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Employment of MM5 in simulating MCSs developed in and around Bangladesh

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सार – मैसोस्केल संवहनीय प्रणाली (एम. सी. एस.) अनेक प्रकार की मौसम आपदाओं को उत्पन्न करती हैं। अतः बांग्लादेश और इसके आस–पास के क्षेत्रों के लिए एम. सी. एस. के बनने की क्रियाविधि को जानना महत्वपूर्ण है क्योंकि यह क्षेत्र इस उष्णकटिबंधीय क्षेत्र में सबसे भारी वर्षा वाले क्षेत्रों में से एक है। मौसम विज्ञानी रेडार और उपग्रह प्रेक्षणों के आँकड़ों का उपयोग करके विभिन्न प्रकार के एम. सी. एस. के बनने की क्रियाविधि का अध्ययन और उनका विश्लेषण कर रहे हैं। केवल वास्तविक समय के आधार पर प्रेक्षण लिए जाते हैं, परन्तु योजना तैयार करने के लिए मेसोस्केल मॉडल से एक निश्चित अवधि में योजनाबद्ध तरीके से प्राप्त किए जाने वाले प्रक्षेपित प्राचलों की आवश्यकता है। परिणामस्वरूप, इस शोधपत्र का उद्देश्य एम. एम.–5 नामक मैसोस्केल मॉडल से प्राप्त किए गए प्रतिरूपित आँकड़ों के माध्यम से मानसून पूर्व अवधि के दौरान बांग्लादेश में और उसके आस–पास के क्षेत्रों में एम. सी. एस. के बनने तथा उसके जीवन चक्र का अध्ययन करना है। इस अध्ययन में इस क्षेत्र की मानसून पूर्व अवधि के दौरान विभिन्न कपासी प्राचलीकरण के लिए एम. एम.–5 मॉडल का कैलीब्रेशन कार्य किया गया है। इस शोध पत्र में 45 कि. मी. × 45 कि. मी. और 15 कि. मी. × 15 कि. मी. के मैश विभेदनों के दो क्षेत्र तैयार किए गए हैं। सवेंदनशीलता परीक्षण के लिए विभिन्न कपासी प्राचलीकरणों का उपयोग करके एम. एम.–5 रन किए गए। इस मॉडल से प्रतिरूपित वर्षा के आँकड़ों की तुलना बांग्लादेश में उष्णकटिबंधीय वर्षा मापन मिशन (टी. आर. एम. एम.) के आँकड़ों, रेडार स्कैन से प्राप्त हुए आँकड़ों, और प्रेक्षित वर्षामापियों के साथ संरचनात्मक और संख्यात्मक आधार पर की गई है। बांग्लादेश में और उसके आस–पास वर्ष 2002 की मानसून पूर्व अवधि में बनी मैसोस्केल संवहनीय प्रणाली के महत्वपूर्ण लक्षणों जैसे उसकी अवधि, अनुरक्षण क्रियाविधि, अनुप्रस्थ मार्ग, संचरण गति और दिशा पर प्रकाश डाला जा सकता है।

ABSTRACT. The Mesoscale Convective Systems (MCSs) produce numerous weather hazards with their variety of forms. The formation mechanism of MCSs is thus important to know for Bangladesh and its surroundings, because this region is one of the heaviest rainfall areas in the tropical zone. The meteorologists are studying and analyzing the formation mechanism of different types of MCSs using radar and satellite observations data. Observations are limited to real time, but for planning purposes projected parameters over a certain period obtained from a mesoscale model is the requirement. Consequently, the motivation of this paper is to obtain the evolution and life cycle of MCSs developed in and around Bangladesh during pre-monsoon period through the simulation by a mesoscale model named MM5. In this work the calibration of MM5 model for different cumulus parameterization has been performed during the pre-monsoon period of this region. In the present study two domains with mesh resolutions 45 km × 45 km and 15 km × 15 km are prepared. MM5 runs using different cumulus parameterizations are carried out for sensitivity test. The precipitation simulated by the model are compared structurally and numerically with that of Tropical Rainfall Measuring Mission (TRMM) data products, available data from radar scan and observed rain-gauges rainfall in Bangladesh. Important features like lifetime, maintenance mechanism, traversed path, propagation speed and direction of MCSs developed during pre-monsoon period of 2002 in and around Bangladesh have been pointed out.

Key words – Rainfall, Cumulus parameterization, Mesoscale convective systems, MM5 model, Bangladesh.

1. Introduction

The extreme drought in one time and prolong flood and/or flash flood on the other are the special climatic status in Bangladesh. In the last four decades Bangladesh suffered from 28 major floods and in an average at least one every other year (Paul, 1997). Most of the time floods and/or flash floods are not anticipated ahead of occurrence. For instance, in 1998 and 2004, it would have been even unthinkable that the flood can be of so large

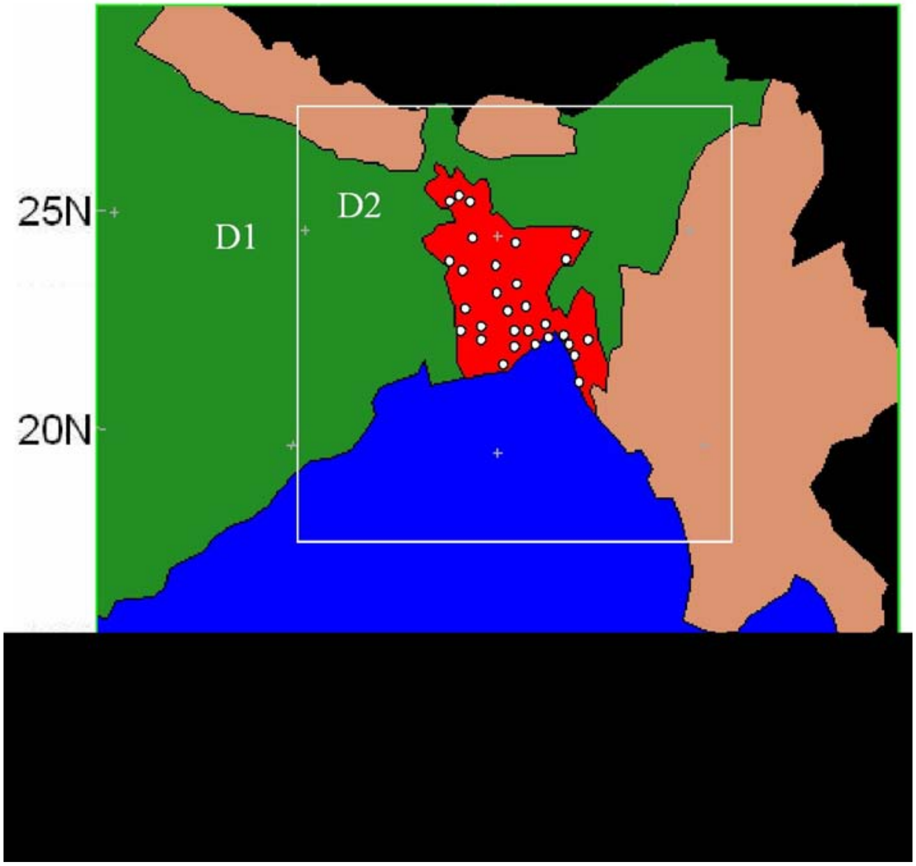

Fig. 1. Analyzing domain to run MM5 (dots indicate the rain-gauge locations)

scale with strong severity. It is because there had neither been proper means to estimate the areal average of precipitation nor to simulate climatic parameters for the forecasting mechanism in Bangladesh. Bangladesh Meteorological Department (BMD) has 34 rain-gauges placed at different locations throughout the country. The data from rain-gauges are point measurements and cannot also reflect the complete picture of precipitation systems over the country due to their limited number and non-homogeneous locations. BMD weather radar (S-band) installed at Dhaka (90.40° E and 23.68° N) is operated to collect data for one hour with two hours pause. Further, this region is one of the most cyclone prone areas. The low pressure phenomenon happens either in pre-monsoon season through April–May or post-monsoon period during October–November. Thousands of people died during the post-monsoon cyclone in 1970 and pre-monsoon cyclone in 1991. The death toll would be much lower if early warning could have been made properly and well in time using numerical weather prediction tools. These severe weathers are the occurrence of different forms of mesoscale convective systems (Maddox, 1980; Parker and Johnson, 2000; Houze, 2004). Thus, the formation mechanism of Mesoscale Convective System (MCS) and estimation of precipitation are the important factors either to predict cyclone in time and its landfall location or to anticipate severity of flood/flash flood.

In this study non-hydrostatic mesoscale model MM5 has been used to simulate precipitation systems during pre-monsoon period of 2002. Basically, the cumulus parameterization schemes for convection play an important role in the simulation process. So, their sensitivity test for Bangladesh region has been done comparing with the TRMM (Tropical Rainfall Measuring Mission) 3B42RT 3-hourly data products (Huffman *et al*., 2003), BMD 32 rain-gauge and radar (available) data. A pre-monsoon case for the period of 20-25 May 2002 has been studied to identify the best suitable parameterization scheme (Nasreen *et al*., 2007) for the convection developed in and around Bangladesh. Here the validity of that test result has been checked using another pre-monsoon case study during 31 March - 05 April 2002. The final common result of these two cases has been

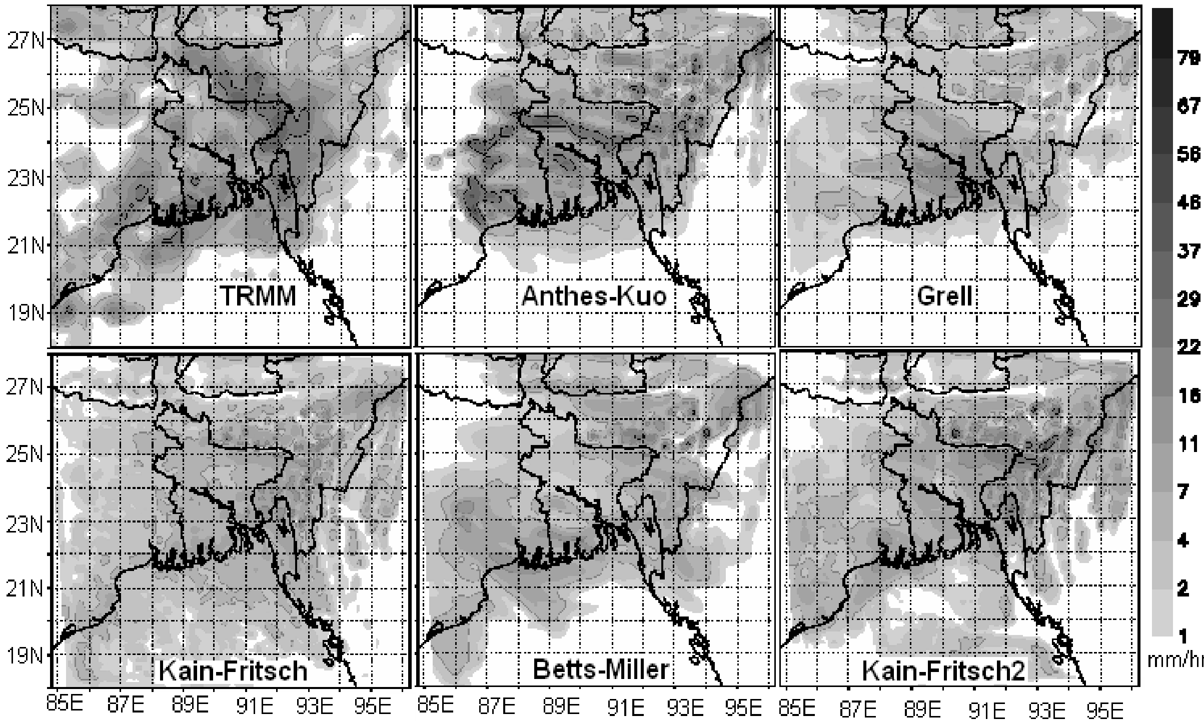

Fig. 2. Structural display of average precipitation in D2 for TRMM 3B42RT and MM5 options from 31 March to 05 April 2002

considered to articulate the best cumulus option of MM5 for Bangladesh region to simulate pre-monsoon MCSs. The best fit parameterization is then used to analyze the organization mechanism and life cycle of MCS simulated by MM5 for 20-21 May 2002.

2. Model configuration and methodology

To simulate precipitation systems developed in and around Bangladesh during pre-monsoon period, the 5th generation of non-hydrostatic PSU/NCAR mesoscale model MM5 (Dudhia, 1993 and Grell *et al.*, 1994) has been utilized. In this study two-way nested grid domains centring at 21° N and 90° E with horizontal resolutions 45 km for the coarse domain D1 and 15 km for fine domain D2 have been prepared. The grid numbers are 49 × 49 for D1 and 79 × 79 for D2, which create areas D1 (12-30° N; 80-100° E) and D2 (18-28° N; 84.8-96.2° E) respectively (Fig. 1). For vertical resolution 23 sigma model coordinates have been applied. Here Dudhia Simple Ice microphysical scheme for moisture anticipation, cloud radiation scheme for radiation calculations, five-layer soil model to predict soil temperature are selected. Also high resolution Planetary Boundary Layer (PBL) schemes MRF are selected for simulation purpose. The sensitivity test of the cumulus schemes for convection for particular region is considered with especial attention.

In this perspective, five different options of cumulus schemes which are Anthes-Kuo, Grell, Kain-Fritsch, Betts-Miller and Kain-Fritsch2 for convection (Anthes, 1977; Betts, 1986; Kain and Fritsch, 1993) has been chosen and utilized for the both course and fine domains. MM5 model is executed for each parameterization scheme separately. USGS 30 min terrain elevation, land use/vegetation and land-water mask data are utilized to provide topographical information. NCEP GRIB format data with 6 hourly intervals and 1° × 1° resolutions are used as input for initialization of MM5 meteorological fields. The model program was run for 138 hours duration with effect from 0000 UTC on 31 March to 1800 UTC on 05 April 2002 for each cumulus options. Outputs of MM5 are taken here at 01 hour interval.

Structural and numerical evaluation have been followed to find out the sensitivity of MM5 options and to determine the most suitable one out of 5 options taken into consideration. Comparisons between the simulated results for 5 different MM5 options and TRMM 3B42RT data products have been carried out structurally for the period of 31 March to 05 April 2002 for D2 domain. Thereafter, similar comparison of MM5 outputs with TRMM products has been done numerically to obtain the average precipitation for Bangladesh area (BD = 21.5-26.7° N; 88-92.6° E). For doing this, TRMM products and MM5 data have been processed to extract precipitation for the

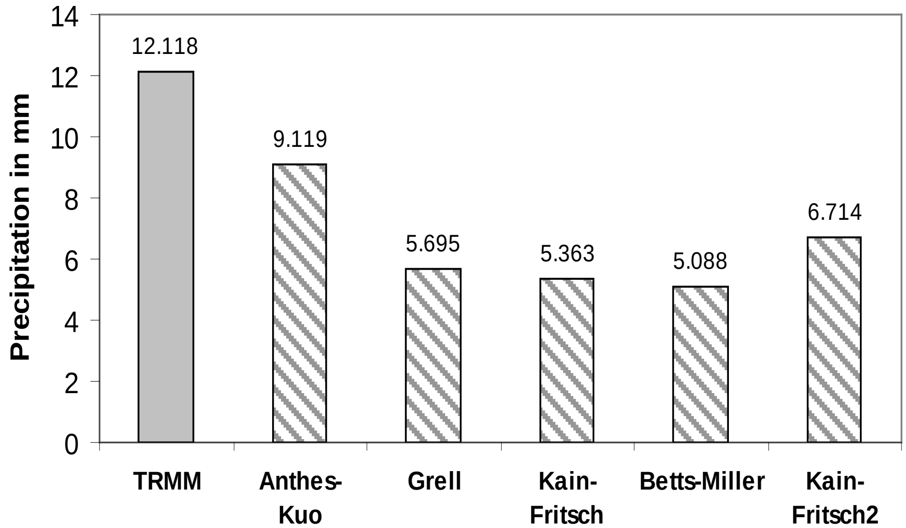

Fig. 3. Comparison of simulated precipitation in BD area for 5 cumulus options of MM5 with that of TRMM value for 138 hrs of simulation

BD region. Simulated precipitations for 5 different MM5 options have also been extracted at rain-gauge sites in Bangladesh (dots in Fig. 1, where reference data are available) from D2. These MM5 outputs have been analyzed structurally and numerically with that of collected by the BMD at the observation sites of rain-gauges. The most suitable MM5 option for the pre-monsoon period is then re-confirmed by observing the structure of the systems with the available BMD radar images. In order to do that, MM5 program is executed taking the best cumulus option into consideration to get the outputs at 10 minutes interval from 0000 UTC of 20 May to 0000 UTC of 21 May 2002. The model outputs are finally used to analyze the organization mechanism of mesoscale convective systems developed in and around Bangladesh. Cloud cells, clusters and MCS development are observed by GrADs display and their speed, direction, length, area are calculated geometrically and presented graphically.

3. Results and discussion

3.1. *Evaluation of MM5 outputs with TRMM product*

The structural comparison of average precipitation field of 5 different MM5 generated pictures with the TRMM 3B42RT products for D2 area during the time period from 0000 UTC of 31 March to 1800 UTC of 05 April 2002 is shown in Fig. 2. If structures of five MM5 outputs are very minutely observed in contrast to TRMM 3B42RT product display, cumulus scheme options Anthes-Kuo and Kain-Fritsch 2 of MM5 depict almost the similar pattern in the distribution of precipitation. These two options also show the better intensity distributions over the northeast region as in the TRMM images. It is mentionable that the northeast area is the heaviest rainfall area of Bangladesh (Islam *et al*., 2005).

Numerical comparison between precipitations simulated by MM5 over Bangladesh (BD) and TRMM 3B42RT data refines the finding of the study. Here, the average precipitations (mm/day) obtained through MM5 for the domain resolution D2 over Bangladesh region are shown graphically in respect with TRMM product in Fig. 3. From the bar diagram it is evident that TRMM 3B42RT gives much higher intensity (12.12 mm/day) than the largest value obtained from MM5 for the area BD. Anthes-Kuo option gives significantly larger and nearer value (9.12 mm/day) to TRMM amongst five cumulus parameterizations of MM5. Root Mean Square Errors (RMSE) of simulated results with respect to TRMM value have also been calculated. MM5 options *i.e.*, Anthes-Kuo, Grell, Kain-Fritsch, Betts-Miller and Kain-Fritsch 2 depict the RMSE values 0.823, 1.448, 1.522, 0.952 and 1.043 respectively. The minimum error is found in case of Anthes-Kuo.

3.2. *Evaluation of MM5 outputs with rain-gauge data*

The average rainfall per 3 hours measured by the 32 rain-gauges of BMD for the period of 31 March to 05

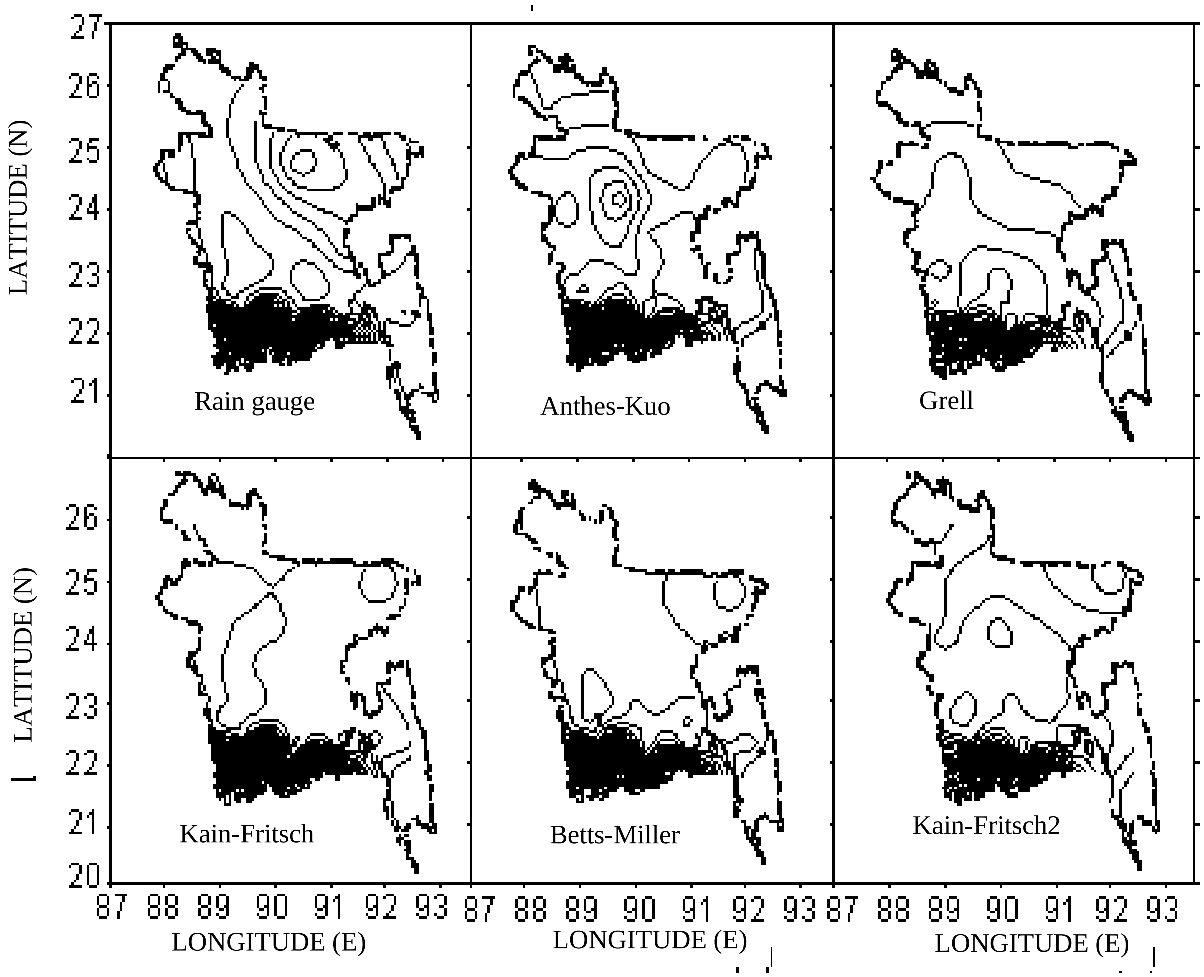

Fig. 4. Comparison of rain gauge data with precipitation simulated by five cumulus MM5 options from 31 March to 05 April 2002

April 2002 is found 2.31 mm. The precipitations at the sites of rain-gauges are extracted from MM5 simulation in all 5 cumulus options for the same analysis duration, *i.e.*, from 31 March to 05 April 2002 and the average values obtained through MM5 options are 2.14, 1.72, 2.01, 1.85 and 1.50 mm respectively. Thus, the Anthes-Kuo indicates the nearest result in comparison with the observed rainfall.

The observed rainfall collected by the BMD have been compared with the above mentioned extracted values of MM5 options in structural form as shown in Fig. 4. The comparison of spatial distribution of precipitation simulated by different parameterization schemes and rain-gauge rainfall distribution indicates reasonable results of MM5. Amongst five options, the Anthes-Kuo represents more similarity in pattern of precipitation to that of rain-gauge rainfall.

The relative status of the precipitations determined by MM5 models and amount of rainfall at the rain-gauge sites is shown in Fig. 5. Interestingly, model detects the peaks very well for Khepupara station. Out of options it is seen that the trends of estimating the rainfall amounts are quite good in Anthes-Kuo and Kain-Fritsch options. The correlation coefficient between rainfalls obtained by rain-gauge and model simulation for both Anthes-Kuo and Kain-Fritsch options is 0.99. This value is mostly influenced by Khepupara station. If this station is excluded from both the options, the correlation coefficients become 0.57 and 0.22 respectively, where Anthes-Kuo option still bears significance. The trend of rainfall for Anthes-Kuo option and its correlation with observed rainfall are shown in the inset of Fig. 5.

Structural and numerical comparison results from both TRMM and rain-gauge express that the common

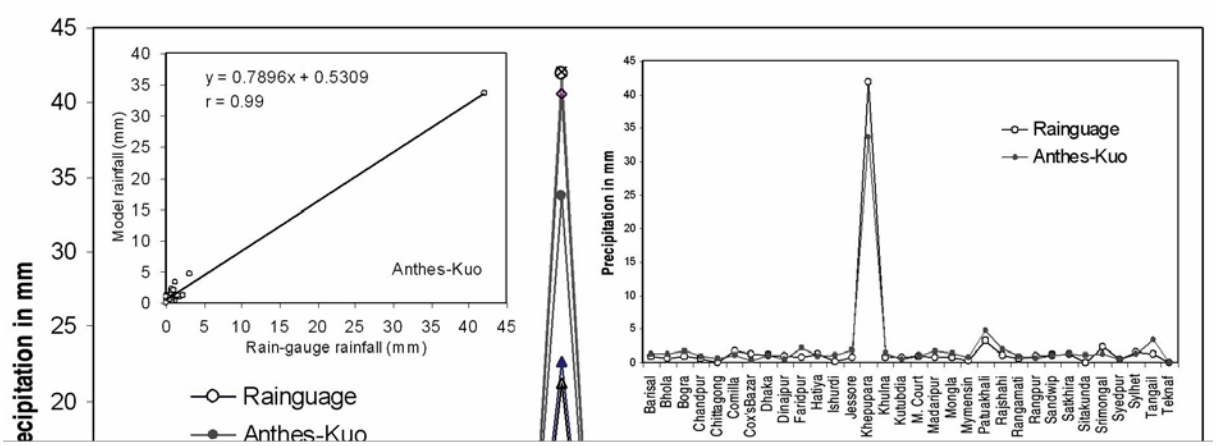

Fig. 5. Comparison of MM5 outputs with rain-gauge data at different locations throughout Bangladesh (inset shows the best trend of Anthes-Kuo and its correlation with rain-gauge) from 31 March to 05 April 2002

suitable cumulus option of MM5 for Bangladesh region is Anthes-Kuo for 31 March - 05 April 2002. The similar finding has also been obtained for the period 20 - 25 May 2002 (Nasreen *et al*., 2007). So Anthes-Kuo option may be selected as the best option for estimation of rainfall during pre-monsoon period in and around Bangladesh.

3.3. *MCS observation using Anthes-Kuo option of MM5*

The available PPI (Plan Position Indicator) scan of S-band BMD radar and MM5 generated precipitation in Anthes-Kuo option at 0900, 1200, 1500, 1800 and 2100 UTC during the pre-monsoon period of 20 May 2002 are arranged to compare the precipitation structures (Fig. 6). From these precipitation fields it is clear that Anthes-Kuo option shows almost similar structure and location as of radar images.

The available BMD radar data is of 2 hourly intervals. As such, MCS status in between could not be made available from BMD radar images. However, MCS developed during pre-monsoon period of 20 May 2002 is simulated successfully with MM5 model using Anthes-Kuo option having outputs at 10 minutes interval to investigate the missing part or intermediate condition. In this way the life cycle of MCS and the propagation continuity is found to be progressive. Basically, MCS encompasses a number of clouds in association of convective cells with contiguous precipitation area and the cloud system deals with individual cells, clusters (multi-cells), fraction parts (fragments) in case of any break up and reunion. The sequential development of MCS observed and the area occupied by them in every 10 minutes interval is shown in Fig. 7. For analyzing the convective systems developed have been named conveniently. For instance new cells, clusters and fraction cells are named as a, b, c etc.; clus1, clus2 and frac1, frac2 etc. respectively. The solid bold line of the graph shows the area of cloud system, *i.e.*, the sum up of area of all cells and clusters at a particular moment. The thin solid line indicates the area of individual cell. The dotted line

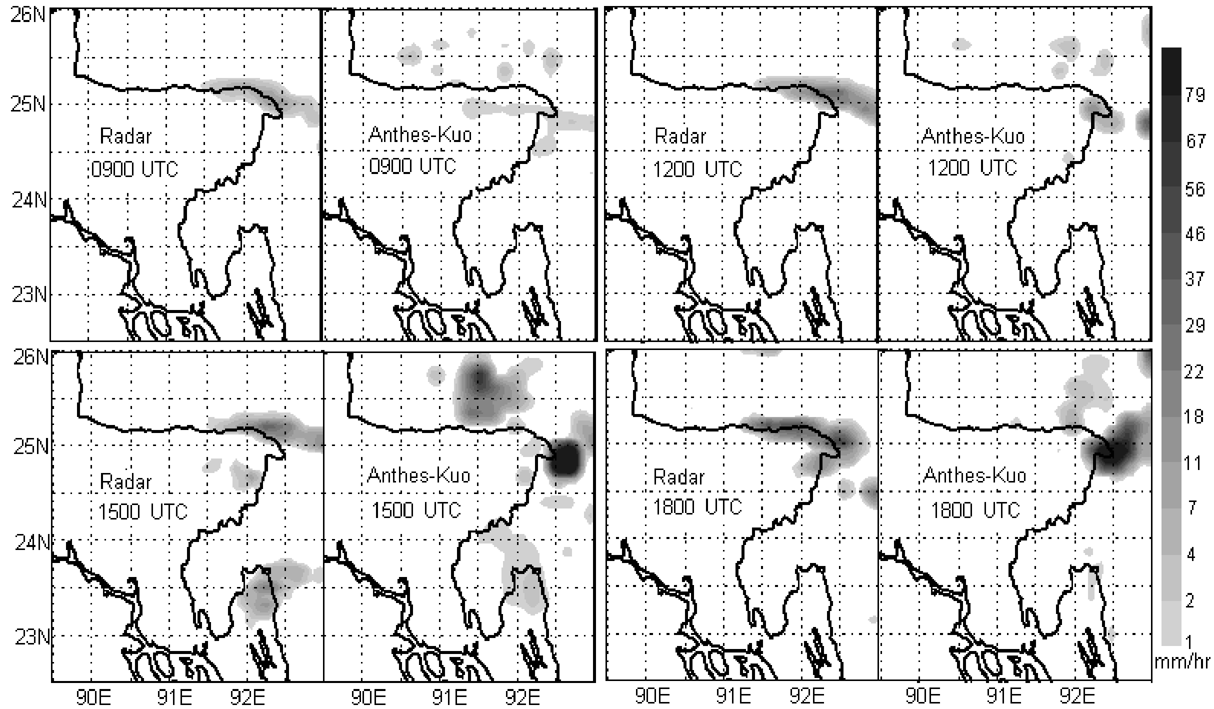

Fig. 6. Display of precipitation for Radar and Anthes-Kuo option at different time of 20 May 2002

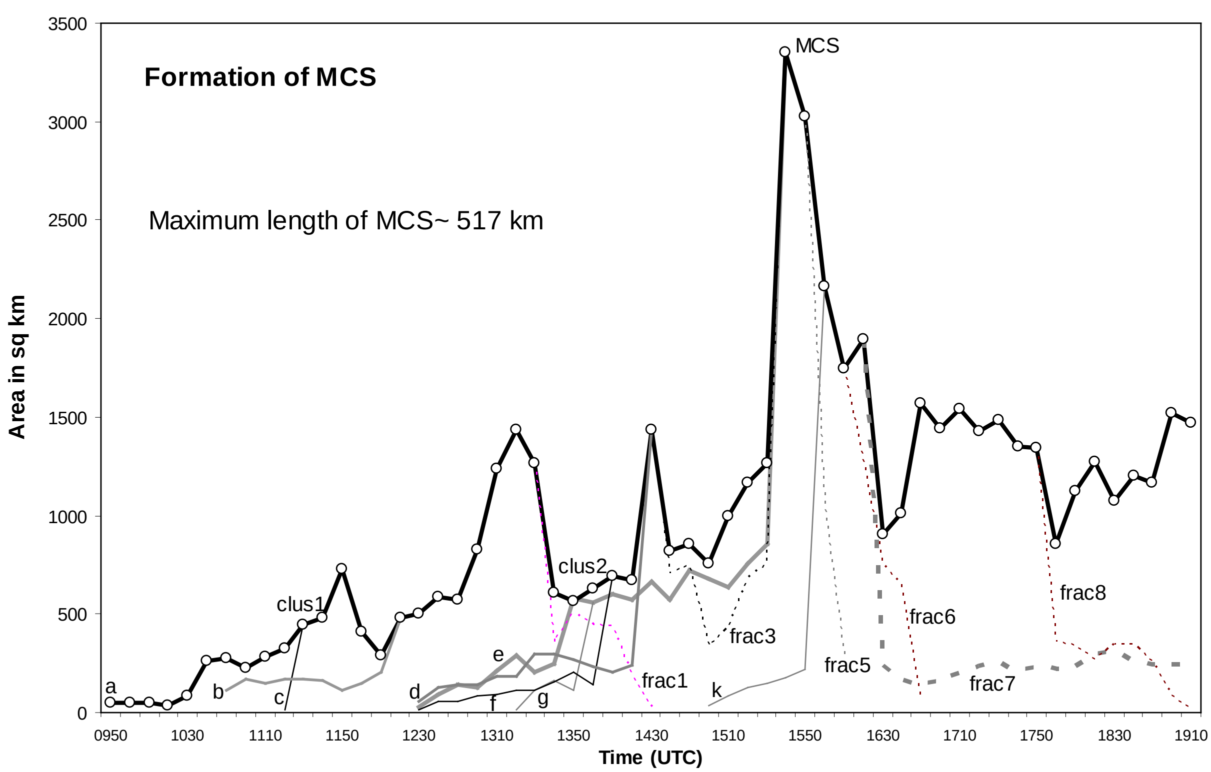

Fig. 7. Area of individual cells, clusters and MCS. Area of the cells h, i, j and fraction frac2, frac4 are not shown because their life time were very short

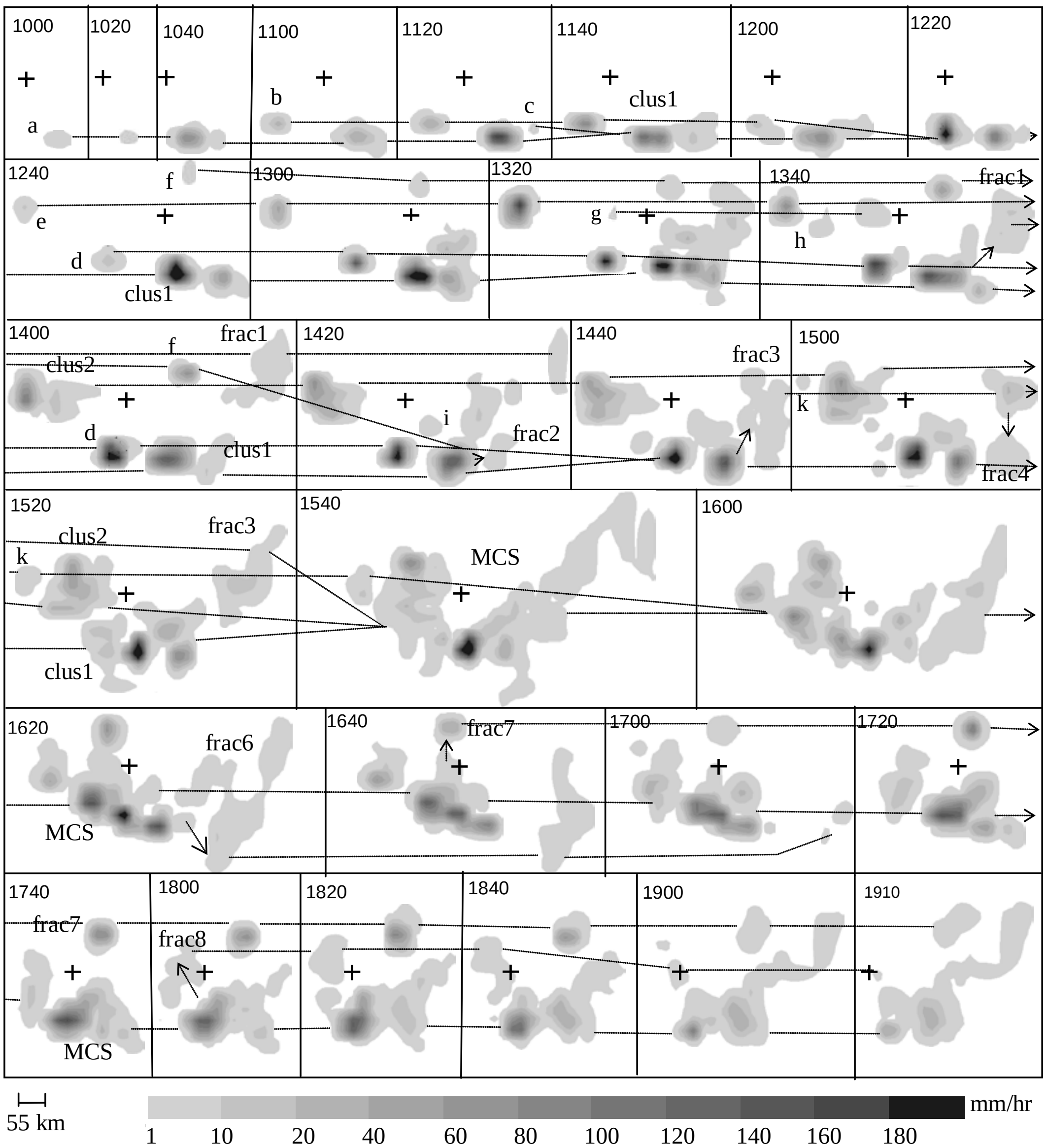

Fig. 8. Structures of cells, clusters and MCS with time (in UTC) and location. Plus mark indicates the position 92.5° E and 25.5° N taken as the relative reference point

indicates the area of fragment with its breaking up time. The MCS area while just formed from its members is the maximum, which goes down for a considerable period and then finally comes to its dissipating stage while its area has again increased to some extent before being die down. The disappearing stage is not shown here because it was out of the analysis domain.

The convective system is developed at the location 92.95° E and 24.8° N at the instant of 0950 UTC as an isolated convective cell. The initial area after just formation is found 47.5 sq km. Thereafter, other cells are formed at 1050 UTC and 1120 UTC and they joined together to form a cloud cluster. The more cells and clusters are formed and finally a MCS is developed at 1540 UTC. MCS has been found with the maximum length of about 517 km and area of about 3355 sq km. It commences dissipating at 1910 UTC and the area then becomes about 1474 sq km. The life time of total system from the formation process of MCS to dissipating stage is

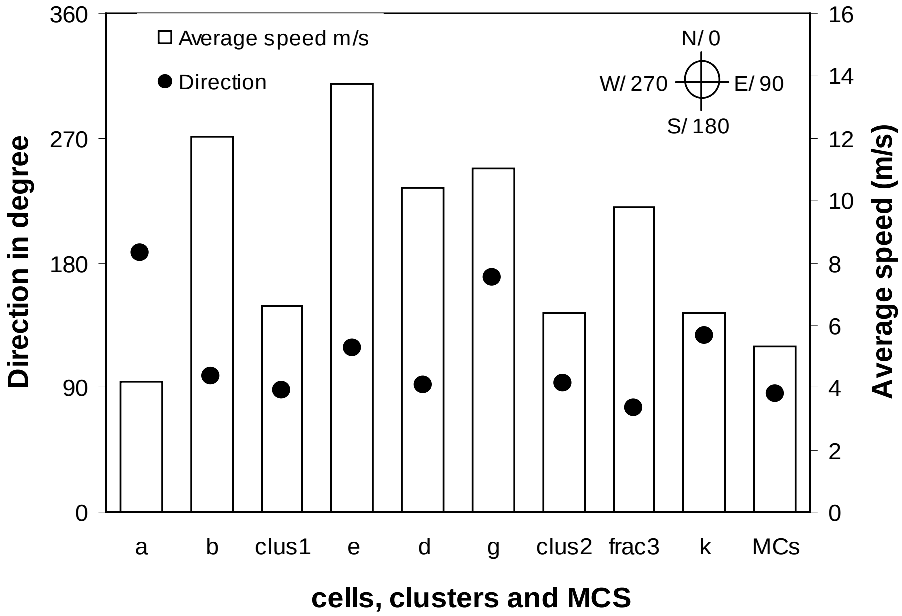

Fig. 9. Speed and direction of cell, cluster and MCS

about 9 hours and 20 minutes. After that it may disappear within short time.

The development of the MCS simulated by MM5 is shown in Fig. 8 indicating their geographical location to understand the proximity of strengthening or weakening at every 20 minutes interval from 1000 UTC to 1910 UTC. Here the plus mark in the figure indicates the location of 92.5° E and 25.5° N taken as relative reference point.

The maximum speed attained by cells, clusters and MCS are found up to 28.42 m/s, 27.5 m/s and 23.8 m/s respectively. Clusters are found with lesser average speed than individual cells. MCS average speed is again less than that of clusters (Fig. 9). Fig. 9 also shows that the average directions of motion of cells, clusters and MCS are almost lying in between 90° & 135°. Therefore, it can be said that system moves in the east-southeast direction and so. This phenomenon has the agreement with Islam *et al.* (2005) where the direction of systems on average was also found towards east-southeast analyzing BMD radar images in the month of May 2000.

4. Conclusions

The sensitivity of the cumulus parameterization schemes of non-hydrostatic mesoscale model MM5 is performed considering its necessity in estimation of precipitation in Bangladesh. The experiment is exercised with the horizontal grid resolutions of 45 km and 15 km. Pre-monsoon case study for 138 hours duration from 31 March to 05 April 2002 has been carried out. Another case study was also carried out for 24 hours on May 2002. Through both the cases, MM5 has been found reasonable in estimation of precipitation over Bangladesh. Anthes-Kuo and Kain-Fritsch2 options of MM5 for D2 area (15 km resolution) give the better structural configuration with TRMM images in both the case studies. On numerical value, Anthes-Kuo option can calculate again better average precipitation over Bangladesh area in comparison with TRMM observed amount. Almost all selected options of MM5 could simulate the heavier rainfall at Khepupara station. Considering the factors like intensity of precipitation or co-relation coefficient, Anthes-Kuo option has been found superior over other options at the locations of rain-gauges. Further, authentication of data generated from the Anthes-Kuo option with the available observed radar data has been verified on the basis of maintenance of MCS over Bangladesh. Thus, the Anthes-Kuo option may be considered as comparatively suitable amongst 5 MM5 cumulus options for the estimation of rainfall over Bangladesh. With the same cumulus scheme the convective system is then analyzed for every 10 minutes interval. The cell attains the maximum speed than cluster or MCS. Most members of pre-monsoon convective system are found moving towards the east-southeast or so. The maximum length and area of MCS are found about

517 km and about 3355 sq km respectively. The life time of mesoscale convective system is counted about 9 hours and 20 minutes. As a whole the MCS development mechanism and its propagation in Bangladesh and adjacent region during pre-monsoon period could be observed reasonably well through Anthes-Kuo option of MM5.

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