Heavy Rainfall Characteristics over Southeastern Part of Bangladesh

Kazi Jebunnesa*, Md. Abdul Mannan, Mostafizar Rahman, Farzana Sultana, Abdur Rahman, Ujjwal Kanti Paul, Abdul Hannan, Md Mizanur Rahman and Md. Abu Sayeed Mia

Bangladesh Meteorological Department, Agargaon, Dhaka-1207

**Corresponding Author E-mail: kazijebubmd@gmail.com*

Abstract

Characteristics of heavy rainfall over southeastern part of Bangladesh is different from the others part of Bangladesh due to the position and its climatic conditions. An attempt has been made to understand the categorical rainfall trend in the southeastern part of Bangladesh. The linear trend of the heavy and very heavy rainfall is decreasing in maximum stations in southeastern part of Bangladesh during 1981-2021. In this study two rainfall events are also been simulated using WRF-ARW model (version 4.4) and the CAPE, CINE, Heavy Rainfall parameters are analyzed. Model is able to simulate these events accurately.

KeyWords: CAPE, CINE and WRF-ARW.

1. Introduction

Rainfall is one of the most important factors of Bangladesh, where the economy is highly based on agricultural. About 80% people of Bangladesh live in rural area and directly or indirectly depend on agriculture. The rainfall associated extreme events may affect ecosystems, productivity of land, agriculture, food security, water availability and quality, health and livelihood of the common people of Bangladesh. Therefore, a better understanding of rainfall has important implications for the economy and society of Bangladesh (Shaheed, 2011).

Geographical location of Bangladesh in South Asia, between 20°34' to 26°38' north latitude and 88°01' to 92°41' east longitude. Maximum extension is about 440 km in E-W direction and 760 km in NNW-SSE direction. Area of Bangladesh is 147,570 sq km and the boundaries are West Bengal (India) on the west; West Bengal, assam and Meghalaya (all the Indian states) on the north; Indian states of Assam, Tripura and Mizoram together with Myanmar on the east; and the BoB on the south. The total length of the land border is about 4,246 km, of which 93.9% is shared with India and the rest 6% with Myanmar.

The topography of southeastern part of the country (21°25'N to 23°45'N latitude and 91°54'E to 92°50'E longitude) the only extensive hill area in Bangladesh lies bordering Myanmar on the southeast, the Indian state of Tripura on the north, Mizoram on the east and Chattogram district on the west. The area of the Chattogram hilly zone is about 13,184 sq km, which is approximately one-tenth of the total area of Bangladesh. Beside this Cox's Bazar, Feni are the plain land area.

Bangladesh tested two different environments, one of the Himalayas to the north and second of the Bay of Bangle to the south. According to the climatic conditions, there are four seasons in Bangladesh. They are (a) Summer (pre monsoon), the period of March to May, rainfall occurred 17%(b) Rainy Season (Southwest monsoon), the period of June to September, rainfall occurred 72%, (c) Autumn (Post monsoon), the period of October to November, rainfall occurred 9%, (d) Winter (Northeast monsoon), the period of December to February, rainfall occurred only 2%. So the period of June to September is important for received rainfall. Bangladesh, is primarily a low-lying plain country, situated on deltas of large rivers flowing from the Himalayas, has a sub-tropical humid climate characterized by wide seasonal variations.

Rainfall is very important for the survival of plants and animals. Rainfall is the source of fresh water of the earth surface. If rainfalls less, there is water scarcity which sometime causes drought like situation. If there is excess of rain, floods eventuated which make the life of the affected people miserable. It is also one of the source of water for rivers, lakes and others aquifers. Rainfall is needed for the cultivation as a good balance of rain and proper irrigation can lead to faster growing plants, which can cut down on germination time and the length between seeding and harvest. The crops are directly dependent on water during their entire life-cycle in order to survive and thrive. Rainfall is the most important factor in defining climate. Excess rainfall can cause flooding and enormous property and crop damage. Beside this, a deficiency of rainfall can cause drought and crop failure. Rainfall is also the major source of energy that drives the circulation of the atmosphere.

Rainfall is an important factor for the population living in coastal Bangladesh. Erratic rainfall and associated extreme events could have negative impacts on the ecosystem, agriculture, business, health and the overall livelihoods of the common people. According to the IPCC 4th assessment report there will be a 5% to 6% increase in rainfall in Bangladesh by 2030. A better understanding of the rainfall pattern is important for formulating efficient resource management and climate change adaptation policies.

In the Southeastern part of Bangladesh rainfall is an important factor. Whereas the topography of southeastern part of Bangladesh is combined of hills and plain land .The Chattogram Hills constitute the only significant hill system in the country. It rises steeply to narrow ridge lines (average 36m wide), with elevation ranges between 600 and 900m above mean sea level. In between the hilly ridges lie the valleys that generally run north to south. West of the Chattogram hills is a narrow, wet coastal plain lying parallel to the shoreline. In this region sometimes heavy rainfall causes mountain collapse. As a result peoples whose living under mountainside they are affected. Coastal people are also affected by heavy rainfall. For agriculture, industry and others sector rainfall is important element but heavy rainfall is harmful.

The rainfall in Bangladesh varies, depending upon season and location. Winter (November to February) is very dry and accounts for only less than 4% of the annual rainfall. Rainfall in this season varies from 20 mm in the west and south to 40 mm in the northeast, which is caused by the westerly disturbances that enter the country from the northwestern part of India. The rainy season (June to October) accounts for 70 to 85% of the annual rainfall, which varies from 70% in the eastern part of the country to about 80% in the southwest, and 85% in the northwest. The amount of rainfall during this season varies from 1000 mm in the west-central part of the country to over 2000 mm in the south and northeast.

Bangladesh is one of the most flood prone countries. The floods in Bangladesh mostly occur during monsoon season due to heavy rainfall. But most of the heavy rainfall events occur in monsoon months, and the northeastern, eastern and southeastern regions of the country are most susceptible for this meteorological phenomenon.

In Bangladesh rainfall is mostly occurs in monsoon period. In the period of monsoon warm air contained more moisture and if this warm air gets enough sufficient moisture supply from the ocean, then it draws up extra moisture. As a result occurred weak tropical depression which brought from the Bay of Bengal over Bangladesh. higher rainfall in the northeast is caused by the additional uplifting effect of the Meghalaya plateau. By the monsoon depression, monsoon wind carried more moisture, so that cloud contained greater number of large rain droplets and heavy rainfall occurred. As the climate continues to warm, this effect will be increased and heavy rainfall also be a common phenomenon.

2. Literature Review

Bangladesh has a sub-tropical humid climate characterized by wide seasonal variations. Rainfall in Bangladesh mostly occurs in monsoon period, caused by the weak tropical depressions that are brought from the Rain gauge stations location of BMD and selected area of northeastern part of Bangladesh used under this study Bay of Bengal into Bangladesh by the wet monsoon winds. More than 75% rainfall occurs in the monsoon period in Bangladesh.

Heavy rainfall dense bamboo and cane bushes, high flood plain and the flashy rivers- all the features are very related and contributed by the hills of this region. Any change of the hydro-climatic pattern in this region is significantly affects the balance among these natural resources of the southeastern part of Bangladesh.

3. Experimental Set Up, Data used and Methodology

As per objectives of this study Chattogram region of Bangladesh has been selected. According to the mandate, Bangladesh Meteorological Department (BMD) has been collecting rainfall data of Bangladesh region through its surface synoptic observatories. For understanding the rainfall variability of the region daily rainfall data collected from the 7 Synoptic stations of BMD (Teknaf, Kutubdia, Cox’s Bazar, Rangamati, Chattogram, Sitakunda, Sandwip) are collected and utilized. Using this data monthly rainfall distribution of each other selected stations are calculated and analyzed. Over the period the period rainfall amounts are varying and accordingly it has the impact on the society. To know this temporal variation of monthly, seasonal and annual rainfall for each of the stations are calculated and analyzed. Similarly, variability of heavy rainfall (HR) including trends and rate of increment or decrement are calculated. The computation provision has been calculated using MS Excel and R codes.

Table 1: List of the simulated Heavy Rainfall events

Sl	Date	Average rainfall over the region	Maximum Rainfall	Location of maximum rainfall
01.	01 July 2021		216 mm	Chattogram
02.	18-19 June 2020		253 mm	Cox's Bazar

The meteorological event of heavy rainfalls over northeastern part of Bangladesh has good impact on the society. But the accurate and timely predictions of HRs are very challenging. Their physical processes are also complex in nature. To understand this and to contribute in this aspect few HR events (Table 1) are selected and accordingly simulations have been conducted using WRF-ARW Model (version: 4.4.1). Model description has been given in Table 2. Simulated result has been highlighted in the respective chapter.

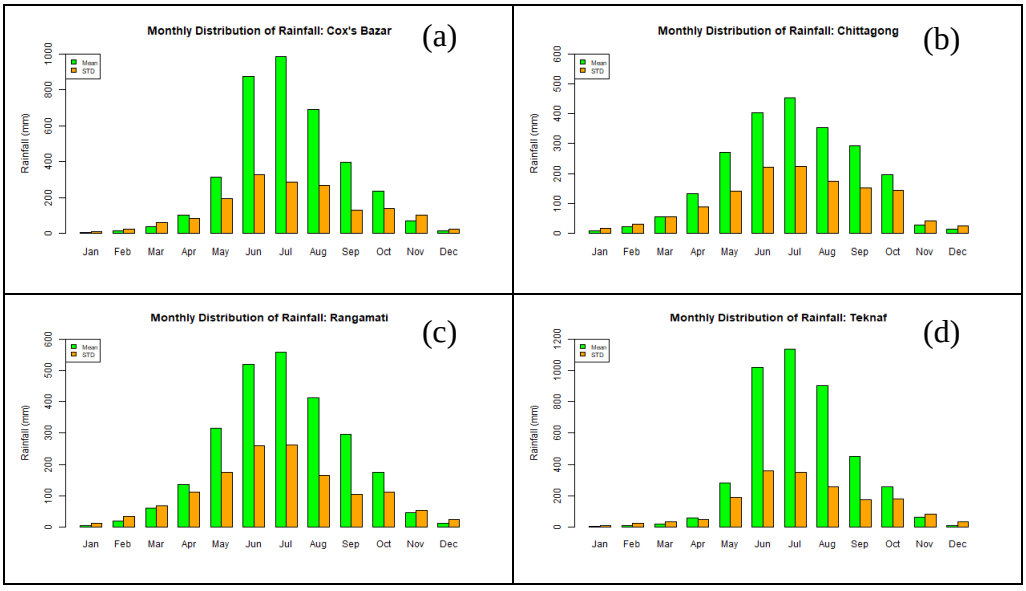
Table-2: Configuration of WRF-ARW model (Version 4.4.1)

	WRF CORE	ARW
Domain and dynamics	Data	NCEP GFS
	Input data interval	3 hour
	Number of domain	1
	Domain central point	20º-24ºN and 90º-93ºE
	Resolution	9 km
	Covered area	15.5º-28.5ºN and 82º-98ºE
	Integration time step	60 sec
	Map projection	Mercator
	Vertical coordinates	Pressure coordinate
	Time integration scheme	Default
	Spatial differencing scheme	Default
Physics	cumulus	Default
	microphysics	Default
	PBL Parameterization	Default

4.Results and Discussion

4.1 Monthly Distribution of Rainfall at Cox's Bazar

Monthly rainfall distribution indicates that the amounts of rainfall are different at different months. It is the highest in July and the lowest in January. Amounts of rainfall are higher in monsoon months and lower in pre-monsoon and post-monsoon months. It is the lowest in winter months. Similarly, the variability of rainfall amounts (as measured through standard deviation, STD) are higher in the monsoon months, lower in pre-monsoon and post monsoon months. The variability of rainfall in winter months are higher compared to mean rainfall is the indication of high variability of rainfall in winter months.



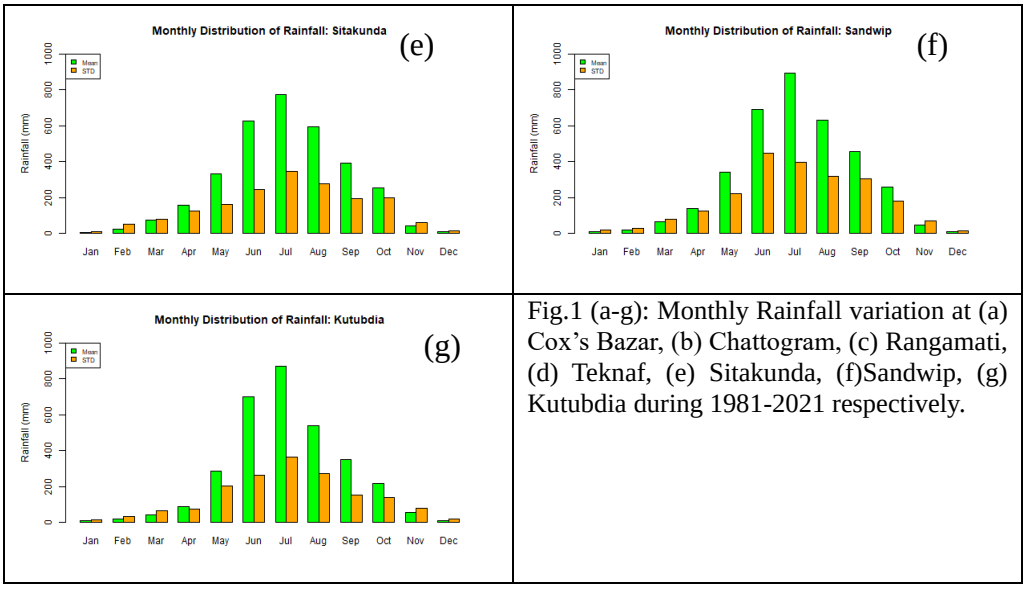
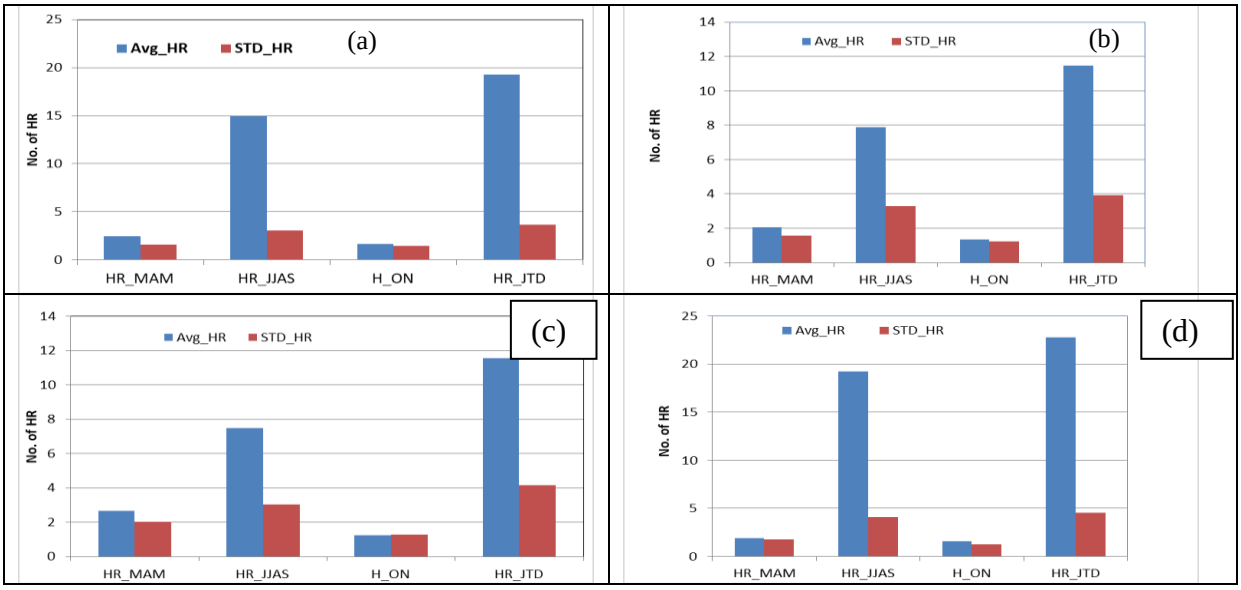


Fig.1 (a-g): Monthly Rainfall variation at (a) Cox's Bazar, (b) Chattogram, (c) Rangamati, (d) Teknaf, (e) Sitakunda, (f)Sandwip, (g) Kutubdia during 1981-2021 respectively.

The amounts of rainfall distribution at Chattogram, Rangamati, Sitakunda, Sandwip and Kutubdia are lower than Cox's Bazar during monsoon months and pre-monsoon months except Teknaf. Amounts of rainfall is highest in monsoon and lowest in winter monsoon. Similarly, the variability of rainfall amounts (as measured through standard deviation, STD) are higher in the monsoon months, lower in pre-monsoon and post monsoon months. The variability of rainfall in winter months are higher compared to mean rainfall is the indication of high variability of rainfall in winter months. This variation is almost similar with excel calculations.

Heavy rainfall activities over Southeastern part of Bangladesh

Heavy Rainfall (HR) activities during winter season are not available over SE-BD during the period under consideration. It is less frequent in pre-monsoon and post-monsoon months and very frequent during monsoon months. As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.5, 14.9 and 1.7 respectively and the annual no. of HR is at Cox's Bazar is 19.2. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.6, 3.1 and 1.5 respectively and the annual no. of HR is 3.7.



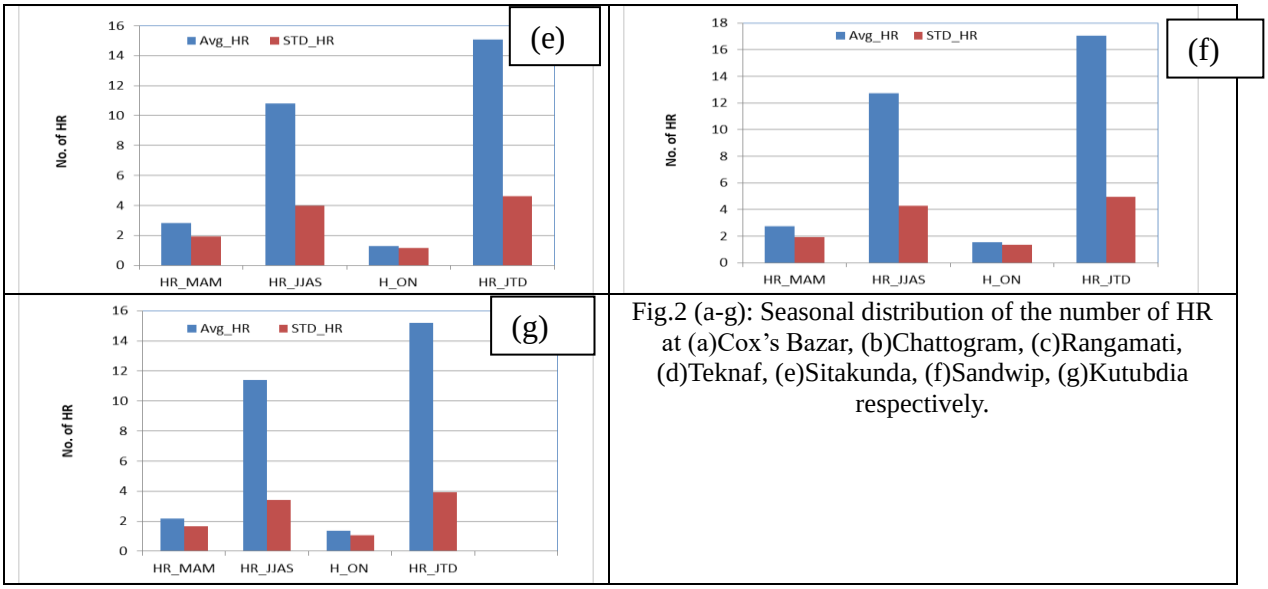


Fig.2 (a-g): Seasonal distribution of the number of HR at (a)Cox's Bazar, (b)Chattogram, (c)Rangamati, (d)Teknaf, (e)Sitakunda, (f)Sandwip, (g)Kutubdia respectively.

Heavy Rainfall (HR) activities are less frequent in pre-monsoon and post-monsoon months and very frequent during monsoon months at Chattogram, Rangamati, Teknaf, Sitakunda, Sandwip and Kutubdia. As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.1, 7.9 and 1.3 respectively and the annual no. of HR is at Chattogram is 11.5. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.6, 3.3 and 1.2 respectively and the annual no. of HR is 3.9.

As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.7, 7.5 and 1.2 respectively and the annual no. of HR is at Rangamati is 11.6. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.0, 3.0 and 1.3 respectively and the annual no. of HR is at Rangamati is 4.1.

As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.9, 19.2 and 1.6 respectively and the annual no. of HR is at Teknaf is 22.8. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.8, 4.2 and 1.3 respectively and the annual no. of HR is at Teknaf is 4.6. Which is highest than any other area of SE-BD zone .

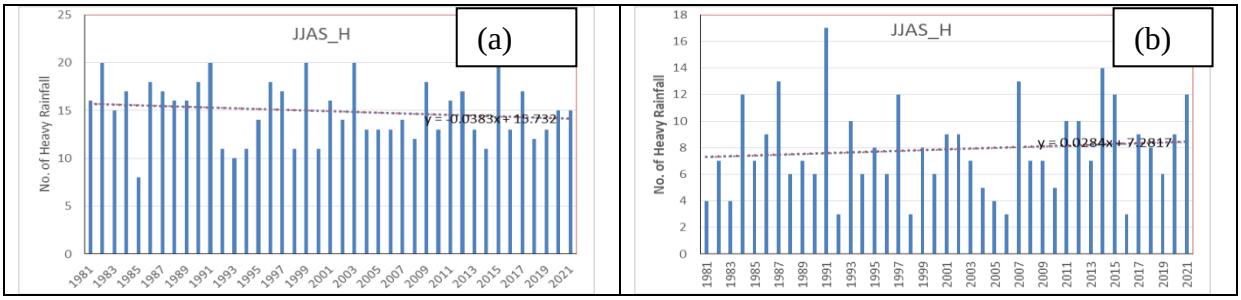
As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.8, 10.8 and 1.3 respectively and the annual no. of HR is at Sitakunda is 15.1. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.0, 6.8 and 0.7 respectively and the annual no. of HR is at Sitakunda is 8.6.

As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.7, 7.5 and 1.2 respectively and the annual no. of HR is at Sandwip is 11.6. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.0, 3.0 and 1.3 respectively and the annual no. of HR is at Sandwip is 4.1.

As a whole the average no. of HR in pre-monsoon, monsoon and post-monsoon seasons are 2.2, 11.4 and 1.4 respectively and the annual no. of HR is at Kutubdia is 15.2. And the STD of HR in pre-monsoon, monsoon and post-monsoon seasons are 1.7, 3.4 and 1.0 respectively and the annual no. of HR is at Sandwip is 3.9.

Temporal variation of the no. of HR:

No. of HR is almost frequent at Cox's Bazar during monsoon season. It was more frequent during 1981-2003. But it becomes quite low frequent during the recent years. It was highest in 1982,1991,1999,2003 and 2015 but lowest in 1985. As a whole the no. of HR shows the decreasing trend at Cox's Bazar.



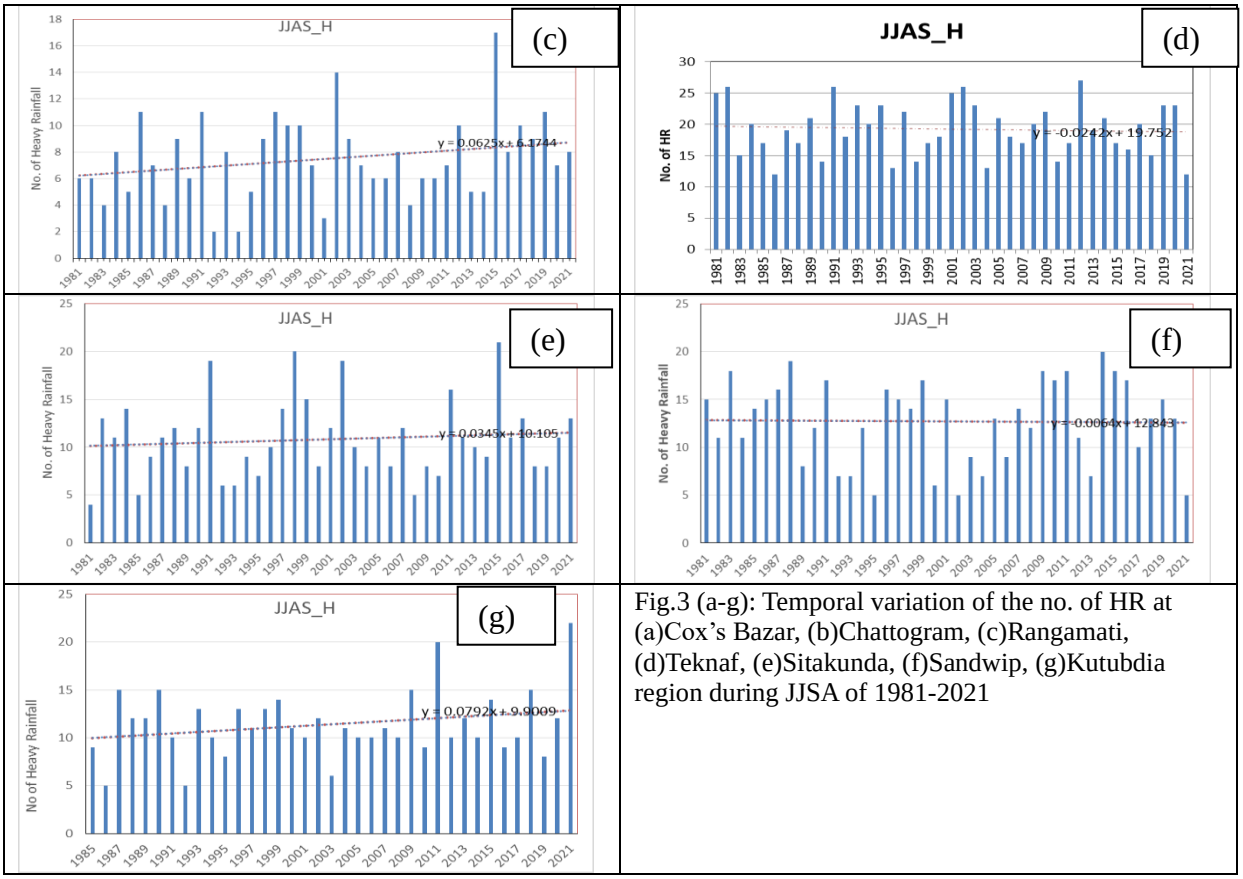


Fig.3 (a-g): Temporal variation of the no. of HR at (a)Cox's Bazar, (b)Chattogram, (c)Rangamati, (d)Teknaf, (e)Sitakunda, (f)Sandwip, (g)Kutubdia region during JJSA of 1981-2021

No. of HR is quite frequent at Chattogram during monsoon season. It was less frequent during 1992-2006. But it becomes more frequent during the recent years. It was high in 2014 and highest in 1991 but lowest in 1992 and 1998. As a whole the no. of HR shows a quite increasing trend at Chattogram.

No. of HR is quite frequent at Rangamati during monsoon season. It was less frequent during 1981-1995. But it becomes more frequent during the recent years. It was high in 2002 and highest in 2015 but lowest in 1992 and 1994. As a whole the no. of HR shows an increasing trend at Rangamati.

No. of HR is quite frequent at Teknaf during monsoon season. It was more frequent during 1981-1995. But it becomes less frequent during the recent years. It was high in 1982,1991,2002 and highest in 2012 but lowest in 1986 and 2021. As a whole the no. of HR shows a decreasing trend at Teknaf.

No. of HR is more frequent at Sitakunda during monsoon season. It was quit frequent during 1981-1990. But it becomes more frequent during the recent years. It was high in 1998 and highest in 2015 but lowest in 1981. As a whole the no. of HR shows an increasing trend at Sitakunda.

No. of HR is frequent at Sandwip during monsoon season. It was high in 1988 and highest in 2014 but lowest in 1995 and 2002. As a whole the no. of HR shows a linear trend at Sandwip.

The no. of HR is more frequent at Kutubdia during monsoon season. It was less frequent during 1981-2010. But it becomes more frequent during the recent years. It was high in 2011 and highest in 2021 but lowest in 1986 and 1992. As a whole the no. of HR shows an increasing trend at Kutubdia.

4.3. Very Heavy rainfall activities over Southeastern part of Bangladesh

4.3.1 Very Heavy rainfall at Cox's Bazar

Very Heavy Rainfall (VHR) activities during winter season are not available over SE-BD during the period under consideration. It is less frequent in pre-monsoon and post-monsoon months and quite frequent during monsoon months. As a whole the average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons are 0.8, 8.4 and 0.6 respectively and the annual no. of VHR is at Cox's Bazar is 9.9. And the STD of the no. of VHR in pre-monsoon, monsoon and post-monsoon seasons are 0.8, 8.4 and 0.6 respectively and the annual no. of VHR is at Cox's Bazar is 9.9.

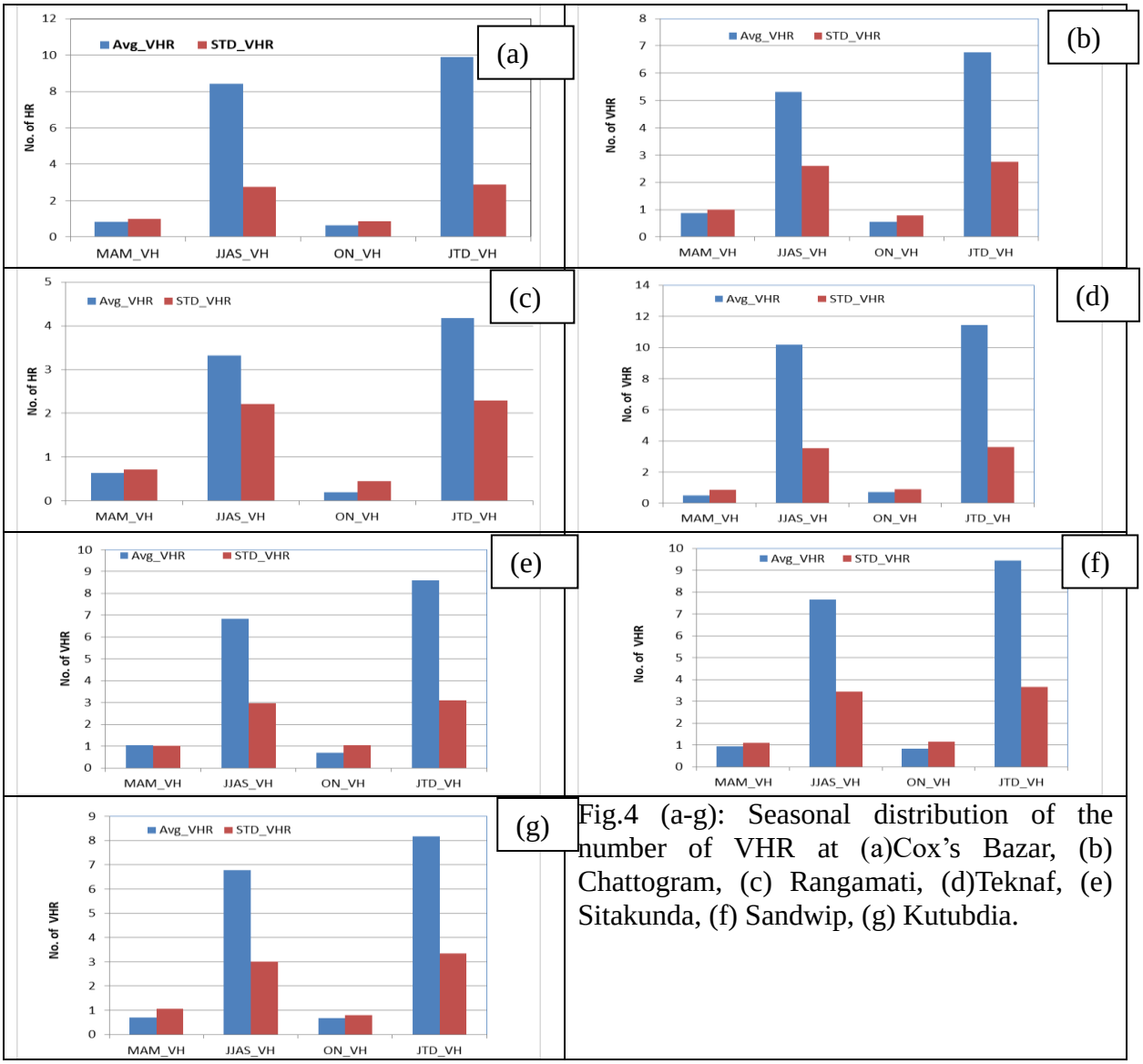


Fig.4 (a-g): Seasonal distribution of the number of VHR at (a)Cox's Bazar, (b) Chattogram, (c) Rangamati, (d)Teknaf, (e) Sitakunda, (f) Sandwip, (g) Kutubdia.

Seasonal distribution of VHR is displayed in Fig. 4.3.2(a). The average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons are 0.9, 5.3 and 0.6 respectively and the annual no. of VHR is at Chattogram is 6.8. The STD of the no. of VHR in pre-monsoon, monsoon and post-monsoon seasons are 1.0, 2.6 and 0.8 respectively and the annual no. of HR is at Chattogram is 2.8.

The average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 0.6, 3.3 and 0.2 and its annual no. is 4.2 at Rangamati. The STD of VHR in pre-monsoon, monsoon and post-monsoon seasons also respectively are 0.7, 2.2 and 0.5 and its annual no. is 2.3.

The average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 0.5, 10.2 and 0.7 and the annual no. of it is 11.4 at Teknaf. Similarly, the STD of VHR in pre-monsoon, monsoon and post-monsoon seasons are 0.9, 3.6 and 0.9 respectively.

Very Heavy Rainfall (VHR) activities are less frequent in pre-monsoon and post-monsoon months and quite frequent during monsoon months. The average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons are 1.0, 6.8 and 0.7 respectively and the annual no. of it is 8.6 at Sitakunda. And the STD of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 1.0, 3.0 and 1.0 and the annual no. of it is 3.1.

Very Heavy Rainfall (VHR) activities are more frequent in pre-monsoon and post-monsoon months and very frequent during monsoon months. As a whole the average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 0.9, 7.7 and 0.8 and the annual no. of it is 9.4. As per the analysis the STD of

VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 1.1, 3.4 and 1.1 and the annual no. of it is 3.6.

Very Heavy Rainfall (VHR) activities are very less frequent in pre-monsoon and post-monsoon months and quite frequent during monsoon months. The average no. of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 0.7, 6.8 and 0.7 and the annual no. of it is 8.2. The STD of VHR in pre-monsoon, monsoon and post-monsoon seasons respectively are 1.1, 3.0 and 0.8 and the annual no. of it is 3.3.

Temporal variation of the no. of VHR:

Analysis indicates that the no. of VHR is quite frequent at Cox's Bazar during monsoon season. It was more frequent during 1987-2015. But it becomes quite low during the recent years. It was the highest in 2000 but lowest in 1981 and 2010. As a whole the no. of VHR shows negative trend but it is not considerable.

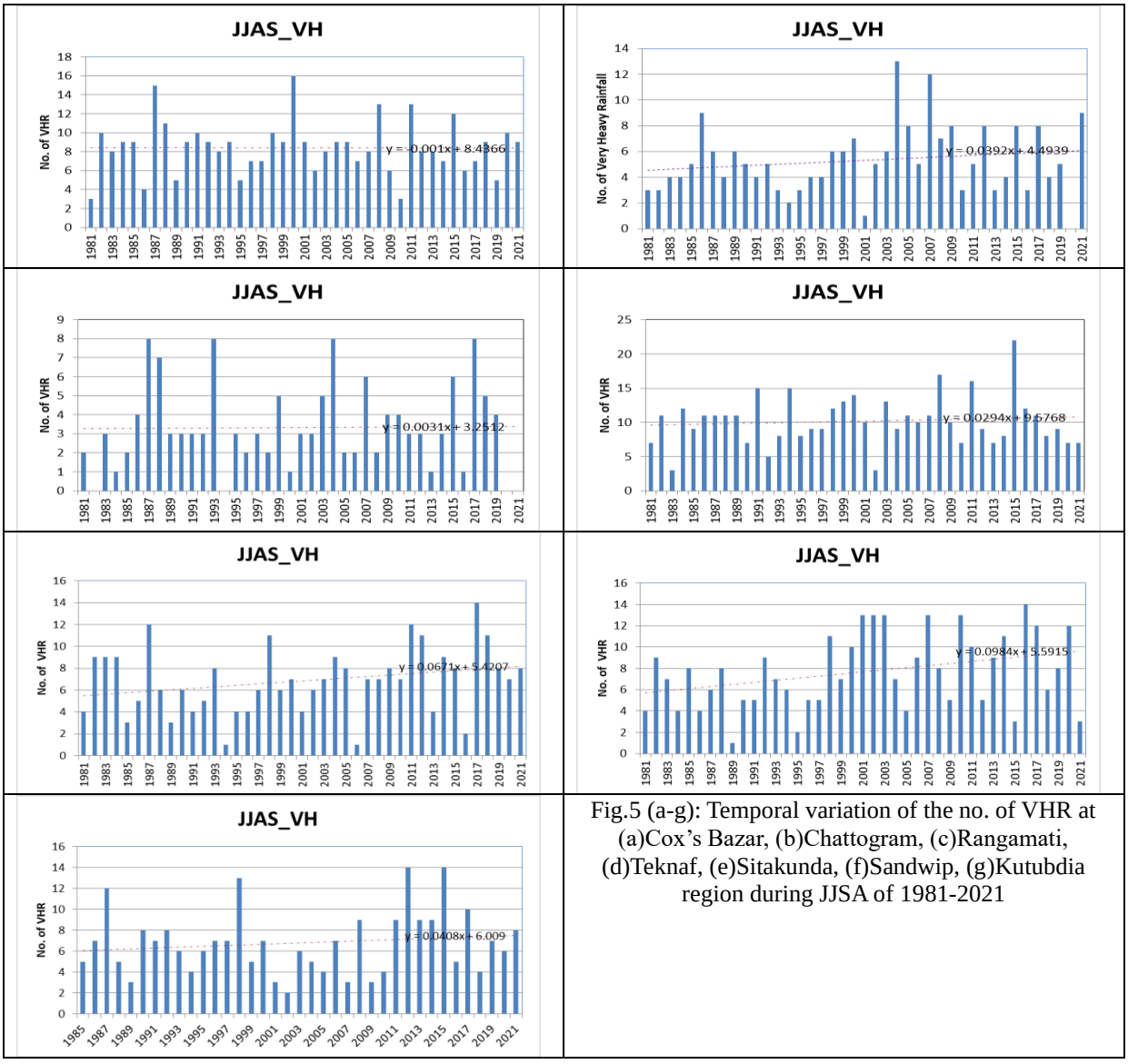


Fig.5 (a-g): Temporal variation of the no. of VHR at (a)Cox's Bazar, (b)Chattogram, (c)Rangamati, (d)Teknaf, (e)Sitakunda, (f)Sandwip, (g)Kutubdia region during JJSA of 1981-2021

No. of VHR is almost frequent at Chattogram during monsoon season as shown in Fig. 4.3.2. It was less frequent during 1981-2003. But it was more frequent during the recent years. The no. of VHR was the highest in 2004, followed by 2007, 1986 and 2021. It was absent in 2020. As a whole the no. of VHR shows an increasing trend of 0.04/year.

The no. of VHR is quite frequent at Rangamati during monsoon season. It was high in 1987, 1993, 2004 and 2017 but low in 1984, 2000, 2013 and 2016. It was absent in 1994, 2020 and 2021. As a whole the no. of VHR shows positive trend at Rangamati but is not considerable.

No. of VHR is quite frequent at Teknaf during monsoon season. It was more recurrent during 1981-1990. But it becomes less frequent during the recent years. It was high in 1991, 2004, 2008 and 2011 and the highest in 2015. Again, it was very low in1983 and 2002. As a whole the no. of VHR shows slight increasing trend at Teknaf.

No. of VHR is more frequent at Sitakunda during monsoon season as displayed in Fig. 4.3.5(b). It becomes more frequent during the recent years. It was considerably high in 1987 and 2011 and the highest in 2017. But it was very low in 1994 and 2006. The no. of VHR shows an increasing trend, which is 0.07/year.

No. of VHR is frequent at Sandwip during monsoon season as shown in Fig.4.3.6(b). It was the highest in 2016 but lowest in 1989. As a whole the no. of HR shows an increasing trend of 0.098/year.

The no. of VHR is quite frequent at Kutubdia during monsoon season. It was less frequent during 1985-1997 but it becomes more frequent during the recent years. It was high in 1987 and 1998 with the highest in 2012 & 2015 and lowest in 2002. As a whole the no. of VHR shows an increasing trend of 0.04/year (Fig. 4.3.7(b)).

Synoptic Conditions during the day of Heavy Rainfall:

Synoptic setting over Bangladesh and adjoining area

As per the surface and upper air observation the axis of monsoon trough runs through Uttar Pradesh, Bihar and West Bengal to Assam of Assam across northern part of Bangladesh with its associated trough extends upto northern part of the Bay of Bengal during 01-03 July 2021. As a result, active monsoon situation prevailed over Bangladesh and it was moderate over North Bay. Accordingly, a wind discontinuity persists over southeastern part of Bangladesh and northeastern part of the Bay of Bengal. Monsoon flow was quite strong for carrying moisture.

Description of the event

As a governing factor of monsoon, the monsoon trough and its north-south orientation plays a vital role for monsoon rainfall activity over Bangladesh. In a similar manner the spatial variation of active and break phases of monsoon are recognized. Due to the presence of monsoon-axis over northern part of Bangladesh and its extension towards east and west, active monsoon situation appear over Bangladesh region and moderately active monsoon over the Bay of Bengal. As a result, high amounts of rainfall were recorded over southeastern part of Bangladesh during 01-03 July 2021. The significant amounts rainfall recorded during this period were 242 mm (at Chattogram), 237 mm (at Cox's Bazar), 180 mm (at Teknaf), 167 mm (at Kutubdia), 164 mm (at Sandwip), 104 mm (at Sandwip) and 91 mm (at Rangamati). The rainfalls were continuing during this period but the highest amounts were during 01 to 02 July 2021. The highest amounts of daily rainfall during this period were 216 mm at Chattogram (01 July) followed by 110 mm (at Cox's Bazar) on 02 July 2021. As a whole, the region was under the substantial influence of rainfall.

4.4 Simulation of the heavy rainfall event on 01-03 July 2021

4.4.1 Convective Available Potential Energy (CAPE)

Spatial distribution of simulated Maximum Convective Available Potential Energy (CAPE) depicts a differential CAPE zone with east-west gradient persists initially over southern part of Bangladesh, when higher CAPE is found over western side (over ocean) and lower CAPE is over eastern side (over landmass). It then intensified and moved slowly eastwards and finally higher CAPE persists over the northern part of the BoB along north-south direction. But lower CAPE persists over southeastern landmass area along north-south direction (Fig 6(a-c). This situation might be very helpful for deep convection over the BoB, vertical lifting of moisture content for high amounts of rainfall over SE-BD.

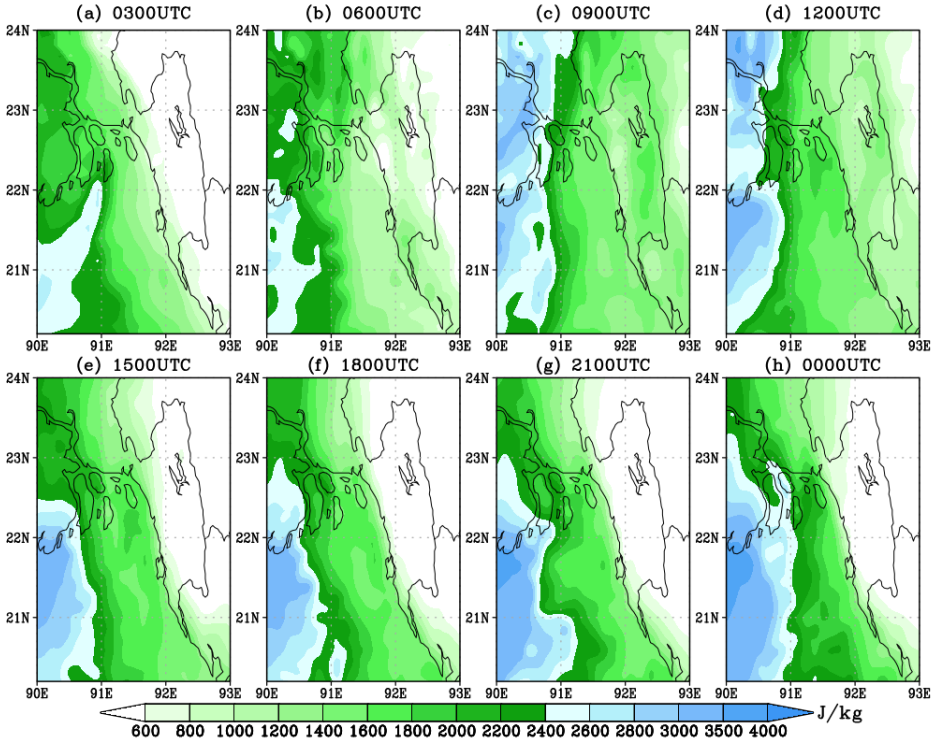


Fig. 6 (a): Temporal variation of surface maximum CAPE on 01 July 2021

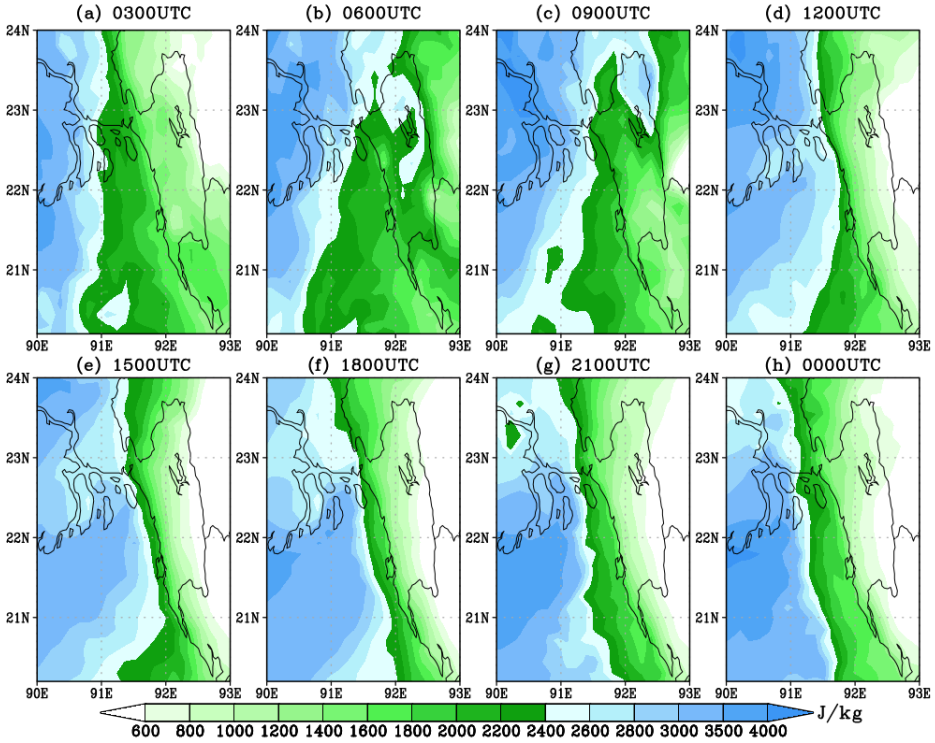


Fig. 6 (b): Temporal variation of surface maximum CAPE on 02 July 2021

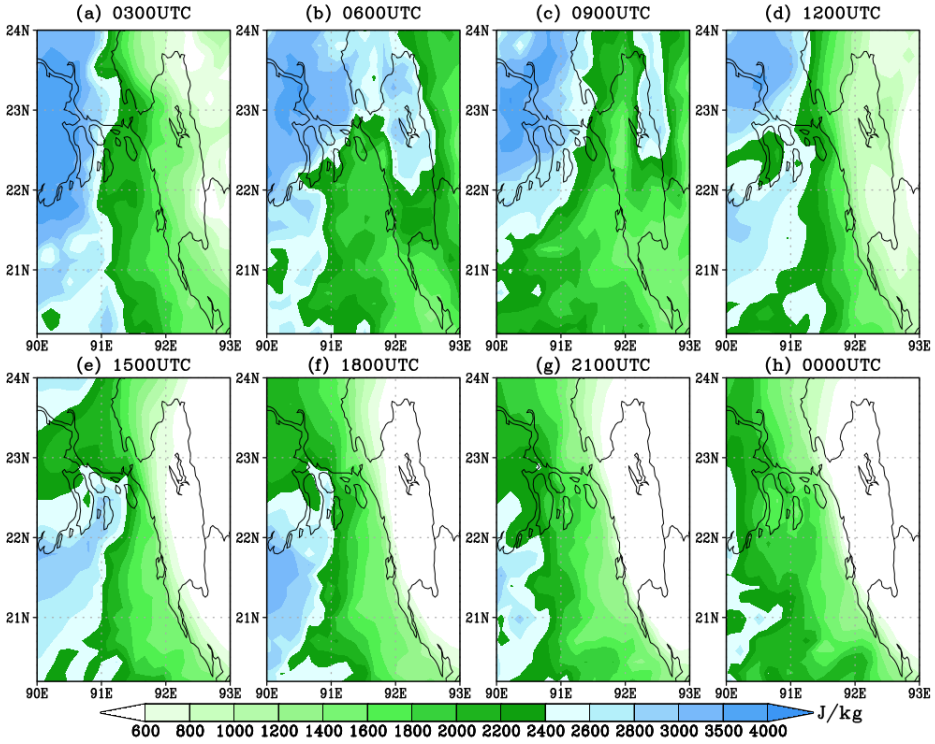


Fig. 6 (c): Temporal variation of surface maximum CAPE on 03 July 2021

4.4.2 Convective Inhibition Energy

Simulation represents low Convective Inhibition Energy (CINE) at surface as well as lower troposphere during the interested period over the heavy rainfall occurrence area, which are the favourable condition of deep convection as well as the occurrence of heavy rainfall (Fig. (a-c).

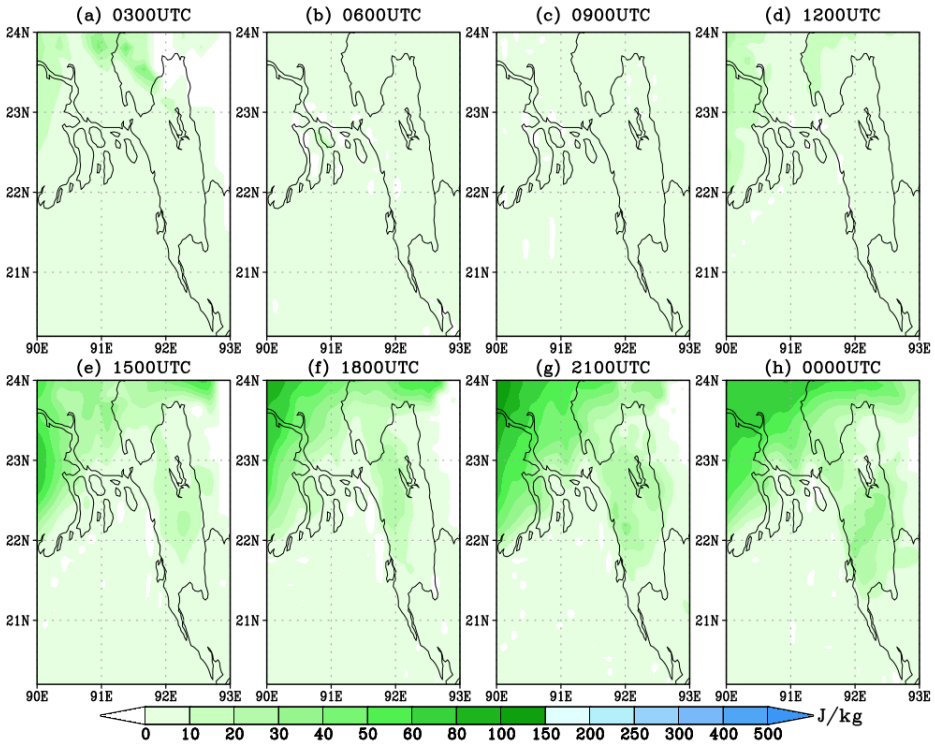


Fig. 7(a)**: Temporal variation of surface minimum CINE on 01 July 2021**

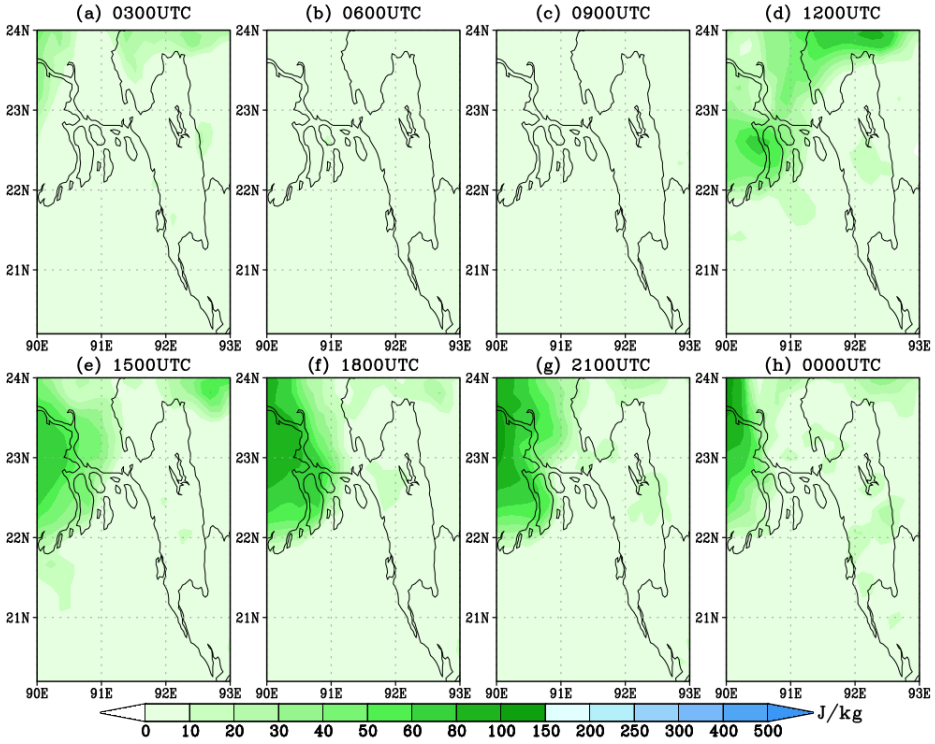


Fig. 7 (b)**: Temporal variation of surface minimum CINE on 02 July 2021**

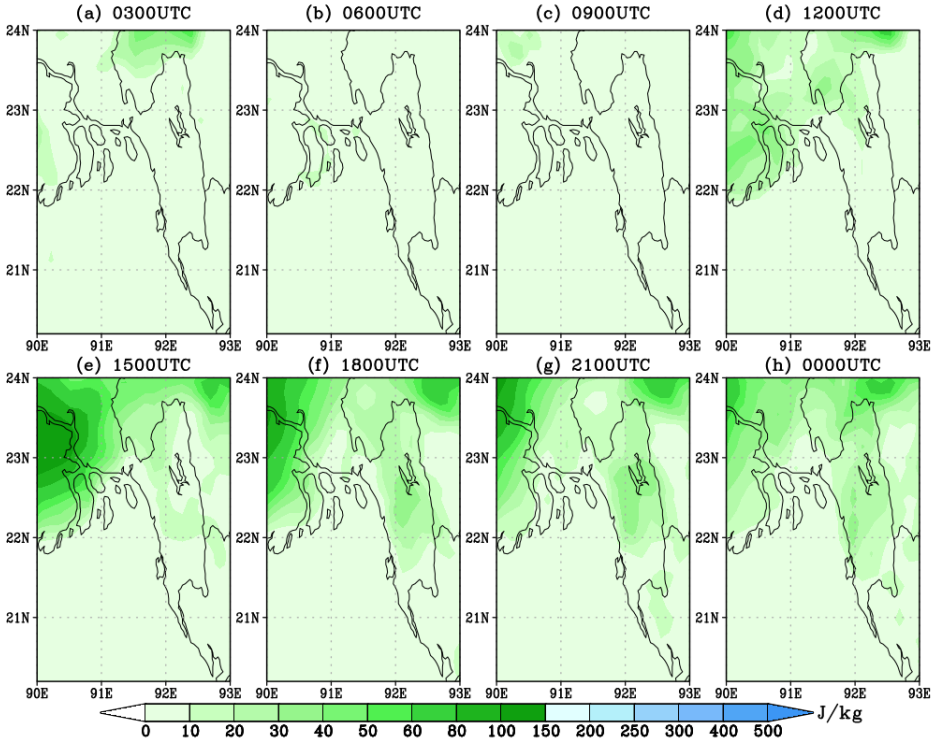


Fig. 7 (c)**: Temporal variation of surface minimum CINE on 03 July 2021**

4.4.3 Simulated Rainfall:

Simulated 3-hourly rainfall of 01July 2021 is displayed in Fig.8 (a-f) reveals the signature of rainfall over southern part of Bangladesh and adjoining northern part of the Bay of Bengal at each of the time window. It is found to increase with progress of time and higher during late hours of 1st July and early hours of 2nd and the amounts of rainfall are highest over southeastern part of Bangladesh and its adjoining coastal areas. The signature of observed rainfall is also recorded over the southeastern part of Bangladesh. The spatial distribution of simulated rainfall pattern is found to analogous with the simulated rainfall.

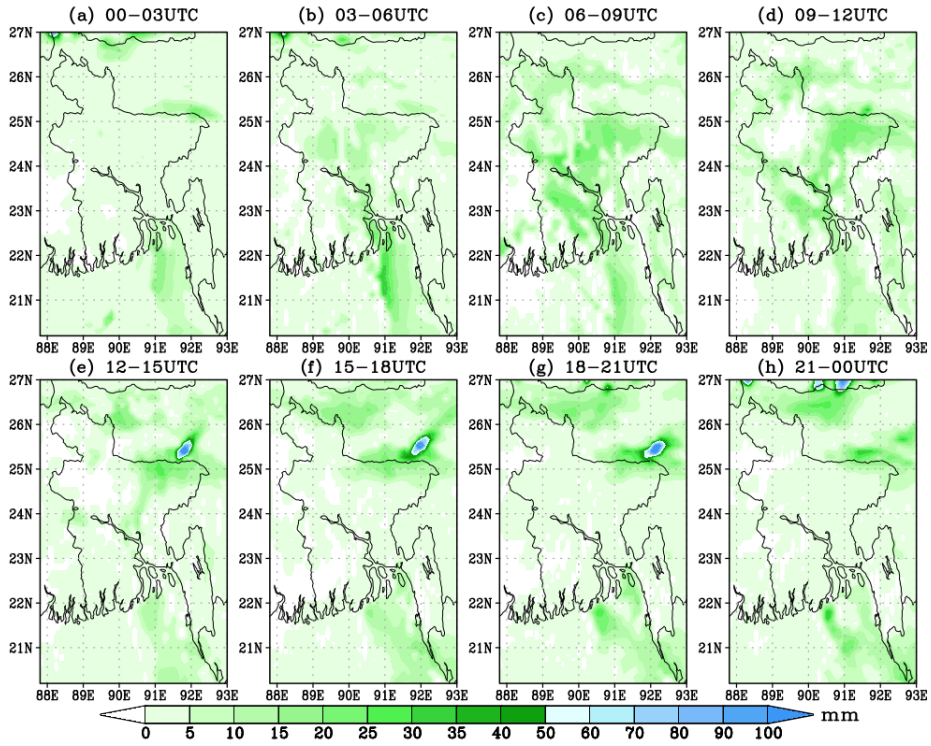


Fig. 8 (a)**: Simulated 3-hourly rainfall (mm) 01 July 2021 covering Bangladesh region**

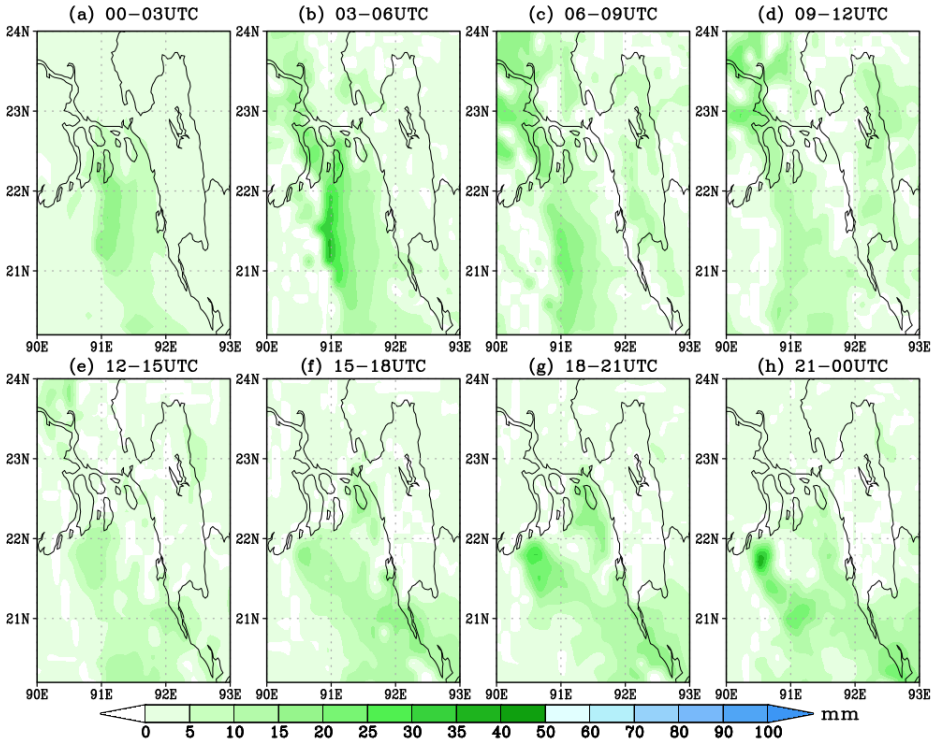


Fig. 8 (b)**: Simulated 3-hourly rainfall (mm) 01 July 2021 covering Chattogram region**

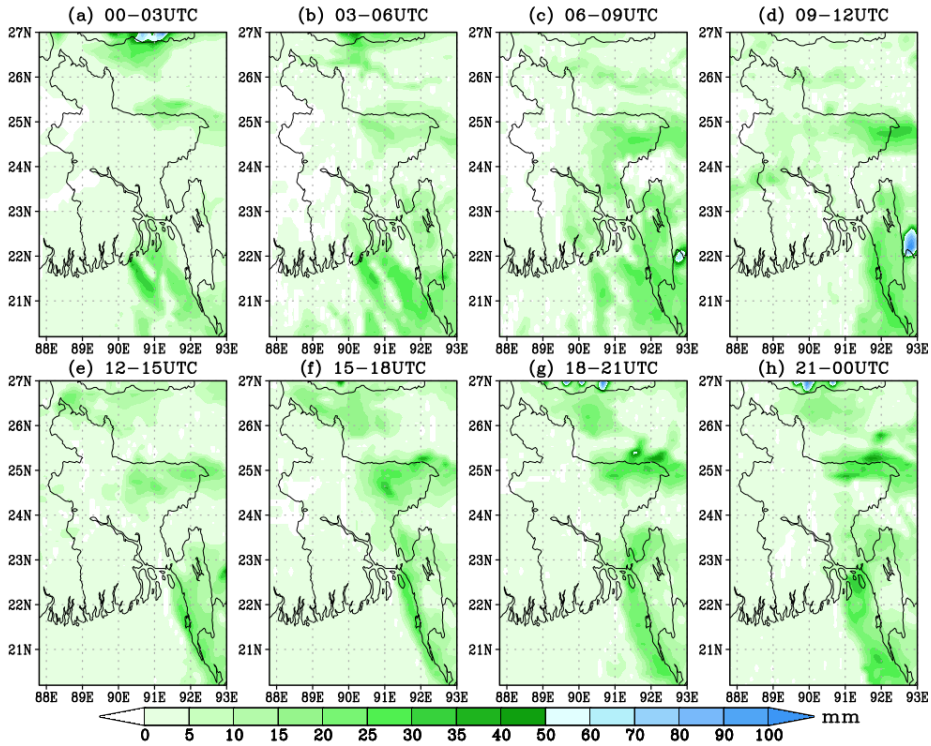


Fig. 8 (c)**: Simulated 3-hourly rainfall (mm) 02 July 2021 covering Bangladesh region**

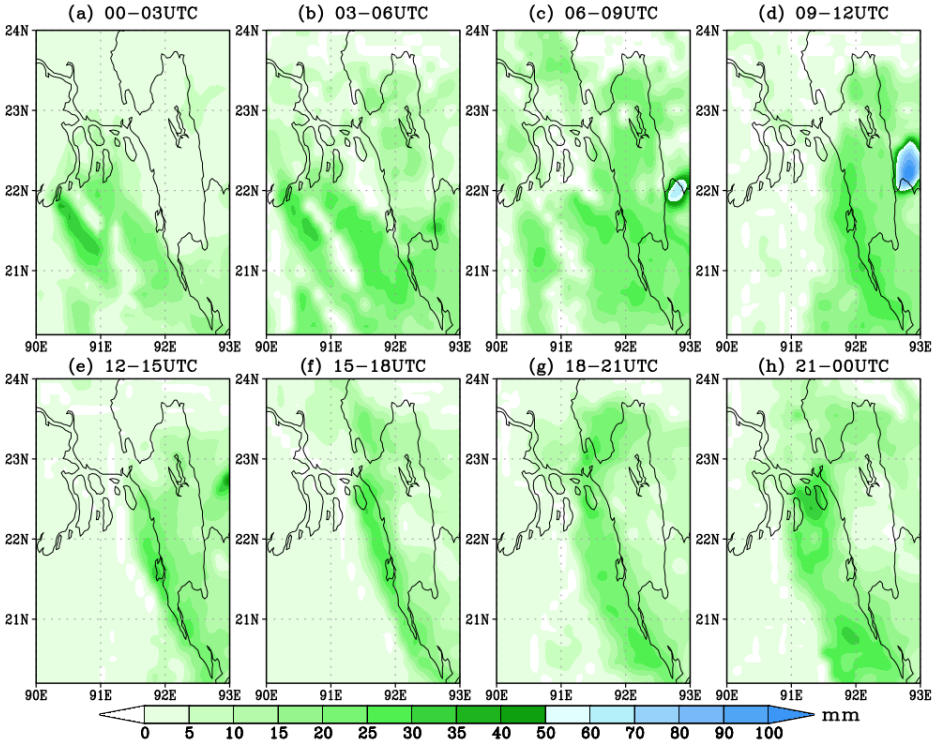


Fig. 8(d)**: Simulated 3-hourly rainfall (mm) 02 July 2021 covering Chattogram region**

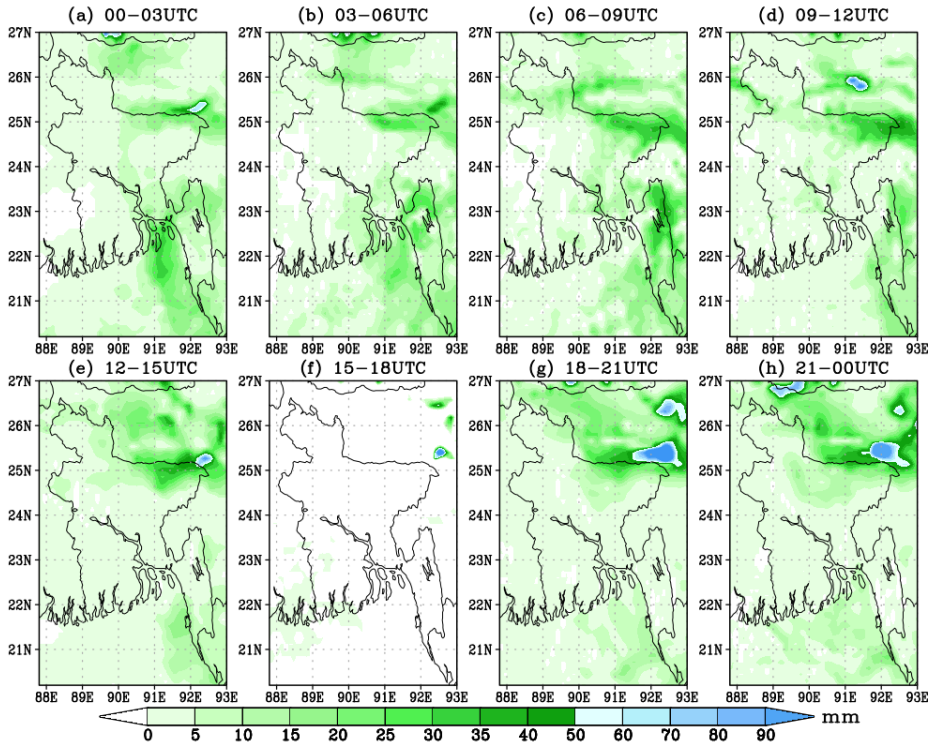


Fig. 8(e)**: Simulated 3-hourly rainfall (mm) 03 July 2021 covering Bangladesh region**

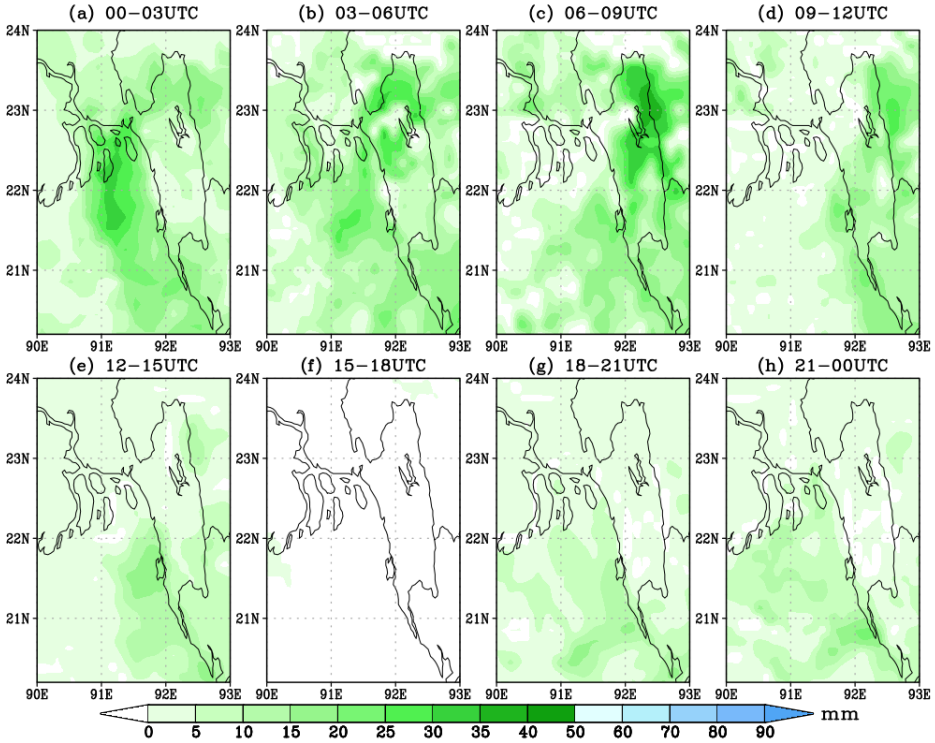


Fig. 8 (f)**: Simulated 3-hourly rainfall (mm) 03 July 2021 covering Chittogong region**

4.4.4 Relative Humidity

The analysis of relative humidity (RH) at 2m height during 0000UTC to 2100UTC of 01 July 2021 specifies that RH was lower (below than 60%) during earlier periods, but increased with the enhancement of convection. The magnitude of RH is found to reach close to 100% over south and southeastern landmass area where heavy rainfall occurred (Fig. 9 (a-c)). Similar situation is found in the lower troposphere. This situation is found to prevail over this area. It indicates that the lower troposphere was saturated during the HR occurrence period.

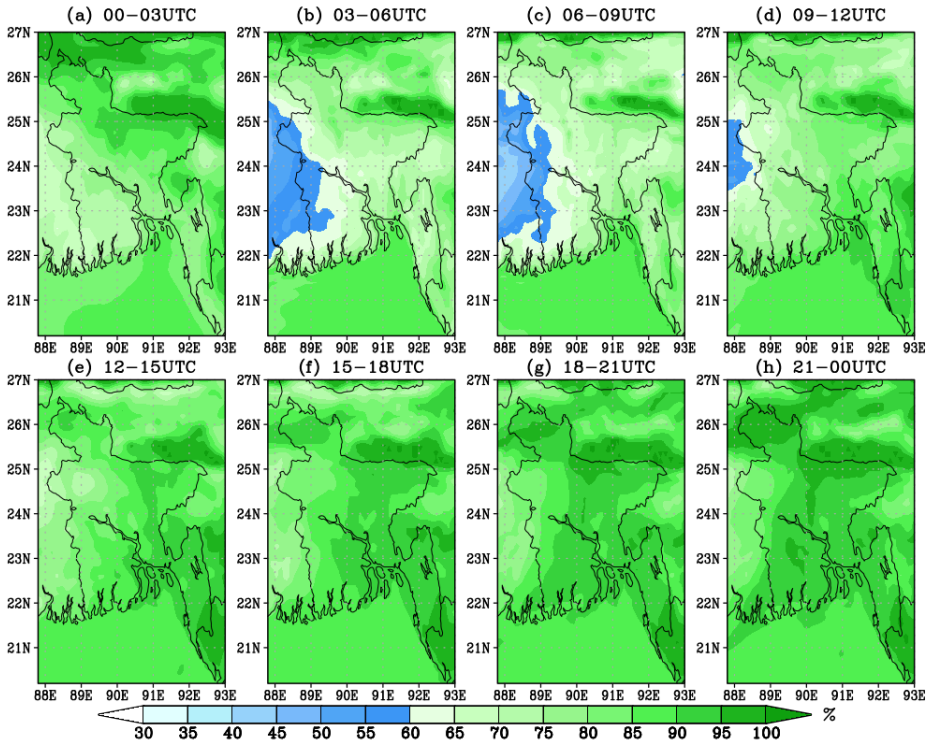


Fig:9a Simulated Relative Humidity on 01 July,2021.

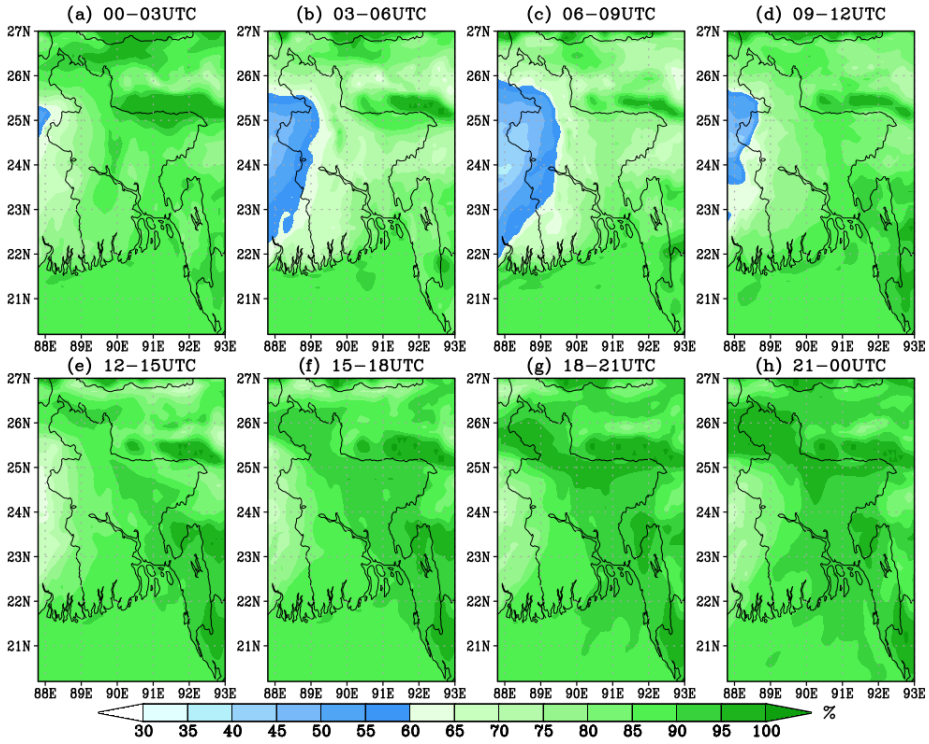


Fig:9b Simulated Relative Humidity on 02 July,2021.

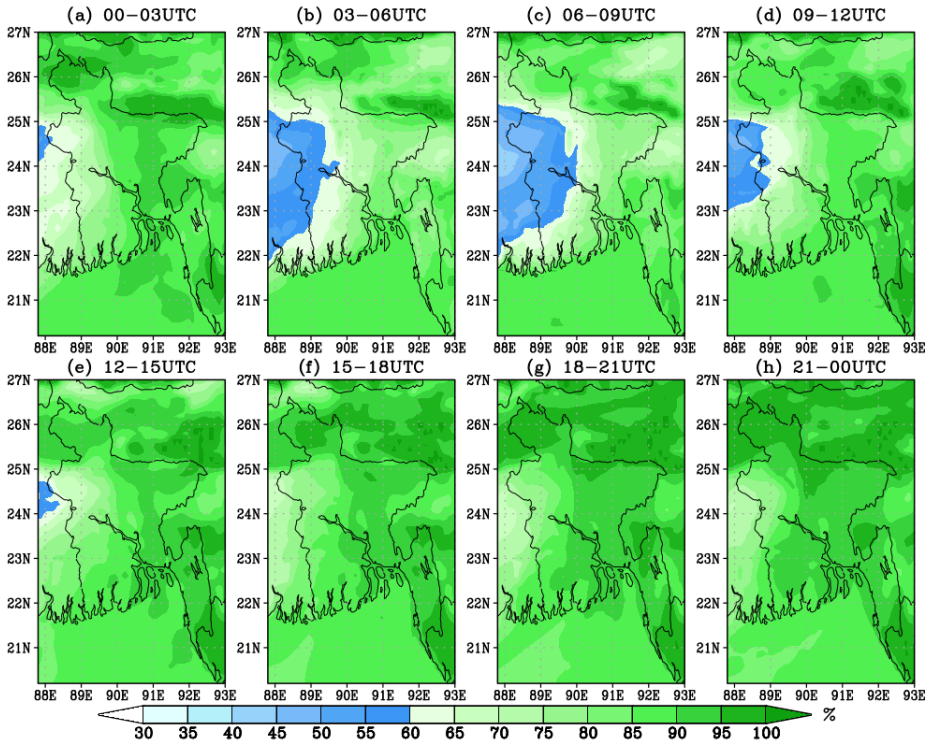


Fig:9c Simulated Relative Humidity on 03 July,2021.

4.6 Mean Sea Level Pressure

Simulation of mean sea level pressure (MSLP) points out that a strong pressure gradient (PG) prevailed during observed period over Northeast Bay and adjoining southeastern part of Bangladesh (Fig. 10(a-c)). This pressure gradient force helped to maintain the monsoon in strong condition, continuous flow from the Bay of Bengal (BoB) for moisture advection. PG is found to be weakened over this area after completion of the life cycle of the convection process.

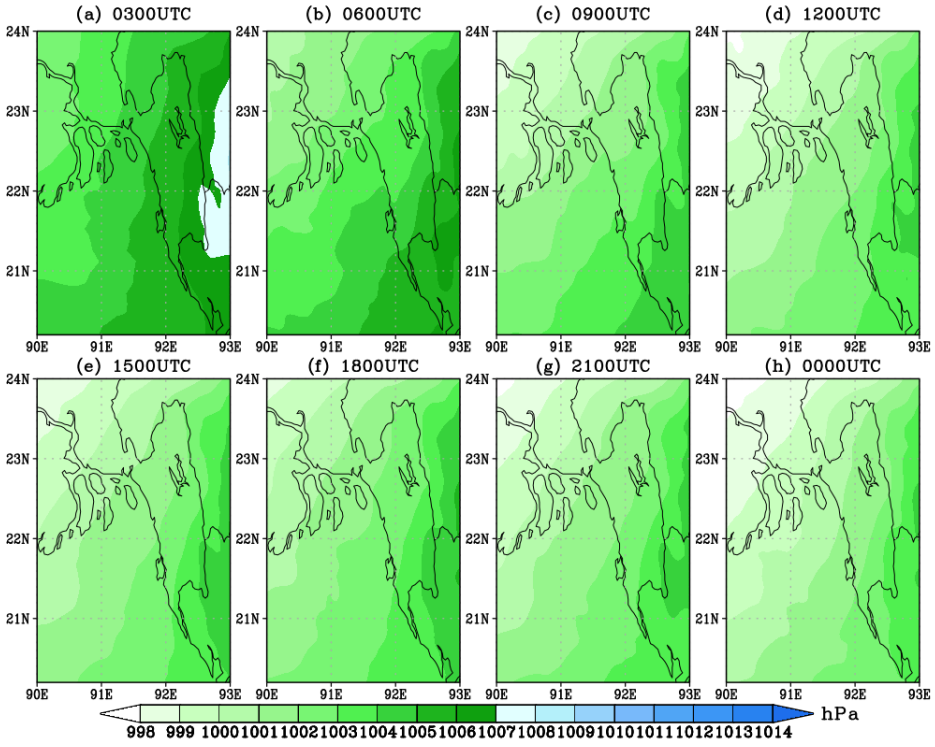


Fig:10a Simulated Sea level pressure on 01 July,2021 over Chattogram region.

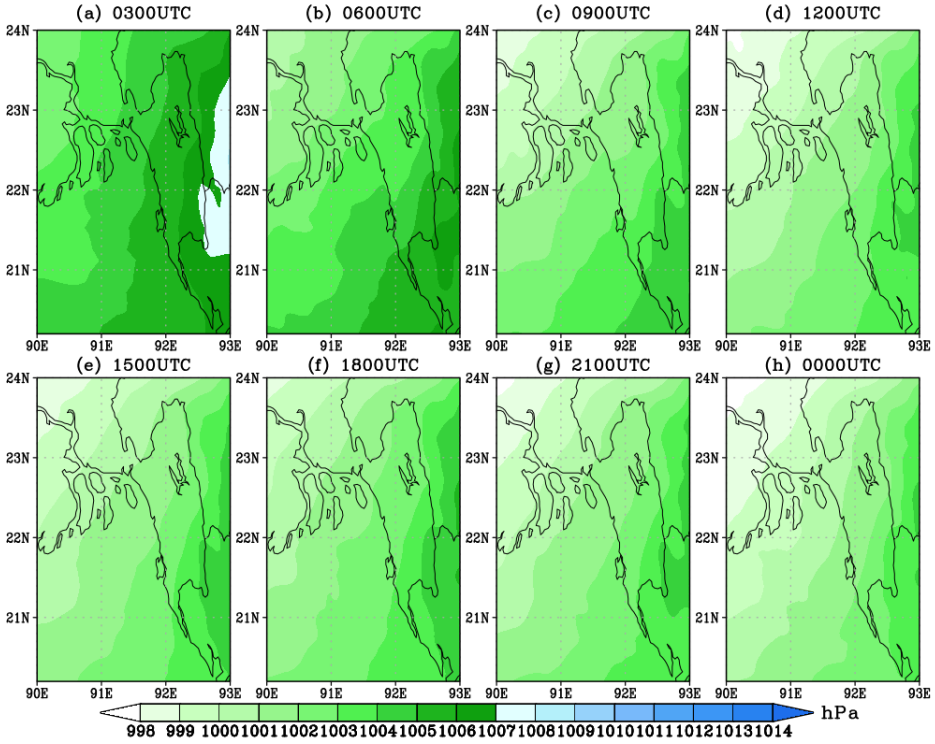


Fig:10b Simulated Sea level pressure on 02 July,2021 over Chattogram region.

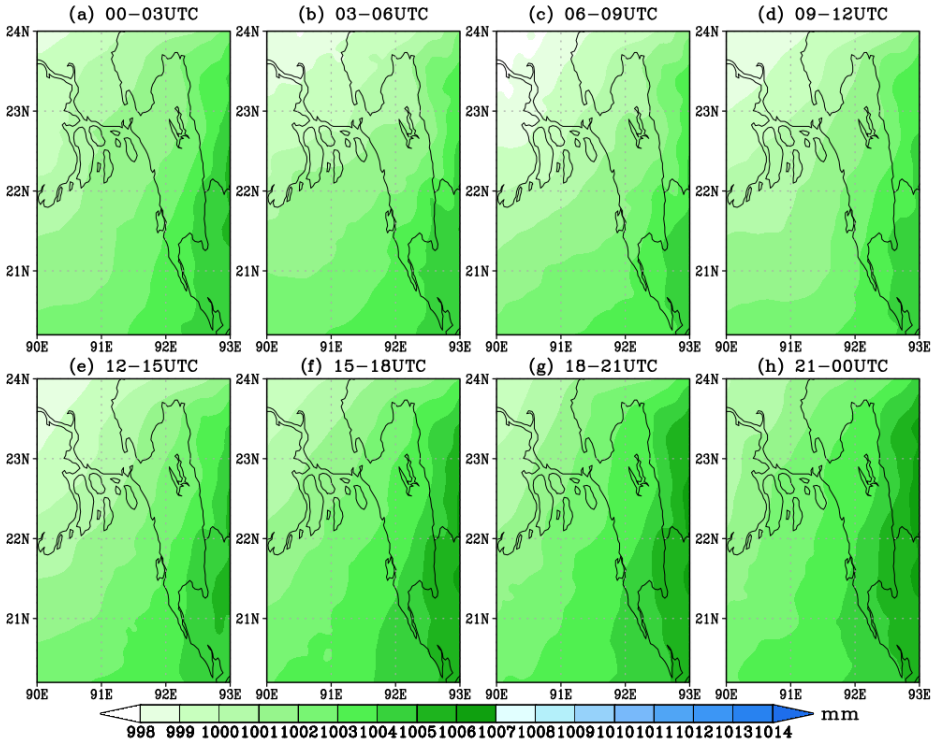


Fig:10c. Simulated Sea level pressure on 03 July,2021 over Chattogram region.

4.7 Vorticity

Analysis of the surface vorticity fields during the simulation period reveals that there were high vorticity over coastal areas and adjoining northern part of the Bay of Bengal. But with the progress of time a sharp different positive and negative vorticity fields evolves and persists along the coastal areas of the southeastern part of Bangladesh (Fig. 11(a-c)). Analysis also depicts that the situation persists in the lower troposphere over the southeastern part of Bangladesh. This side-by-side position of vorticity and its persistence may be one of the main causes for strong convection and occurrence of high amounts of rainfall over southeastern part of Bangladesh.

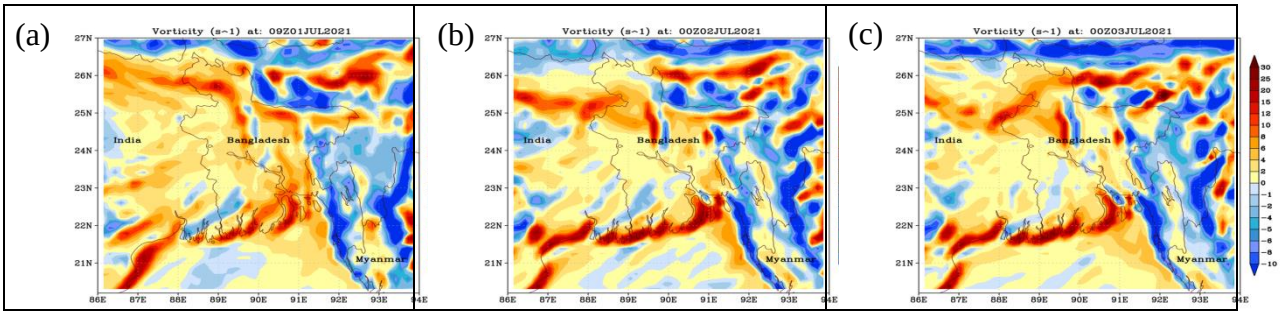


Fig. 11(a-c): simulated vorticity at surface level at 09 UTC of 01 July, 00 UTC of 02 July, 00 UTC of 03 July 2021

4.8 Divergence

Analysis of the divergence fields at surface level during 01 July to 03 July 2021 indicates that there were weak negative divergence (indicate as convergence) lies over southern coastal region and adjoining northern part of the Bay of Bengal initially. But with the progress of time during the simulation period the convergence condition enhanced and a strongly marked north-south aligned convergence patch appeared over southeastern coastal areas of Bangladesh (Fig. 12), which might the responsible for low-level convection for the occurrence of heavy rainfall. Again, convergence condition in the lower troposphere is appeared to deepen with time and finally it is found to be marked strongly (with its extension upto 850 hPa) over the same region as marked in the surface level (Fig. 12). This situation is found to be favourable for the occurrence, as because a divergence field appeared in parallel over southeastern landmass area of Bangladesh at surface and at lower troposphere level (upto 920 hPa).

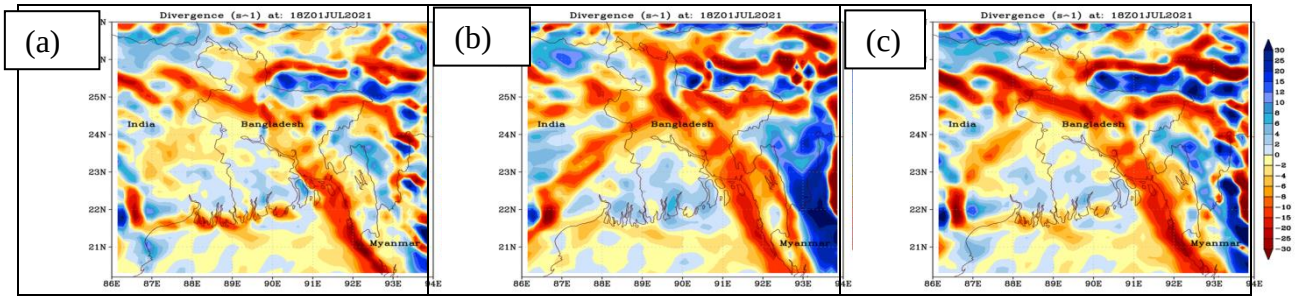


Fig.12 (a-c): Simulated surface level divergence at 1800 UTC, at 850 hPa, 920 hPa of 01 July 2021

Conclusion

From the present study, the most of the heavy rainfall events occurred in monsoon season and the linear trends are decreased in maximum cases. The heavy rainfall occurred due to the extension of the westerly trough, where the convergence zone saturated with high amounts of moisture carried by south/south-westerly wind flow to the southeastern part of Bangladesh. The model simulated CAPE and CINE fields supportive for the heavy rainfall events. Model is able to rainfalls events, but it requires verification.

Acknowledgements

Acknowledgements are due to Bangladesh Meteorological Department (BMD), NCAR and NCEP for providing the laboratory facilities, data and cordial cooperation. I'm very much grateful to my supervisor Dr. Abdul Mannan, Meteorologist, Bangladesh Meteorological department and also thankful to Meteorological Training Institute.

Reference:

1. Banglapedia: National Encyclopedia of Bangladesh.
Asiatic Society of Bangladesh.
2. Zaheed Hasan, January 2014, European Journal of scientific Research , vol.10(2):25-39.
3. Mannan and karmakar, January 2008, Climatic feature of heavy rainfall activities in monsoon season and its socio-economic impact in Bangladesh.
4. Abdul Mannan and S. Karmakar, Rainfall prediction in northeast part of Bangladesh in monsoon season, DEW-DROP 01(2015) 14-25.
5. Kain J.S.(2004). The kain-Fritsch Convective Parameterization: An update.