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Some aspects of convective clouds around Delhi

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सार — 1980 से 1982 के मानसून पूर्व और मानसून के दौरान मेघों के रेडार प्रेक्षणों का प्रयोग करते हुए दिल्ली क्षेत्र में संवहनी मेघों की अवधि के साथ-साथ उनकी वृद्धि और क्षय दरों का अध्ययन किया गया है। मानसून पूर्व काल के दौरान इन मेघों स रेडार प्रतिध्वनि की उर्ध्वाधर वृद्धि दर में 1.0 और 25.0 मी०/से० के बीच परिवर्तन था और मानसून काल के दौरान यह परिवर्तन 0.9 और 12.8 मी०/से० के बीच था इन दोनों ऋतुओं में प्रतिध्वनियों की क्षय दर में क्रमश: 0.6 और 10.4 मी०/से० और 0.9 और 15.3 मी०/से० के बीच परिवर्तन पाए गए। मानसून पूर्व और मानसून ऋतु में प्रतिध्वनियों की औसत अवधि के बीच कोई विशेष अन्तर (क्रमश: 39 और 36 मिनट) नहीं पाया गया। इस शोधपत्र में इन मेघों से सम्बन्धित वृष्टि आरंभ होने के प्रकम की भी छानबीन और चर्चा की गई है।

ABSTRACT. Growth and decay rates as well as the durations of convective clouds in the Delhi region have been studied using radar observations of such clouds, made during the pre-monsoon and monsoon seasons of 1980 to 1982. Vertical growth rates of radar echoes from such clouds varied between 1.0 and 25.0 m/sec during pre-monsoon and between 0.9 and 12.8 m/sec during the monsoon season. Decay rates of the echoes are found to vary between 0.6 and 10.4 m/sec, and between 0.9 and 15.3 m/sec in these two seasons respectively. No significant difference was found between the average durations of the echoes in the pre-monsoon and monsoon seasons (39 and 36 minutes respectively). The mechanisms of precipitation initiation involved in these clouds have also been investigated and discussed in the paper.

1. Introduction

With the advent of radar, a good deal of studies relating to the frequency of occurrence of convective clouds as well as their height distribution, have been made in different regions of India during the last three decades. However, only a limited number of studies have been made regarding some of the other important aspects of convective clouds, namely, their growth rates, decay rates, durations and mechanisms of precipitation formation in them (De and Rakshit 1961, Koteswaram and De 1959, Mani and Venkiteshwaran 1961, Mukherjee *et al.* 1977, Ramanamurty *et al.* 1961). Therefore, in this paper, an attempt has been made to further examine the above aspects of convective clouds using radar observations of precipitation echoes from such clouds within 100 km around Delhi, made during the pre-monsoon (March-June) and monsoon (July-September) seasons of 1980 to 1982. Results of the study are presented and discussed.

2. Equipment used and observational procedure

A Japanese radar of type NMD-451A, operating on 3.2 cm wavelength and having peak output power of 250 kw has been used for the study. The radar is installed on a ridge near National Physical Laboratory, New Delhi. The beam width of the radar set is sufficiently narrow (1.2° in both horizontal and vertical), and maximum range is 300 km. The duration of the transmitted pulse is one microsecond and its repetition frequency is 300 per second. Minimum detectable signal is — 90 dBm.

Two displays, namely, Plan Position Indicator (PPI) and Range Elevation Indicator (REI) of the radar set were used for making each complete set of observations in connection with the present study. The PPI was used for keeping track of the echo and REI was used for determining the height of the echo-top. Radar echoes from isolated convective clouds within 100 km around the station, which appeared at an antenna elevation of 2.5° or higher were selected for the present study. Each echo was continuously followed from the moment it was first observed till it dissipated and its height was measured at short intervals of time.

3. Data

Radar observations for quite a large number of isolated convective cloud cases were collected during the pre-monsoon and monsoon seasons of 1980 to 1982 for the purpose of the present study. However, about 50 per cent of them had to be discarded on account of two main reasons. First, some radar echoes when first observed were found to have already grown considerably. Secondly, in some cases, one or more other echoes appeared quite close to the echo under survey which ultimately merged into one large echo. Echo merger cases were avoided due to the reason that after an original radar cell merges with neighbouring cells, the original cell loses its identity and, therefore, it becomes very difficult to follow it subsequently, and specify how long it survived afterwards. Therefore, radar data of only those convective echoes which

TABLE 1

Summary of the characteristics of convective echoes

Date	Distance of the echo from the station (km)	Horizontal extent of the echo		Height of the echo top		Temperature at the top of initial echo (°C)	Mean rate		Echo duration (min.)	Echo category
		Initial (km)	Max. (km)	Initial (km)	Max. (km)		Growth (m/sec)	Decay (m/sec)		
(a) Pre-monsoon season										
5 Mar 80	70	—	—	3.1	5.2	2.9	1.8	2.4	29	B
,,	61	—	—	3.6	8.8	−0.2	2.7	1.7	83	C
,,	82	8.4	—	4.6	6.1	−6.2	3.6	2.5	24	B
,,	61	—	—	3.1	5.7	2.9	1.5	0.6	59	B
6 Jun 80	29	—	—	3.7	4.7	2.9	2.8	8.3	15	A
,,	32	—	—	4.2	4.7	−0.3	1.4	10.4	14	A
24 Jun 80	8	—	—	2.9	4.0	15.4	1.0	1.9	31	A
,,	77	—	—	3.5	7.1	11.5	2.2	1.8	74	C
,,	26	—	—	4.7	6.7	4.2	2.0	4.2	39	B
,,	14	—	—	3.3	5.9	12.8	2.5	2.6	38	B
,,	51	—	—	4.6	8.6	4.8	2.3	3.0	72	C
,,	61	—	—	2.6	5.1	17.4	8.3	4.5	19	B
20 Mar 81	10	3.9	4.6	3.4	7.0	1.1	7.5	3.3	34	C
30 Apr 81	54	6.9	—	6.1	6.6	−9.5	1.7	4.8	21	A
22 May 81	68	5.1	—	4.6	5.6	0.3	2.1	4.7	24	A
,,	70	4.2	—	7.1	9.6	−14.7	10.4	4.8	36	B
3 Jun 81	77	4.0	9.8	3.0	6.4	12.7	8.1	3.3	40	C
9 Jun 81	27	5.1	—	6.3	7.4	−10.6	3.7	8.5	18	A
23 Jun 81	67	7.5	—	5.0	5.7	2.4	5.8	1.9	42	A
,,	42	—	—	6.7	7.2	−7.0	4.2	2.6	33	A
26 Jun 81	6	—	—	5.0	9.4	1.5	2.3	10.4	42	C
,,	16	—	—	7.3	9.3	−9.6	1.4	3.2	57	B
24 Mar 82	56	9.4	—	5.6	6.3	−17.1	2.3	2.8	44	A
,,	85	4.2	8.4	4.0	4.5	−6.8	2.8	1.7	38	A
,,	82	6.0	8.4	4.6	5.4	−10.8	2.2	2.2	39	A
20 May 82	29	5.8	6.8	3.7	9.7	2.2	10.0	6.1	37	C
26 May 82	30	5.9	8.6	6.3	8.5	−12.8	1.2	2.3	74	C
18 Jun 82	65	5.8	7.2	8.0	9.8	—	3.8	8.7	23	B
,,	47	3.9	—	5.6	8.6	—	25.0	6.2	26	B
(b) Monsoon season										
7 Jul 81	34	—	—	5.1	7.7	2.3	4.8	5.6	30	B
,,	31	3.0	—	7.0	8.2	−7.1	5.0	6.3	24	A
,,	39	—	—	6.2	6.7	−3.1	1.4	15.3	15	A
16 Jul 81	22	7.8	—	6.8	7.7	−8.3	3.8	2.0	55	A
,,	13	4.2	—	6.7	7.0	−7.8	1.3	2.1	33	A
,,	25	—	—	3.3	7.4	9.2	3.1	2.1	50	C
18 Jul 81	29	2.6	—	3.2	6.8	14.6	4.3	5.4	30	C
20 Jul 81	26	2.6	—	4.7	5.3	4.5	2.0	8.6	15	A
,,	35	4.0	—	4.0	6.4	8.4	4.4	3.9	28	B
21 Jul 81	35	5.8	6.4	5.7	7.2	−8.1	2.1	3.7	39	B
17 Sep 81	40	3.4	—	4.2	7.7	1.1	9.7	6.1	25	C
26 Sep 81	38	5.4	—	5.5	5.9	−4.8	1.3	10.0	15	A
6 Jul 82	67	5.5	—	7.9	9.5	−15.0	5.3	2.3	43	B
,,	89	—	—	5.6	8.1	−7.8	10.4	7.4	21	B
7 Jul 82	31	5.4	—	4.7	5.2	−2.1	2.1	8.1	13	A
13 Jul 82	50	3.8	21.6	5.6	9.6	−0.1	5.6	2.0	83	C
14 Jul 82	61	3.8	15.0	3.1	7.9	12.2	4.4	0.9	50	C
15 Jul 82	89	4.0	4.8	4.1	5.9	7.7	1.8	2.2	45	B
31 Jul 82	52	—	—	6.8	8.1	−4.4	0.9	3.1	55	A
2 Aug 82	41	1.8	6.6	6.4	9.7	−1.9	3.2	7.7	28	C
,,	35	2.8	9.0	4.3	10.7	5.3	3.7	4.2	60	C
,,	37	4.7	—	3.7	11.4	13.8	12.8	11.7	21	C
4 Aug 82	53	3.6	10.6	5.2	7.6	1.3	8.0	1.3	66	B
16 Aug 82	33	8.0	—	4.7	8.2	3.5	7.3	3.2	28	C
17 Aug 82	30	4.6	5.3	5.9	9.7	−1.1	3.2	5.3	48	C
21 Aug 82	92	2.8	5.8	3.5	7.3	11.0	4.5	7.3	33	C

could be observed right from the time of their first occurrence and which remained completely isolated till they dissipated have been considered. There were 29 such cases during the pre-monsoon and 26 cases during the monsoon season in all, which constitute the data for the present study. Heights of the echo tops measured from REI, were duly corrected for the errors due to the curvature of the earth and also due to the finite beam width. Summary of the characteristics of the convective echoes studied during the two seasons, as well as the temperature at their initial tops are given in Tables 1 (a) and (b). Mean vertical growth rate of each echo, shown in the Tables 1 & 2 has been computed by taking the difference between the height of the initial echo and the maximum height reached, and dividing it by the time interval between them. Similarly, mean decay rate of each echo has been computed by considering the maximum height reached by the echo, last height measured before the echo dissipated and the time interval between them. Temperatures at the tops of the initial radar echoes have been computed using upper air data of 1200 GMT (1730 IST) radiosonde ascents at Delhi. Last column of the Tables 1 (a & b) shows the category of the echoes (see para 4.3 of the text for the abbreviations used for this purpose).

4. Results and discussions

4.1. *Growth, decay and duration of convective echoes*

Mean vertical growth and decay rates of different convective echoes were classified into different groups and their seasonwise frequency distributions are shown in Tables 2 (a) and (b) respectively. Table 3 shows the seasonwise frequency distribution of the echo durations. The following features have been observed :

(a) *Growth rates*

During the pre-monsoon season, the mean vertical growth rates of the echoes were found to vary between 1. 0 and 25. 0 m/sec (Table 2). Out of the 29 cases studied in this season, the mean growth rates were limited to 6.0 m/sec in about 80 per cent cases. The range of variation of the growth rates of the convective echoes observed in Delhi region in this season compares well with the growth rates reported by Mani and Venkiteshwaran (1961) for such echoes studied in Pune region. They reported the growth rates of the pre-monsoon convective echoes to vary between 2 and 22 m/sec. A similar study of De and Rakshit (1961) undertaken in Calcutta region indicated the growth rates to vary between 0.9 and 6.6 m/sec (170 and 1300 ft/min.), while Mukherjee *et al.* (1977) reported the growth rates to vary between 1.5 and 16.0 m/sec for convective clouds studied in Bombay region in the season.

During the monsoon season, the mean growth rates were found to vary between 0.9 and 12.8 m/sec. Out of the 26 cases studied, the growth rates were limited to 6.0 m/sec in about 80 per cent cases in this season also. De and Rakshit (1961) reported the growth rates to vary between 0.3 and 8.9 m/sec (55 to 1640 ft/min.) for monsoon clouds studied in Calcutta region.

(b) *Decay rates*

The mean vertical decay rates of the echoes varied between 0.6 and 10.4 m/sec during the pre-monsoon season (Table 2). Out of the 29 cases studied, decay rates were found to be limited to 6.0 m/sec in 76 per cent cases. A similar study of Mukherjee *et al.* (1977) made in Bombay region indicated the decay rates to vary between 0.3 and 7.0 m/sec.

During the monsoon season, the mean decay rates of the echoes varied between 0.9 and 15.3 m/sec. In this season decay rates were found to be limited to 6.0 m/sec in comparatively less percentage of cases (62 per cent cases) as compared to that found in pre-monsoon season.

(c) *Echo durations*

During pre-monsoon, durations of the convective echoes were found to vary between 14 and 83 minutes (Table 3). Similar range of variations of echo durations were observed during the monsoon season also (*i.e.*, 13 to 83 minutes). Also, the present analysis did not show any marked difference in the mean duration of the echoes in the pre-monsoon and monsoon seasons and they were respectively 39 and 36 minutes.

Out of the total 55 echo cases studied in this region in the two seasons, their life time were limited to one hour in about 90 per cent cases, with a mean duration of 38 minutes. The mean duration of the convective echoes found in this region is comparatively higher than that found by Battan (1953b) for such echoes studied in USA, (*i.e.*, 23minutes). However, a study of the duration of convective echoes by Blackmer (1955) yielded a mean duration of 42 minutes which compares well with the mean duration reported in this paper.

4.2. *Relationship between the horizontal extents of the convective echoes, and their growth, decay and durations*

Correlations (r) between the initial horizontal extents of different convective echoes, and their vertical growth rates, decay rates and durations have been computed in order to study whether there exists any relationship between the initial horizontal extents and other three echo parameters. Such study has also been made in relation to the maximum horizontal extents reached by different echoes. For this purpose, horizontal extents of different echoes, at their different stages of growth, have been determined by measuring their respective areas from PPI photographs and determining their respective equivalent diameters. Initial and maximum equivalent diameters reached by an echo have been taken as its initial and maximum horizontal extents respectively. It may be mentioned that horizontal extents for quite a large number of echo cases could not be determined as their PPI photographs were not available. This is for the reason that the radar observations were not initially motivated to study the relationships between the horizontal extents of the echoes and their other parameters, and therefore, for most of the cases, photographs of PPI observations were not taken as

TABLE 2

Distribution of mean growth and decay rates of the radar echoes from convective clouds

Season	Mean growth/decay rate (m/sec)								Total No. of cases	Growth/decay rate	
	<2.0	2.1 to 4.0	4.1 to 6.0	6.1 to 8.0	8.1 to 10.0	10.1 to 12.0	12.1 to 14.0	>14.0		Min. (m/sec)	Max. (m/sec)
(a) Growth rate											
Pre-monsoon (Mar-Jun)	8	13	2	1	3	1	—	1	29	1.0	25.0
Monsoon (Jul-Sep)	6	7	8	2	1	1	1	—	26	0.9	12.8
(b) Decay rate											
Pre-monsoon (Mar-Jun)	6	11	5	2	3	2	—	—	29	0.6	10.4
Monsoon (Jul-Sep)	4	8	4	5	3	1	—	1	26	0.9	15.3

TABLE 3

Distribution of durations of radar echoes from convective clouds

Season	Duration (min.)								Total No. of cases	Duration (min.)		
	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90		Min.	Max.	Mean
Pre-monsoon (Mar-Jun)	4	6	10	3	2	—	3	1	29	14	83	39
Monsoon (Jul-Sep)	4	9	3	5	3	1	—	1	26	13	83	36

systematically as it should have been for undertaking such study. PPI was essentially used to track the echoes correctly before each REI observation from their initial occurrence till their dissipation. This deficiency has been fully realised while analysing the data. In view of the limited data of horizontal extents of the echoes available for such study, results were evaluated considering the data of both the seasons together. There are 36 echo cases for which initial horizontal extents are available and out of this there are 16 echo cases for which maximum horizontal extents could be determined. Results of the study are given below.

(a) *Relationship with the initial horizontal extents*

No linear relationships were found between the initial horizontal extents of the echo, and their growth rates, decay rates and durations. The values of correlation coefficients (r) computed between the initial horizontal extent and the other three echo parameters are respectively -0.15, -0.24 and 0.003 which are not statistically significant even at 10 per cent level. Therefore, the present analysis has not indicated any dependence of vertical growth rates, decay rates and durations of convective echoes on their initial horizontal extents.

TABLE 4

Temperature at the top of initial radar echoes

Group	Temperature (°C)												Total no. of cases	Mean temperature (°C)
	—15.1 to —18.0	—12.1 to —15.0	—9.1 to —12.0	—6.1 to —9.0	—3.1 to —6.0	—0.1 to —3.0	0.0 to 2.9	3.0 to 5.9	6.0 to 8.9	9.0 to 11.9	12.0 to 14.9	15.0 to 17.9		
Pre-monsoon														
A	1	—	3	2	—	1	3	—	—	—	—	1	11	—4.0
B	—	2	1	1	—	—	2	1	—	—	1	1	9	—0.9
C	—	—	—	—	—	1	3	1	—	1	1	—	7	+4.5
Total	1	2	4	3	—	2	8	2	—	1	2	2	27	—0.8
Cumulative (%)	4	11	26	37	37	44	74	81	81	85	93	100	—	—
Monsoon														
A	—	—	—	3	3	1	—	1	—	—	—	—	8	—4.1
B	—	1	—	2	—	—	2	—	2	—	—	—	7	—1.6
C	—	—	—	—	—	3	1	2	—	2	3	—	11	+6.1
Total	—	1	—	5	3	4	3	3	2	2	3	—	26	+0.9
Cumulative (%)	—	4	4	23	35	50	62	73	81	88	100	—	—	—

(b) *Relationship with the maximum horizontal extents*

No linear relationship was found between the maximum horizontal extents of the echoes and their vertical growth rates. The value of correlation coefficient (r) computed between them was 0.16 which was not statistically significant. Correlation between the maximum horizontal extents and decay rates have been found to be negative (r=—0.45, which was significant at better than 10 per cent level), whereas, highly significant positive correlation was found between the maximum horizontal extents and durations of the echoes (r = 0.67, significant at 1 per cent level). The study showed that echoes attaining large maximum horizontal extents tend to decay rather slowly and survive for longer time as compared to the echoes attaining smaller maximum horizontal extents during their life time. However, the analysis has not indicated any dependence of vertical growth rates on the maximum horizontal extents of the echoes

4.3. *Growth of convective clouds vis-a-vis cloud top temperature*

The extent of vertical growth of convective clouds, which may be taken as a measure of the strength of convection within the cloud, has been studied in relation to the temperature at the tops of their initial radar echoes. For this purpose 53 echo cases for which temperature data were available have been considered. The echoes were divided into three group similar to those of Battan (1953a) and De and Rakshit (1961), namely, Group A : all the echoes which grew less than 1.5 km after first detection; Group B : all those which grew by 1.5 to 3.0 km after first detection and Group C : all those which grew more than 3.0 km after first detection. Summaries of the temperatures at the top of the initial radar echoes in Groups A, B and C are given seasonwise in Table 4. The table shows that during pre-monsoon, the mean temperatures at the tops of the initial echoes in Groups A, B and C were respectively — 4.0°,—0.9° and 4.8° C respectively. Application of t-test showed that the mean temperatures of the initial echo tops of Groups A and B echoes were not statistically significant, whereas it was significant for Group C echoes (at 5 per cent level). During the monsoon season, the mean temperatures of the initial echo tops in the above three groups were — 4.1°, — 1.6° and 6.1° C respectively. During this season computed mean temperatures of the initial echo tops have been found to be statistically significant for Groups A and C echoes at 1 per cent and 2 per cent level respectively.

TABLE 5

Summary of the vertical growth and decay rates, and durations of the three groups of echoes

Group	Mean growth rate (m/sec)		Mean decay rate (m/sec)		Mean duration (min.)	Total No. of cases
	At the initial stage	At the time of reaching max. ht	At the start of decay	At the dissipating stage		
Pre-monsoon						
A	2.9	2.6	5.3	5.5	29	11
B	6.6	6.0	4.1	6.8	38	11
C	6.7	6.4	4.3	8.1	55	7
Monsoon						
A	2.5	2.0	4.4	9.4	28	8
B	6.0	5.0	4.3	6.7	39	7
C	7.7	5.2	4.2	8.1	42	11

Although the mean temperatures of the initial echo tops, computed for the three groups of echoes were not found statistically significant in all the groups, however, the general trend of the result showed that the average temperature at the top of the initial radar echo gradually increased from Group A to Group C in both the seasons, *i.e.*, the echoes which grew the most after their first detection were having warmest first echo on the average. These findings agree with those of Battan (1953a) who also observed similar features for convective clouds over Ohio in U. S. A. However, the results are in contrast to the findings of De and Rakshit (1961) for clouds over Calcutta region. They found that the initial echoes having lower echo top temperature are susceptible to more growth.

Growth rates of the echoes at the initial stage of their development as well as at the time of reaching maximum height, their decay rates when first decay started as well as towards their complete dissipation, and durations of echoes have also been studied for the above three groups separately. Results of the study are summarised in Table 5. Following features have been observed.

(a) *Growth rates*

During the pre-monsoon season, initial growth rates of the tops of the echoes in Groups A, B and C were found to be 2.9, 6.6 and 6.7 m/sec respectively on the average. During the monsoon season the mean initial growth rates of the echo tops of the these three groups were respectively 2.5, 6.0 and 7.7 m/sec. Although the difference in the initial growth rates of Groups B and C echoes were not so marked during the pre-monsoon season, however, the trend of results shows that in both the seasons, the initial growth was faster in the case of echoes growing to greater heights than in the case of smaller one. A similar trend was also observed in the growth rates of echoes at the time of reaching their maximum heights. Mean growth rates of the echo-tops at the time of reaching maximum heights were 2.6, 6.0 and 6.4 m/sec for Groups A, B and C echoes respectively during the pre-monsoon, and 2.0, 5.0 and 5.2 m/sec respectively during the monsoon season. Also, in both the seasons, the growth rates of the echoes were found to be faster at their initial stage of development than at the time of reaching maximum height. A similar trend was also observed by De and Rakshit (1961) in respect of the growth of convective echoes in Calcutta region.

(b) *Decay rates*

During the pre-monsoon season, initial decay rates of the tops of the echoes of the three groups showed no specific trend, while towards the dissipating stage, decay rates of the echo tops progressively increased from Groups A to C. In this season, mean decay rates of the echoes for Groups A to C were respectively 5.3, 4.1 and 4.3 m/sec at their initial stage of decay and 5.5, 6.8 and 8.1 m/sec respectively towards their complete dissipation. During the monsoon season, average initial decay rates of the tops of the echoes in Groups A to C were respectively 4.4, 4.3 and 4.2 m/sec, showing thereby that there was practically no difference in the initial decay rates of echoes grown to different heights. However, towards the dissipating stage, decay rates of the echoes have been found to be comparatively higher for Group A than for Groups B and C echoes. The mean decay rates of the Groups A, B and C echoes toward their dissipating stage were 9.4, 6.7 and 8.1 m/sec respectively. Also, in both the seasons decay rates of echoes have been found to be higher towards their dissipating stage than at the initial stage of their decay for all the three groups of echoes.

(c) *Echo duration*

The duration of the echoes progressively increased from Group A to C in both the season. The mean durations of echoes in Groups A to C were respectively 29, 38 and 55 minutes during pre-monsoon and 28, 39 and 42 minutes during monsoon season. The corresponding figures for echoes from convective clouds over Calcutta region, reported by De and Rakshit (1961) are 12.3, 21.3 and 36.2 minutes, suggesting thereby that the convective clouds forming over Delhi region during the pre-monsoon and monsoon seasons are comparatively of longer durations than those forming over Calctutta region in these seasons.

4.5. *Mechanisms of precipitation initiation*

It is well known that there are two mechanisms whereby precipitation may form in clouds. The first involves the direct collision-coalescence of water droplets to form rain drops and this process may be important in the initiation of precipitation in any cloud, irrespective of its top lying either below or extending above the freezing level. The second mechanism called Bergeron-Findeisen mechanism involves the interaction between supercooled water droplets and ice crystals and this process is confined only to those clouds whose tops extend beyond freezing level. It is of interest to study 'which of the two processes plays dominant role in the formation and development of precipitation in convective clouds forming in Delhi region'. It must be emphasised that conventional radars detect clouds only after the droplets grow to precipitable sizes and not earlier. Therefore, first appearance of an echo on the radar from a cloud shows that precipitation formation has begun in it. It may, however, be stated that occurrence of initial radar echo from a cloud below or above freezing level is not unmistakable proof that the release of precipitation is by either the collision-coalescence process or the Bergeron-Findeisen process. This is in view of the fact that, as mentioned earlier, the radar detects drops only after they reach precipitable size and precipitation may have been initiated either above or below the freezing level and carried down or up, where it first became detectable by radar. Nevertheless, so far as the convective clouds are concerned, occurrence of their initial radar echoes lying entirely below freezing level may be taken as a reasonably good evidence that the release of precipitation is an all water process of collision-coalescence growth of droplets, and no ice mechanism is involved. This subject has been discussed in detail by Mani and Venkiteshwaran (1961).

Referring again to Table 4 it may be seen that during pre-monsoon season, out of 27 convective cloud cases, the tops of their first radar echoes extended beyond freezing level in 44 per cent cases. During the monsoon season, out of the 26 cloud cases, tops of the first radar echoes extended beyond freezing level in 50 per cent cases. While no definite conclusion, in regard to the broad mechanism of precipitation initiation, could be drawn in such cases, as the data in the table show that in both the seasons, quite a good proportion of convective clouds had their first radar echoes with tops confined to below freezing level, indicating precipitation initiation by pure collision-coalescence process. The percentage frequency of such occasions during pre-monsoon and monsoon seasons were 56 and 50 per cent respectively. A similar study was conducted by De and Rakshit (1961) in Calcutta region. They found that in 90 per cent of the cloud cases studied by them, the tops of their initial radar echoes were below freezing level. Hence, they concluded that pure collision-coalescence process is mainly responsible for the initiation of precipitation in convective clouds in that region. On the other hand, study of convective clouds by Mani and Venkiteshwaran (1961) in Pune region showed that in about 77 per cent cases, the tops of the initial radar echoes extended above freezing level. They, therefore, left the question open as to which of the two processes is dominant in the release of precipitation in convective clouds in that region.

5. Conclusions

Radar data of precipitation echoes from 55 convective clouds within 100 km around Delhi, collected during the pre-monsoon and monsoon seasons of 1980 to 1982 have been analysed to study some of the features of these clouds forming in this region. Analysis showed that the vertical growth and decay rates as well as the durations of the radar echoes from these clouds varied considerably from day to day and also on the same day on different occasions. Both in pre-monsoon and monsoon seasons, the average growth rates of the echoes were found to be limited to 6.0 m/sec in 80 per cent cases. However, average decay rates of the echoes were found to be limited to 6.0 m/sec in larger percentage of cases in pre-monsoon than in monsoon season (*i.e.*, in 76 and 62 per cent cases respectively). No marked difference was observed in average echo durations in the two seasons (*i.e.*, 39 minutes in pre-monsoon and 36 minutes in monsoon).

A comparative study of the vertical growth rates, decay rates and durations of convective echoes in relation to their initial horizontal extents showed no linear relationships between the initial horizontal extents of the echoes and the other three echo parameters. On the other hand, a similar study in relation to their maximum horizontal extents showed that the durations of the echoes were positively correlated with their maximum horizontal extents, whereas their decay rates were negatively correlated. However, no specific relationship was found between the maximum horizontal extents of the echoes and their growth rates.

The study further suggested that pure collision-coalescence process is responsible for the formation and development of precipitation in at least 50 per cent of the convective clouds forming in Delhi region during pre-monsoon and monsoon seasons.

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