Prediction of a Heavy Rainfall Event of 23 August 2014 over Sylhet, Bangladesh using WRF-ARW Model

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Abstract

Orographic rainfall is usually occurred in Sylhet and adjoining area of Bangladesh. An attempt has been made to simulate a heavy rainfall event of 23 August 2014 over Bangladesh using WRF model of version 3.9.1. The simulation was conducted using WRF-ARW for 48 and 72 hours. The model was run on a single domain of 10 km horizontal resolution with Microphysics of Morrison double-moment scheme (MP-10), Cumulus Physics of Kain-Fritsch scheme (Cu-01) and Planetary Boundary Layer Physics of Yonsei University scheme (pbl-01) for simulating the very severe orographic rainfall. The model performance has been evaluated by examining the different predicted parameters like mean sea-level pressure, wind pattern, upper and lower level circulations, moisture, wind shear, vorticity, Maximum Convective Available Potential Energy (MCAPE) and rainfall pattern. The analysis shows that the CAPE of magnitude 1500 – 2500 J/Kg, positive vorticity in order of (6-10) $x10^{-5}$ s^{-1} and relative humidity of 80 – 100% up to 200 hPa level are responsible for occurring of this heavy rainfall.

Keywords: WRF-ARW Model, MP-10, Cu-01, pbl-01 and MCAPE.

1. Introduction

Bangladesh is a tropical country, situated mainly on the deltas of large rivers flowing from the Himalayas. The Brahmaputra River, known locally as the Jamuna, unites with part of the Ganges to form the Padma, which, after its juncture with a third large river, the Meghna, flows into the Bay of Bengal. Offshoots of the Ganges-Padma, including the Burishwar, Garai, Kobadak, and Madhumati, also flow south to the Bay of Bengal. No part of the delta area is more than 150 m above sea level, and most of it is but a meter or two above sea level. Its soil consists mostly of fertile alluvium, which is intensively farmed; mineral deposits are negligible. During the rainy season floodwater covers most of the land surface, damaging crops and injuring the economy. The northwestern section of the country, drained by the Tista River, is somewhat higher and less flat, but the only really hilly regions are in the east, notably in the Chittagong Hill Tracts to the southeast and the Sylhet District to the northeast. Near the Myanmar border, in the extreme southeast, is the Keokradong, which at 1,230 m is the highest peak in Bangladesh. The orographic rainfall occurred in the hilly region in Bangladesh.

Orographic precipitation is produced when moist air is lifted as it moves over a mountain range. As the air rises and cools, orographic clouds are formed which serve as the source of the precipitation, most of which falls upwind of the mountain ridge. Some also falls a short distance downwind of the ridge and is sometimes called spillover. On the lee side of the mountain range, rainfall is usually low, and the area is said to be in a rain shadow. The influence of mountains upon rain is often profound, creating some of the Earth's wettest places (e.g., Cherrapunji in India, where monsoon flow encounters the southern Himalayas, has received 26.5 m in one year) and driest places (e.g. the central valleys of the Atacama Desert, shielded by surrounding mountains, can go for decades without rainfall). Orographic effects on precipitation 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, precipitation is greatly enhanced on the windward side and suppressed in the lee. However, the full gamut of orographic influences is much broader than this: precipitation can be enhanced in the lee, over the crest, or well upwind of a mountain.

Orographic precipitation is shaped by myriad non-linear processes operating on scales ranging from the 1000 km size of storms and major mountains to the sub-micron size of cloud droplets. Still, the most fundamental of these processes are thermodynamic in nature and are well understood. Almost all orographic influences on precipitation occur due to rising and descending atmospheric motions forced by topography. These motions can be forced mechanically, as air impinging on a mountain is lifted over it, or thermally, as heated mountain slopes trigger buoyancy-driven circulations. Rising motion causes the air to expand and cool, which is important since the amount of water that may exist as vapor in air is an approximately exponential function of temperature (described by the Clausius Clayperon equation). Thus, if cooling is sufficient, air saturates and the water vapor condenses into cloud droplets or forms cloud ice crystals. These droplets and crystals grow by various processes until they become large enough to fall as rain and snow. It is important to emphasize that moist ascent over topography alone is typically insufficient to generate precipitation: these orographic effects mainly modify precipitation during preexisting storms [1,2]. Conversely, when air descends it warms and dries, and both cloud and precipitation evaporate.

The Advanced Research version of the Weather Research and Forecasting system (ARW), developed at the National Center for Atmospheric Research (NCAR), is one of the two distinct dynamical cores of the Weather Research and Forecasting (WRF) model. The other core version, the Nonhydrostatic Mesoscale Model (NMM), was developed at the Environmental Modeling Center of the National Centers for Environmental Prediction (NCEP). Over the Indian monsoon region, and indeed globally, the ARW model is being widely used for the simulation of a variety of weather events, such as heavy rainfall [3-6] and TCs [7-9].

2. Experimental setup, data used and methodology

The Advanced Research version of the Weather Research and Forecasting system (ARW), developed at the National Center for Atmospheric Research (NCAR), is one of the two distinct dynamical cores of the Weather Research and Forecasting (WRF) model. The other core version, the Nonhydrostatic Mesoscale Model (NMM), was developed at the Environmental Modeling Center of the National Centers for Environmental Prediction (NCEP). The NWP model used in this study is the Advanced Research Weather Research and Forecasting model version 3.9.1 The WRF model has been developed by the National Center for Atmospheric Research (NCAR) and provides a flexible and portable open-source community model for both atmospheric research and operational forecasting [10]. It is a limited-area, non-hydrostatic primitive equation model with multiple options for various parameterization schemes for different physical processes.

The 1°-resolution FNL data covering the entire globe every 6-hr were taken as the initial and lateral boundary condition. 30 sec United States Geological Survey (USGS) data (Interpolated depending on resolution) GTOPO30 were used as Topography and 25 Categories United States Geological Survey (USGS) data were taken as vegetation/landuse (Modis and Hi-Def Lakes) coverage. The observed rainfall data of Bangladesh Meteorological Department (BMD) were used to compare or validate the model simulated rainfall.

The experiment was performed on a single domain of 10 km horizontal resolution. The domain configuration in WRF model for the present study is shown in Fig. 1. The Domain has 251×251 grid points in the west-east and north-south directions, respectively. The domain was configured to have the same vertical structure of 30 unequally spaced sigma (non-dimensional pressure) levels. The selected physical parameterization schemes in this study are Kain-Fritsch (new Eta) scheme for cumulus parameterization [11] and Morrison double-moment scheme for microphysics, Yonsei University scheme for planetary boundary layer. The WRF model was run for 48 and 72 hours based on the initial condition of 0000 UTC of 21 and 22 August 2014.

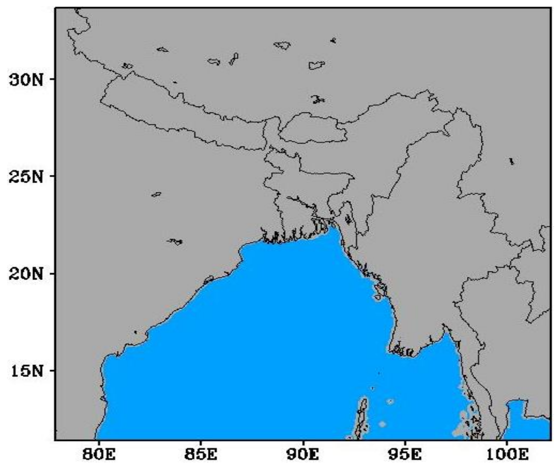

Fig. 1: Model domail Domain

3. Results and Discussion

The results and discussion of the study are given in the following sections.

3.1 Sea Level Pressure

The analysis of Sea Level Pressure from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 which is shown in Fig. 2 (a-d) and Fig. 3 (a-d), respectively. The analysis indicates that a tough of low extends up to NE part of Bangladesh from West Bengal. The model has also simulated the high pressure area over Meghalaya and Eastern Part of Bangladesh. As the NE part is hilly region and buoyancy occurred in the wind side of the hilly region. So, it is the supportive condition for the formation of orographic cloud. It is also mentionable that a belt of pressure gradient found to the right side of the trough. So, there is a possibility of incursion of huge amount of moisture towards NE part of Bangladesh from the Bay of Bengal which is the source of energy to accelerate the buoyancy process in wind side. At 1200 UTC on 23 August, 2014 the lowest sea level pressure of magnitude 1003 - 1005 hPa was found over Sylhet and adjoining area based on 48 h and 72 h advanced model run which is the indication of convergence zone and afterwards it starts to increase which is supportive for the divergence.

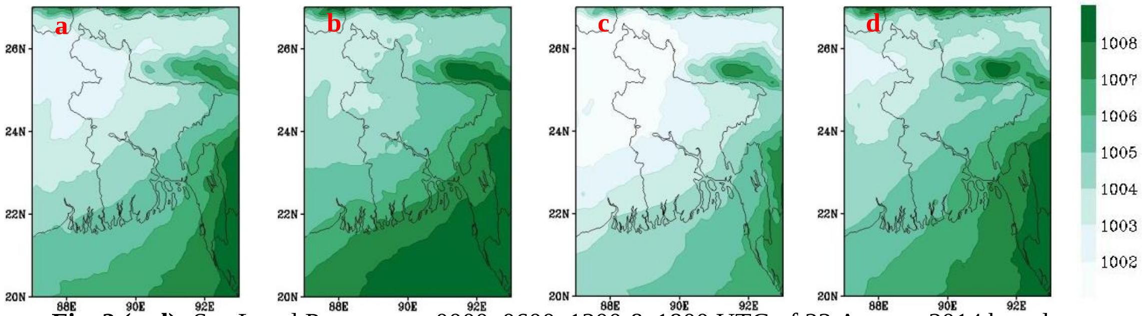

Fig. 2 (a-d): Sea Level Pressure on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014 respectively.

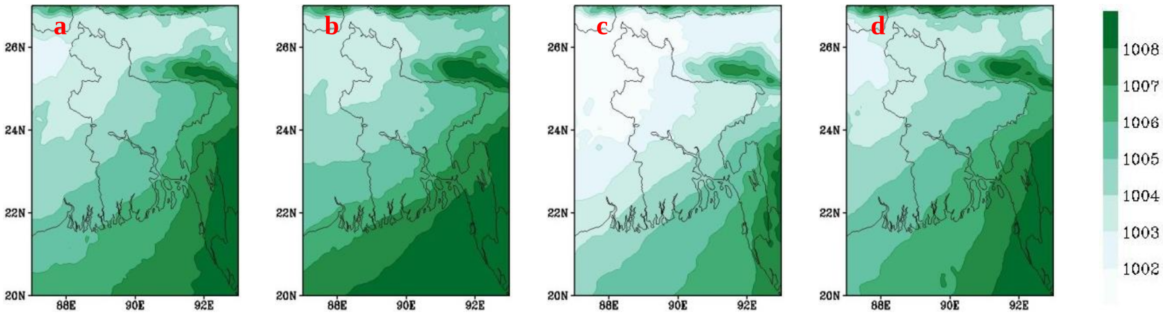

Fig. 3(a-d): Sea Level Pressure on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014 respectively.

3.2 Wind Flow at 850 and 500 hPa level

The model simulated wind flow at 850 hPa and 500 hPa level from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 which is shown in Fig. 4 (a-d), Fig.5 (a-d), Fig. 6 (a-d) and Fig. 7 (a-d), respectively. From the analysis of wind flow at 850 hPa level, it is found that south-south-westerly wind is blowing from the Bay of Bengal towards Sylhet through central part of Bangladesh which is shown in Fig.4 (a-d) and Fig.5 (a-d) during 0000 UTC to 1800 UTC of 23 August, 2014 based on 7 2 hours and 48 hours advanced run respectively. This wind flow carries high amount of moisture towards Bangladesh which is very much related to cloud formation. Due to the orographic effect in the NE part of Bangladesh, this high amount of moisture uplifted and enhanced shallow or deep convection. It is the favourable condition for rainfall processes. The model predicted wind of 500 hPa level represents west-north-westerly wind

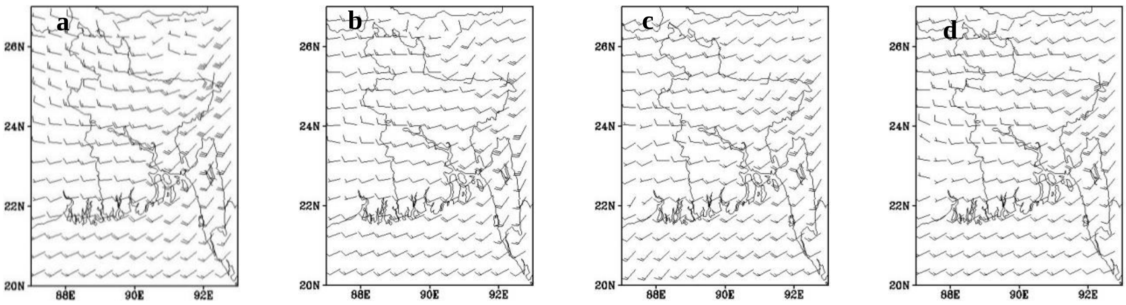

Fig.4 (a-d): Wind flow analysis at 850 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

flow is pushing towards Sylhet which is shown in Fig. 6 (a-d) and Fig. 7 (a-d) during 0000 UTC to 1800 UTC of 23 August, 2014 based on 72 hours and 48 hours advanced run respectively.

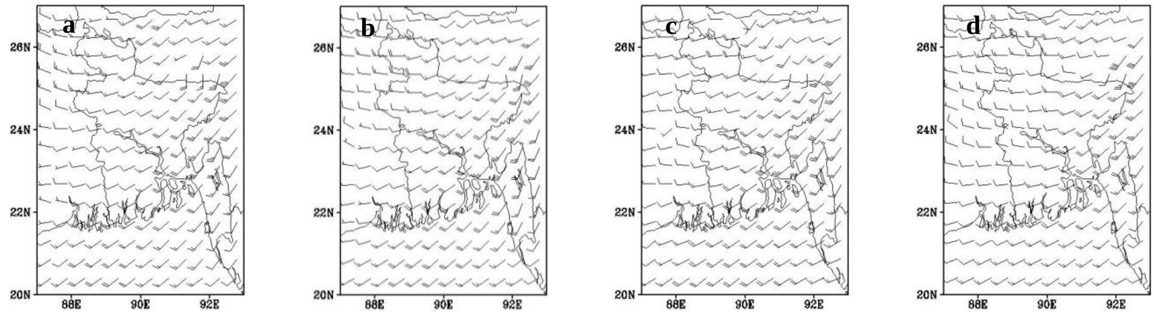

Fig. 5 (a-d): Wind flow analysis at 850 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

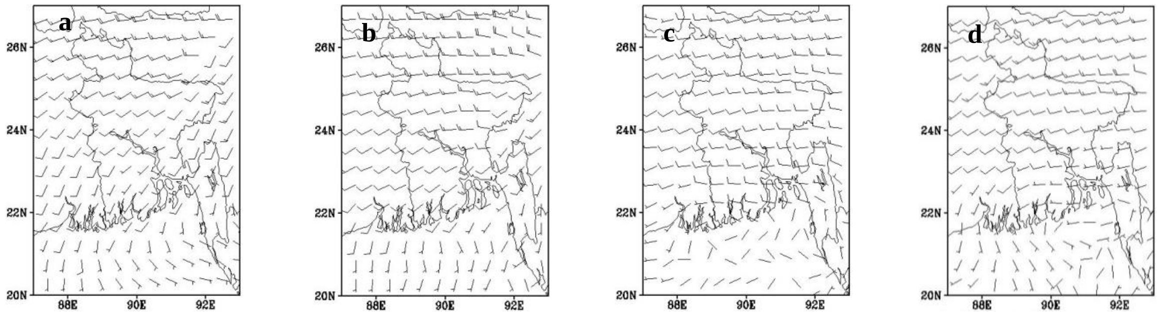

Fig. 6 (a-d): Wind flow analysis at 500 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

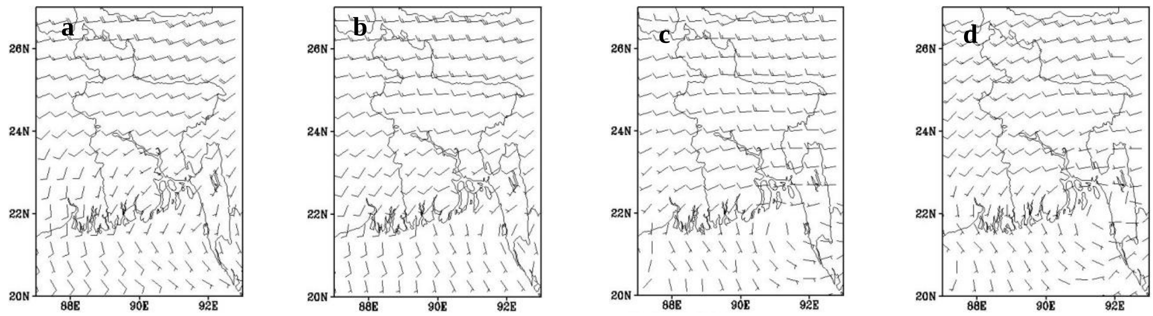

Fig. 7 (a-d): Wind flow analysis at 500 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

3.3 Relative Humidity at 2m Height and its Vertical Cross-section

The analysis of relative humidity at 2m height from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 which is shown in Fig.8 (a-d) and Fig.9 (a-d), respectively. It is found that the relative humidity is 80-100% over Sylhet and adjoining area which is shown in Fig. 8 (a-d) and Fig. 9 (a-d) during 0000 UTC to 1800 UTC of 23 August, 2014 based on 72 hours and 48 hours advanced run, respectively. The high amount of moisture is responsible for buoyant of air and ultimately cloud formation. It is also mentionable that the relative humidity is more than 95% at wind side of the hilly region of Sylhet. The heavy rainfall occurred at the right side of the dry line (border of dry and hot air with moist and warm air).

The vertical cross-section of relative humidity from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 for zonal (at lat. 24.9° N) which is shown in Fig.10 (a-d) and Fig. 11 (a-d) and for meridional (at lon. 91.9° E) which is shown in Fig. 12 (a-d) and Fig. 13 (a-d,) respectively. The model simulated vertical cross-section of zonal relative humidity indicates that 60-80% of moisture is extended up to 150 hPa level along 87-90°E and 80-100% of moisture is extended up to 300 hPa level along 90-93° E, whereas the meridional relative humidity indicates that 80-100% of moisture is extended up to 300 hPa level along 20-27° N. It is clear that initially the relative humidity is uplifted from a different single cloud cell; afterwards they are emerged as a single cell. It also indicates that the vertically uplifted moisture is responsible for cloud formation and it is the indication of occurring heavy rainfall.

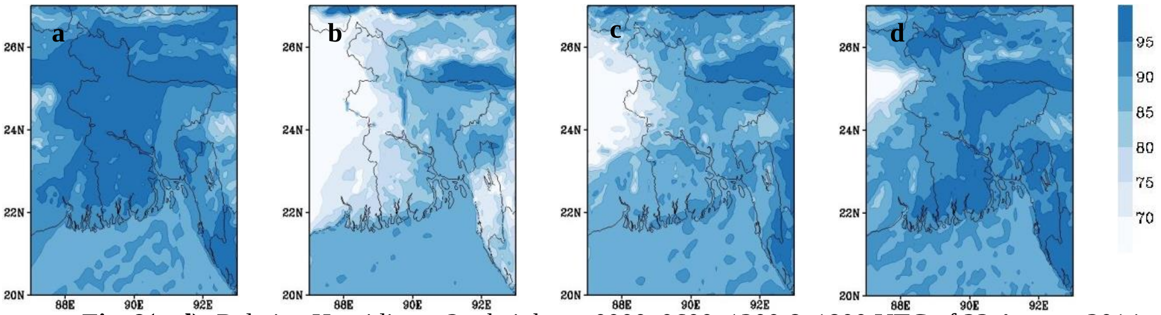

Fig. 8(a-d): Relative Humidity at 2m height on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

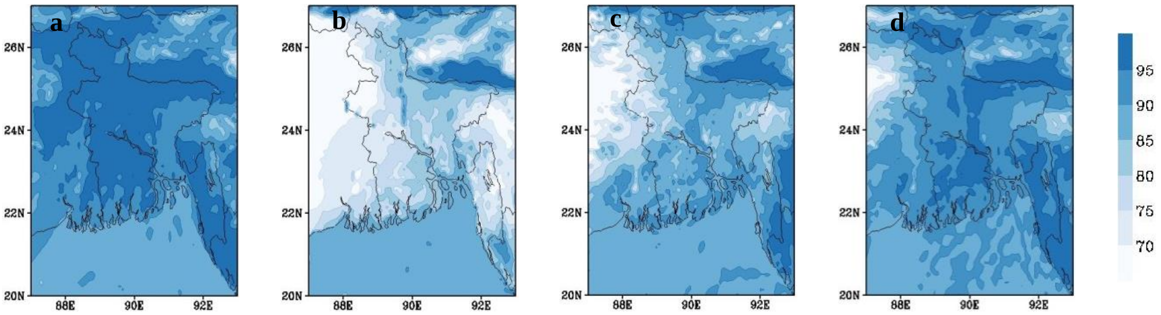

Fig.9 (a-d): Relative Humidity at 2m height on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

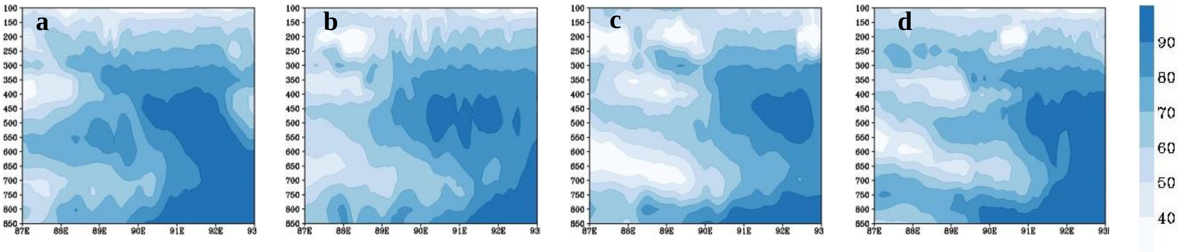

Fig. 10 (a-d): Vertical cross-section of Relative Humidity along 24.9°N on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

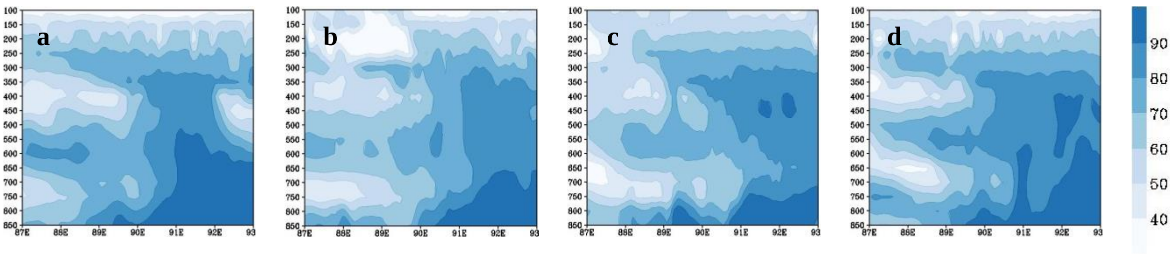

Fig. 11 (a-d): Vertical cross-section of Relative Humidity along 24.9°N on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

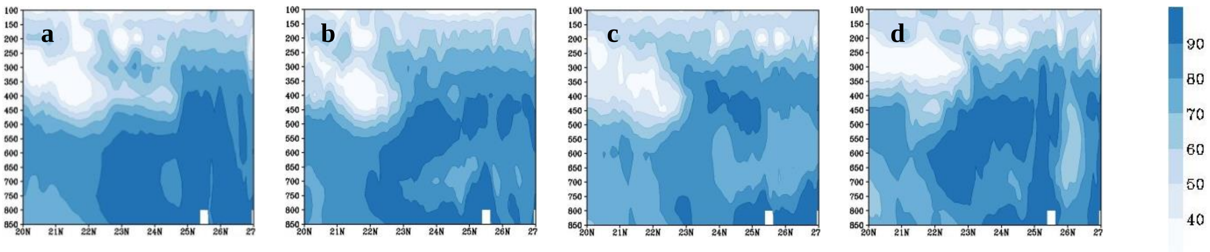

Fig. 12 (a-d): Vertical cross-section of Relative Humidity along 91.9°E on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

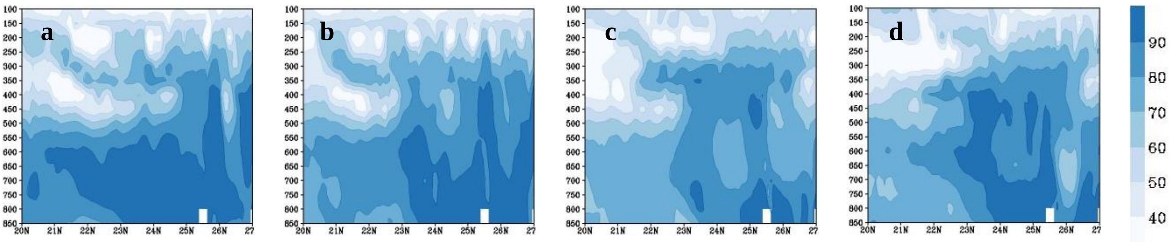

Fig. 13 (a-d): Vertical cross-section of Relative Humidity along 91.9°E on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

3.4 Vorticity at 850 hPa and 500 hPa level

The vorticity analysis at 850 hPa and 500 hPa level from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 which is shown in Fig. 14 (a-d), Fig. 15 (a-d), Fig. 16 (a-d) and Fig. 17 (a-d), respectively. Positive vorticity is related to uplift and negative vorticity governs downdraft. From the analysis, it is found that the vorticity at 850 hPa level over Sylhet and adjoining area is positive of magnitude (6-10) $\times 10^{-5} s^{-1}$ and negative of magnitude (8-10) $\times 10^{-5} s^{-1}$ which is shown in Fig. 14 (a-d) and Fig. 15 (a-d) based on 72 hours and 48 hours advanced run, respectively. This positive and negative vorticity is supportive for occurring of heavy rainfall. On the other hand, the vorticity at 500 hPa level over Sylhet and adjoining area is dominated by negative vorticity which is the indication of priority of downdrafts depicted in Fig.16 (a-d) and Fig. 17 (a-d) based on 72 hours and 48 hours advanced run, respectively. This negative vorticity hinders the further updraft of the system.

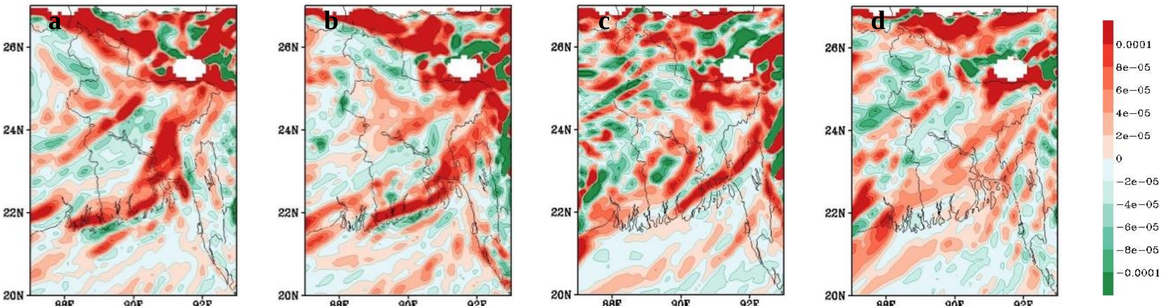

Fig. 14 (a-d): Vorticity analysis at 850 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

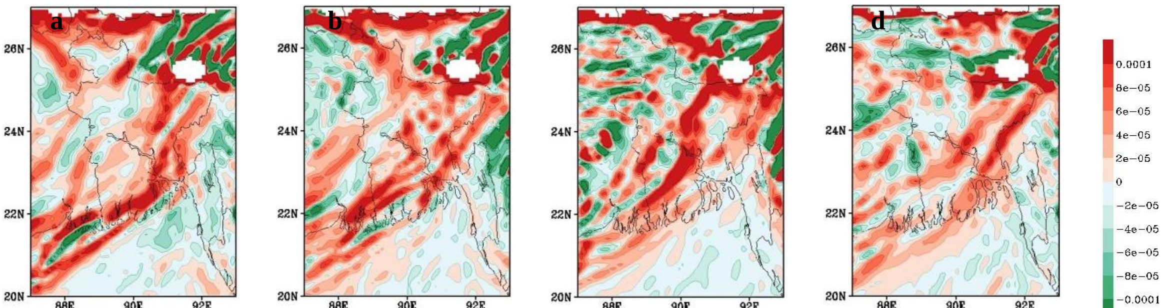

Fig. 15 (a-d): Vorticity analysis at 850 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

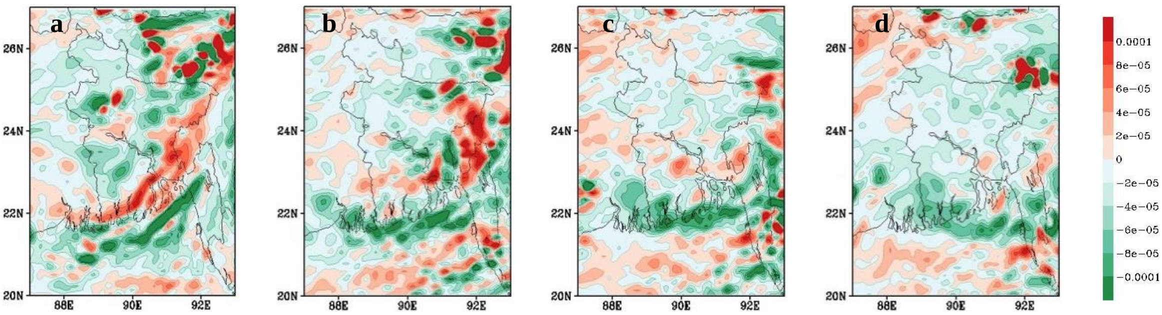

Fig. 16 (a-d): Vorticity analysis at 500 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

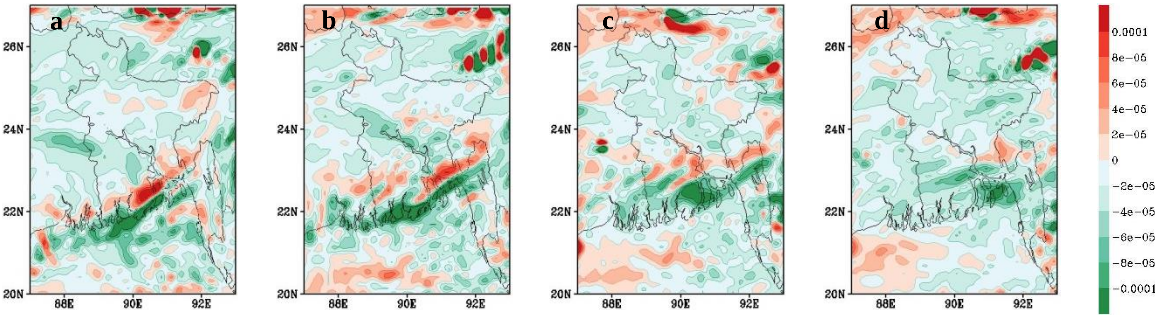

Fig. 17 (a-d): Vorticity analysis at 500 hPa level on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

3.5 CAPE

The model simulated Maximum Convective Available Potential Energy (MCAPE) from 0000 - 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 which is shown in Fig. 18(a-d) and Fig. 19(a-d), respectively. From 0000 to 0600 UTC of 23 August, 2014 MCAPE is found 1000 – 2000 J/KG over Sylhet and adjoining area based on the initial condition of 15 and 23 August, 2014 at developing stage of the system. Then it is started to increase till 1200 UTC 17 April, 2010 of magnitude 1500-2500 J/Kg. Afterwards it is decreasing over that region. So the model predicted that the system is a short spell phenomenon. The value of 1500 J/Kg or more is the indication of the unstable condition of the atmosphere and favourable condition for the convection. The high amount of rainfall over the orographic region, Sylhet was recorded, 161 mm (BMD) which is consistent to the MCAPE value.

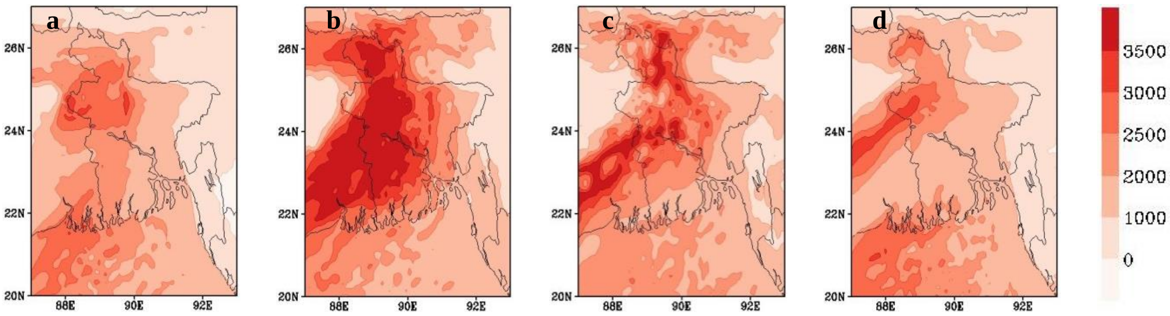

Fig. 18 (a-d): MCAPE analysis on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 21 August, 2014, respectively.

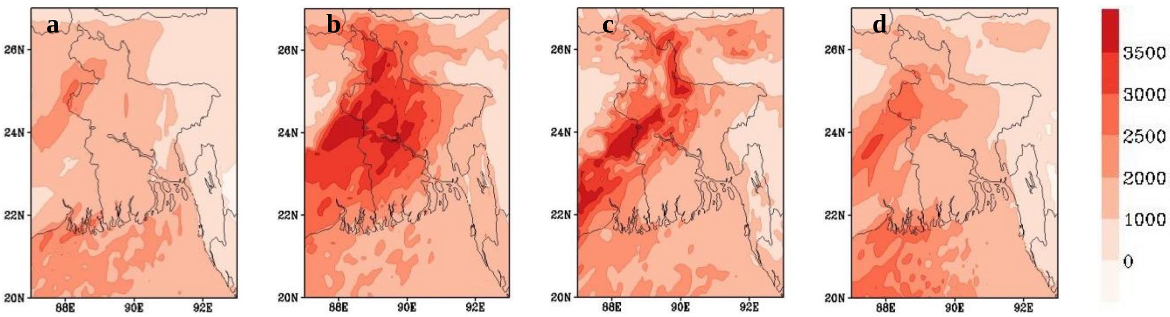

Fig. 19 (a-d): MCAPE analysis on 0000, 0600, 1200 & 1800 UTC of 23 August, 2014 based on the initial condition of 0000 UTC of 22 August, 2014, respectively.

3.6 Rainfall

The model predicted 24 hour rainfall of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 is shown in Fig. 20 (a-b) which is compared with 24 hour TRMM, ECMWF and observed rainfall is shown in Fig. 20 (c-e). The computational 24 hour observed rainfall of Sylhet of 23 August, 2014 is compared with model simulated rainfall based on 72 hours and 48 hours advanced run which is shown in Fig. 21. The signature of the spatial distribution of model and observed rainfall is well matched. From the computational analysis, it is clear that the model simulated 24 hour rainfall is underestimated by 48 hour and overestimated by 72 hour advanced run. But in both cases very heavy rainfall is predicted by the model reasonably well over the wind side of orographic region in Sylhet compare than TRMM and ECMWF.

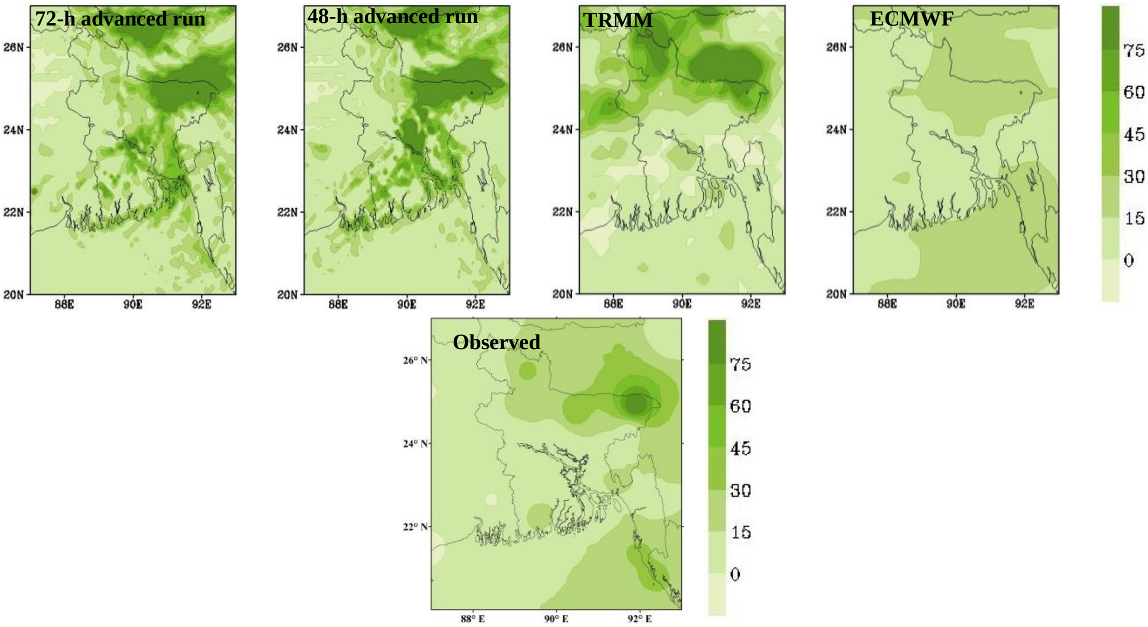

Fig. 20 (a-e): Model predicted 24 hour rainfall of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 and TRMM, ECMWF and observed rainfall of 23 August, 2014 respectively.

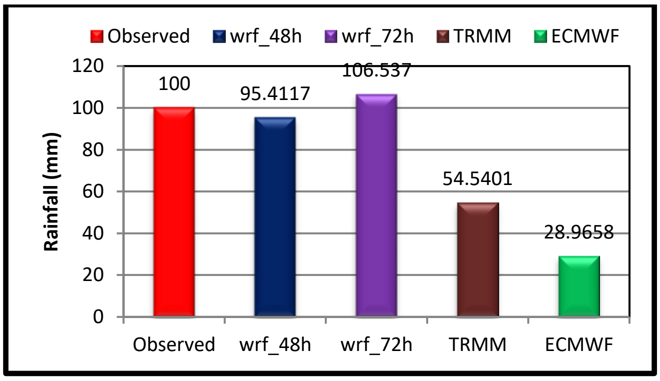

Fig. 21: Bar Graph of model predicted 24 hour rainfall at Sylhet of 23 August, 2014 based on the initial condition of 0000 UTC of 21 and 22 August, 2014 and TRMM, ECMWF and observed rainfall at Sylhet of 23 August, 2014.

4. Conclusions

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

i. The heavy rainfall under study occurred due to the extension of the westerly trough, the convergence zone enriched with high amount of moisture carried by south-south-westerly wind flow towards Sylhet.

ii. The pressure drop over the orographic region, Sylhet is 1004 -1008 hPa characterized by high amount of moisture (80 – 100%) extended up to 200 hPa level which is the energy source for system buoyancy.

iii. The model simulated positive vorticity of magnitude (6-10) $x10^{-5}$ s^{-1} and negative vorticity of magnitude (8-10) $x10^{-5}$ s^{-1} is also supportive for uplift and downdraft.

iv. The model captured high amount of rainfall reasonably well though some spatial and computational error exits. So by the bias correction, the capability of the model for prediction of orographic rainfall may be predicted more precisely and accurately.

Acknowledgement

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