Numerical Simulation of Flash-Flood-Producing Heavy Rainfall of 16 April 2016 in NE Regions of Bangladesh

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ABSTRACT

A flash-flood event affecting areas in the north-eastern Bangladesh during 16-17 April 2016 is documented. 24 hours accumulated rainfall of 100 mm was recorded over the Meghalaya region and 153 mm was recorded in the haor (wetland) region of Bangladesh, producing severe damages. Synoptic observations from the surface and upper air stations and TRMM data are used here to describe the evolution of the flash flood producing storm event. The Weather Research and Forecasting (WRF) model is set up in a nesting configuration including two domains. The simulations indicate the significant synergy of lower and upper tropospheric features which act as the triggering mechanism for the occurrence of flash flood producing rainfall event.

Keywords**:** *Flash flood, Haor, WRF and Precipitation.*

1. Introduction

A flash flood occurred over the northeast haor (wetland) region of Bangladesh on 16 and 17 April 2016. To predict such event is one of the issues in numerical weather prediction (NWP) models, determination of the timing of an event accurately is very challenging. Since the time evolution of flash flood events is quite short, a systematic improvement in flash flood prediction might prevent a projected increase in life and property losses. Flash flood hamper the socio-economy of the region and cause loss of lives.

Strong heating of landmass during mid-day initiates convection over Chota Nagpur and Meghalaya Plateau in India, which moves towards northeast (Assam and Bangladesh area) and gets aggravated by incorporating with the lower level warm moist air mass from the Bay of Bengal (Das 2010, Tyagi, 2000 and Karmakar 2005). The Low Level Jet (LLJ) of southerly from the Bay of Bengal is very usual during the pre-monsoon period due to the thermal low attained over land. The LLJ gets fixed in the east of the thermal low (IMD 1944). The area of wind discontinuity that creates due to these wind flow system and the heat low acts as a triggering procedure for the creation of local severe thunderstorms (Science Plan 2005 and Dalal *et al.*, 2012).

Convective storms occurring at the steep edge of board topography, such as the Meghalaya is notorious for producing surprising and destructive flash floods.

Such a storm happened over the Meghalaya range on 16 and 17 April 2016. It produced a devastating flash flood in the haor area of Sunamganj and nearby haor areas of Bangladesh. The ingestion of moisture from the Bay of Bengal and then energized the mesoscale convective system (MCS) just as it was passing over Meghalaya and northern parts of Bangladesh thus generated heavy convective and/or stratiform precipitation over Meghalaya and the surroundings mountainsides areas (Dimri et al., 2016; Rasmussen and Houze, 2012). The flash flood was a ramification of this heavy precipitation and runoff (Kumar et al., 2014). Additionally, previous rainstorms had moistened the soil during the entire week and especially over the few days leading up to the flash flood, so the mountainsides were likely not able to expeditiously consume the surplus rainfall of the unusual 16 and 17 April 2016 convection.

The pre-monsoon rainfall systems develop mainly due to the incorporation of dry and cold northwesterly winds aloft and southerly low level moist and warm winds impending from the Bay of Bengal (Das 2010 and Das *et al.*, 2015 a-d). The Nor'westers produce surface wind squalls, heavy rain showers, lightning, thunder, hail-storms, dust-storms, downbursts, flash flood, landslides. Tornado cells are occasionally embedded in the mother cumulonimbus cloud. On many occasions, there is an outburst of MCSs when a passing westerly trough at 500 hPa is overlapped over the LLJ. The thunderstorms may also emanate *in-situ* in Bangladesh or invigorate from the ensuing propagation of the storms produced over the Sub-Himalayan West Bengal, Sikkim, Assam valley and the plateau of the Meghalaya (IMD 1944). Usually, these thunderstorms have the spatial length of a few kilometers and life time less than an hour. However, multi-cell thunderstorms evolved due to organized strong convection may have a life spell of several hours and may travel over a few hundred kilometers (Islam *et al.*, 2005). These MCS reach severity when continental air meets warm moist air from the ocean. Flash floods producing thunderstorms are typical mesoscale systems dominated by intense convection (Das *et al.*, 2017; Houze et al., 2017). The understanding and prediction of these weather systems are, therefore, the challenges to the meteorologist and atmospheric researchers.

An attempt is made to simulate the flash flood event in Sunamganj and nearby haor areas using the Advance Research WRF (ARW) model at nested domains of 18 and 6 km resolution. The outputs are obtained for every hourly from inner domain (Das et al., 2015b). The study indicates that NWP models are very essential for acquiring guidelines for forecasting flash flood producing storm.

2. Weather Research and Forecasting (WRF) Model

The WRF model has been employed for simulation of the MCSs associated with flash flood in this study. The WRF Model is a recent generation mesoscale NWP system designed to serve both atmospheric research and operational forecasting (NCAR 2009). The ARW system consists of the ARW dynamics solver with other components of the WRF system required to generate a simulation. The model physics options and parameterization details are presented in Skamarock *et al.*, (2008).

3. Experimental Design and Study Domain

The ARW model, version 3.7.1 used in this study which is a fully compressible, three-dimensional, nonhydrostatic mesoscale model. The model uses the Runge–Kutta third-order time integration scheme and the vertical coordinate is a terrain-following hydrostatic pressure coordinate. The parameterization schemes have been selected from studies conducted by Das *et al.*, (2015 b, d) and Litta *et al.*, (2011). The schemes of planetary boundary layer (PBL) is Yonsei University (YSU) scheme (Hong et al., 2006), Microphysics is the WRF Single-Moment 6-Class (WSM6) Scheme (Hong and Lim 2006), and Cumulus scheme Kain–Fritsch (Kain 2004) is used for domain 1 and 2. For short wave (SW) and long wave (LW) radiation widely used Dudhia (1989) and RRTM (Mlawer *et al.*, 1997) schemes has been used.

A nested domain with 18 and 6 km horizontal spatial resolution was designed (Figure 1), which is suitable in representing the mesoscale cloud clusters. Data from the National Centers for Environmental Prediction (NCEP) 6 h Final (FNL) Global Analyses at 1.0° × 1.0° grids were used as initial and Lateral Boundary Conditions (LBC) for the domain. In the present simulation, the model was integrated for a period of 48 h, starting at 0000 UTC of 16 April 2016, as initial values.

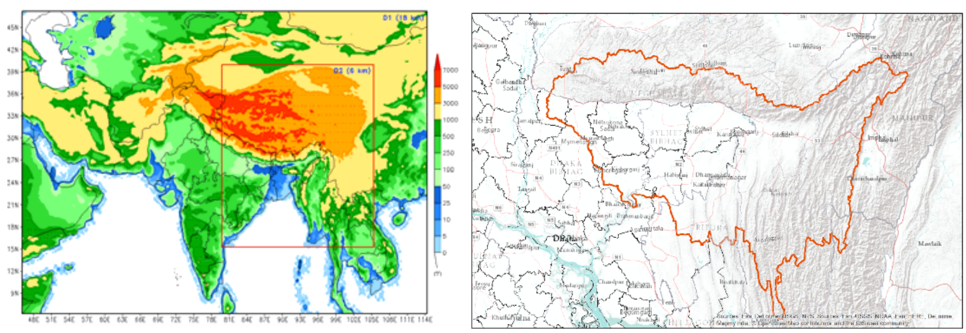

Figure 1: Left Panel: The study domain with the terrain heights at 18 km resolution. Values greater than 0 m are shaded. Right Panel: Meghna basin outlined by thick red line

From the hydrologic point of view, the affected areas are under Meghna basin. The basin collects water from an area of 44 thousand square kilometers outside international border of Bangladesh and drains through the areas prone to flash flood (Figure 1 Right panel). All the results are presented on Meghna basin.

4. Results and Discussion

In this section, certain diagnostics of the flash flood producing storm event simulated by the model are presented. The structure of the flash flood producing rain has been obtained by the model and compared with available satellite observations data from Tropical Rainfall Measuring Mission (TRMM). For additional validation ground-based radar are diagnosed too. Though it is impossible to measure all cloud microphysical and dynamical characteristics such as the hydrometeor species etc. through instruments, an attempt is made to study and verify some of the available parameters.

4.1 Synoptic situation

The Western Disturbance was marked over North Pakistan and adjoining Jammu and Kashmir. It had induced cyclonic circulation over the northeast of Bangladesh and adjoining Meghalaya region. Strong southerly moister flow from the Bay of Bengal was prominent. Observed skew-T at 0000 UTC over Guwahati region indicate moderate to high convection over the region (Figure 2). The model simulated skew-T at 0600 UTC over the same region showed strong convection persisted over the region and Total Totals index was 49 which indicate highly unstable environment. 24 hours precipitation observed and retrieved from Bangladesh Meteorological Department (BMD) and TRMM respectively present in Table 1.

Table 1. Observed 24 hours accumulated rainfall

BMD and TRMM observed 24 hours rain Date and Time (UTC)	Station/Location	24 hours rain (mm)
16-04-2016 (0000Z16April2016 to 0000Z17April2016)	Sylhet	153
16-04-2016 (0000Z16April2016 to 0000Z17April2016)	Meghalaya	100

4.2 950 hPa Wind Vector and 10 m Wind Speed and 500 hPa wind analysis

The model simulated highest value of wind speed at 10 m is 21 m s^{-1}. There is a strong trough at 950 hPa simulated by the model in the event (Figure 3).

The 950 hPa horizontal wind shows a trough and high wind velocity over the north and north-eastern part of Bangladesh with the presence of micro low. Figure 4 showed the diurnal variation of westerly cold flow persists over the area.

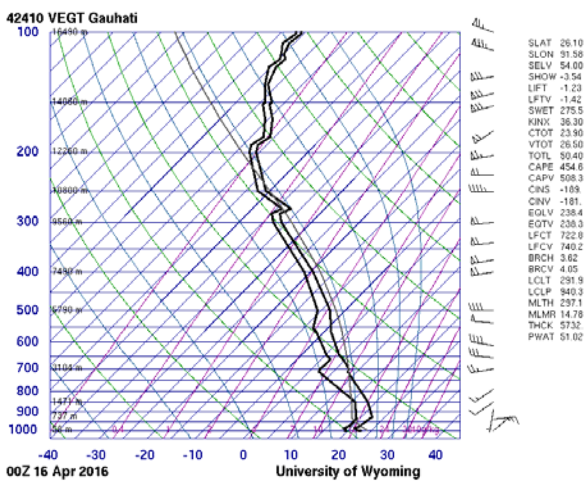

Figure 2: skew-T (a) observed model at 0000 Z 16 April 2016

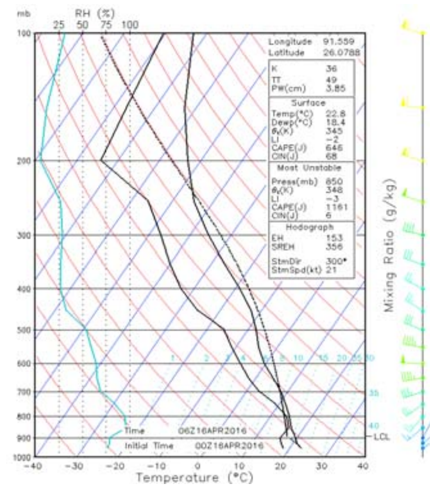

Figure 2b: skew-T simulated model at 0600 Z of 16 April 2016

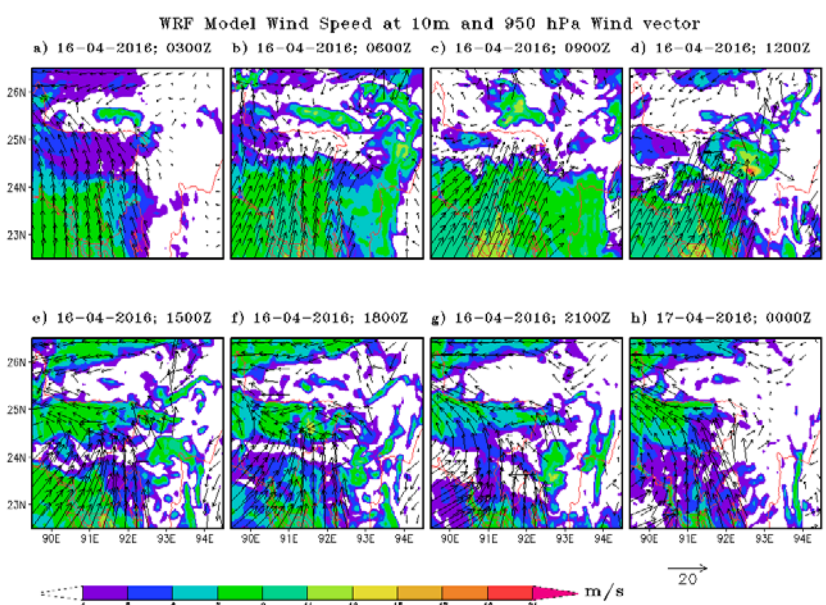

Figure 3: WRF model simulated forecasted vector wind at 950 hPa and wind speed at 10m

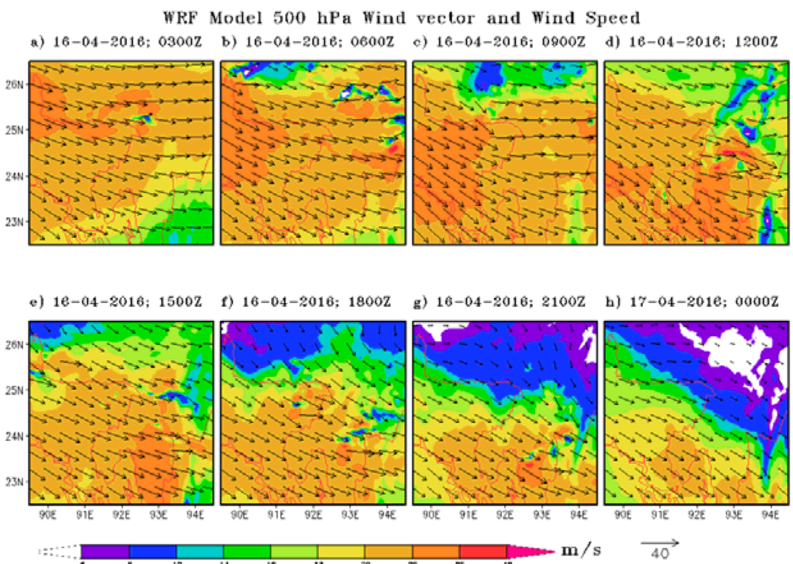

Figure 4: WRF model simulated forecasted vector wind at 500 hPa

4.3 Radar derived rain rated model simulated reflectivity (dBZ)

Moulvibazar radar derived rain rate indicate more than 50 mmh^{-1} over the northeast region of Bangladesh (Fig. 5a). The reflectivity of hydrometeor in the atmosphere has been simulated at different synoptic hours on 16 April 2016. Analysis has shown that the reflectivity becomes maximum and distinct at 0600 to 1800 UTC on 16 April 2016 over the place of occurrence as can be seen from Figure 5. The value of reflectivity is more than 50 dBZ (Figure 5 b).

(a) **(b)**

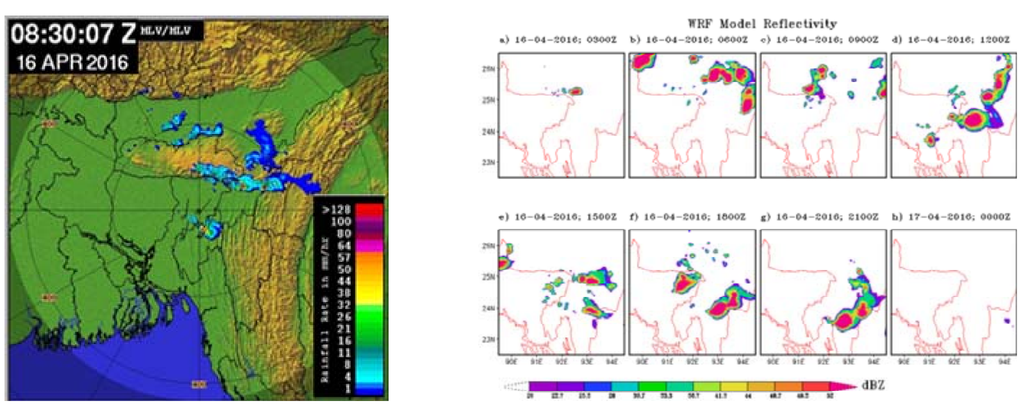

Figure 5: (a) Moulvibazaar radar derived rain rate and (b) WRF model simulated reflectivity

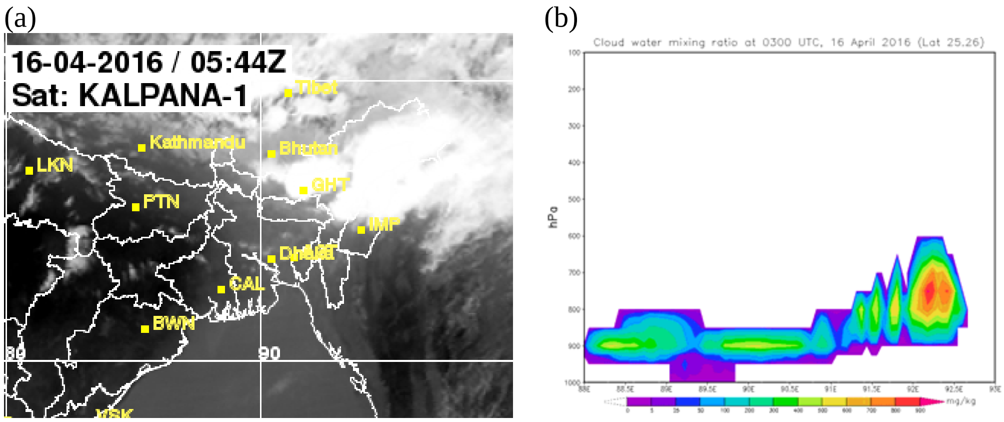

Figure 6: (a) Kalpana-1 satellite image and (b) WRF model simulated cloud water mixing ratio

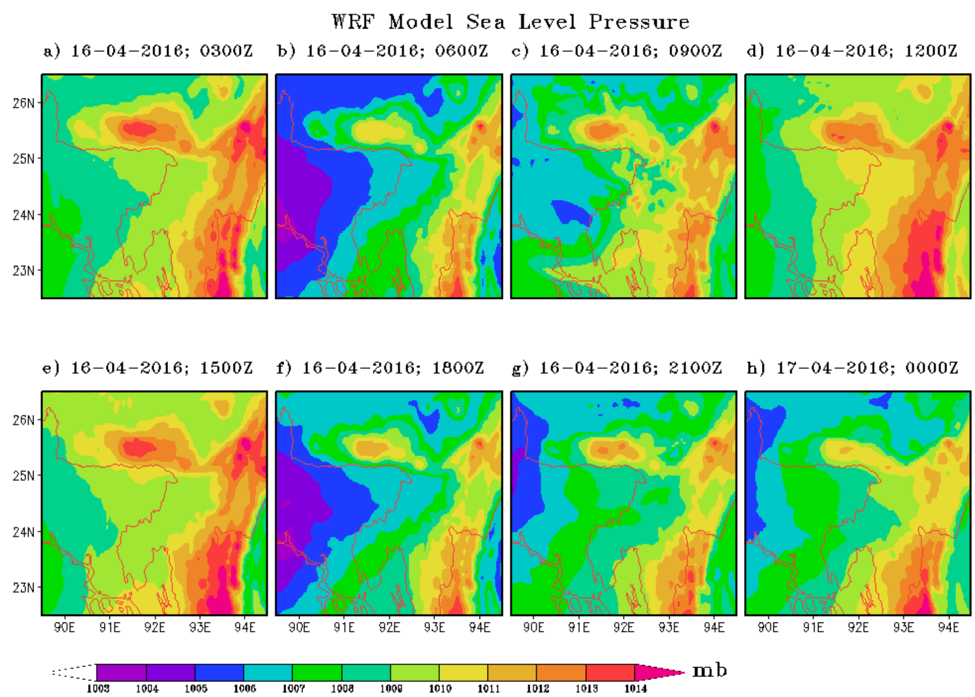

Figure 7: WRF model simulated Sea Level Pressure (SLP).

4.4 Satellite image and model simulated cloud water mixing ratio

Kalpana-1 infrared satellite image indicates deep convection persisted over the region of Thimphu, Bhutan, Guwahati and Imphal of India (Figure 6 a). The vertical cross-section of cloud water mixing ratio is given in Fig. 6 (b) for the places of maximum convection showing maximum convection reach up to 600 hPa and the amount cloud water mixing ratio is 900 mg kg^{-1}.

4.5 Time evolution of Sea Level Pressure (SLP)

Figure 7 shows the time evolution of SLP at the flash flood reported stations for the event. Strong surface heating due to solar insolation causes the formation of heat low at the surface. SLP seems to be less than 994 hPa (Figure 7) over western parts of Bangladesh due to existence of heat low during the pre-monsoon season (Dalal *et al.*, 2012).

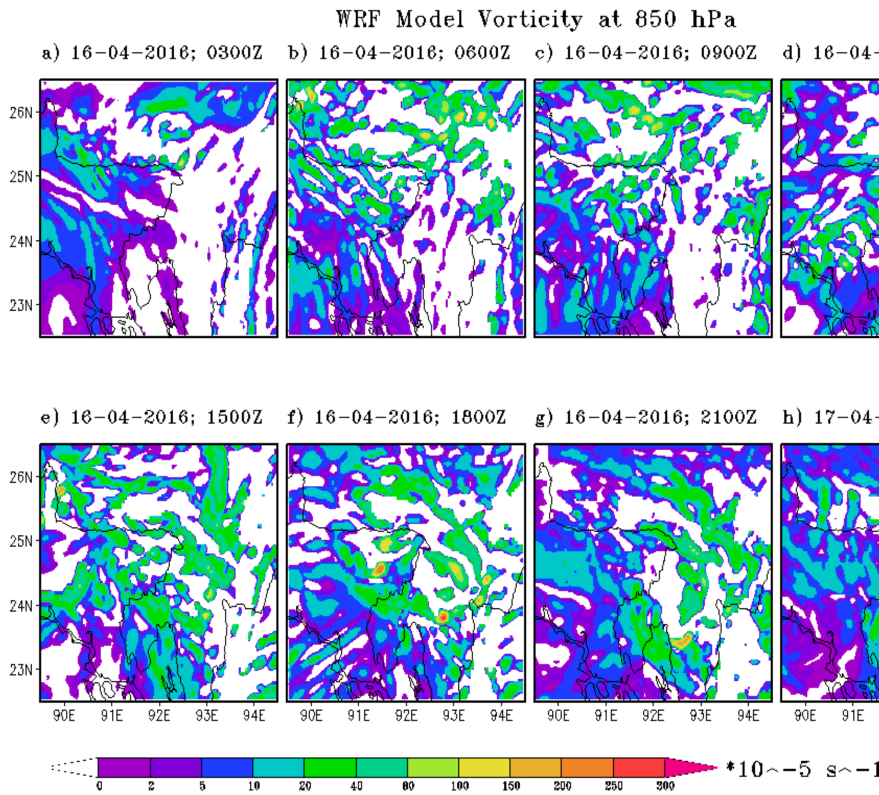

Figure 8: Model simulated vorticity at 850 hPa.

4.6 Vorticity at 850 hPa

Vorticity field at 850 hPa indicate an increament of vorticity at 1200 UTC over the northeast and neighbourhood region. After that it is reduced slightly and again increased at 1800 UTC (Fig. 8 d and f)

4.7 TRMM retrieved and model simulated rainfall

The observed and simulated rainfall differs from each other both in time and spatial distribution as shown in earlier studies (Das *et al.*, 2006). However, the model did simulate the precipitation on the days of the flash flood. The rainfall obtained from the model simulations is compared with TRMM-3B42RT (Simpson *et al.*, 1996) precipitation data (Fig. 9 a, b). The model moved the areas of rainfall both in time and locations. The intensities of the rain rates are simulated very well. From the spatial pattern of rainfall, it can be clearly seen that the rainfall amount and spread are well captured for the event (Fig. 9). It is found that the model overestimated 10 to 15% daily precipitation over the northeast region of Bangladesh.

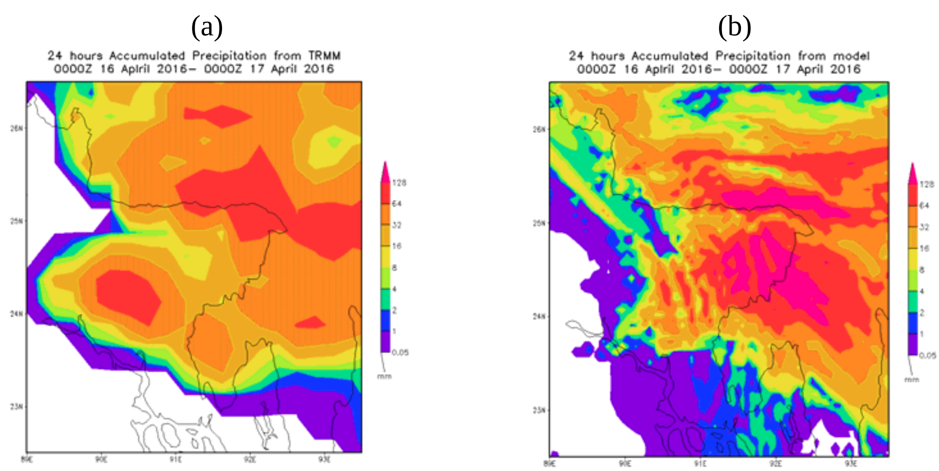

Figure 9: 24 hours accumulated rainfall (a) retrieved from TRMM and (b) model simulated

5. Conclusions

We have investigated the ability of the WRF to reproduce the convective cells associated with the flash flood event over the haor region of Bangladesh. The ability of WRF model with the highest resolution of 6 km horizontal grid spacing to predict heavy rainfall near the northeastern part of Bangladesh during 16-17 April 2016 was evaluated. For the flash flood event, comparison with remotely sensed rainfall measurement shows that the model captured the pattern and evolution of rainfall however there a shift of position. The model overestimated 10 to 15% daily precipitation.

The model simulated the dry and moist zones at 0000 UTC in the event. This presence of dry and moist zones at 0000 UTC is favorable for the occurrence of extreme weather. At the time of occurrence of precipitation, the conjugation of dry and moist lines vanishes.

The model has captured major features of the flash flood producing storm during 16-17 April 2016. The model simulated a micro low over the northern part of Bangladesh, which has been favorable and responsible for the occurrence of the severe convective system.

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