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L E T T E R S

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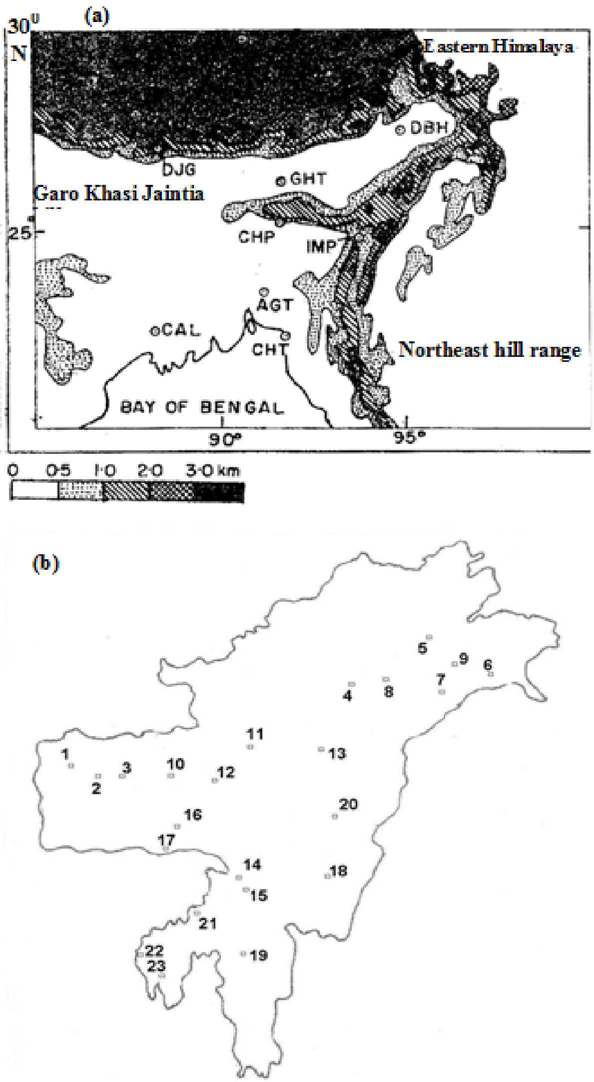
SOME CHARACTERISTICS OF HEAVY RAINFALL EVENTS OVER NORTHEASTERN STATES OF INDIA

1. The monsoon over India is characterised by heavy to very heavy rainfall events leading to floods over different regions. These heavy to very heavy rainfall events are caused by the interaction of basic monsoon flow with the orography and the synoptic disturbances over the region (Dhar and Nandargi, 1993 & 1993a). According to them, during the period from 1880 to 1990, 97 rainstorms have occurred over the country. The break up of meteorological disturbances causing the rainstorms indicates that most of them are caused due to Low Pressure systems (LPSs) comprising of lows, depressions and cyclonic storms. They further found that the boundaries of zones of occurrence of rainstorms broadly tally with the orographic boundaries of mountain ranges in the respective region. Smith (1979) has shown that a small scale cyclonic circulation (cycir) can interact with the orography to cause enhancement of rainfall. Banerjee (1929) has shown the enhancement of precipitation due to lifting of air as a result of perturbation caused in it by the orography leading to cooling, condensation and precipitation of moisture. However, the nature of the interaction is closely linked with the dynamics of the airflow. Hence, the intensity of rainfall due to orographic interaction depends on the characteristics of monsoon circulation and embeded synoptic systems.

There have been many studies on heavy rainfall over different regions (Dube and Balakrishnan, 1992; Desai *et al*., 1996; Chand and Gupta, 1991 and Ganesan *et al*., 2001). Most of the above are case studies. However, Rakhecha and Pisharoty (1996) have studied point and spatial distribution of heavy rainfall over India during monsoon season. Dube and Balakrishnan (1992) have studied the frequency distribution of very heavy rainfall days over different stations in Madhya Pradesh and the causative systems of these very heavy rainfall events. Mohapatra and Mohanty (2005) have analysed different characteristics of very heavy rainfall over Orissa during monsoon season and associated synoptic systems. However there are a few studies on the characteristic of heavy rainfall over northeast India. The southwest monsoon season (June-September) contributes about 66% of the annual rainfall over northeast India (Srinivasan *et al*., 1972). It is one of the rainiest places in the world. In most of the publications of India Meteorological Department (IMD), the 24 hours highest rainfall ever recorded has been maintained as 1036.3 mm in respect of Cherrapunji (Police Station) in northeast India reported on 14th June 1876 (Srivastava and Mandal, 1995).

The heavy rainfall over northeast India is influenced by the monsoon trough, tropical disturbances and the extra tropical systems in westerlies (Srinivasan *et al*., 1972). During the normal location of the monsoon trough, the rainfall over northeast India, which comprises meteorological sub-divisions of Assam & Meghalaya (A & M), Arunachal Pradesh (AP) and Nagaland, Manipur, Mizoram & Tripura (NMMT) is significantly less than the normal. During all India break monsoon condition, the monsoon trough shifts to the foothills of the Himalayas (Ramamurty 1969). Accordingly, the maximum rainfall zone shifts to the northeast India. Comparing the good and bad all India monsoon years (15 years each), Mooley and Shukla (1989) have found that the LPS days over northeast India and neighbouring Bangladesh, Bhutan and Nepal is less in all India good monsoon years than in all India bad monsoon years. However, some of LPSs over the Bay of Bengal may move north/northeastwards towards northeast India under the influence of the upper tropospheric trough in westerlies (Rao, 1976 and IMD, 1979). In addition, some of the LPSs that develop over east Uttar Pradesh (UP) and adjoining Madhya Pradesh (MP) may move east/northeastwards towards the northeast states under the influence of the upper tropospheric westerly flow.

The northeast India is marked by eastern Himalayas in the north, Garo Khasi-Jaintia hills extending from west to east in the centre and northeast hill range extending from south to north over the eastern parts of the region [Fig. 1(a)]. Another important aspect of the physiography is the Brahmaputra Valley extending from east AP in the east to west Assam in the west. The prevailing winds during southwest monsoon season are from southerly direction over southern parts of the region (Srinivasan *et al*., 1972). From Fig. 1(a), the windward slope of the Garo Khasi-Jaintia hills lies almost in the direct path of the monsoon winds, thus getting copious rainfall and heavy clouding. The normal rainfall is found to increase from south to north as we proceed along a profile from the plains of Tripura to the Garo-Khasi and Jaintia hills. The orographical influence on the airflow over Bramhaputra valley has been discussed by Mukherjee and Ghosh (1965). According to Sinha Ray *et al.*, (1982), heavy rainfall over northeastern states and western ghat region can be explained to be an orographic effect.



1. Kokrajhar, 2.Gossaingaon, 3. Panbari, 4. Chouldhoaghat, 5. Itanagar, 6. Passighat, 7. Margherita, 8. Mohanbari, 9. Dhollabazar, 10. Guwahati, 11.Tezpur, 12. Dharamtul, 13. Golaghat, 14. Silchar, 15. Dholai, 16. Shillong, 17. Cherrapunjee, 18. Imphal, 19. Aizwal, 20. Kohima, 21. Kailashahar, 22. Agartala and 23. Khowai

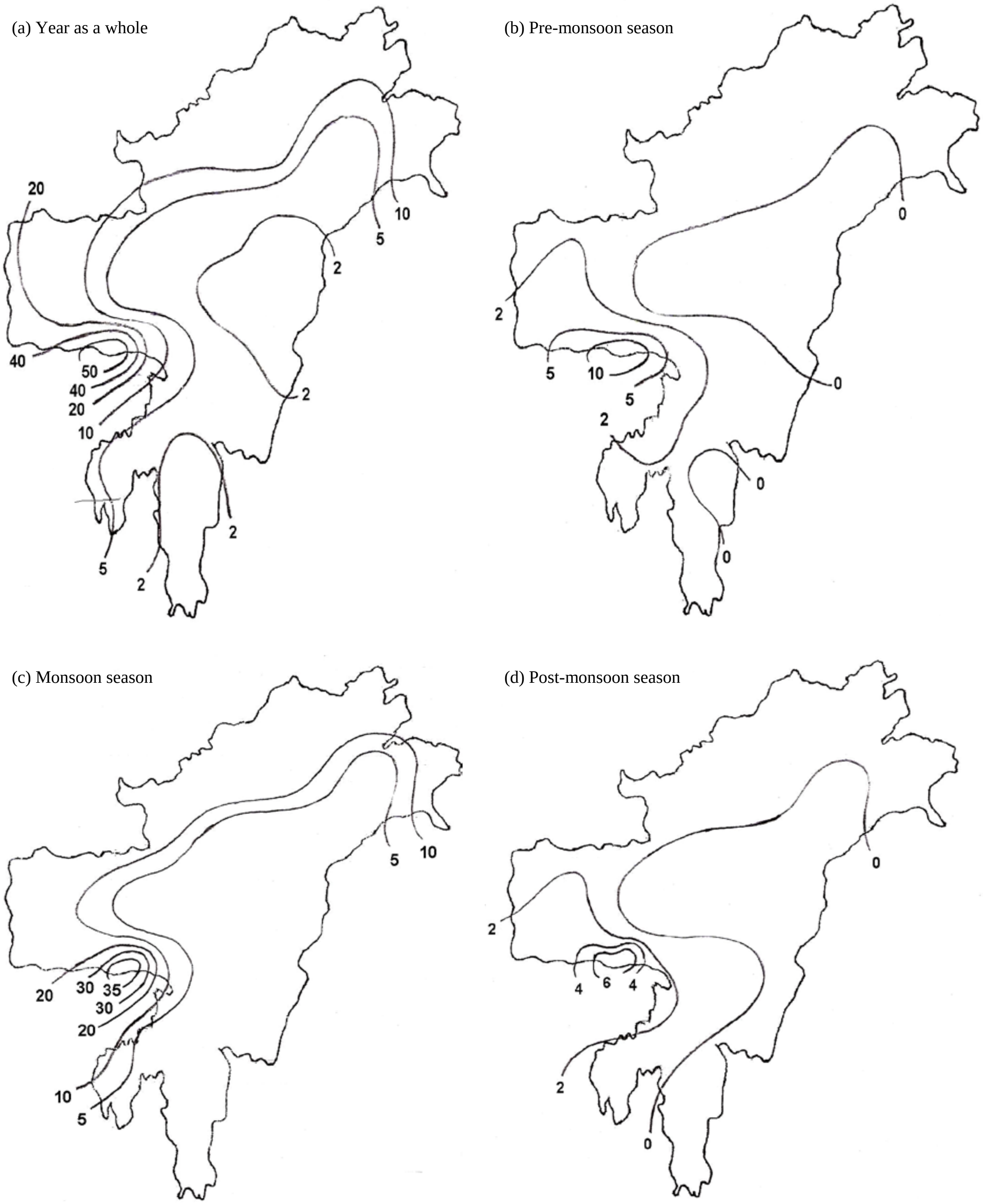
Figs. 1(a&b). (a) Physiography of northeast India and (b) selected rain gauge stations under consideration

Though the heavy rainfall usually organises on the mesoscale but story in the northeast could be different because of complex orography. Keeping this thing in mind, an attempt is made to study the large scale heavy rainfall events in association with different synoptic settings. Study may be useful to forecasters to predict heavy rainfall events in association with different synoptic systems. A heavy rainfall events for this purpose is defined in the subsequent paragraphs.

2. The daily rainfall data of 10 years (1991-2000) over 23 representative stations, almost uniformly distributed in the region have been considered in this study [Fig. 1(b)]. The necessary quality control has been carried out and the missing data (very few) for these 23 stations have been filled up, considering the rainfall at surrounding stations. The average number of heavy rainfall days over different stations are found out and spatial patterns of heavy rainfall days for pre-monsoon season (March-May), monsoon season (June-September), post-monsoon season (October-December) and the year as a whole are prepared and analysed. For this purpose, a station is considered to have recorded heavy rainfall, if the past 24 hours accumulated rainfall is 7 cm or more ending at 0830 hours (IST) of the day as per IMD criteria. The percentage contributions of heavy rainfall days to total rainfall during pre-monsoon, monsoon & post-monsoon seasons and the year as a whole are calculated for all the stations. The spatial patterns of percentage contributions are also prepared and analysed.

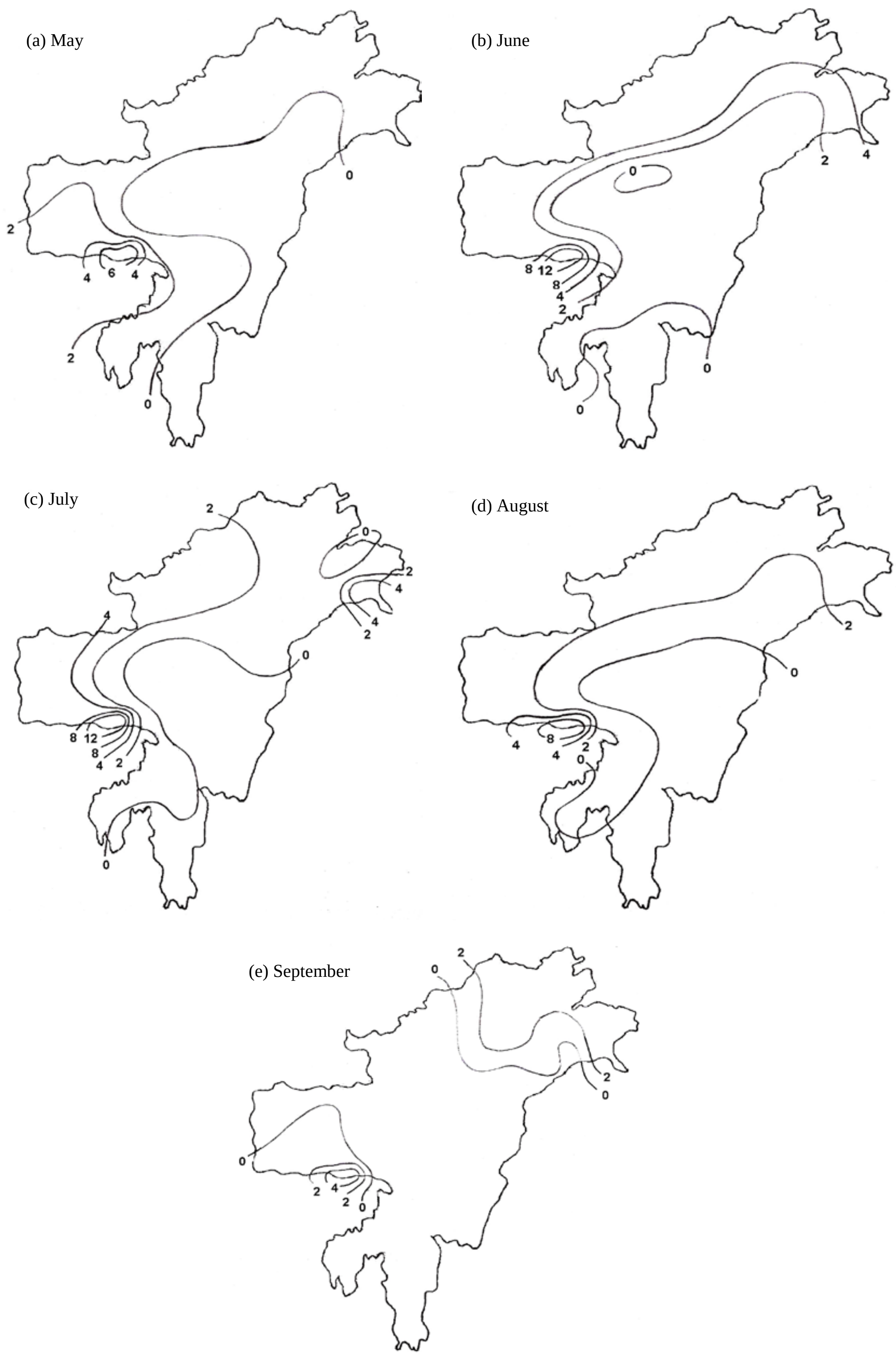
The heavy rainfall events over northeast India in association with the synoptic systems are also found out and analysed. In this connection, a day is considered to be associated with the heavy rainfall event, if at least 5 stations out of total 23 stations under consideration recorded heavy rainfall. The associated synoptic systems for these heavy rainfall events are analysed. For this purpose, the data on day of occurrence and intensity etc. of the synoptic systems and the position of the monsoon trough are collected from daily weather reports published by IMD. The depression and deep depression are considered together without any differentiation. A day is considered as an LPS/Cycir/LLC day over a region, if the system is located at 0300 UTC observation. The regions of occurrence of LPS, Cycir and LLC under consideration in this study are west central (WC) Bay of Bengal, northwest (NW) Bay of Bengal, northeast (NE) Bay of Bengal, Orissa, Gangetic West Bengal (GWB), Jharkhand (JKD), Bihar, Sub-Himalayan West Bengal (SHWB) & Sikkim, AP, A & M, NMMT and Bangladesh (BDS). The contributions from the systems over the above regions are considered, as the influence from the systems over other regions is very small.

The monsoon trough at mean sea level in four categories, *viz*., (*i*) the trough lying along/close to the foothills of the Himalayas (*ii*) the monsoon trough extending through northeast Assam and neighbourhood (*iii*) the monsoon trough extending through Manipur/Mizoram/Tripura and (*iv*) Secondary trough passing through northeast Assam and neighbourhood, while the primary monsoon trough lies in its normal position extending to north Bay of Bengal are considered. The heavy rainfall distribution during all the above four conditions of monsoon trough is analyzed. While studying daily rainfall due to individual synoptic systems, it is

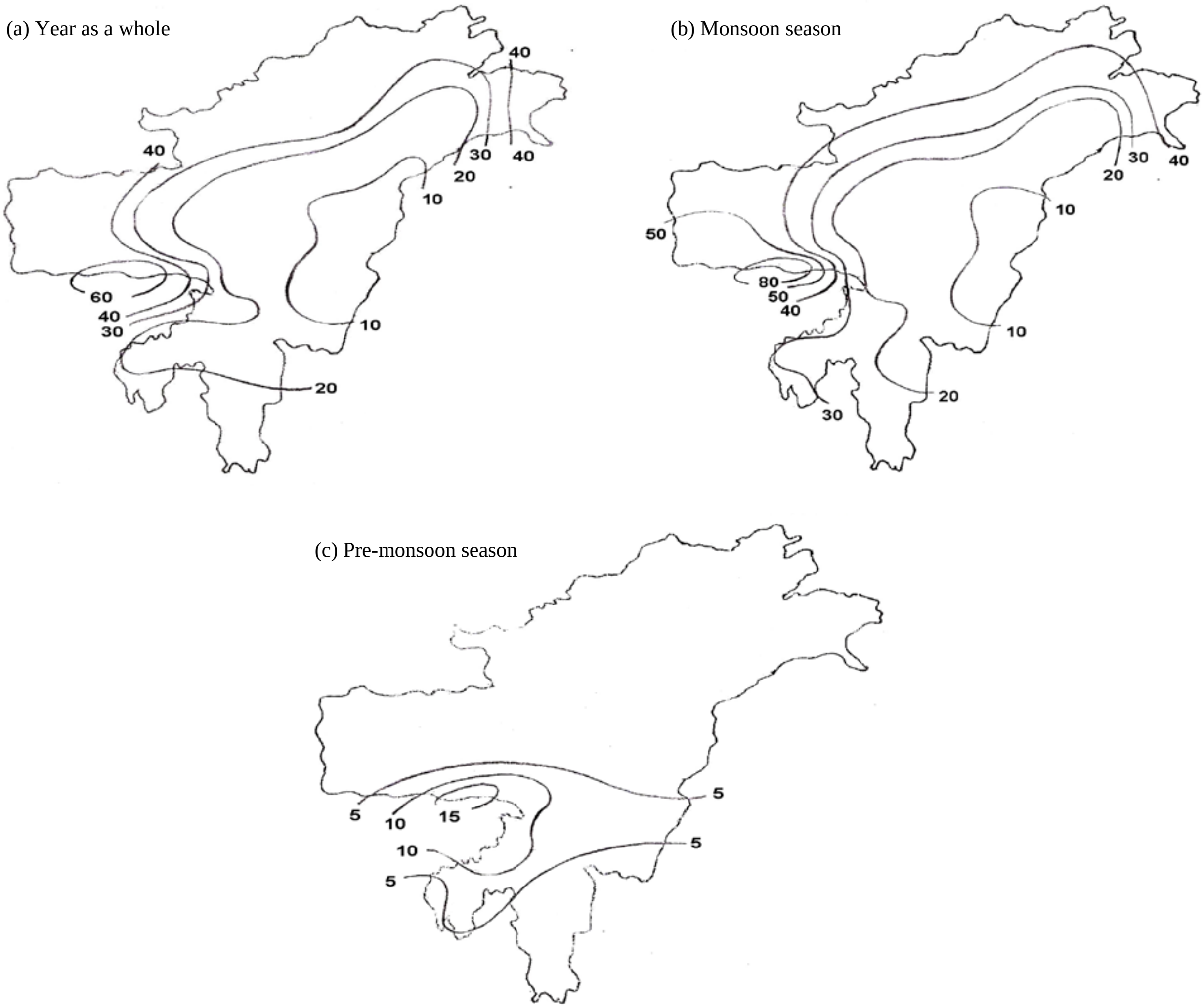


Figs. 2(a-d). Average number of heavy rainfall days over northeastern states during (a) year as a whole, (b) pre-monsoon season, (c) monsoon season and (d) post-monsoon season

noted that on some occasions, there are more than one system at the same time or overlapping systems contribute to the daily rainfall. In these cases, the systems closer to the northeast India have been considered.



Figs. 3(a-e) Average frequency of heavy rainfall days during (a) May, (b) June, (c) July, (d) August and (e) September



Figs. 4(a-c). Percentage contribution of heavy rainfall to the total rainfall during (a) year as a whole, (b) monsoon season and (c) pre-monsoon season

3. The spatial patterns of average number of heavy rainfall days over northeastern states during year as a whole and also in pre-monsoon, monsoon and post-monsoon seasons are shown in Figs. 2(a-d). The spatial patterns are almost similar during different seasons under consideration with difference in average number of days of heavy rainfall. The number of heavy rainfall days is maximum during monsoon season followed by the pre-monsoon season. The spatial pattern during the year as a whole is the reflection of the pattern during monsoon season. Figs. 2(a-d) further indicates that the orography of the region plays a dominant role in the occurrence of heavy rainfall as the average number of heavy rainfall days is significantly high to the south of the Khasi-Jaintia hills including Cherrapunjee region. Though the net work of gauges used is not adequate to reveal the finer details of heavy rainfall, its localisation indicates the pre-dominant mesoscale forcing of heavy rainfall.

As the number of heavy rainfall days is significantly higher during monsoon season, the intraseasonal variation of the number of heavy rainfall days are analysed by considering the monthly average during individual monsoon months. The monthly average of heavy rainfall days during the month of May has also been analysed, as most of the heavy rainfall events during pre-monsoon season occurs during this month. The results of the analysis are presented in Figs. 3(a-e). The number of heavy rainfall days gradually increases from the month of May and becomes maximum in June. It then decreases towards September. According to Srinivasan *et al.*, (1972), the rainfall over Assam and adjoining states increases from May to June. During the monsoon season, the rainfall is more in June and July than in the latter half of the season. According to them, the monthly rainfall during May, June, July, August and September is 34, 48, 45, 40 and 32 cm respectively. The number of heavy rainfall days is again higher over southern side of Khasi-Jaintia hills during all the months. The spatial distribution further indicates orographic forcing of heavy rainfall.

4. The spatial distributions of percentage contributions of heavy rainfall events to the total rainfall during pre-monsoon season, monsoon season and the year as whole are shown in Figs. 4(a-c). The contribution to the annual rainfall is significantly higher (> 50%) over southern part of Garo-Khasi-Jaintia hills including Cherrapunjee region and less (< 10%) over eastern side of northeast hill range covering major part of Manipur. Hence it endorses the findings in previous section that the orography plays a dominant role in the occurrence of heavy rainfall. From Figs. 4(a&b), the percentage contribution is relatively higher during the monsoon season than during the year as a whole over southern part of Garo-Khasi-Jaintia hills due to convective type of rainfall over this region during monsoon season. The contribution of heavy rainfall event to the total rainfall during pre-monsoon season is significantly less [Fig. 4(c)]. However it is again higher on the southern side of Garo-Khasi-Jaintia hills and maximum over Cherrapunjee region.

5. The number of days with heavy rainfall over at least 5 stations in the northeast (large scale heavy rainfall events) during different months are shown in the Table 1. The large scale heavy rainfall events mostly occur during pre-monsoon month of May and the monsoon season. The probability of occurrence of such heavy rainfall events is maximum during June, the month of onset of monsoon over India followed by May and July. The frequency of occurrence of heavy rainfall gradually decreases from June to September like the monthly total rainfall (Srinivasan *et al*., 1972). There are no heavy rainfall events during winter season and are very less during post-monsoon season as well as in the month of March and April.

The heavy rainfall events during pre-monsoon season are dominantly associated with the LPS (Table 2a) as 10 out of 19 events (Table 1**)** are associated with LPS/Cycir. The most favourable locations of LPS/Cycir are BDS, A & M and GWB (Table 2a). The trough in sea level extending from east Uttar Pradesh to northeastern states and the north-south trough roughly running along 90° E to the north of 20° N are also favourable for heavy rainfall events over the northeastern states during pre-monsoon season (Table 2b). The above stated synoptic features usually appear during the month of May and cause the heavy rainfall over the region.

TABLE 1

Number of days of heavy rainfall over at least 5 stations in northeast India during 1991-2000

Period	Total number of days
March	01
April	0
May	18
June	24
July	18
August	10
September	07
Oct-Dec	04
Year as a whole	82

From Tables 3(a&b), about 40% (23 out of 59) of the heavy rainfall events during monsoon season occur in association with the LPS/Cycir. The favourable locations of the LPS/Cycir to cause large scale heavy rainfall events include Bihar, JKD, GWB, BDS, NE Bay of Bengal and WC Bay of Bengal. With the system over BDS, the monsoon trough lies to the north of its normal position and the southerly component of wind increases over the region. With the system over Bihar, the monsoon trough passes through A & M or lies close to the foothills of the Himalayas. These conditions are favourable for higher rainfall over the northeastern states. Also, the systems over Bihar, JKD and BDS some times move northeastwards under the influence of the extra-tropical westerly trough at upper tropospheric levels, especially during the onset and withdrawal phases of monsoon (June and September). With the northeastward movement of the above system, southerly wind over the region increases leading to higher rainfall.

About 54% (32 out of 59) of the heavy rainfall events over northeastern states during monsoon season occur during the days when (*i*) the monsoon trough lies close to the foothills of the Himalayas (*ii*) monsoon trough extends to north Bay of Bengal alongwith the secondary trough running across A & M and (*iii*) the monsoon trough lying to the north of its normal position across BDS, Mizoram and Tripura (Table 3b). All the above mentioned synoptic systems are associated with all India weak monsoon condition. During the weak phase of

TABLE 2(a)

Number of days with at least 5 stations reporting heavy rainfall due to different synoptic systems during pre-monsoon season (March to May)

Synoptic system	Location of synoptic system						Total
	BDS	NE Bay	JKD	Bihar	GWB	A & M	
Depression	0	1	0	0	1	0	2
Low/ Well marked low	0	0	1	1	1	1	4
Cycir	1	0	0	0	2	1	4
Total	1	1	1	1	4	2	10

TABLE 2(b)

Number of days with at least 5 stations reporting heavy rainfall due to trough at mean sea level/ lower tropospheric levels during pre-monsoon season (March to May)

S. No.	Synoptic system	No of days
1.	Trough on sea level extending from East UP to northeastern states	3
2.	North-South trough along 90° E & north of 20° N at lower tropospheric levels	4
	Total	7

TABLE 3(a)

Number of days with at least 5 stations reporting heavy rainfall due to different synoptic systems during monsoon season (June to September) over the period of 10 years (1991-2000)

S. No.	Synoptic system	Geographical location of synoptic system						Total
		BDS	WC Bay	NE Bay	JKD	Bihar	GWB	
1.	Depression	0	1	0	0	0	0	1
2.	Low/ Well marked low	2	3	2	2	1	0	10
3.	Cycir	3	2	0	0	4	3	12
4.	Total	5	6	2	2	5	3	23

TABLE 3(b)

Number of days with at least 5 stations reporting heavy rainfall due to trough at mean sea level/lower tropospheric levels during monsoon season (June to September)

S. No.	Synoptic system	No of days
1.	Monsoon trough close to the foot hills of the Himalayas with/without north-south trough along 90° E & north of 20° N at lower tropospheric levels	16
2.	Monsoon trough extending to north Bay of Bengal and the secondary trough running from east UP to A&M	8
3.	Monsoon trough to the north of its normal position, running across BDS and Mizoram /Tripura	8
4.	Monsoon trough at normal position extending to north Bay of Bengal	2
5.	Monsoon trough to the south of its normal position	2
	Total	36

monsoon, the monsoon trough gradually shifts northward towards the foothills of the Himalayas. As a result, the southerly component of wind at lower tropospheric levels over the region increases leading to moisture convergence. Also sometimes a trough in mid-latitude westerlies passes through the region. When this trough lies to the west of the region, the southerly component of wind further strengthens leading to heavy to very heavy rainfall over the region. The four heavy rainfall events during post-monsoon season (Table 1) have been associated with the depression over WC Bay, NE Bay, GWB and BDS (one each). These systems have moved north-northeastward causing heavy rainfall over northeast region.

6. The above results and analysis suggest that though the rainfall associated with large scale synoptic setting might be organizing on the large scale, the heavy rainfall usually organizes on the mesoscale. Though the mesoscale models are supposed to simulate the heavy rainfall events, it actually does not often happen in reality. Thus, the prediction of the timing, location, organization and structure of the mesoscale cloud system, especially over tropics is recognized as one of the biggest challenges in mesoscale modeling. It is eventually the numerical models that have to improve further to increase the warning skill. A high resolution numerical model with good physics and dynamics that uses the modern sophisticated 4DVAR data assimilation technique may be able to resolve this mesoscale forcing of heavy rainfall.

7. The following broad conclusions are drawn from the above results and discussion.

(*i*) The results confirm the earlier findings (Srinivasan *et al*., 1972) that heavy rainfall events are dominantly associated with the interaction of orography of the region with the monsoon trough and synoptic scale systems.

(*ii*) On an average, there are 8 heavy rainfall events in a year including 2 each in the month of May, June and July, when at least 5 out of 23 stations under consideration record heavy rainfall over northeast India. While the heavy rainfall events in pre-monsoon and post-monsoon seasons are predominantly associated with LPS/Cycir (about 53% and 100% respectively during pre-monsoon and post-monsoon seasons), about 54% of heavy rainfall events during monsoon season are associated with the monsoon trough lying close to the foothills of the Himalayas or over the northeast region with/without north-south trough in mid-latitude westerlies running roughly along 90° E. at lower tropospheric levels.

(*iii*) Though, the rainfall associated with large scale synoptic settings might be organizing in large scale, the heavy rainfall usually organizes in the mesoscale. A high resolution numerical model with good physics and dynamics that uses the modern sophisticated 4DVAR data assimilation technique may be able to resolve mesoscale forcing of heavy rainfall.

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