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A radar study of premonsoon thunderstorms (Nor'westers) over Gangetic West Bengal

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ABSTRACT. Development of premonsoon thunderstorms around Calcutta during 1958 and 1959 has been studied with the help of a high-powered storm detecting radar with P.P.I., R.H.I. and 'A' scopes at Dum Dum airport (Calcutta). The location and type of the initial formation of the radar echoes and their subsequent development into line-type echoes and directions of movement have been discussed. The characteristics of the thundersqualls which reached Dum Dum have also been studied in relation to the corresponding radar observations and results so obtained have been summarised. Stronger squalls are apparently produced from *Cb* clouds with greater vertical growth.

1. Introduction

It is well-known that severe thundersqualls occasionally accompanied by rain are prevalent over Gangetic West Bengal during the premonsoon months (March—May). These are called Nor'westers and they generally move from northwest to southeast. But on some occasions they move from other directions as well. A radar study of these premonsoon thunderstorms has already been reported recently by Koteswaram and De (1959). They examined the radar observations made during 1955-1957 with a medium-powered (30 KW peak) 3-cm radar (Decca Type 41) installed at Dum Dum airport. In the absence of R.H.I. facility, they based their study on P.P.I. observations only. The aim of the present paper is to throw some more light on the structure and movement of nor'westers with the help of a more powerful radar having R.H.I. facility, which was installed at Calcutta (Dum Dum airport) in 1958.

2. Radar observations

The observations were made with a high-powered radar operating on 3-cm wave band. The beam width of the radar is 1·2° in both vertical and horizontal and the peak power is 250 KW. The radar has got a maximum operating range of 300 km. Apart from P.P.I. scope, the radar is provided with R.H.I. and 'A' scopes. The height information is obtained in the following way—The aerial unit is rotated and fixed pointing to the selected direction of azimuth and then tilted vertically from 0° to +30°. The picture thus obtained is seen on the R.H.I. scope. R.H.I. information can be obtained for targets upto a maximum range of 100 km. This limitation of range can be eliminated by another method of presentation called Range Elevation Indication (R.E.I.), which can be seen on the P.P.I. scope. For obtaining the R.E.I. presentation, the aerial is tilted vertically from 0° to +90° and the picture thus obtained is seen on the P.P.I. scope. The R.E.I. information is available for the full range of the equipment.

The radar is operated for 15 minutes every hour as a matter of routine. Precipitation echoes as seen on the P.P.I. scope are plotted every hour on a polar diagram. Significant portions of the individual cells or line-type echoes are also scanned vertically and height information as obtained from R.H.I./R.E.I. scope is recorded on the same diagram. If the successive radarscope pictures show significant development, the radar is operated more frequently and when the thunderstorm activities are noticed within about 100 km around Dum Dum airfield, the radar is operated continuously. Interesting cases have also been photographed.

3. Data used

The radar described above was installed at Dum Dum airport on 29 April 1958. The radar observations for May 1958 and March to May 1959 have been analysed from various aspects, and the results obtained from these observations are presented in this paper. In studying these radarscope observations, the following points were looked into—

(a) Whether the first appearance of a radar echo, which ultimately developed into a line-type of echoes, was in the form of an isolated cell or a line-type at the start itself, (*b*) The time-lapse between the first appearance of the radar echo and the formation of a line-type of echoes, (*c*) Whether the radar echoes during the mature stage were in the form a solid line or a broken line, (*d*) Dimensions (length, width and height) of the line-type echoes, (*e*) Duration of the line-type echoes, (*f*) Speed and direction of movement of the line-type echoes, (*g*) Type of echoes during dissipating stage, and (*h*) Characteristics of the line-type echoes which reached Calcutta (Dum Dum airfield) and its relation with the observed weather.

For the above studies, only those occasions were taken into consideration when an initial echo, in the form of an isolated cell or a line, ultimately developed into a squall line with definite movement. Meteorological observations recorded at the Meteorological Office, Dum Dum, including autographic records, *viz.*, anemograms, thermograms and hyetograms, and current weather records of Dum Dum, were utilised for studying the radar observations in relation to the observed weather.

4. Analysis of the data

There were 15 occasions during May 1958 and 46 occasions during March-May 1959 (61 occasions in all) when significant thundersquall line-echoes were detected on the radarscope. Out of these 61 occasions, movements could be studied for 54 occasions, while on the remaining 7 occasions, the lines did not show any appreciable movement. Characteristics of the initial formation of the radar echo, dimensions of the squall lines at their mature stage of development and their movement as observed on the radar, and characteristics of thundersquall, rain at Dum Dum, if any, are summarised in Table 1. As mentioned earlier, the movements of the line-type echoes have been studied with the help of hourly traces of P.P.I. records.

The frequencies of movement of the line-echoes from different directions in different months are shown in Table 2. It may be seen from Table 2 that on 70 per cent occasion (43 out of 61 occasions), the lines moved from northwest or north. Percentage frequencies of movements from other directions were as follows – 5 per cent from northeast, 6 per cent from south, 2 per cent from southwest and 5 per cent from west. These percentage figures are similar to those reported by the earlier radar study (Koteswaram and De 1959).

5. Initial formation of radar echoes and development into line formation

The location and type of the initial formation on each occasion as observed on the radar have been indicated in Table 1. The initial echoes appeared on most of the occasions in the late afternoon as isolated or scattered cells, which developed into line-type echoes within 1-2 hours (Table 1). The locations of the initial echoes on individual occasions as observed are shown on a polar diagram (Fig. 1). Where the initial echo was observed as scattered cells or a line, the mean position has been shown in the diagram. It will be seen from this diagram that the location around Calcutta where the initial growths were observed can be grouped into 4 sectors. These are (1) NNW/NNE—80/300 km; (2) WSW/WNW—160/300 km; (3) ENE —150/280 km and (4) SW—150/300 km. The majority of the initial growths (about 75 per cent) were, however, in the first two sectors. It is noteworthy that among the initial cells which subsequently gave thundersquall at Calcutta (Dum Dum), a large proportion were those which initially formed in sector (2), *i.e.*, towards WSW/WNW of Dum Dum. It is obvious that the growths in the other three sectors would move away from Calcutta when following their usual direction of movement from northwest to southeast.

It has been mentioned earlier that the radar observations were taken every hour for 15 minutes as a matter of routine. Evidently, formation of all the radar clouds, could not be detected exactly at the initial stage of echo formation. However, from the available records, it is found that out of 61 occasions studied, at least on 31 occasions the thundersqualls had its origin as isolated cells. This would suggest that if the radar were operated continuously instead of at hourly intervals, a large majority of the thunderstorms would perhaps be detected on the radar as isolated cell to start with. Among the 30 cases when the initial radar observations had shown more echoes than just isolated cells, on 12 occasions the radar clouds appeared as scattered cells and on the remaining 18 occasions as broken or continuous lines, *i.e.*, already in somewhat developed stages.

6. Duration of the squall lines

It has been stated that on a large number of occasions, the radar clouds could be studied since their first appearance as isolated or scattered cells. These cells later developed into squall lines. By taking all such cases into account, the average time taken by these cells to form "lines" is found to be about 1·5 hours. It is also observed that isolated cells or scattered cells, which do not form into squall lines within two or three hours, generally dissipate without appreciable development.

Once the squall line is formed, the next point of importance is its duration. From the cases studied here, it is found that on an average, the duration of the squall line is about 3-4 hours, after which the squall lines are generally found to die out or dissipate away as a diffuse pattern.

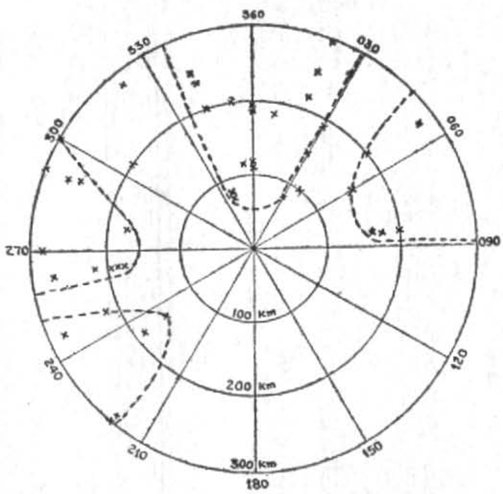

Fig. 1. Location of initial radar echoes on different occasions

7. Radar observations and characteristics of thundersqualls which reached Dum Dum

As indicated in Table 1, out of 61 occasions when line-type radar echoes were observed around Calcutta, on 21 occasions the thundersquall lines passed over Dum Dum airfield. The sequence of radar observations on those 21 occasions and the characteristics of the thundersqualls at Dum Dum have been studied in some details with the available observations. It may be mentioned that out of those 21 occasions when the line-type echoes passed over Dum Dum, development of the radar clouds on 17 occasions could be studied right from their initial appearance as isolated or scattered cells on the radarscope. Dum Dum experienced thunderstorm/rain on these 21 occasions, 16 of which gave squall at Dum Dum.

8. Movement of radar clouds *vis-a-vis* direction of squalls at Dum Dum

In the absence of a close network of observatories around the observing station, squalls recorded at Dum Dum Observatory only have been studied in relation to the observed radar echoes. The frequencies of movement of the radar echoes from different directions as against the directions of squalls recorded at Dum Dum are shown in Table 3. It will be

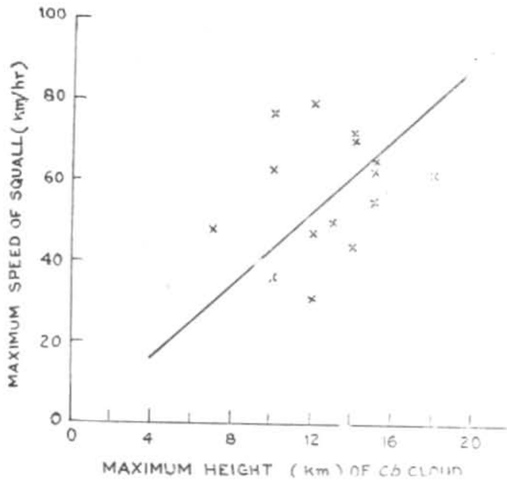

Fig. 2. Maximum speeds of squall and the maximum heights of corresponding ***Cb*** **clouds**

seen from this table that on 11 (52 per cent) out of 21 occasions, Dum Dum Observatory recorded squall from northwest/north and out of these, on 9 occasions the radar clouds also moved from northwest/north. These figures are comparable with the observation reported by Koteswaram and De who found the corresponding frequencies as 62 per cent and 33 per cent respectively. Though northwest/northerly squalls predominated, squalls from other directions also occurred on 5 out of 16 occasions (31 per cent).

It will be seen from Table 3 that the direction of thundersqualls generally coincided with the direction of movement of radar clouds. On 3 out of 21 occasions, however, the thundersqualls came from an entirely different direction. On 18 May 1958, though the radar cloud approached from the south, the squall at Dum Dum came from north; on 31 March 1959 and 30 May 1959 the radar clouds moved from northwest, whereas the squall at Dum Dum came from northeast and southeast respectively. A scrutiny of the relevant upper air charts revealed that direction of movement of the radar clouds and that of thundersquall on most occasions is generally governed by direction of wind at upper levels, say above 6 km. On the 3 occasions when thundersquall came from a direction different from radar cloud movement, the direction of squalls are apparently not related to upper level wind. On these occasions, however, pronounced low level wind discontinuity was noticed around Calcutta. The exact mechanism of thundersquall coming from a different direction unrelated to that of the radar cloud is, however, not clearly understood.

9. Intensity of squalls

Forecasting the squall speed while issuing warnings against nor'westers always involves considerable uncertainty. Attempts were made to find whether any aspect of the radarscope observations could give rough idea about the intensity (*i.e.*, the speed) of squall. For this purpose, any possible correlation of the observed squall speed with (*i*) the dimensions of the squall lines and (*ii*) maximum height of the top of the thunder clouds comprising the squall lines, was looked into. The data presented in Table 1 were utilised for the purpose.

From a scrutiny of the available data, it is found that the dimensions (length and width) of the squall lines do not bear any relationship with the intensity of the squalls recorded at Dum Dum. Next, the maximum height reached by the top of the *Cb* clouds during the life cycle of the squall lines were compared against the maximum speed of squalls as depicted by scatter diagram in Fig. 2. It is seen from this figure that there is a definite tendency of the squall speed to be stronger with higher maximum height of the *Cb* cells. Such a relation may be theoretically expected, because the violence of thundersquall should depend on the strength of the downdraft, which again is predominant only during the mature stage of the thunderstorm cell (Byers and Braham 1949) when growth of the *Cb* cells extend to higher altitude. Although the available data (presented in Fig. 2) are not adequate, it seems that a tentative mean line could be drawn with majority of the squall speeds satisfying an approximate linear relation with corresponding heights of tops of *Cb* cells. According to this diagram

Cb heights of 10 km roughly corresponds to squall speed of 45 km hr^{-1} and that with height 20 km to squall speed of 90 km hr^{-1} It is obvious that this relationship cannot always yield accurate result. However, it seems that such relationship, if verified on more observations on this line, could be of some practical help, particularly because more dependable objective means are not available for anticipating the squall speed.

As stated earlier, for comparison of the squall speeds against the heights of *Cb* cells, the maximum height of *Cb* cell reached during the life cycle of the squall line was recorded. This height naturally might not correspond to that portion of the cloud cell which gave squall at Dum Dum airfield. It is possible that if heights of the portion of the cell which gave squall at the stations could be recorded at a time shortly earlier than the occurrence of the squall, one might expect to obtain a still better correlation between the squall speeds and the heights of the corresponding *Cb* cells.

10. Rainfall

It is well-known that the premonsoon thundersqualls (nor'westers) are often associated with rain. Out of 21 occasions when the thundersquall line passed over Dum Dum airfield, the number of occasions when rainfall exceeding 5 mm and 10 mm occurred at Dum Dum were 9 (43 per cent) and 7 (33 per cent) respectively. Rainfall exceeded 50 mm only on 2 occasions. On majority of occasions, rainfall asssociated with the thundersquall was less than 5 mm. These figures give us an idea about the amount of precipitation that may normally be expected from a nor'wester squall at Calcutta.

It may be seen from Table 1 that on two occasions, (*i.e.*, on 26 May 1959 and 31 May 1959), Dum Dum Observatory recorded more than 50 mm rainfall. It is noteworthy that the maximum height of the *Cb* cells comprising the squall lines on those two occasions was only 12 km, whereas on 21 May 1959 when the maximum height of *Cb* cells reached 20 km, rainfall recorded at Dum Dum airfield was only 11 mm. From the 21 occasions studied as incorporated in Table 1, no definite relation could be found between the height of *Cb* clouds and the associated rainfall. In any case, it appears that rainfall from *Cb* clouds with higher vertical development may not necessarily be heavier.

It may be reasonable to expect that the amount of rainfall should have some relation with width of the *Cb* cell if not with the height of *Cb* cell. The width of the *Cb* cell as observed on radarscope, however, depends upon the attenuation of radar beam illuminating the radar cloud. Attenuation depends upon a large number of factors, *viz.*, the wavelength and power of the radar set, the physical characteristics of the intervening space between the radar antenna and the radar cloud, the mass concentration of water droplets inside the radar cloud etc. If we assume the effect of these factors to be the same on different occasions and we also assume that the radar beam has penetrated through the entire cloud mass, then the width of the radar cloud may be treated as representative of width of the cloud. From the data available on width of the line echoes and associated rainfall for this study, no such relationship could, however, be detected.

It is likely that the intensity of radar echo as received may be directly related to the intensity of rainfall. However, during the period under study, no systematic record was maintained of the relative amplitudes observed on the A-scope from the shower clouds approaching Dum Dum airport for the purpose of comparison with the actual rainfall.

REFERENCES

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Koteswaram, P. and De, A. C. 1959 *Indian J. Met. Geophys.*, **10**, 3, pp. 275-282.

TABLE

Serial No.	Date	Initial appearance of radar echoes				Time lapse between initial echo and line formation (hr)
		Time (IST)	Location		Type	
			Azimuth (°N)	Distance (km) from Dum Dum		
	1958					
1	10 May	1600	330—360	120—130	Isolated cell	1
2	11 ,,	1800	255—015	80—170	Continuous line	0
3	12 ,,	1600	250—270	150—200	Isolated cell	1
4	13 ,,	1400	255—270	140—210	Do.	1
5	17 ,,	1200	170—100	70—100	Broken line	0
6	17 ,,	1200	340—350	60— 90	Isolated cell	2
*7	17 ,,	1600	130—200	30— 50	Broken line	1
*8	18 ,,	0900	070—175	50—200	Do.	1
9	20 ,,	1400	020—040	140—220	Scattered cells	1
10	20 ,,	1500	230	150	Isolated cell	1
11	28 ,,	1600	070—130	50— 70	Continuous line	0
12	28 ,,	1500	030—050	20—170	Scattered cells	2
13	29 ,,	1700	220—240	30	Isolated cell	1
14	29 ,,	1900	170—220	60—100	Broken line	1
15	31 ,,	2000	316—030	110—150	Continuous line	0
	1959					
16	5 March	0830	095—200	110—240	Broken line	0
*17	23 ,,	1430	020—040	70—170	Do.	0
18	25 ,,	1230	055—080	210—350	Continuous line	0
*19	25 ,,	1500	240—280	190—230	Scattered cells	3
20	26 ,,	2100	015—090	200—350	Do.	2
21	27 ,,	1000	065—100	70—250	Do.	1
22	27 ,,	2000	360—060	60—100	Do.	2
*23	31 ,,	1000	270—075	20—250	Do.	1
*24	31 ,,	1615	280—080	50—250	Do.	1
25	1 April	1200	270—090	70—360	Broken line	1
26	1 ,,	1900	350—020	140—250	Isolated cell	1
27	5 ,,	1200	240—260	240—320	Isolated cell	2
28	14 ,,	1500	003—020	220—250	Continuous line	0
*29	15 ,,	1400	240—270	140—250	Isolated cell	3
30	17 ,,	1100	300—320	150—200	Broken line	2
*31	17 ,,	1400	All sectors	100—300	Scattered cells	1½
32	18 ,,	1200	080—085	150—360	Isolated cell	4

*Indicates the occasions when the thundersquall lines passed over Dum Dum airfield

1

Dimension of squall lines at maximum development: Max. length (km)	Max. width (km)	Max. height (km)	Duration of squall lines (hrs)	Movement of squall line: Average direction from	Average speed (km/m)	Weather at Dum Dum: Squall Direction	Squall Speed (km/m)	Rain (mm)
300	8	18	4	N	20	..	..	10·0
250	10	15	3	NW	30	NW	63	4·6
120	10	15	1	Uncertain		..	..	0·0
125	15	18	2	NNW	50	..	..	0·0
90	8	5	2	NW	30	..	..	0·0
70	3	..	1	Uncertain		..	..	0·0
160	5	8	5	SSE	16	..	..	2·0
115	15	7·5	9	SSE	20	N	48	0·0
70	15	14	3	N	20	..	..	0·0
80	15	14	2	S	15	..	..	0·0
70	25	12	1	S	15	NW	31	3·3
180	30	12	1	NNW	25	SE	39	0·0
50	10	8	1	NNE	20	S	28	0·0
140	30	4	1	NW	15	S	35	0·0
50	15	5	1	NNE	30	..	..	0·0
200	20	8	2	NW	10	..	..	0·0
60	8	15	2	NE	25	N	37	1·5
125	15	15	1	N	25	..	..	0·0
140	30	14	4	NW	25	N	42	6·0
160	15	13	4	NW	12	..	..	0·0
200	15	15	3	N	25	..	..	0·0
60	12	12	2	N	30	..	..	0·0
260	20	10	4	NW	20	NE	77	6·5
150	10	12	1	Uncertain		..	..	16·8
200	10	13	3	NW	15	..	..	10·0
175	10	12	3	WNW	15	..	..	0·0
100	15	8	1	NW	15	..	..	0·0
60	10	15	4	WNW	30	..	..	0·0
80	15	15	2	W	40	SSW	72	0·8
100	6	5	1	..	..	..	..	0·0
150	25	12	3	WNW	40	..	..	0·0
200	30	8	17	..	..	..	..	0·0

TABLE

Serial No.	Date		Initial appearance of radar echoes: Time (IST)	Location: Azimuth (°N)	Location: Distance (km) from Dum Dum	Type	Time lapse between initial echo and line formation (hr)
	1959						
*33	20	April	0600	360—160	90—250	Scattered cells	6
34	20	,,	1400	280—320	220—290	Do.	2½
35	30	,,	0800	008—025	300—360	Do.	1
36	4	May	1400	347	200	Isolated cell	1
37	5	,,	1400	360—060	110—360	Do.	2
38	6	,,	1300	330—360	170—230	Do.	1
39	6	,,	1900	065—076	105—280	Broken line	0
40	8	,,	1200	344	240	Isolated cell	2
*41	8	,,	1300	254	210	Do.	3
*42	9	,,	1300	322	80	Do.	1
				341	250		
43	9	,,	1300	252—278	210—310	Do.	1
*44	10	,,	1300	284—315	300—320	Do.	1
45	11	,,	0700	268—295	140—170	Do.	1
46	14	,,	1500	022—033	110—180	Do.	2
47	15	,,	1600	340—015	70—180	Do.	2
48	16	,,	1400	010—025	200—230	Do.	1
49	19	,,	1400	050—065	120—180	Do.	3
50	20	,,	1500	042—052	105— 50	Broken line	0
*51	21	,,	1200	040—200	200—310	Isolated cell	3
52	22	,,	1500	040—200	100—200	Scattered cells	2
53	23	,,	1300	270—080	120—290	Do.	1
54	24	,,	0600	220—360	100—250	Do.	1
55	24	,,	1300	265—285	270—320	Isolated cell	1
*56	25	,,	0600	080—200	100—200	Scattered cells	1
*57	26	,,	0900	300—070	100—200	Do.	5
*58	27	,,	1600	180—270	120—360	Do.	2
*59	29	,,	1800	300—320	180—200	Isolated cell	2
*60	30	,,	1200	287—305	250—360	Do.	2
*61	31	,,	1300	274—320	200—310	Broken line	0

*Indicates the occasions when the thundersquall lines passed over Dum Dum airfield

1 (*contd*)

Dimension of squall lines at maximum development			Duration of squall lines (hrs)	Movement of squall line		Weather at Dum Dum		
						Squall		Rain (mm)
Max. length (km)	Max. width (km)	Max. height (km)		Average direction from	Average speed (km/m)	Direction	Speed (km/m)	
300	30	13	3	..	..	..	..	0·0
120	12	12	4	NW	25	..	..	0·0
80	15	10	2	WNW	20	..	..	0·0
300	8	12	6	WNW	50	..	..	0·0
120	20	14	4	NW	25	..	..	0·0
100	6	11	3	NW	20	..	..	0·0
160	15	12	3	NW	25	..	..	0·0
100	25	8	4	NW	20	..	..	0·0
100	15	10	3	NW	20	NW	63	2·0
200	20	15	9	NW	30	N	72	18·8
150	15	15	6	NW	18	..	..	0·0
120	10	15	8	NW	35	NW	66	0·5
80	6	8	1	WNW	15	..	..	0·0
110	10	20	3	N	25	..	..	0·0
50	6	16	1	..	..	..	..	0·0
40	15	15	4	NW	32	..	..	0·0
120	35	16	4	NW	15	..	..	0·0
65	10	15	4	NW	25	..	..	0·0
350	30	20	5	NW	25	NW	92	11·0
140	25	10	4	N	25	..	..	0·0
200	20	18	6	NW	25	NW	62	18·0
90	20	12	4	NW	20	..	..	0·0
90	10	16	4	NW	40	..	..	0·0
130	15	13	5	SW	20	S	50	5·5
200	10	12	6	N	20	N	79	55·5
200	40	15	5	SE-W-NW	30	..	..	0·5
200	50	10	7	W	40	W	36	0·5
160	50	15	5	NW	40	SE	56	0·5
250	10	12	9	NW	30	WNW	48	53·3

TABLE 2

Number of occasions of movements of thunderstorm cells from different directions in different months

Month	W	NW	N	NE	E	SE	S	SW	Uncertain
March 1959		4	3	1					1
April 1959	1	7							3
May 1958		3	4	2			4		2
May 1959	2	19	3					1	1
Total	3	33	10	3			4	1	7

TABLE 3

Direction of movement of radar echoes and squall direction observed at Dum Dum

No. of squalls from	No. of radar echoes from							
	NW	N	NE	E	SE	S	SW	W
NW	6							
N	2	1	1			1		
NE	1							
E								
SE	1							
S							1	
SW								1
W								1