



INSTITUTE OF PHYSICS - SRI LANKA

**Research Article**

**Prediction of high impact rainfall events of summer monsoon over Bangladesh using high resolution MM5 model**

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**Abstract**

An attempt has been made to predict the high impact rainfall events of summer monsoon over Bangladesh using the Fifth-Generation PSU/NCAR Mesoscale Model (MM5) conducting two historical rainfall events on 11 June 2007 and 14 September 2004. The model was run on two way triple-nested domains at 45, 15, 5 km horizontal resolutions using Anthes-Kuo cumulus parameterization schemes (CPS) with MRF planetary boundary layer (PBL). Bangladesh is the main focus area in this study. Thus Bangladesh is taken as inner most (D3) domain with 5 km horizontal resolution to study the variability of predicted rainfall. The model predicted rainfall was compared with TRMM 3B42V6 and BMD observed rainfall.

The MM5 model produces realistic prediction of high impact rainfall events in terms of intensity and structure. The predictions have been made for Day-1 (24-h), Day-2 (48-h) and Day-3 (72-h) in advance. The predictions are more accurate for Day-1 (24-h) and Day-2 (48-h). The prediction deteriorates as the prediction time increases. The prediction has been found to be good even for longer prediction time [(more than Day-2 (48-h)] for relatively stronger case (i.e., 11 June 2007). The prediction accuracy is low for relatively weak case (i.e., 14 September 2004) specially over Day-2 (48-h) of prediction. The prediction may be updated in every 24 hours which would provide more realistic prediction.

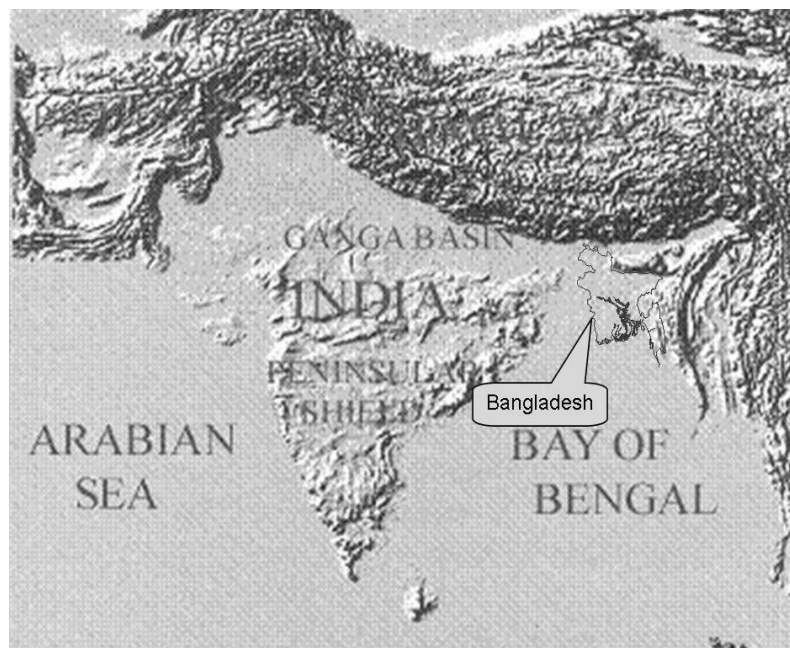
**Keywords:** Prediction; Rainfall; High Impact; TRMM; MM5 Model

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## 1. INTRODUCTION

Bangladesh (latitudes  $20^{\circ}34'$ - $26^{\circ}38'$  north and longitudes  $88^{\circ}01'$ - $92^{\circ}41'$  east) is situated at the interface of two different environments, with the Bay of Bengal to the South and Himalayas to the north. The position of the country at the bottom of the Ganges-Brahmaputra-Meghna (GBM) catchments and the tropic of cancer passes through the middle of the country. The geographical location of Bangladesh and surroundings are presented in Figure 1. Due to these geographical position, Bangladesh experiences highest amount of monsoon and annual rainfall (country average) among SAARC countries<sup>1</sup>. The Khasi-Jaintia-Garo hill complex and the plateau of Shillong, and Arakan Mountains and Mizo hills play important role in modifying the rainfall pattern in northeast and southeast part of the country respectively<sup>2</sup>. Summer monsoon (JJAS) is the main rainy season of Bangladesh that accounts about 72% of the annual rainfall<sup>3</sup>. The rainfall of Bangladesh is mainly governed by the activities of southwest summer monsoon system (i.e., position and intensity of monsoon trough), tropical cyclonic disturbances (lows, depressions and cyclones), local land origin weather systems (land depressions, thunderstorms and mesoscale convective systems) and extra-tropical western disturbances<sup>3</sup>.



**Figure 1:** The geographical location of Bangladesh and surroundings.

The summer monsoon rainfall over Bangladesh is known to be characterized by significant heavy to very heavy rainfall spells<sup>2</sup>. These heavy to very heavy rainfall spells are the results of the active monsoon conditions over Bangladesh (i.e., normal position or northerly position of seasonal monsoon trough). Monsoon trough is an extended trough of low pressure which runs across Gangetic plains of north India with its western end anchored to the seasonal heat low (thermal low) over northwest India and Pakistan, and eastern end emerging into the head Bay of Bengal<sup>2</sup>. In the mean, the axis of this trough

runs from Ganganagar in Rajasthan to Kolkata via Allahabad. Paradoxically, the zone along the monsoon trough axis on sea level has minima of annual and seasonal monsoon rainfall. The maximum of rainfall lies to the south of its axis. Another cause of these heavy to very heavy rainfall spells are the results of occurrence of monsoon lows and depressions over the head Bay of Bengal and moving towards the inland. Sometimes monsoon depressions also forms in the land as a monsoon land depression and occurrence of a lot of rainfall over the region where it lies. Two historical cases of high impact rainfall events on 11 June 2007 and 14 September 2004 have been selected for the present NWP study.

The high impact rainfall events become significant in human affairs when they are combined with other hydrological elements. The high impact rainfall event is an extreme rainfall event occurred over an area with high intensity which interrupted the normal rhythms of life by damaging the lives and properties<sup>4</sup>. The problem of forecasting high impact rainfall is specially difficult since it involves creating a quantitative rainfall forecast, recognized as a challenging task. Simulation of active mesoscale systems such as western disturbances, severe thunderstorms, tropical cyclones and high impact rainfall episodes during active monsoon season, with high-resolution mesoscale models such as the Fifth-Generation PSU/NCAR Mesoscale Model (MM5), has been attempted by many researchers (e. g. Prasad, 2005<sup>2</sup>; Das, 2002<sup>5</sup>; Akter and Islam 2009<sup>6</sup>). Application of numerical weather prediction (NWP) model in weather research and prediction is very new in Bangladesh. But, some studies have been carried out about thunderstorms of pre-monsoon season<sup>5-6</sup> and heavy rainfall of summer monsoon season over in and around Bangladesh<sup>2-4</sup>.

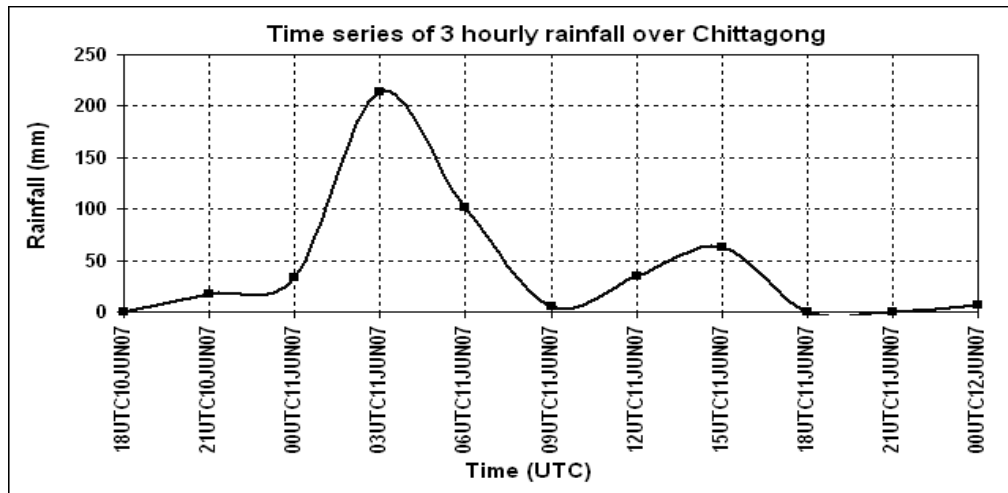
The present study is the first of its kind in the context of Bangladesh, and it is firmly believe that it will improve the general understanding of NWP application in prediction of high impact rainfall events of summer monsoon over Bangladesh. The objective of the present study is to predict the high impact rainfall events which occurred over Chittagong on 11 June 2007 and over Dhaka on 14 September 2004 using high resolution (grid spacing of 5 km) MM5 model.

## 2. CASE DESCRIPTION

### (a) Case-1: 11 June 2007

On 11 June 2007, Chittagong (22.35°N, 91.82°E) – the southeastern coastal metropolitan city of Bangladesh – received unprecedented heavy rainfall and more than one-third of the metropolitan city was inundated. This extraordinary rainfall event was localized over a region of 20-30 km. Bangladesh Meteorological Department (BMD) recorded rainfall was 425 mm within a span of 24-h on that eventful day, out of which 315 mm in just six hours (00 UTC-06 UTC)<sup>7</sup>. Other nearby weather stations of BMD recorded rainfalls were 225 mm at Sandwip, 146 mm at Rangamati, 110 mm at Kutubdia and 101 mm at Cox's Bazar. This torrential rain disrupted life in the metropolitan city, caused flash

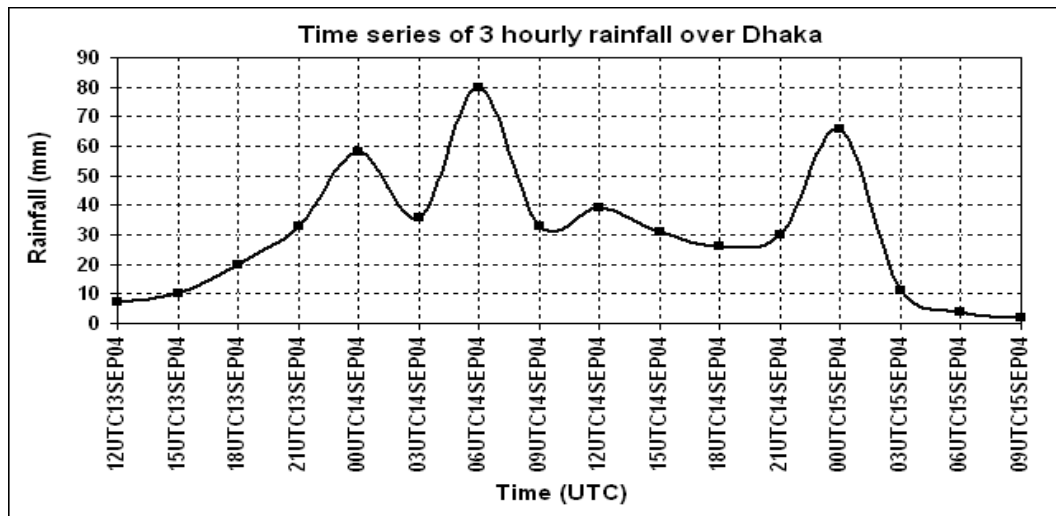
flood situation<sup>7</sup>. In addition to the floods, the rains triggered devastating landslides in the deforested hills on which the city is built. The city-wide death toll from the floods and landslides was nearly 130 on June 12 as reported in the print media (Reuters). Most of the deaths were a result of the landslides or from buildings collapsing in the rain. Time series of 3 hourly rainfall at Chittagong, Bangladesh on 11 June 2007 is shown Figure 2(a).



**Figure 2(a):** Time series of 3 hourly rainfall at Chittagong, Bangladesh on 11 June 2007. BMD recorded 315 mm rainfall in just six hours between 00UTC – 06UTC.

(b) Case-2: 14 September 2004

On 14 September 2004, Dhaka (23.77°N, 90.38°E) – the capital city of Bangladesh – received unprecedented heavy rainfall and more than two-third of the city was inundated<sup>8</sup>. This is an extraordinary rainfall event. The highest rainfall recorded in 24 hours were 341mm at Dhaka and 376mm at Majidi Court, which were also the highest rainfall ever recorded<sup>8</sup>. Due to this high impact rainfall, flash flood situation was created in Dhaka and some parts of the country<sup>8</sup>. There was an historical monsoon depression formed over the Bay of Bengal during 11-16 September, 2004 which was responsible for this high impact rainfall event over Dhaka and some parts of Bangladesh on 14 September 2004. Time series of 3 hourly rainfall at Dhaka, Bangladesh on 14 September 2004 is shown in Figure 2(b).



**Figure 2(b):** Time series of 3 hourly rainfall at Dhaka, Bangladesh on 14 September 2004.

### 3. DATA USED, MODEL EXPERIMENTAL SETUP AND METHODOLOGY

The Fifth-Generation PSU/NCAR Mesoscale Model (MM5)<sup>9-10</sup> version 3.7 has been adopted for mesoscale weather simulation and prediction at SAARC Meteorological Research Centre (SMRC), Dhaka, Bangladesh. The MM5 is a limited area, non-hydrostatic, terrain following, sigma coordinated model designed to simulate or predict the atmospheric circulation including mesoscale phenomena<sup>9-10</sup>.

#### (a) Data used

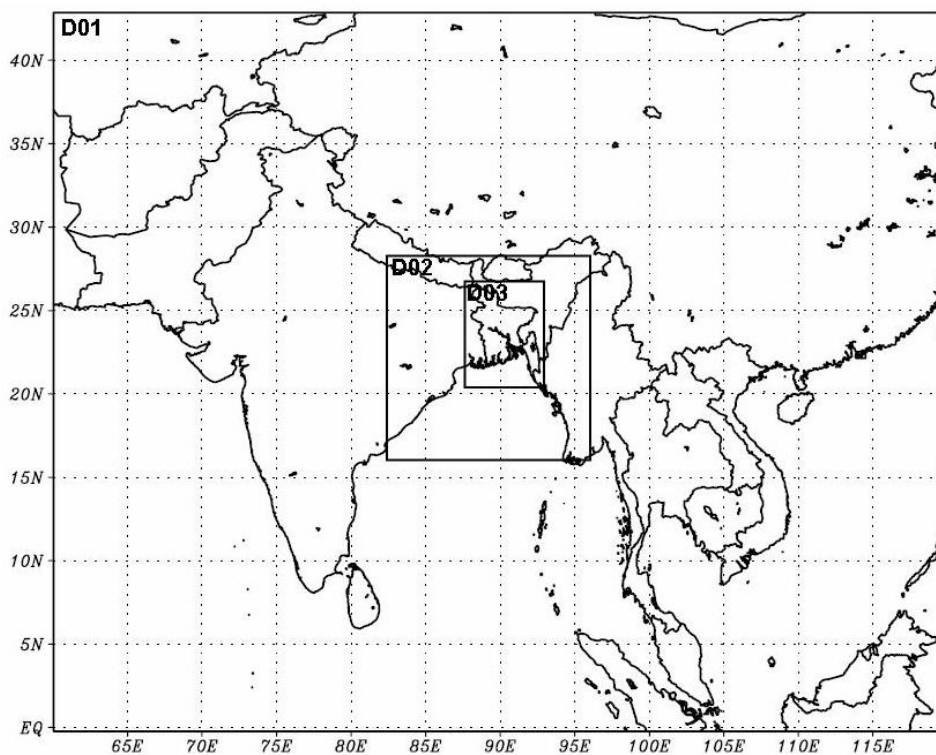
The National Centers for Atmospheric Research (NCEP) high-resolution Global Final (FNL) Analysis data on  $1.0^{\circ} \times 1.0^{\circ}$  grids covering the entire globe every 6-h were taken as the initial and lateral boundary condition. The 30 second United States of Geological Survey (USGS) data GTOPO30 (Interpolated depending on resolution) were used as Topography and 25 Categories USGS were taken as a vegetation / land use. The 5 Layer soil moisture data used as land surface process.

The daily Tropical Rainfall Measuring Mission (TRMM) 3B42V6 rainfall data with  $0.25^{\circ} \times 0.25^{\circ}$  resolution have been downloaded from their website (<http://lake.nascom.nasa.gov>) to validate the model predicted rainfall structure, development time and location. Moreover, daily observed rainfall data of 34 rain gauge stations have been collected from the archive of BMD for further validation of the model predicted rainfall.

(b) Model Experimental Setup and Methodology

The MM5 model was run on triple-nested domains at 45, 15 and 5 km resolutions using Anthes-Kuo (AK) cumulus parameterization schemes (CPS)<sup>11</sup>. The configured domains are shown in Figure 3. Domain 1 (D1) was the coarsest mesh and has 120×105 grid points in the north-south and east-west directions, respectively, with a horizontal grid spacing of 45 km. Within Domain 1, Domain 2 (D2) was nested with 100×94 grid points at 15 km grid spacing. The fine-mesh Domain 3 (D3) was 151×115 points with 5 km grid spacing. Bangladesh was the main focus area in this study. The model used two way nesting, where coarse grid data were interpolated to finer grid boundaries and the finer grid provides updated data to the coarse grid. All domains were centered (20°N, 90°E) over Bangladesh to represent the regional-scale circulations and to solve the complex flows in this region. All these domains were configured to have the same vertical structure of 23 unequally spaced sigma (non-dimensional pressure) levels. The other physical parameterization schemes used in this study were the MRF scheme for a planetary boundary layer<sup>12</sup>, Simple ice for an explicit moisture scheme (Dudhia), Simple cooling as radiation scheme and Five layer soil model as land surface processes.

The model performance was evaluated by comparing the model predicted rainfall with TRMM 3B42V6. It was also further compared with the BMD observed rainfall data. The model simulated precipitation at surface level was considered as rainfall throughout this study.



**Figure 3:** Triple nested domains D1, D2 and D3 configuration in MM5 model

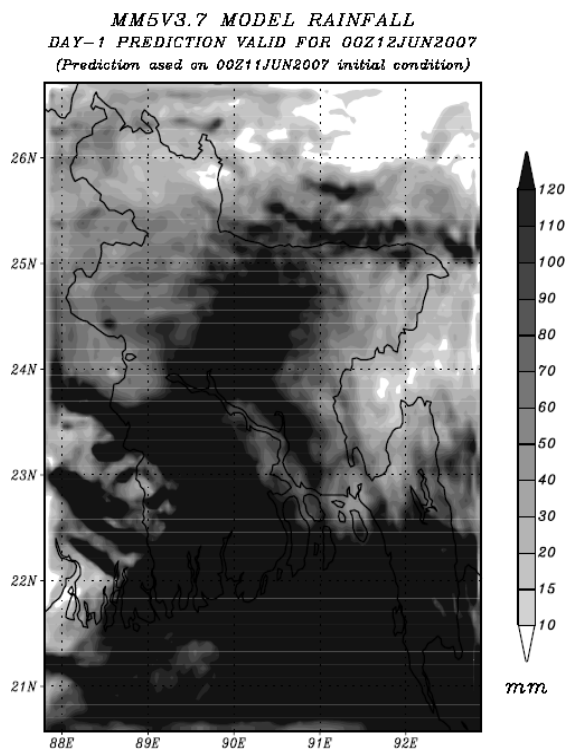
#### 4. RESULTS & DISCUSSION

Bangladesh is the main focus area in the present study. Thus MM5 predicted rainfall at D3 resolution for Bangladesh has been considered with special attention. Case-1 is assumed as stronger case than case-2 considering the intensity of rainfall over the studied area. The results are discussed in the following section.

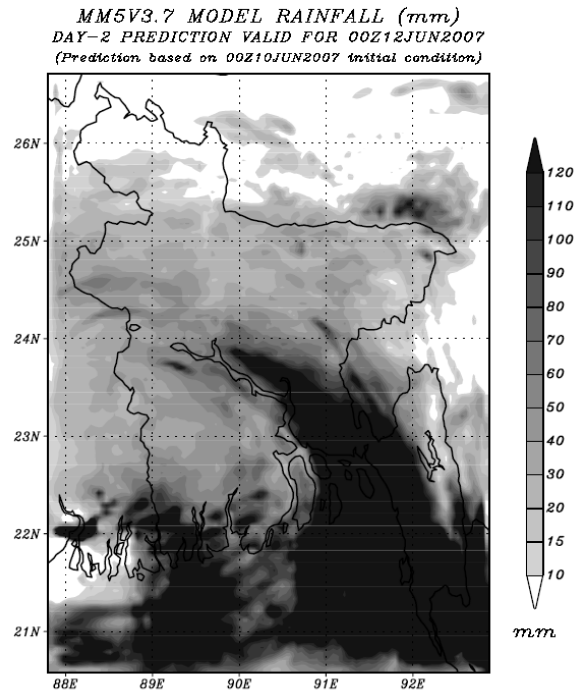
##### (a) Case-1: 11 June 2007

The prediction of this extra-ordinary high impact rainfall event on 11 June 2007 is made by using MM5 model and discussed below.

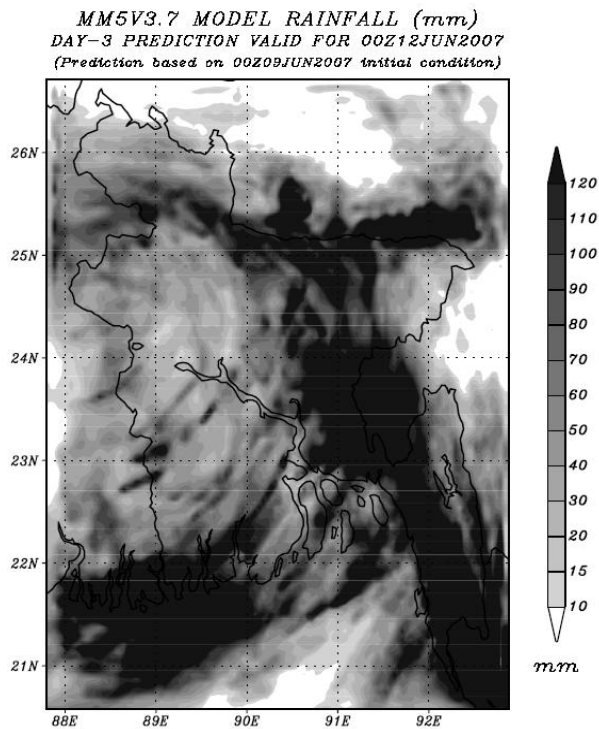
The MM5 model predicted rainfall for the Day-1, Day-2 and Day-3 prediction valid for 11 June 2007 (00Z12JUN2007) are presented in Figure 4(a-c) respectively. The inner most domain D3 at 5 km resolution was used for the rainfall prediction. The Day-1, Day-2 and Day-3 rainfall prediction for 11 June 2007 (00Z12JUN2007) were made based on the initial conditions on 00Z11JUN2007, 00Z10JUN2007, 00Z09JUN2007 respectively. The model predicted rainfall was compared with TRMM 3B42V6 and BMD observed rainfall for validating the predicted rainfall. Figure 5(a) shows the TRMM observed rainfall on 11 June 2007 and Figure 5(b) shows the BMD observed rainfall on 11 June 2007.



**Figure 4(a):** Model predicted rainfall for Day-1 prediction valid for 00 UTC of 12 June 2007 (i.e. 11 June 2007).



**Figure 4(b):** Model predicted rainfall for Day-2 prediction valid for 00 UTC of 12 June 2007 (i.e. 11 June 2007).



**Figure 4(c):** Model predicted rainfall for Day-3 prediction valid for 00 UTC of 12 June 2007 (i.e. 11 June 2007).

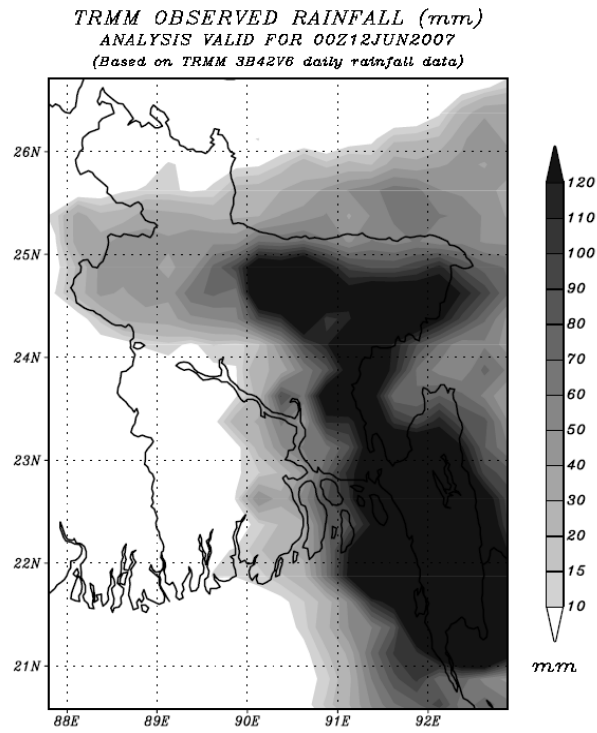


Figure 5(a): TRMM 3B42V6 observed rainfall valid for 11 June 2007

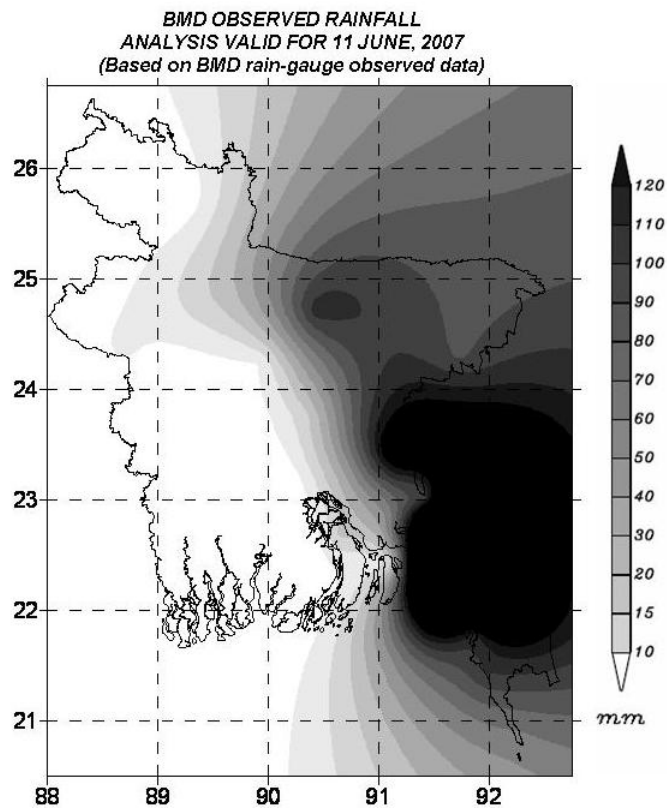


Figure 5(b): BMD observed rainfall valid for 11 June 2007

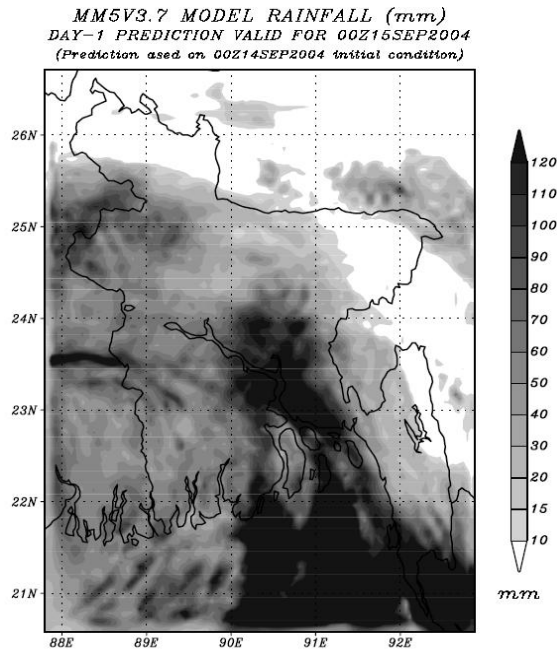
It is seen that the prediction for all the 3 ranges indicate high values of rainfall in the vicinity of Chittagong. For Day-1 prediction, model predicted rainfall is reasonably well over Chittagong and neighbourhoods, but it also predicted some rainfall over south-west Bangladesh which is not seen in TRMM as well as BMD observed rainfall. For Day-2 prediction, model predicted comparatively low rainfall over Chittagong and neighbourhoods than Day-1, but it predicted rainfall is fairly good. Model predicted rainfall for Day-3 is considerably good as compared with TRMM and BMD observed rainfall. It also predicted some rain over south-west part of the country which is not observed in TRMM and BMD observed rainfall.

**(b) Case-2: 14 September 2004**

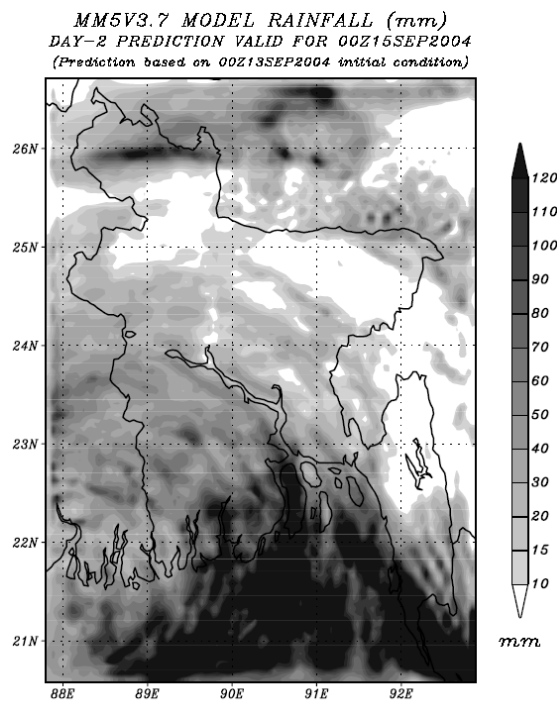
The prediction of this high impact rainfall event on 14 September 2004 is made by using MM5 Model and discussed below.

The MM5 model predicted rainfall for the Day-1, Day-2 and Day-3 prediction valid for 14 September 2004 (00Z15SEP2004) are presented in Figure 6(a-c) respectively. The inner most domain D3 at 5 km resolution was used for the rainfall prediction. The Day-1, Day-2 and Day-3 rainfall prediction for 14 September 2004 (00Z15SEP2004) were made based on the initial conditions on 00Z14SEP2004, 00Z13SEP2004, 00Z12SEP2004 respectively. The model predicted rainfall was compared with TRMM 3B42V6 and BMD observed data for validating the predicted rainfall. Figure 7(a) shows the TRMM observed rainfall on 14 September 2004 and Figure 7(b) shows the BMD observed rainfall on 14 September 2004.

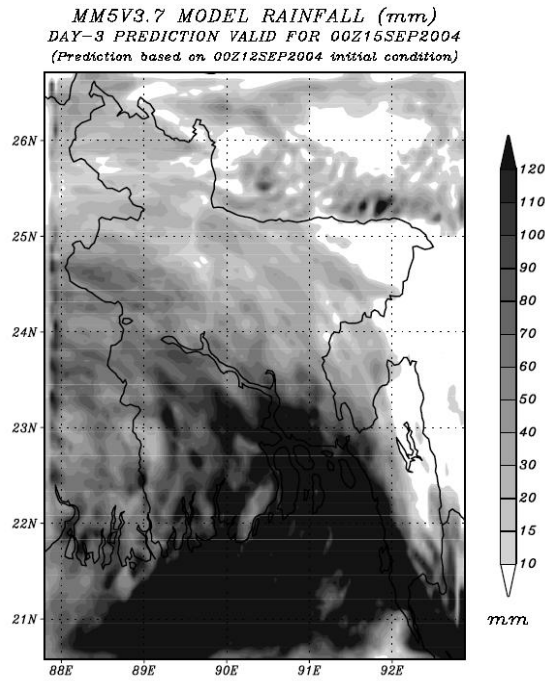
All the ranges of predictions indicate high rainfall in the vicinity of Dhaka and neighbourhoods. For Day-1 prediction, model predicted rainfall over Dhaka and neighbourhoods is fairly good, but the rainfall is over predicted as compared with TRMM and under predicted as compared with BMD. For Day-2 prediction, model predicted comparatively less rainfall over Dhaka and neighbourhoods than Day-1. But the structure of the predicted rainfall is reasonably well. Model predicted rainfall for Day-3 is considerably good as compared with TRMM and BMD observed rainfall. The predicted rainfall over the southern part of Dhaka is comparatively more and comparatively less over Dhaka and neighborhoods.



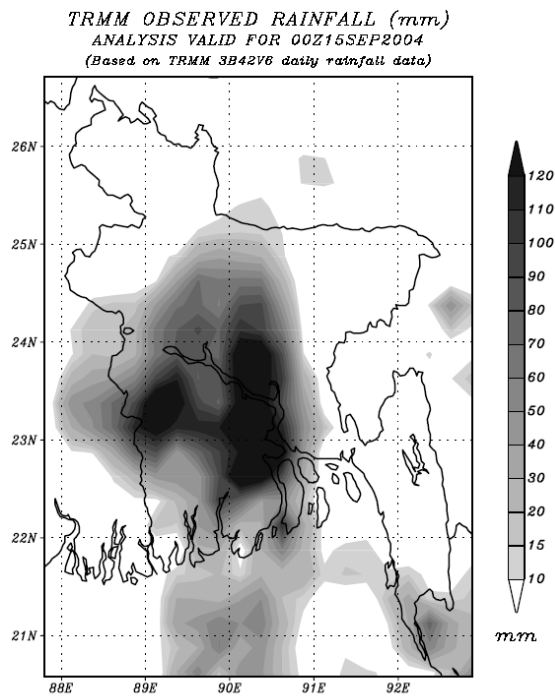
**Figure 6(a):** Model predicted rainfall for Day-1 prediction valid for 00 UTC of 15 September 2004 (i.e., 14 September 2004).



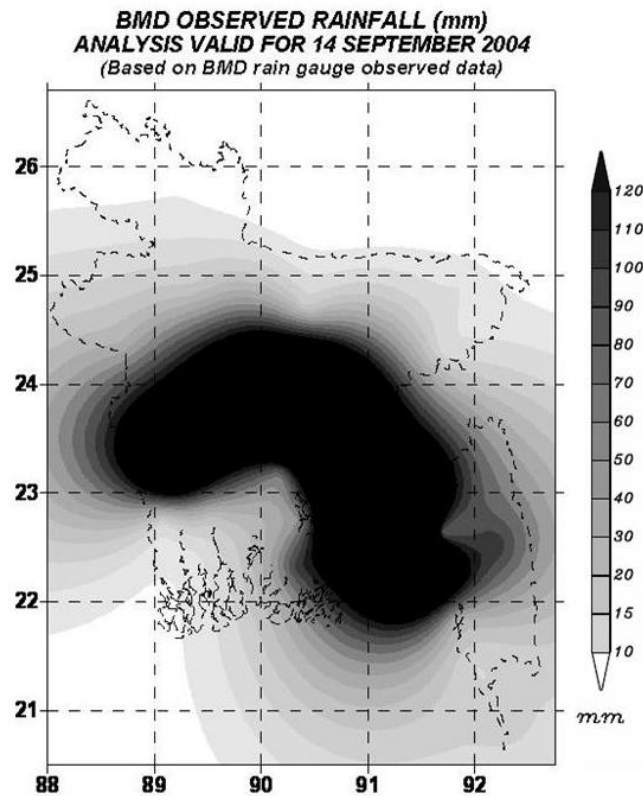
**Figure 6(b):** Model predicted rainfall for Day-2 prediction valid for 00 UTC of 15 September 2004 (i.e., 14 September 2004).



**Figure 6(c):** Model predicted rainfall for Day-3 prediction valid for 00 UTC of 15 September 2004 (i.e., 14 September 2004).



**Figure 7(a):** TRMM 3B42V6 observed rainfall valid for 14 September 2004



**Figure 7(b):** BMD observed rainfall valid for 14 September 2004

The model predicted rainfall using AK cumulus parameterization scheme with MRF PBL captured well the location and structure of the studied case in above spatial comparison. The model predicted area average rainfall is further compared quantitatively with country average BMD observed rainfall which are shown in Table-1. It is found that the model over predicted for Day-1, Day-2 and Day-3 in the order of 41.20%, 31.92% and 24.28% as compared with BMD in case of 11 June 2007 (Case-1). On the other hand, model over predicted the BMD for Day-1 in the order of 11.16%, but under predicted the BMD for Day-2 and Day-3 in the order of 21.17% and 19.40% in case of 14 September 2004 (Case-2).

The predictions are found more accurate for Day-1 (24-h) and Day-2 (48-h) in both of the cases. The prediction deteriorates as the prediction time increases. The prediction has been found to be good even for longer prediction time [(more than Day-2 (48-h)] for relatively stronger case (e.g., 11 June 2007). The prediction accuracy is low for relatively weak case (e.g., 14 September 2004) specially over Day-2 (48-h) of prediction. The prediction may be updated in every 24 hours which would provide more realistic prediction.

**Table 1:** Quantitative comparison of model predicted area average rainfall with BMD observed rainfall.

Case No	Model predicted area average rainfall (mm)for inner most domain D3			Observed Rainfall (mm)
	24-h	48-h	72-h	BMD*
	(Day-1)	(Day-2)	(Day-3)	
Case-1: 11 June, 2007	68.34	63.85	60.15	48.40
Case-2: 14 September, 2004	80.28	56.54	58.21	72.22

\*Country average rainfall

It is to mention in this regards that the network of rain-gauge stations of Bangladesh is not dense enough to capture the realistic picture of mesoscale processes unless one or more stations are located on the passage of convective systems. So far the TRMM data is concerned, it was found by Islam and Uyeda, 2007<sup>13</sup> that TRMM underestimates the monsoon rainfall in this region. Thus, the MM5 model-simulated rainfall seems to be more or less realistic both for quantitative assessment of rainfall and geographical distribution.

Moreover, the terrain data over this region is not so good. Accurate and high resolution terrain data of this region will improve the terrain fields and thus the performance of the model will also improve.

## 5. CONCLUSIONS

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

- (1) The MM5 model produces realistic prediction of high impact rainfall events in terms of intensity and structure. The predictions are more accurate for Day-1 (24-h) and Day-2 (48-h) in both of the cases. The prediction deteriorates as the prediction time increases.
- (2) The prediction has been found to be good even for longer prediction time [(more than Day-2 (48-h)] for relatively stronger case (e.g., 11 June 2007). The prediction accuracy is low for relatively weak case (e.g., 14 September 2004) specially over Day-2 (48-h) of prediction.
- (3) The prediction may be updated in every 24 hours which would provide more realistic prediction.
- (4) The terrain data over this region is not so good. Accurate and high resolution terrain data of this region will improve the terrain fields and thus the performance of the model will also improve.

Finally, it may be concluded that the MM5 Model version 3.7 with the right combination of the nesting domain, horizontal resolution and cumulus parameterization schemes might be able to predict the high impact rainfall events over Bangladesh, though there are some spatial and temporal biases in the simulated rainfall pattern.

Therefore, the Fifth-Generation PSU/NCAR Mesoscale Model MM5 may be adopted for the prediction of the high impact rainfall events of summer monsoon over Bangladesh by doing more case studies.

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## ACRONYMS:

JJAS	: June July August September
MRF	: Medium Range Forecast
NCAR	: National Centre for Atmospheric Research
PSU	: Pennsylvania State University
SAARC	: South Asian Association for Regional Cooperation
TRMM	: Tropical Rainfall Measuring Mission

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