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SELECTION OF PARAMETERIZATION IN MM5 FOR THE ESTIMATION OF RAINFALL IN BANGLADESH

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ABSTRACT

Bangladesh is one of the regions of heaviest rainfall in the world. But Bangladesh Meteorological Department (BMD) is having only s-band weather radar to collect data for one hour with two hours pause to save the cost of magnetron. Such type of break of data collection is great hindrance to study the convective systems developed here. Also the surface rain-gauges are very limited in number. In this circumstance, non-hydrostatic mesoscale model MM5 would be a good tool for the estimation of precipitation in Bangladesh area once its sensitivity is known to the concerned. With a view to estimate the rainfall in a better manner, a comparison of rain-gauge data and TRMM 3B42RT products with the outputs of ten MM5 model options has been conducted for the duration of 138 hours from 20 to 25 May 2002. By this way, the suitable parameterization scheme of MM5 for the simulation of rainfall in Bangladesh is investigated as a case study. The simulated rainfall pattern from MM5 nearly agrees with the ground-based observational data. However, different MM5 options demonstrate some variations in different observation methods as well as domains. For coarse resolution (45 × 45 km mesh) Anthes-Kuo (Ku) cumulus scheme with Blackadar planetary boundary layer (PBL) and for nested domain mesh resolutions 15 × 15 km^2 and 5 × 5 km^2 Ku and Grell cumulus schemes with MRF PBL respectively are found better with respect to TRMM value.

KEY WORD: Precipitation, calibration, simulation, cumulus parameterization.

1. INTRODUCTION

Convective activities in the tropic play an important role as a driving force of atmospheric circulation. The Asian monsoon, in particular, is composed of a diurnal cycle (Nitta and Sekine, 1994) and intraseasonal variation (Madden and Julian, 1972; Yasunari, 1979). During summer, the Bay of Bengal is characterized as the unique cloudiest oceanic area in the global tropic (Kodama et al., 2005). The monsoon wind carries water vapour from the Bay of Bengal to the inland and produces convection systems in and around Bangladesh. This phenomenon results the maximum climatic rainfall over Bangladesh to approximately 6000 mm during the summer monsoon (Matsumoto et al., 1996). Here the characteristics of rainfall fluctuate frequently with respect to place and time (Islam and Uyeda, 2005). Moreover, the monsoon rains in Bangladesh commands over life and economy. Therefore, it is very pertinent to quantify the exact amount of rainfall in different locations of the country for various application purposes. With that intention, the PSU/NCAR mesoscale model (MM5) (Dudhia, 1993; Grell et al., 1994) has been used to simulate the precipitation systems developed in Bangladesh. Moreover, for forecasting purpose model is the useful tool. However, to make the model projected parameters useful, it is essential to adopt a particular option of the model for a particular region.

Kataoka and Satomura (2005) used MM5 model for the study of diurnal variation of precipitation in this region and Islam et al. (2004) also used MM5 in simulating a case study of mesoscale convective system (MCS) developed over Bangladesh. But, there is no work on the model parameterization and estimation of precipitation using MM5. In adaptation purpose of a model, parameterization is very important because model outputs do vary with the selection of parameterization and the best fit parameterization has to be determined for capturing the local phenomena. Taking this in mind, ten MM5 options have been selected for generating precipitation systems and estimation of rainfall in this study. The precipitations obtained from these options have been compared with the Tropical Rainfall Measuring Mission (TRMM) 3B42RT products datasets (Kummerow et al., 2000) to identify the best suitable MM5 option in estimating the correct amount of rainfall over Bangladesh. Besides of TRMM datasets, rainfall data collected by the Bangladesh Meteorological Department (BMD) at 32 rain-gauge stations are also utilized for finding the suitable MM5 option for the convection systems developed in Bangladesh.

2. MODEL CONFIGURATION AND ANALYSIS METHOD

The fifth generation Pennsylvania State University/National Centre for Atmospheric Research (PSU/NCAR) mesoscale model (MM5) has been used to simulate precipitation over Bangladesh for 138 hours from 00:00 UTC of 20 to 18:00 UTC of 25 May 2002. The models have been run for three domains those are D1 (12-30N; 80-100E), D2 (18-28N; 84.8-96.2E) and D3 (22.8-26.8N; 89.7-94.2E) using two-way nesting (Fig 1).

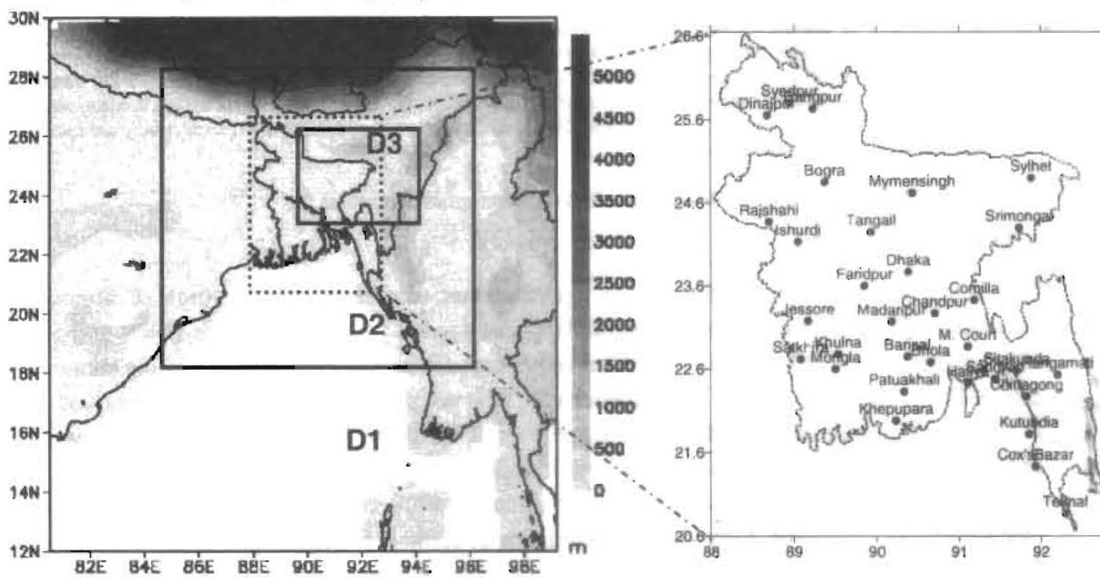

Fig 1: Analysis area showing three domains 1, 2 and 3 by D1, D2 and D3 respectively. Right panel shows the name and location (dot) of rain-gauges.

To run MM5 model, the horizontal resolutions have been taken 45 km, 15 km and 5 km with grid cells of 49×49, 79×79 and 100×100 for domains 1, 2 and 3 respectively. And the vertical layers are the default 23 sigma levels with the model top 100 hPa. The National Centre for

Environmental Prediction (NCEP) data with 6 hourly intervals and 1×1 degree resolutions are used as atmospheric initial and lateral boundary conditions data. MM5 physics options which are used include: i) Dudhia Simple Ice microphysical scheme (IMPHYS) for moisture anticipation, ii) Cloud radiation scheme (IFRAD) for radiation calculations, iii) Five-Layer Soil model (ISOIL) to predict soil temperature, iv) Two high resolution planetary boundary layer (PBL) schemes i.e. Blackadar and MRF and v) Five cumulus schemes i.e. Anthes-Kuo, Grell, Kain-Fritsch, Betts-Miller and Kain-Fritsch2 for convection (Anthes, 1977; Betts, 1986; Kain and Fritsch, 1993). Out of these five options the first three are common and two PBL of Blackadar and MRF are taken with 5 cumulus parameterization schemes for ten (2 × 5 =10) independent runs. All these options except cumulus schemes have been applied for all three domains. Cumulus schemes are applicable only for domains 1 and 2 but not for high resolution domain 3. Outputs of all ten options have been produced at one hour intervals and processed using Grid Analysis and Display system (GrADS) software for visual and numerical analysis.

MM5 outputs have been used to obtain the areal average precipitation for Bangladesh region (BD=21.5-26.7N; 88-92.6E) in D1 and D2. The same areal average has also been taken for the NE region (22.8-26.8N; 89.7-94.2E) of Bangladesh in all three domains. TRMM 3B42RT products are processed to extract precipitation for the same BD and NE area in order to compare it with the MM5 generated data. It may be mentioned here that the TRMM 3B42RT algorithm provides a combination of the TRMM real-time high quality merged passive microwave (HQ; 3B40RT) and microwave-calibrated IR (Variable Rain-rate Infrared or VAR; 3B41RT) (Huffman et al 2003). This girded output is on a 3-hour temporal resolution and a 0.25-degree by 0.25-degree spatial resolution in a global belt extending from 60 degrees South to 60 degrees North latitude.

Also MM5 model generated precipitations have been extracted at 32 rain-gauge sites in Bangladesh (right panel, Fig. 1) for D2. The data collected by the BMD at every observation sites of rain-gauges have compared with MM5 outputs. Throughout the method, at the surface simulated precipitation is considered as rainfall.

3. RESULTS AND DISCUSSION

Sensitivity study using TRMM 3B42 data

The comparison between precipitations simulated by MM5 over Bangladesh (BD) and TRMM 3B42 data has been carried out to find out the sensitivity of MM5 options and to determine the most suitable one out of 10 options taken into consideration in this study. Here, areal average precipitations (in mm) for BD area have been taken for both the domains D1 and D2 for the duration of 20 to 25 May 2002. It is found that the cumulus parameterization scheme Anthes-Kuo with Blackadar PBL (KuB) option of MM5 estimates the rainfall closer to TRMM value for D1, whereas the Anthes-Kuo with MRF PBL (KuM) option depicts the best result for D2 (Fig. 2). Hence, Anthes-Kuo scheme is found commonly suitable for both the domains but PBL are different due to the different mesh resolution in domains. In KuM and KuB options, the precipitations are 13.16 and 13.48 mm for D1, and 15.86 and 15.54 mm for D2 respectively, where TRMM value is 16.17 mm. It is clear that KuM for D2 has provided the nearest amount of rainfall to the TRMM value in BD area.

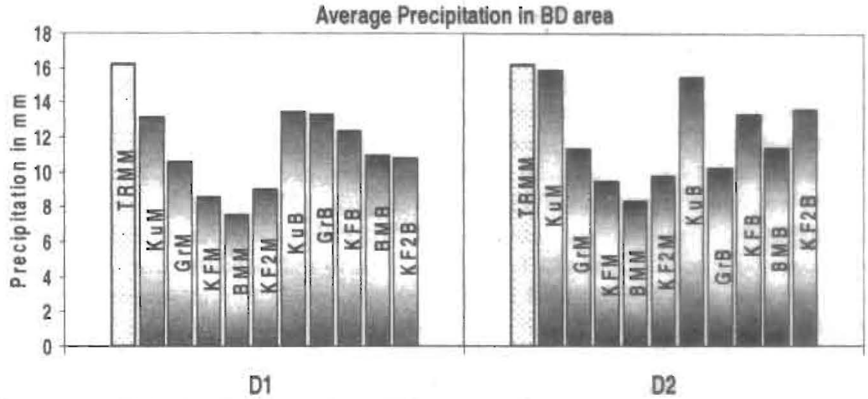

Fig 2: Comparison of simulated precipitation in BD area for 10 MM5 options with that of TRMM value for both domains 1 and 2.

In Bangladesh, intensity of precipitation varies substantially from place to place and time to time. During monsoon, heavy rainfall occurs in the north east region of Bangladesh (Islam et al., 2005). As such, this NE area (22.8-26.8N; 89.7-94.2E) has been taken as D3 to observe the consequence of high resolution on MM5 options comparing the obtained precipitation value with the TRMM one. And the Grell cumulus parameterization with MRF PBL (GrM) is found as the most suitable anticipating option. The precipitation of this NE area has also been verified for the resolutions of D1 and D2. For D1 the average precipitation of NE area is found fairly accurate to TRMM value in the Grell cumulus parameterization with Blackadar PBL (GrB) option and for D2 the KuM option shows better. The precipitations are 21.80 mm in D1 for GrB, 21.44 mm in D2 for KuM and 18.05 mm in D3 for GrM respectively, where TRMM value is 28.38 mm. The average precipitation of NE area for all three domains has been shown in Fig 3. In fact, the data resolution for TRMM is about 110 km by 102 km whereas the resolutions for D1, D2 and D3 are 45 km by 45 km, 15 km by 15 km and 5 km by 5 km respectively. Thus, the precipitation amounts generated are not expected to match perfectly, but closer one may be considered. Due to the different mesh resolutions for three domains, the individual MM5 option may be the prospective participant for each domain.

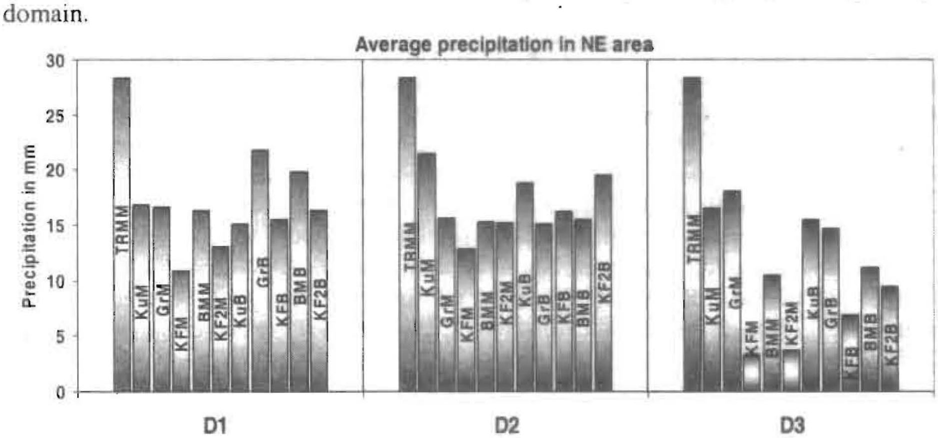

Fig 3: Comparison of simulated precipitation in NE area for 10 MM5 options with that of TRMM value for domains 1, 2 and 3.

Sensitivity study using rain-gauge data

There are BMD installed 32 rain-gauge stations scatteredly located throughout Bangladesh. The average rainfall measured by these rain-gauges for the period of 20 to 25 May 2002 is 2.24 mm. The precipitations at the locations of rain-gauges are extracted from MM5 simulation in all ten options i.e. KuM, GrM, KFM, BMM, KF2M, KuB, GrB, KFB, BMB and KF2B for the same analysis duration (20-25 May 2002) and the average values are found 3.04, 3.50, 2.34, 2.84, 2.83, 2.93, 1.36, 3.12, 2.84 and 3.02 respectively. From this objective analysis the KFM indicates the nearest result to be considered in comparison with the observational data.

The observed data collected by the BMD rain-gauges have been compared with the above mentioned extracted values of MM5 options in structural form (Fig. 4a and 4b). Figure 4a shows the comparison of spatial distribution of precipitation simulated by using MRF PBL in different parameterization schemes and rain-gauge rainfall distribution. Here, the KuM option represents the similar pattern of precipitation to that of rain-gauge rainfall.

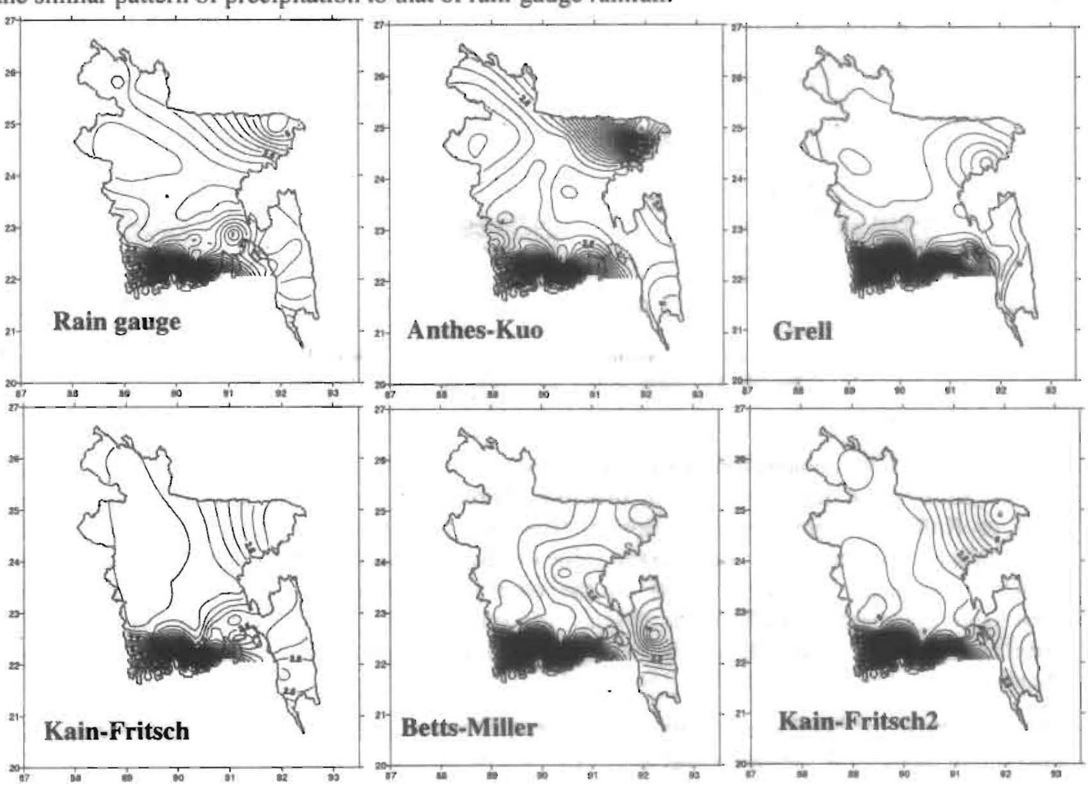

Fig 4a: Comparison of rain gauge data with precipitation simulated by five cumulus MM5 options having MRF PBL.

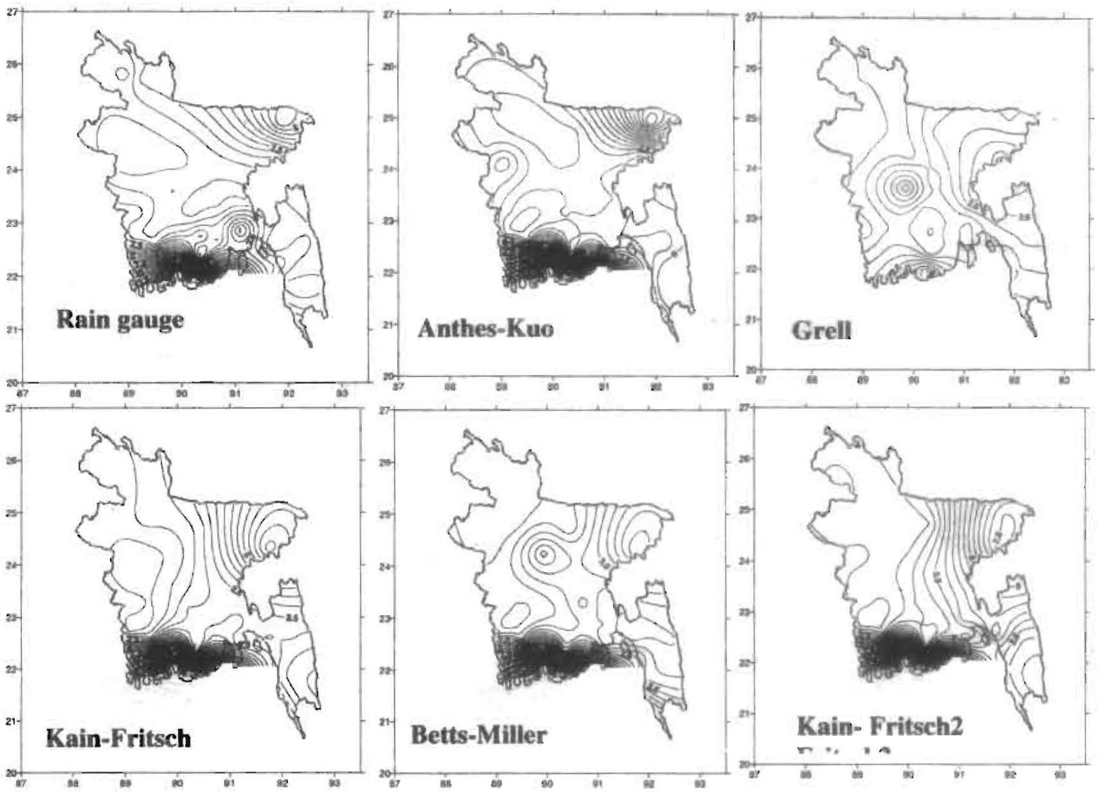

Fig 4b: The same as Fig. 4a except for Blackadar PBL.

Figure 4b shows the comparison of similar schemes as of Fig 4a but with Blackadar PBL. In this case the KuB option depicts the similar structure of precipitation to that of rain gauges. So either KuM or KuB may come as prime option. However, both KuM and KuB over estimate the precipitation in comparison to the average value of observed data. Even though the average value of KFM measured rainfall is closer to the observed data, in structural representation the remarkable drawback of KFM is the absence of rainfall estimation in the north-west region of Bangladesh. Hence, Anthes-Kuo scheme in both Blackadar and MRF options are seemed to be suitable for the detection of MCS in Bangladesh.

The comparison has also been carried out between the precipitations determined by MM5 models and rainfall amounts at the rain-gauge sites as shown in the Fig 5. Out of ten options it is seen that the trends of estimating the rainfall amounts are quite good in KuM option except only in one station i.e. Teknaf (inset, Fig 5). Interestingly, model detects the peaks very well for Khepupara and Sylhet. These two stations are located in the region of wet and heavy rainfall of the country (Islam el al., 2004). Thus the rainfall estimations at Khepupara and Sylhet regions have influenced the result significantly. Therefore, an attention may be required before using the simulated rainfall whether the same model estimates the rainfall well in the heavy rainfall regions.

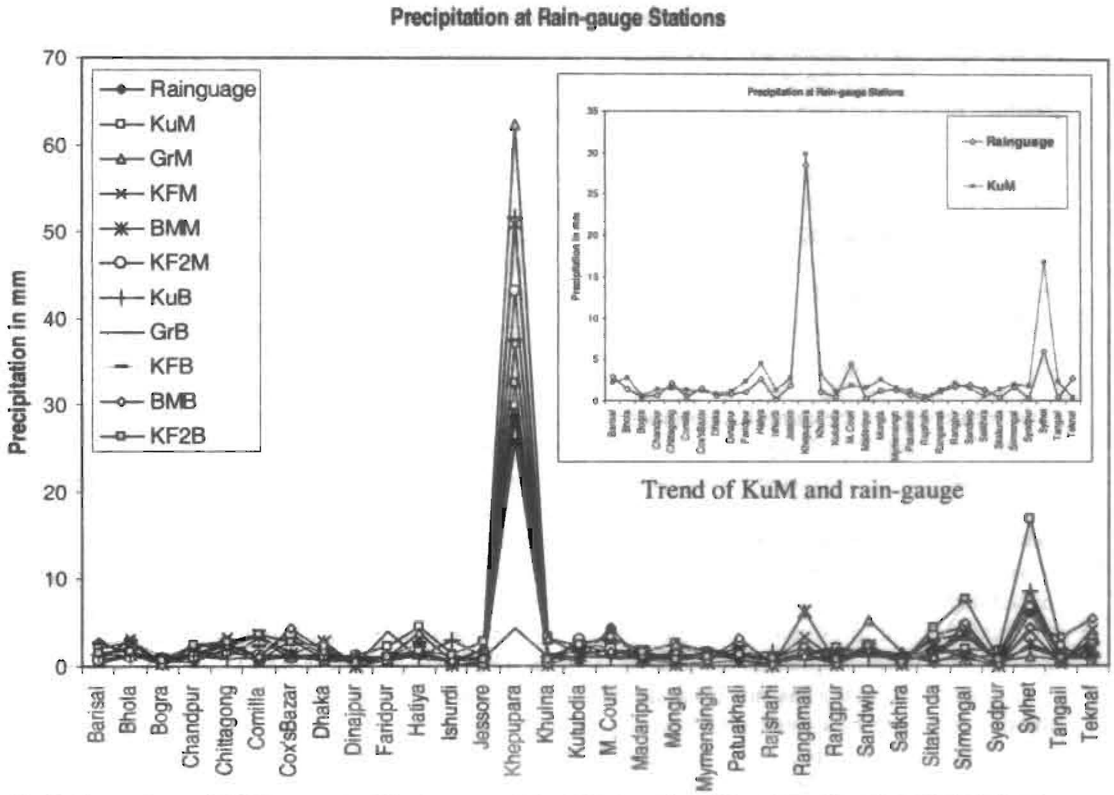

Fig 5: Comparison of MM5 outputs with rain-gauge data at different locations throughout Bangladesh (inset shows the best trend of KuM).

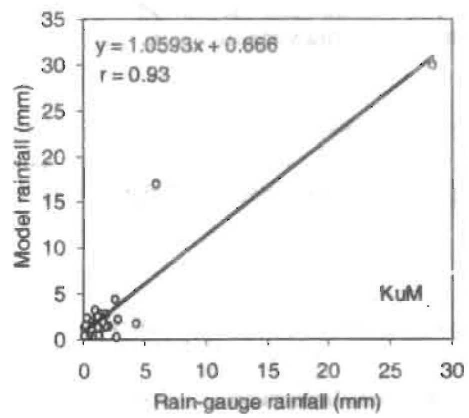

Fig 6: Correlation of rainfall between model (KuM) and rain-gauge.

The correlation between rain-gauge data and model simulated rainfall has also indicated that KuM is the most nearer option amongst ten since the coefficient for this correlation is 0.93 (Fig. 6). As indicated in Fig. 5, the correlation also highlights the reasonable comparison of rainfall in all the stations except at Sylhet. Out of 32 observational sites, KuM has overestimated at 25 sites with the range 2.18 to -2.62 excluding Sylhet. If Sylhet is excluded, correlation coefficient becomes 0.98. If Khepupara is excluded then the correlation coefficient is 0.7, which still bears significance. Taking the contribution of heavy rainfall of Khepupara into consideration, strong correlation is observed between rain-gauge and model as indicated in figures 4 and 5 and KuM of MM5 may be selected as the best option for estimation of rainfall in Bangladesh. However, from one case study it may not be enough to wind up about the suitable option of MM5 for Bangladesh. More case studies are obviously important and presently ongoing so as to find out the unconditional authenticity.

4. CONCLUSIONS

The sensitivity of the cumulus parameterization schemes and planetary boundary layer options in estimating rainfall in Bangladesh is investigated using a non-hydrostatic mesoscale model MM5. The experiment is performed with the horizontal resolution 45 km, 15 km and 5 km in domain 1, 2 and 3 respectively. The high resolution third domain is focused on northeastern part of Bangladesh, where the rainfall is comparatively heavier. For 138 hours run from 00:00 UTC of 20 May 2002, MM5 system has shown considerable results in estimating the rainfall of Bangladesh. Simulated pattern of rainfall for individual option in every domain agrees with observable evidences. Point to be noted that the options for simulation of rainfall with MM5 has been found dependable on resolution and location of the area. The best option of MM5 found for one region or with lesser resolution has not been similarly the best for another region or higher resolution. So, the option has to be a very selective one for a particular region and resolution in order to obtain reasonable accuracy. However, KuB and KuM have been observed superior over other options of MM5 for D1 and D2 domains respectively to estimate the rainfall of Bangladesh while TRMM data have been used. Furthermore, KuM generated rainfall extracted at 32 rain-gauge sites of Bangladesh has been found superior over other options. According to this case study, the Anthes-Kuo option with MRF PBL (KuM) may be considered as the most suitable amongst 10 MM5 options for the assessment of rainfall over Bangladesh. However, further study is required in different time frame and duration to draw the final conclusion in choosing the best option of MM5.

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