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Cumulonimbus tops around Gauhati airport

G. N. SHARMA

Hydrogen Factory, Agra

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ABSTRACT. Cumulonimbus clouds around Gauhati Airport observed during 1970-75 with the help of 3 cm Bendix radar were studied. The study revealed that generally *Cb* tops did not exceed 12 km. Highest probability for *Cb* development is around 08, 12 and 16 GMT during pre-monsoon in southern and western sectors.

When monsoon rainfall is higher than normal, *Cb* development is more in southern sector and monsoon rainfall curve follows the trend of pre-monsoon *Cb* curve.

1. Introduction

The most thundery area in the country is Assam with the highest annual frequency (Rao and Raman 1961, Raman and Raghavan 1961) exceeding 100 days and the existence of very high cumulonimbus over northern and northeastern India is also fairly well known. Quite a number of studies have been reported in literature (Deshpande 1961, 1964; Kulshrestha 1962, 1964; De and Bhattacharya 1966) on this subject. In this field study for a period 1960-61 (Mukherjee *et al.* 1964) was based on observations taken on Decca type 41 radar installed at Gauhati airfield. Later Ray (1971) analysed observations from 1967 to June 1970 taken on 3·2 cm low power (20 kw) Bendix radar. The available data for the period March 1970 to October 1975 of pre-monsoon, monsoon and post-monsoon seasons have been analysed in this paper. The frequency of occurrence of *Cb*, spatial distribution and diurnal variation in different months and seasons with reference to height of clouds around Gauhati airfield has been analysed. Also, an effort has been made to correlate Gauhati airfield rainfall with number of *Cb* cells.

Weather over Gauhati airport is very much influenced by the surrounding topography. Gauhati is situated in Brahmaputra valley and at the foot of Garo-Khasi-Jaintia range on the southern bank of *Brahmaputra* river (Fig. 1). To the north lies the Himalayan range with great average height and many snow covered peaks. The average heights of Garo-Khasi-Jaintia range is 1 to 1·5 km. The valley is 550 km long and 70 km wide with a gentle slope from east to west.

2. Data

At Gauhati airfield from 15 March to 15 November round the clock hourly observations are recorded at full hour GMT from the PPI-scope of 3·2 cm Bendix radar with a maximum range of 100 nautical miles. All echo observations in which tops have gone 5 km and above have been included for analysis. Most of the echoes were found to fall within 50 nautical miles range.

Clouds whose tops are 7 km or more have sufficient charge separation to be classified as thunder clouds. Only such 1542 cloud observations are considered for main study. 5 to 6 km high *Cb* cloud do normally give a shower without thunder hence they are included for tabular analysis and rainfall considerations.

3. Data processing

3·1. The seasons have been taken as pre-monsoon (March, April and May), monsoon (June, July, August and September) and post-monsoon (October).

3·2. To find out spatial distribution, echoes were divided into 8 sectors of 45° each, *e.g.*, N, NE, E etc.

3·3. To study diurnal variation in 8 sectors separately in individual months, number of echoes recorded at full hour GMT in a particular sector were tabulated at individual hour for all the days of a month. Seasonal totals were found by summing up for different months of a season.

3·4. For calculation of frequencies, number of echoes in individual hours were combined to give occurrences for the four 6 hourly periods, *viz.*, N_i forenoon (00-06 GMT), N_{ii} afternoon (06-12 GMT), N_{iii} evening (12-18 GMT) and N_{iv} night (18-24 GMT). These totals are given in Table 1. The last column of each month gives the percentage frequency (%F) obtained by dividing the

TABLE 1

Monthwise diurnal variation of *Cb* (≥ 7 km) in 8 sectors

(Total frequencies in the 6-year period)

Sector	Forenoon		Afternoon		Evening		Night		ΣN	%F
	Ni	*P*	*Nii*	*P*	*Niii*	*P*	*Niv*	*P*		
March										
N	0	0	6	3·2	5	2·7	1	0·5	12	10·6
NE	1	0·5	0	0	2	1·1	0	0	3	2·7
E	0	0	3	1·6	2	1·1	0	0	5	4·4
SE	5	2·7	17	9·1	3	1·6	5	2·7	30	26·5
S	3	1·6	11	5·9	4	2·1	3	1·6	21	18·6
SW	7	3·8	10	5·4	0	0	0	0	17	15·1
W	5	2·7	5	2·7	6	3·2	2	1·1	18	15·9
NW	1	0·5	4	2·1	1	0·5	1	0·5	7	6·2
Total	22		56		23		12		113	
% *f*	19·3		49·4		20·7		10·6			
April										
N	7	3·9	10	5·6	16	8·9	13	7·2	46	10·4
NE	2	1.1	1	0·6	7	3·9	1	0·6	11	2·5
E	5	2·8	6	3·3	8	4·4	3	1·7	22	5·0
SE	8	4.4	26	14.4	6	3.3	2	1.1	42	9.5
S	9	5·0	34	18·9	56	31·2	10	5·6	109	24·6
SW	3	1·7	31	17·5	14	7·8	6	3·3	54	12·2
W	12	6·7	26	14·4	39	21·7	16	8·9	93	20·9
NW	15	8·3	16	8·9	17	9·4	18	10·0	66	14·9
Total	61		150		163		69		443	
% *f*	13·9		33·9		36·9		15·3			
May										
N	5	2·7	4	2·1	16	8·6	10	5·4	35	10·5
NE	0	0	1	0·5	4	2·1	0	0	5	1·5
E	1	0·5	6	3·2	1	0·5	0	0	8	2·4
SE	4	2·1	21	11·3	3	1·6	1	0·5	29	8·7
S	7	3·8	32	17·2	13	7·0	10	5.4	62	18·6
SW	8	4·3	19	10·2	15	8·1	3	1·6	45	13·5
W	15	8·1	37	19·9	29	15 6	28	15·1	109	32·8
NW	6	3·2	5	2·7	21	11·3	8	4·3	40	12·0
Total	46		125		102		60		333	
% *f*	13·8		37·5		30·6		18·1			
June										
N	6	3·3	4	2·2	11	6·1	4	2·2	20	10·9
NE	0	0	2	1·1	1	0·6	1	0·6	4	1·7
E	2	1·1	12	6·7	2	1·1	0	0	16	7·0
SE	5	2·8	14	7·8	5	2·8	0	0	24	10·5
S	10	5·6	17	9·4	8	4·4	4	2·2	39	17·1
SW	7	3·9	16	8·9	8	4·4	4	2·2	35	15·3
W	8	4·4	39	21·7	10	5·6	6	3·3	63	27·5
NW	3	1·7	8	4.4	8	4·4	4	2·2	23	10·0
Total	41		112		53		23		229	
% *f*	17.9		48·9		23·2		10·0			

TABLE 1 (*contd*)

Sector	Forenoon		Afternoon		Evening		Night		Σ N	%F
	Ni	*P*	*Nii*	*P*	*Niii*	*P*	*Niv*	*P*		
July										
N	2	1·1	5	2·7	1	0·5	3	1·6	11	8·3
NE	1	0·5	2	1·1	0	0	0	0	3	2·3
E	2	1·1	8	4·3	4	2·1	1	0·5	15	11·3
SE	1	0·5	9	4·8	4	2·1	1	0·5	15	11·3
S	1	0·5	12	6·4	1	0·5	1	0·5	15	11·3
SW	2	1·1	18	9·7	0	0	2	1·1	22	16·7
W	6	3·2	22	11·8	6	3·2	3	1·6	37	28·1
NW	1	1·1	8	4·3	4	2·1	1	0·5	14	10·7
Total	16		84		20		12		132	
% *f*	12·2		63·6		15·2		9·1			
August										
N	0	0	4	2·1	2	1·1	5	2·7	11	9·1
NE	0	0	2	1·1	2	1·1	0	0	4	3·4
E	1	0·5	3	1·6	7	3·8	3	1·6	14	11·4
SE	1	0·5	8	4·3	0	0	0	0	9	7·3
S	2	1·1	17	9·1	7	3·8	2	1·1	28	23·0
SW	3	1·6	19	10·0	1	0·5	0	0	23	18·8
W	0	0	14	7·8	3	1·6	2	1·1	19	15·6
NW	2	1·1	4	2·1	1	0·5	7	3·8	14	11·4
Total	9		71		23		19		122	
% *f*	7·3		58·3		18·8		15·6			
September										
N	5	2·8	0	0	0	0	2	1·1	7	5·9
NE	0	0	1	0·6	0	0	0	0	1	0·9
E	0	0	4	2·2	2	1·1	0	0	6	5·0
SE	0	0	20	11·1	2	1·1	0	0	22	18·4
S	0	0	16	8·9	2	1·1	1	0·6	19	15·7
SW	8	4·4	16	8·9	2	1·1	0	0	26	21·6
W	2	1·1	24	13·7	3	1·6	0	0	29	24·2
NW	1	0·6	5	2·8	3	1·6	1	0·6	10	8·3
Total	16		86		14		4		120	
% *f*	13·3		71·7		11·7		3·3			
October										
N	0	0	2	1·1	0	0	0	0	2	4·0
NE	1	0·5	0	0	0	0	0	0	1	2·0
E	0	0	3	1·6	0	0	0	0	3	6·0
SE	0	0	9	4·8	1	0·5	0	0	10	20·0
S	0	0	12	6·4	1	0·5	0	0	13	26·0
SW	0	0	7	3·8	0	0	1	0·5	8	16·0
W	1	0·5	6	3·2	1	0·5	0	0	8	16·0
NW	0	0	2	1·1	2	1·1	1	0·5	5	10·0
Total	2		41		5		2		50	
% *f*	4·0		82·0		10·0		4·0			

TABLE 2

Number of occasions *Cb* tops reaching different heights during 1970-75

Year	Height (km) 5	6	7	8	9	10	11	12	13	14	15	Total
1970	185	183	161	103	54	34	33	13	3	6	—	775
1971	623	327	146	27	4	2	1	1	—	—	—	1131
1972	443	307	124	70	27	19	2	6	1	2	1	1002
1973	377	412	145	29	8	8	1	—	—	—	—	980
1974	213	231	77	43	24	18	3	—	3	2	—	617
1975	303	271	169	107	35	17	6	3	1	—	—	912
Total	2144	1731	822	379	152	98	46	26	8	10	1	5417
Percentage frequency	39·6	31·9	15·2	6·9	2·8	1·8	0·95	0·5	0·15	0·18	0·02	

TABLE 3

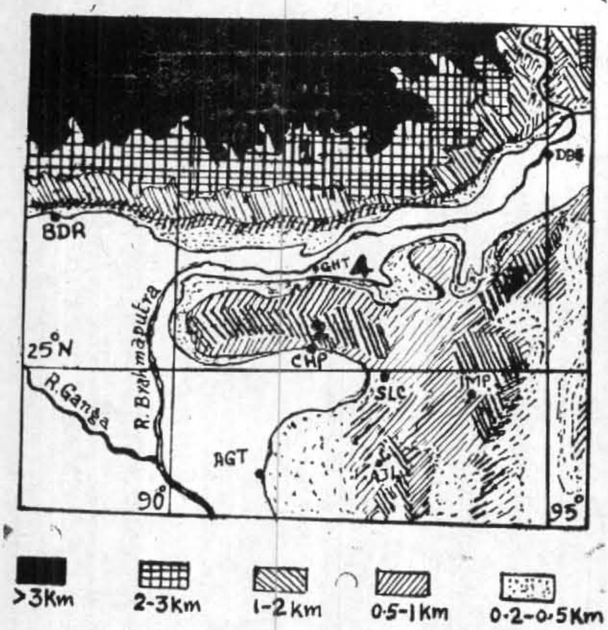
Number of occasions *Cb* tops reaching different heights during various months

Month	Height (km) 5	6	7	8	9	10	11	12	13	14	15	Total	Percentage frequency
Mar	65	73	55	22	19	9	7	1	—	—	—	251	4·6
Apr	215	303	217	97	41	47	23	8	5	5	—	961	17·8
May	423	395	157	93	31	20	11	14	2	4	1	1151	21·3
Jun	311	227	117	60	33	11	3	3	1	1	—	767	14·1
Jul	280	248	86	34	6	6	—	—	—	—	—	660	12·2
Aug	359	222	84	27	10	1	—	—	—	—	—	703	12·9
Sep	328	178	75	33	9	1	2	—	—	—	—	626	11·6
Oct	163	85	31	13	3	3	—	—	—	—	—	298	5·5

TABLE 4

Sectorwise frequency of occurrence of *Cb* in various months and seasons

Sector	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Pre-monsoon total	Monsoon total	Post monsoon total	%Freq. pre-monsoon season	%Freq. monsoon season	%Freq. Post-monsoon season
N	25	103	116	73	71	52	38	26	144	234	26	6·3	8·5	9·3
NE	8	30	30	36	26	38	33	8	68	133	8	2·9	4·8	2·7
E	17	70	63	62	64	64	54	16	150	244	16	6·4	8·9	5·3
SE	45	113	125	94	68	77	91	49	383	330	49	16·4	12·0	16·4
S	44	215	211	137	96	161	116	79	470	510	79	19·9	18·5	26·3
SW	41	117	172	109	95	125	104	37	330	433	37	13·7	15·7	12·3
W	43	186	282	178	160	120	120	51	511	578	51	21·7	21·0	17·0
NW	28	127	152	78	80	66	70	32	307	294	32	12·9	10.6	10·7
Total	251	961	1,151	767	660	703	626	298	2,363	2,756	298			



1. Himalayan range, 2. Garo-Khasi-Jaintia hills
3. Manipur and Naga hills, 4. Brahmaputra valley

Fig. 1

number of occurrences ΣN for each sector by total number of occurrences during the month. Similarly last row of each month gives percentage frequency ($\%f$) obtained by dividing total number of occurrences in all sectors in a period by the number of occurrences during the month. The percentage probability or chance ($\% P$) of occurrence was obtained by dividing the number of occurrences during a 6-hour period of a sector by the total number of such mathematically possible periods in the same sector during the six years under study (*e.g.*, month of March has a total number of 186 such 6 hourly periods).

4. Limitations

It is necessary to mention the limitations of data presented in the study. They are :

(*a*) Due to wide beam width (2·9°) of Bendix radar WTR-1, cloud heights need correction.

(*b*) Possibility of missing some clouds immediately after the passage of thunderstorm.

(*c*) Radar observations remained suspended from 14 GMT to 22 GMT during March and April 1972.

(*d*) Radar developed some intermittent defect in pre-monsoon season of 1974. As a result nearly 185 observations were lost.

5. Data analysis

5.1.1. It is seen from Table 2 that there is a wide variation in the number of *Cb* cell in different years. Nearly 70 per cent of the cells around Gauhati dissipate after attaining 6 km height or earlier. Only 30 per cent develop higher than 6 km. Only once in six years cloud attained 15 km height in May 1972. There were 45 occasions in which clouds reached 12 to 15 km height.

5.1.2. The percentage frequency of *Cb* development does not differ much in pre-monsoon and monsoon seasons being 43·7 and 49·2 respectively as seen from Table 3. Frequency is highest in the month of May and least in March. Instances of tops going to higher heights are more in the months of April, May and June.

5.1.3. From Table 4 it can be inferred that nearly 67 to 72 per cent cells develop in southeastern to northwestern (through southern) sectors; highest, being in western followed by southern sector. Minimum frequency is in northeastern sector. Out of 40 per cent of the total number of cells developing in southern and western sectors, western maxima are found in the months of May, June, July and September and southern maxima in rest of the months.

5.1.4. Table 5 gives total number of cells recorded at individual hour of a month. There is a minimum at 22 GMT in pre-monsoon season while over a period starting from 20 GMT to 23 GMT there is very little *Cb* development in monsoon and post-monsoon seasons. Apart from this minimum there is a decrease in the number of cells at 04 GMT which forms a dip in the months of April, May, June and July. This dip can be visualised in other months by sharp increase in the number after 04 GMT.

All season maximum at 08 GMT shifts in individual months from 11 GMT in April to 08 GMT in October. Period of more marked *Cb* development contracts from 22 to 15 GMT from April to October.

5.2. As the clouds which do not attain a height of at least 7 km are normally not associated with thunder, squall or hail, such echoes were deleted to arrive at details of preferred sectors and period of thunder cloud in different seasons and individual months. The results are presented in the form of curves.

In six years only 1542 instances were recorded in which clouds have developed to 7 km or more. Highest number of instances have been

TABLE 5

Hourly frequency distribution of *Cb* during various months and seasons

Month	Time (GMT) 00	01	02	03	04	05	06	07	08	09	10	11	12
Mar	2	2	9	9	10	9	20	15	23	21	18	22	18
Apr	28	29	32	30	24	34	40	55	65	60	65	74	57
May	33	30	30	32	25	36	57	91	109	115	94	72	49
Jun	16	19	21	27	19	36	50	68	77	67	65	50	40
Jul	15	13	16	15	12	21	35	53	71	68	58	57	48
Aug	6	8	9	10	13	25	48	60	84	83	82	64	53
Sep	12	13	9	12	21	33	55	65	86	72	59	53	31
Oct	3	4	3	7	5	12	21	38	47	38	29	24	15
Pre-monsoon total	63	61	71	71	59	79	117	161	197	196	177	168	124
Freq.	2·7	2·6	3·0	3·0	2·5	3·3	4·9	6·8	8·3	8·4	7·4	7·2	5·2
Monsoon total	49	53	55	64	65	115	188	246	318	290	264	224	172
Freq.	1·8	1·9	2·0	2·3	2·4	4·2	6·8	8·9	11·6	10·5	9·6	8·2	6·3
Post-monsson total	3	4	3	7	5	12	21	38	47	38	29	24	15
Freq.	1·1	1·3	1·1	2·3	1·7	4·0	7·0	12·7	15·8	12·8	9·7	8·0	5·0

TABLE 5 *(contd)*

Month	Time (GMT) 13	14	15	16	17	18	19	20	21	22	23	Total (00-23)
Mar	15	5	7	7	10	8	7	8	2	1	3	251
Apr	53	51	47	43	33	32	29	26	18	15	21	961
May	40	38	46	48	36	40	32	26	21	24	27	1,151
Jun	28	27	28	23	23	19	16	12	11	11	14	767
Jul	37	31	19	14	13	12	16	11	13	6	6	660
Aug	28	30	18	20	12	11	6	5	11	10	7	703
Sep	24	22	13	8	8	6	3	5	4	6	6	626
Oct	13	7	11	4	4	3	4	1	3	1	1	298
Pre-monsoon total	108	94	100	98	79	80	68	60	41	40	51	2,363
Freq.	4·6	4·0	4·2	4·1	3·3	3·4	2·9	2·5	1·7	1·7	2·2	
Monsoon total	117	110	78	65	56	48	41	33	39	33	33	2,756
Freq.	4·2	3·9	2·8	2·4	2·0	1·7	1·5	1·2	1·4	1·2	1·2	
Post-monsoon total	13	7	11	4	4	3	4	1	3	1	1	298
Freq.	4·4	2·3	3·8	1·3	1·3	1·1	1·3	0·3	1·1	0·3	0·3	

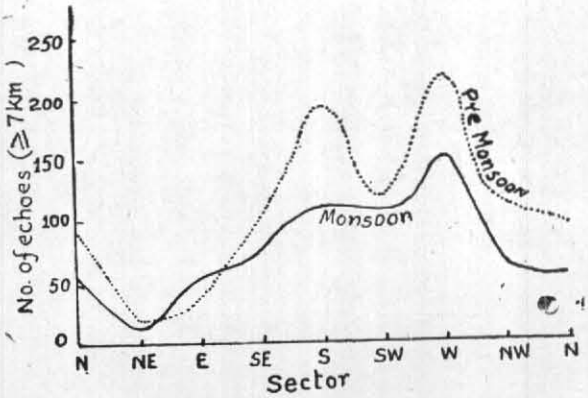


Fig. 2. Seasonal distribution of *Cb* in various sectors

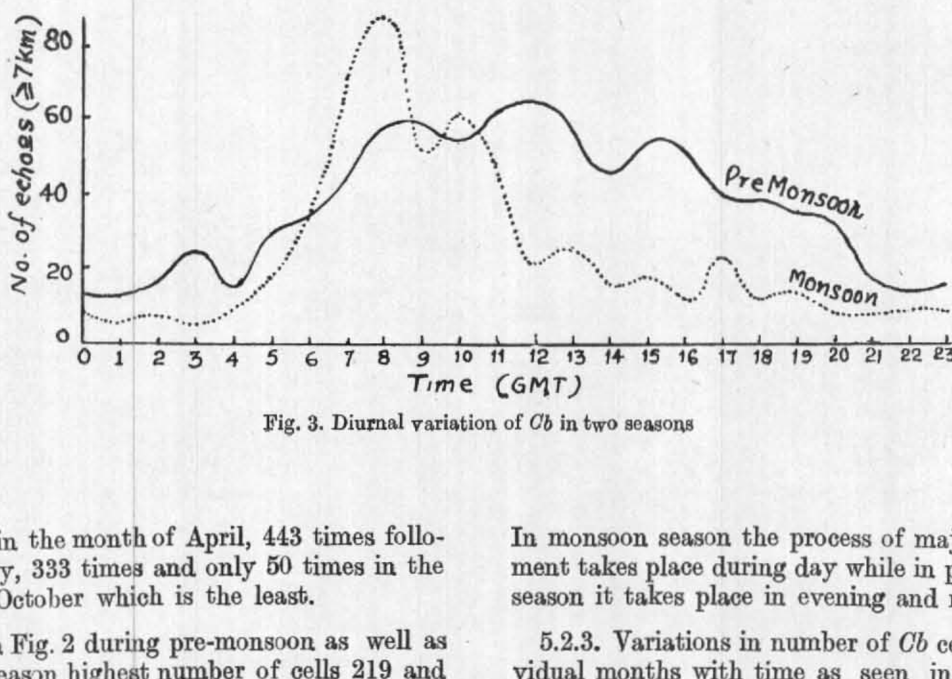


Fig. 3. Diurnal variation of *Cb* in two seasons

registered in the month of April, 443 times followed by May, 333 times and only 50 times in the month of October which is the least.

5.2.1. In Fig. 2 during pre-monsoon as well as monsoon season highest number of cells 219 and 146 developed in western sector in respective seasons. 19 and 12 numbers are recorded in northeastern sector which is least among all the sectors in both seasons. In pre-monsoon season a second peak is in the southern sector which does not appear in monsoon season. Pre-monsoon curve is higher than monsoon curve in all sectors except eastern.

5.2.2. Time of maximum development differs appreciably in these two seasons. Pre-monsoon maximum as seen in Fig. 3 is at 12 GMT while in monsoon season it is at 08 GMT. The period of appreciable development also differs in two seasons. During monsoon season maximum number of cells develop during 06 to 12 GMT while in pre-monsoon it is further extended upto 20 GMT. In monsoon season the process of major development takes place during day while in pre-monsoon season it takes place in evening and night.

5.2.3. Variations in number of *Cb* cells in individual months with time as seen in Fig. 4 also indicate three peak periods around 08, 12 and 16 GMT in April and May and to some extent in June also. The maximum around 08 GMT is a common feature in all months except April. *Cb* activity during night gradually decreases from April to October.

5.2.4. Fig. 5 shows diurnal variation of *Cb* cells in all sectors. Apart from smaller undulations in curves which may be attributed to differences in topography, following features need attention :

(*i*) In southern and southeastern sectors the maxima are around 08 GMT.

(*ii*) In western, northwestern and northern sectors 12 GMT peak is prominent.

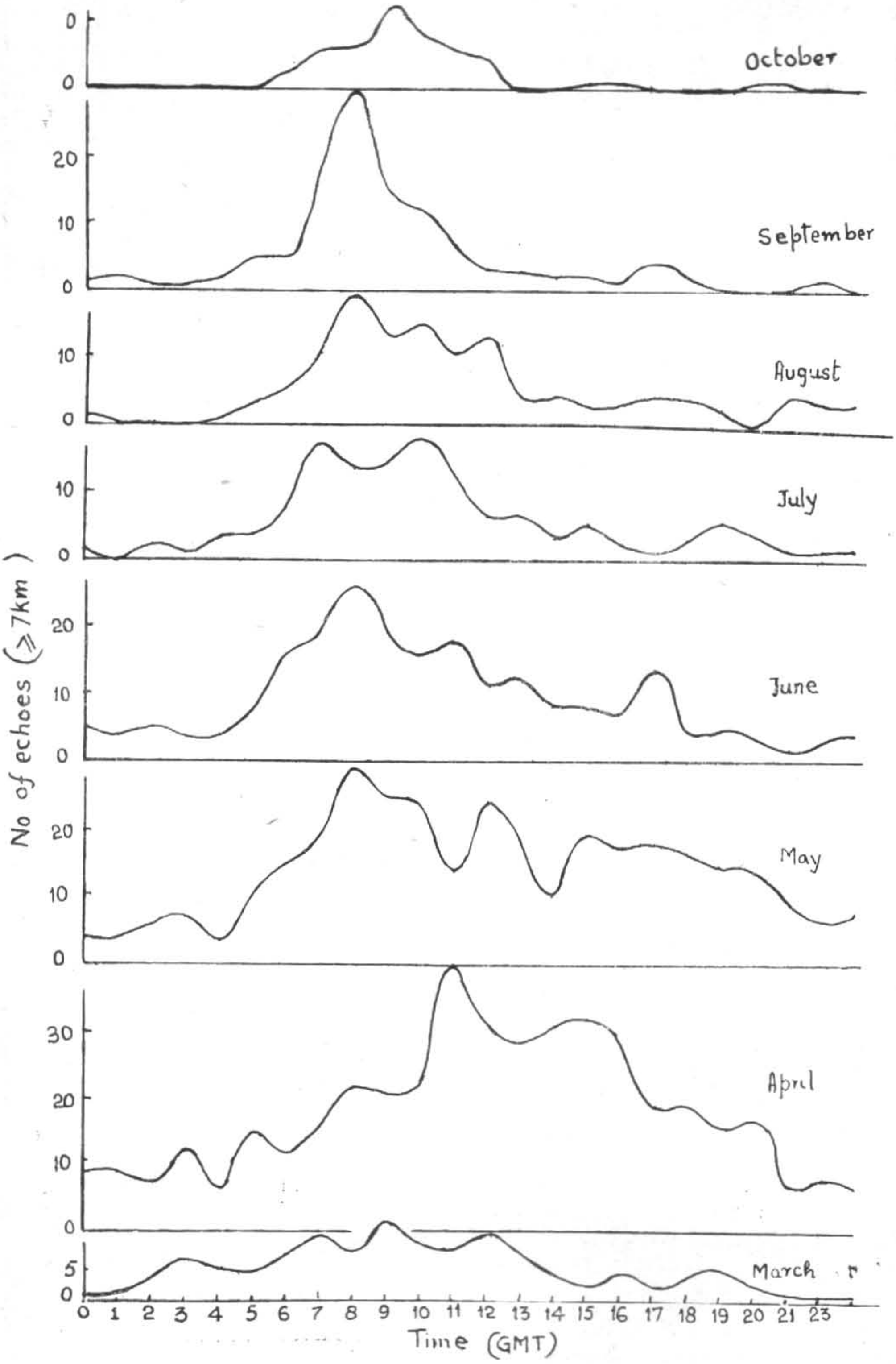


Fig. 4. Diurnal variation of *Cb* in various months

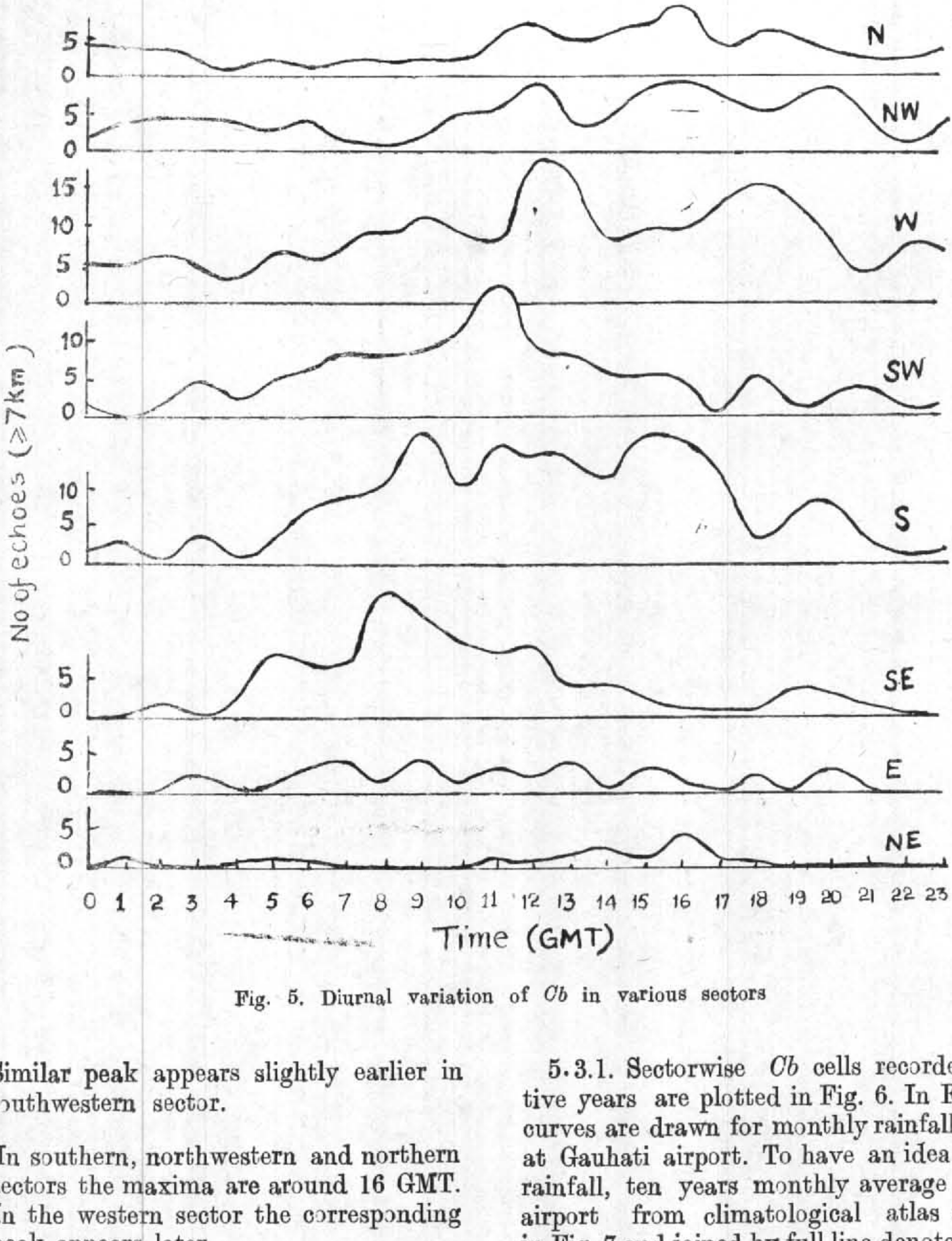


Fig. 5. Diurnal variation of *Cb* in various sectors

Similar peak appears slightly earlier in southwestern sector.

(*iii*) In southern, northwestern and northern sectors the maxima are around 16 GMT. In the western sector the corresponding peak appears later.

5.2.5. From Table 1 it is seen that the highest values of F are in southern and western sectors. F values are highest in afternoons and evenings. The value of per cent probability P is highest in the month of April in southern sector during evening followed by western sector in the same period.

5.3. As more than 80 per cent of the recorded echoes lie within fifty nautical miles of Gauhati airport, the situations under which *Cb* development take place and the resultant rainfall recorded at the station can be taken to be representative of those situations.

5.3.1. Sectorwise *Cb* cells recorded in respective years are plotted in Fig. 6. In Fig. 7 yearly curves are drawn for monthly rainfall as recorded at Gauhati airport. To have an idea of average rainfall, ten years monthly average of Gauhati airport from climatological atlas are plotted in Fig. 7 and joined by full line denoted by N.

It is seen that southern peaks are high whenever monsoon rainfall is more than average. There is high occurrence of *Cb* in western sector when pre-monsoon rainfall is high.

5.3.2. Seasonal totals of *Cb* cells are plotted against corresponding year in Fig. 8. The curves of pre-monsoon and monsoon are compared with the monsoon rainfall of that year.

Pre-monsoon *Cb* curve presents the trend which will be followed by the future rainfall during the following monsoon season. Troughs and crests of

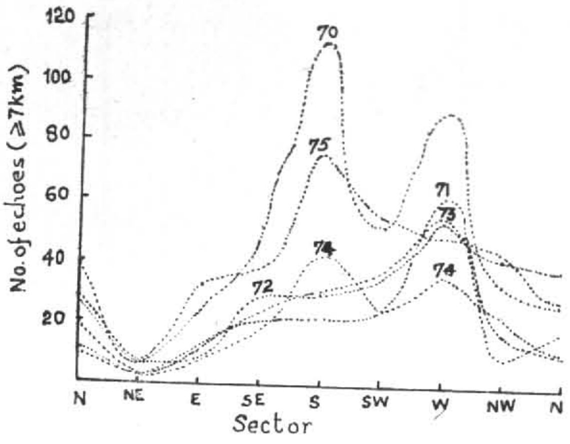


Fig. 6. Sectorwise distribution of *Cb* during 1970-75

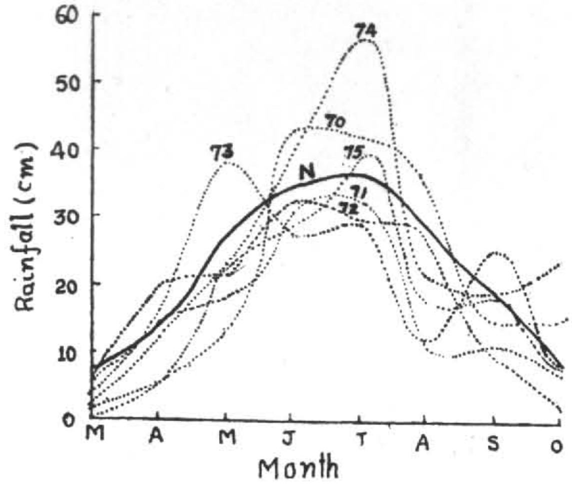


Fig. 7. Monthly rainfall during 1970-75

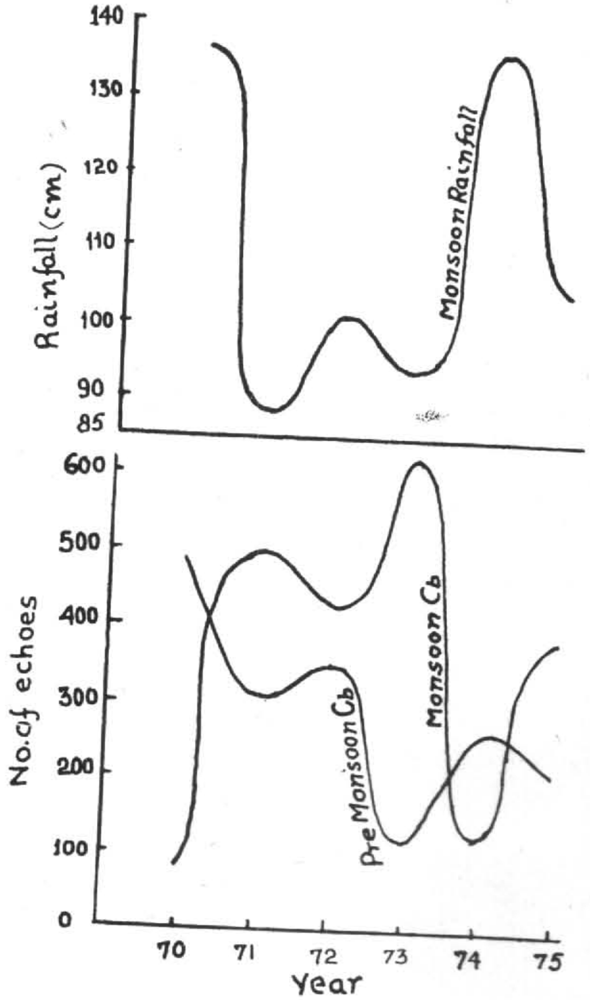


Fig. 8. Seasonal distribution of *Cb* compared to monsoon rainfall

TABLE 6

D stribution of *Cb* (≥9 km) over various periods

Height (km)	Period			
	Fore-noon	After-noon	Even-ing	Night
9 to 12	38	112	112	34
≥12	0	12	25	8

TABLE 7

Distribution of *Cb* (≥9 km) over various sectors

Height (km)	Sector							
	N	NE	E	SE	S	SW	W	NW
9 to 12	31	9	11	22	89	41	65	28
≥12	4	0	1	3	13	12	12	0

pre-monson *Cb* curve correspond to the crests and troughs of rainfall curve. This is true in opposite sense for monsoon *Cb* curve, *i. e.*, more rainfall, less *Cb* and *vice versa*.

6. Discussion

Cb activity reaches a maximum in the afternoon around 08 GMT and attains a minimum during morning hours. Afternoon *Cb* cells are due to convective instability, and are caused by intense insolation which reaches its maximum also during this period of the day (the maximum temperature epoch).

Sen and Basu (1961) have studied thunderstorms during 1955-59 and have found that most of the thunderstorms which originate in afternoon/evening in West Bengal move eastwards giving thunderstorms in adjoining Assam stations after 1900 IST and extend to eastern stations later in the night. For occurrence of widespread thunderstorms incursion of warm moist SW/S'ly air upto atleast 3000 ft a.s.l. is an essential condition. Normally SW/S'lies are prevented by Garo-Khasi-Jaintia hills barrier whose average height is 1·5 km. As this current is warm and moist, is expected to remain above the cold dry easterlies over the Brahmaputra valley.

One mechanism to bring down warm moist southerlies during night is suggested by Mukherjee and Ghosh (1965) when katabatic wind blows down the slope towards the valley.

Booker (1963) has studied modification of convective storms by lee waves in Allegheney mountains. It is mentioned that lee waves are best developed just before sunset.

It appears whenever conditions of direction and speed of wind flow with respect to mountain ranges and variations of Scorer's (1949) l^2 parameter are satisfied in the evening for the formation of high amplitude lee waves, the southerlies are brought down in the troughs and development of *Cb* cells take place in the ascending sections of the wave. This may be a possible reason for high number of *Cb* cells observed at 12 GMT in western, northwestern and northern sectors. By the advance of monsoon the speed of southerlies weakens and the possibility of formation of waves or lee side trough reduces.

The B-type thunderstorms as classified in India met. Dep. Tech. Note 10 (1949) which are triggered from the outflow of air from a parent thunderstorm follow a time sequence as observed by Desai (1950) and are not likely to give maxima in west, northwest and north of Gauhati at same time. Overall effect of such secondaries, tertiaries, quaternaries etc is to increase the number of *Cb* cells over an extended period, as the cold air from the outflow spreads from primaries, secondaries, tertiaries etc.

The larger number of *Cb* cells in south in relation to higher than normal rainfall at Gauhati during monsoon season may be due to large thundery activity in south when the axis of monsoon trough shifts north giving copious rainfall in foot hills and north Assam during 'break' spells.

The reasons for large *Cb* activity in pre-monsoon if monsoon rainfall is likely to be more, are not very well understood.

7. Conclusions

As observed by Sen and Basu (1961), it was found during 1971-75, squalls which affected Gauhati airport came mainly from northwest and with wind speed of 40 knots or more occurred during night. It is interesting to note from Tables 6 and 7 that in northwestern sector not a single cell developed to 12 km or more and majority of cells developed in southern and western sectors during evening or night.

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