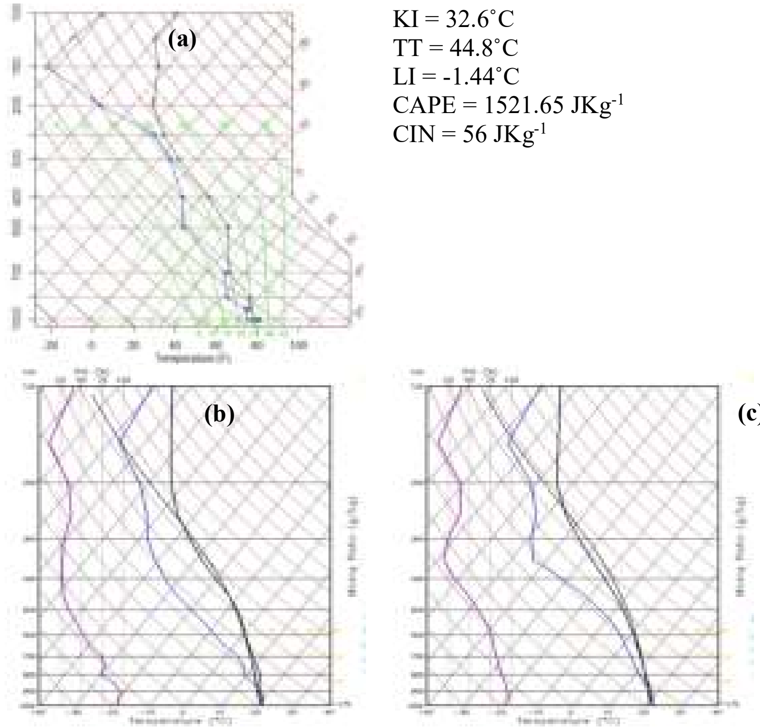
The model simulated CIN at 850 hPa level on 0000, 0600, 1200 and 1800 UTC of 29 March 2017 based on 0000 UTC of 27 and 28 March 2017 is shown in Figures 14(a-h). The model simulated CIN is found 0–80 JKg^{-1} over Sylhet and adjoining area from 0000 to 1800 UTC at developing and dissipating stage of the system. The value of CIN is supportive for potentially unstable (Jeff Haby) atmospheric condition and it is the favorable condition for the convection and afterwards occurring of very heavy rainfall over Sylhet and adjoining area.

3.8 Different Indices of Thermodynamic Diagram

The Rawinsonde observation over Sylhet was not available, so, the nearby Sylhet station is chosen for thermodynamic diagram and validation for different indices. The model simulated thermodynamic parameters as well as thermodynamic diagram at Sylhet, Bangladesh on 0000 UTC of 29 March 2017 based on 0000 UTC of 27 and 28 March 2017 is compared with BMD's thermodynamic parameters and diagram on 0000 UTC of 29 March 2017 which is shown in Figures 15(a-c). The model predicted sounding diagram of T and T_d lines are very close to the observation and it is the indication of unstable atmosphere. Different thermodynamic indices are described as follows:

The model simulated LI is found negative (-1.2˚C for 48h and -2˚C for 72h model run) and the observed LI is found also negative (-1.52˚C) which is the marginal unstable to large instability of the atmospheric condition (UK Ag Weather Center). The model predicted K-index is found 43˚C for 48h and 45˚C for 72h model run and the observed K-index is found 32.6˚C which is the Moderate convective potential of the atmospheric condition (Jeff Haby). This thermodynamic index is predicted by the model good enough and it is consistent to the observation. So that the WRF model can be used for predicting this parameter even 72 h before of the event occurrence. The model generated TT is found 44˚C for both 48h and 72h model run and the observed TT is found 39.8˚C which is supported for likely thunderstorm formation (Jeff Haby).

The model predicted CAPE at Sylhet is found 1522 JKg^{-1} for 48h and 1632 JKg^{-1} for 72h model run and the observed CAPE is found 1521.65 JKg^{-1} which is liable for marginal to moderate unstable [UK Ag Weather Center] condition of the atmosphere. The model predicted CIN at Sylhet is found 103 JKg^{-1} for 48h and 64 JKg^{-1} for 72h model run and the observed CIN is found 56 JKg^{-1} at 0000 UTC which is supportive for moderate to potentially unstable (UK Agriculture Weather Center) condition of the atmosphere. These thermodynamic indices indicate to favorable condition for occurring heavy to very heavy rainfall.

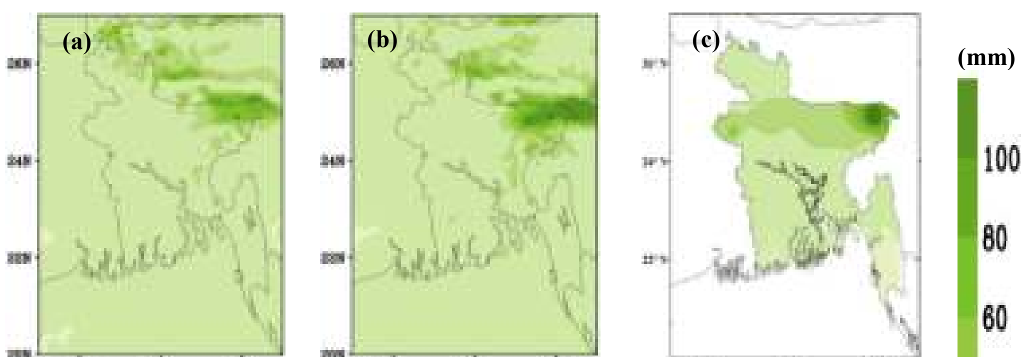


KI = 32.6˚C
TT = 44.8˚C
LI = -1.44˚C
CAPE = 1521.65 JKg^{-1}
CIN = 56 JKg^{-1}

KI = 31˚C; TT = 43˚C; LI = -1.2^{0}C
CAPE = 1522JKg^{-1}; CIN = 103JKg^{-1}

KI = 35˚C; TT index = 45˚C; LI = -2˚C
CAPE = 1632JKg^{-1}; CIN = 64JKg^{-1}

Figure 15: Observed thermodynamic diagram and thermodynamic parameters at Sylhet, Bangladesh on 0000 UTC of (a) 29 March 2017; Predicted thermodynamic diagram and thermodynamic parameters on 0000 UTC of 29 March 2017 of 0000 UTC of (c) 27 March and (b) 28 March 2017, respectively.



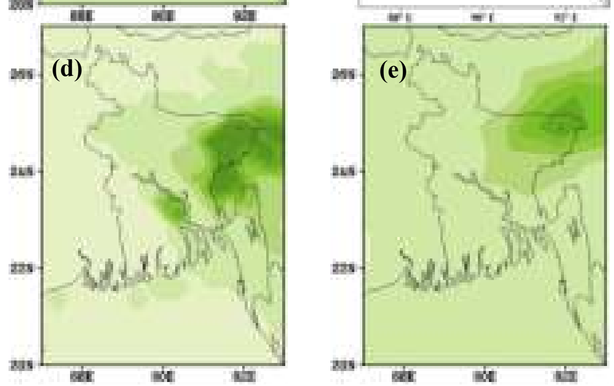


Figure 16: Predicted 24 hour accumulated rainfall of 29 March 2017 based on 0000 UTC of (a) 27 March 2017 (b) 28 March 2017; (c) Observed, (d) TRMM and (e) ECMWF 24 hour accumulated rainfall of 29 March 2017 respectively.

3.9 Rainfall Analysis

The model predicted accumulated 24-hour rainfall of 29 March 2017 based on 0000 UTC of 27 and 28 March 2017 is compared with observed, TRMM and ECMWF accumulated 24-hour rainfall of 29 March 2017 which is shown in Figures 16(a-e). The signature of the spatial distribution of WRF model is well-matched to the observed rainfall than that of TRMM and ECMWF. In both cases very heavy rainfall is predicted by the WRF model equitably well over the wind side of orographic region, Sylhet. The WRF model simulated rainfall is overemphasized by TRMM and underestimated by ECMWF.

The model predicted 24-hour rainfall of 29 March 2017 based on 0000 UTC of 27 and 28 March 2017 is compared with 24-hour observed, TRMM and ECMWF rainfall of 29 March 2017 at Sylhet which is shown in Figures 17(a-e). The computational analysis represents that the model simulated 24-hour rainfall by 48-hour advanced run is closer than that of TRMM, ECMWF and 72-hour prediction. The model performance is good enough and gives the better results with the minimization of the lead time to predict the rainfall over Sylhet and adjoining area.

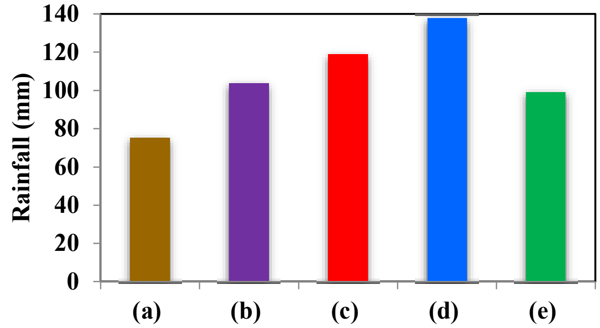


Figure 17: Predicted 24-hour rainfall of 29 March 2017 at Sylhet based on the initial condition of 0000 UTC of (a) 27 March 2017 and (b) 28 March 2017, (c) observed, (d) TRMM and (e) ECMWF rainfall of 29 March 2017 respectively at Sylhet, Bangladesh.

4. CONCLUSIONS

On the basis of the present study, the following conclusions can be drawn:

i. The NSSL 2-moment microphysics coupling to the Kain–Fritsch cumulus scheme and YSU PBL scheme options of WRF model produces representative results in both spatial and quantitative evaluations. Therefore, these schemes have been considered as the prediction of thunderstorm which passes over NE part of Bangladesh.

ii. The model predicted lowest MSLP of the thunderstorm is about 1006-1008 hPa for 48-h, and 72-h model run. The model captured the south-westerly wind flow at 10-m height and 850 hPa level which transports of moisture from the enormous area of the BoB towards the NE part of Bangladesh and neighborhood, this south-westerly wind changes to easterly by the confrontation of hills. One of its components is uplifted and conjugate with the west-northwesterly dry and cold wind at 500 hPa which is very close to the observation.

iii. The model predicted vorticity over NE part of Bangladesh at 850 hPa level is positive of magnitude (06-10)$\times 10^{-5}$ s^{-1} and negative of magnitude (6-10)$\times 10^{-5}$ s^{-1} for 48-h and 72-h model run which directs updraft and downdraft. At 500 hPa level, positive vorticity is dominant, is the indication of further updrafts of the system.

iv. The model predicted positive vertical wind shear of the order of (0-20) knots is governing and it is the indication of further updraft of the system.

v. The RH is found 75-100% over Sylhet and adjoining area which is very close to the observation and 60-100% moisture is extended up to 600-350 hPa levels.

vi. The model simulated CAPE is found 400 – 800 JKg^{-1} at developing stage and 800-1000 JKg^{-1} or more at mature stage over Sylhet and adjoining area which is moderately liable for unstable condition of the atmosphere. The model simulated LI is -2 to -1.2˚C, K-index lies between 31 to 35˚C and TT is found 43 to 45˚C which are close to the observation and responsible for the marginal unstable to large instability of the atmospheric condition.

vii. The model captured the rainfall event reasonably well enough though some spatial and computational error exits. The bias correction may increase the competency of the model for prediction of orographic rainfall and may be forecasted more precisely and accurately.

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