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Characteristics of layer type radar echoes around Delhi

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Some characteristics of the precipitation echoes from layer type clouds in Delhi region have been studied using radar observations made during 1960-1962. The study showed that the height of the layer echoes first observed varied between 3.0 and 13.0 km. Mean height of the first observed layer echoes was about 8 km in summer (April-June), 10 km during monsoon (July-September) and 7 km during winter (November-March). The depth of these echoes have been found to be usually in the range 0.5-6.0 km and horizontal extensions varied between wide limits ranging from 12 to 200 km. Occurrence of layer echoes preceded by convective development has been found to be maximum during summer while melting band feature occurred more frequently during monsoon. Rainfall rate and liquid water content in layer clouds as well as the percentage contribution towards season's rainfall from such clouds have also been estimated.

1 Introduction

The study of different aspects of clouds has been the matter of great interest in different parts of the world since long. With the advent of radar, tremendous progress has been made in this field during the last four decades. In India, most of the studies[1-13] made so far have been chiefly confined to the study of different features of convective clouds, such as the mechanisms of precipitation formation in them, their size distributions, vertical growth and decay rates, durations, fractal dimensions etc. However, only a limited number of studies[14,15] have been made in this country in respect of layer clouds. They were mainly confined to different characteristics of melting band (also called bright band) which is, sometimes, observed in radar echoes from layer clouds as a nearly horizontal band of high echo intensity. The present study describes different characteristics of precipitation echoes from layer clouds observed in Delhi region in different seasons, viz., heights at which layer echoes are first observed, their horizontal extents, rate of their vertical spread, rainfall rate and liquid water content in such clouds and height at which melting band appears. For this purpose radar echoes of such clouds observed during summer (April-June), monsoon (July-September) and winter (November-March) seasons of the three year period from 1960 to 1962 have been examined.

2 Equipment used

Equipment used is a Japanese radar of type NMD-451A. The characteristics of the radar set are given in Table 1. In addition to the conventional plan position indicator (PPI), range height indicator (RHI) and A-scope, the radar is equipped with a special arrangement called range elevation indicator (REI) on which depth and range of the echoes are portrayed in true proportions when scanned at elevation angles between $-1°$ and $90°$.

3 Analysis and discussion

In analysing the data, we have taken those radar echoes as layer type when the horizontal extension of an echo was more than five times its vertical depth and the structure, as seen on the radar scope, was not cellular or columnar. The growth and decay rates of the echoes were much slower and their life as such was much longer as compared to the convective type of echoes. They were generally associated with slow rate of precipitation. Particular care was taken not to be misled by the group of convective precipitating cells appearing extensive from ground as layer type echoes. Depending on the origin, development

Table 1—Radar characteristics

Wavelength	3.2 cm
Peak power transmitted	250 kW
Pulse length	1 μs
Minimum detectable signal	-90 dBm
Pulse repetition frequency	300 Hz
Horizontal and vertical beam width	1.2°

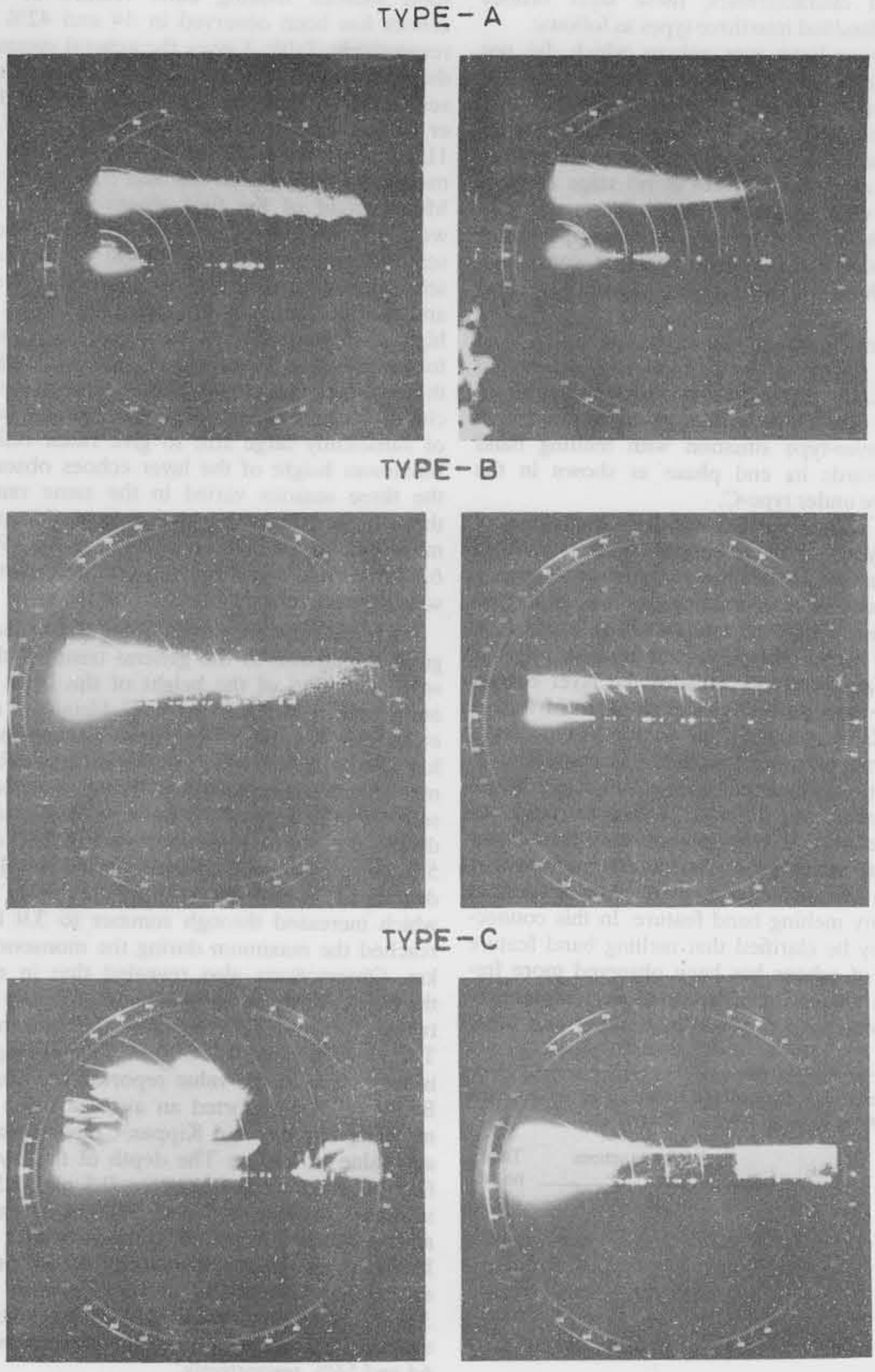

Fig. 1—REI pictures showing different types of layer echoes [Type-A: Layer without melting band feature; Type-B: Layer with melting band feature; Type-C: Convective (left) to layer (right)]

and growth characteristics, these layer echoes have been classified into three types as follows:

Type-A: Those layer type echoes which did not show any melting band feature and were not associated with any form of convective activity.

Type-B: Those layer type echoes in which melting band feature was noticed either from the beginning or at later stage, but at no stage convective activity was observed.

Type-C: Those layer type echoes that appeared at the dissipating stage or end phase of convective activity with or without showing any melting band feature.

Typical examples of the above three types of echoes are shown in Fig. 1. It may be mentioned that the LHS picture shown under type-C in Fig. 1 is of convective type of precipitation, which depicted layer-type situation with melting band feature towards its end phase as shown in the RHS picture under type-C.

Table 2 shows the seasonwise distribution of different types of layer echoes. It is seen from Table 2 that during summer, maximum frequency of occurrence of layer type echoes was of C-type (as much as 75% of the total). Only in 8 and 17% cases they were of type-A and type-B, respectively. During monsoon, 50% of the layer echoes were of B-type, and 17 and 33% were of type-A and type-C, respectively. In winter, A-type layer echoes occurred more frequently as compared to B- and C-types (their percentage frequency of occurrence being 46, 27 and 27, respectively). As already defined, C-type echoes are those layer echoes that appeared at the dissipating stage or end phase of convective activity with or without showing any melting band feature. In this connection, it may be clarified that melting band feature in C-type of echoes has been observed more frequently in winter (in 62% cases) as compared to those in other two seasons. In summer and monsoon seasons melting band feature in C-type echoes has been observed in 44 and 42% cases, respectively. Table 3 gives the general summary of the different characteristics of layer echoes observed during different seasons. Height of the layer echoes first observed varied between 5.5 and 11.0 km in summer, between 5.5 and 13.0 km in monsoon and between 3.0 and 9.0 km in winter. Mean height of the first observed layer echoes were 8.3, 9.6 and 6.7 km during the above three seasons, respectively. The height of the layer as seen mostly corresponds to medium cloud level and in a few cases to the high cloud level. These high level echoes were observed with the layer formation after convective activity suggesting thereby that the cirrostratus formation from Cb clouds contain supercooled water or ice particles of sufficiently large size to give radar reflection. Maximum height of the layer echoes observed in the three seasons varied in the same ranges as those of first observed layer echoes. Mean maximum heights of layer echoes were 8.8, 9.8 and 6.7 km during summer, monsoon and winter seasons, respectively.

Table 2—Percentage frequency distribution of layer echoes among different types in different seasons

Season	Type of layer echoes			Total no. of cases
	A	B	C	
Summer (Apr.-June)	8.0	17.0	75.0	12
Monsoon (July-Sep.)	17.0	50.0	33.0	36
Winter (Nov.-Mar.)	46.0	27.0	27.0	30
For the complete period	27.0	36.0	37.0	78

It may also be seen from Table 3 that there is a good parallelism in the general trend of the seasonal variation of the height of the layer echoes and height of the freezing level. Height of the layer echoes was lowest in winter corresponding to low freezing level, which slowly increased by summer and became maximum during monsoon season. Mean heights of the freezing level over Delhi during the above three seasons are 3.0, 4.3 and 5.5 km, respectively. Melting band level (when developed) is also lowest in winter, being 2.7 km which increased through summer to 3.9 km and reached the maximum during the monsoon to 5.1 km. Observations also revealed that in most of the cases, centre of melting band generally lies between 200 and 500 m below the freezing level. The average value was 300 m. This average value is very close to the value reported by Austin and Bemis[16]. They reported an average value of 250 m, while Hooper and Kippax[17] reported an average value of 100 m. The depth of the layer echo first observed varied between 0.5 and 5.5 km in summer, between 0.5 and 5.0 km in monsoon, and between 0.5 and 6.0 km in winter season. However, the depth of majority of the first layer echoes has been found to vary between 1.5 and 3.0 km. The percentage of such layer echoes in summer, monsoon and winter seasons were 89, 64 and 56%, respectively.

Horizontal extents of the layer varied between 12 and 100 km in summer, between 20 and 200

Table 3—Summary of the characteristics of layer echoes in different seasons

Characteristics of layer echoes	Season		
	Summer	Monsoon	Winter
Number of cases	12	36	30
Range of variation of the height of the layer first observed (km)	5.5-11.0	5.5-13.0	3.0-9.0
Mean height of the layer first observed (km)	8.3	9.6	6.7
Range of variation of the maximum height reached by the layer (km)	5.5-11.0	5.5-13.0	3.0-9.0
Mean maximum height (km)	8.8	9.8	6.7
Range of variation of the depth of the first observed layer (km)	0.5-5.5	0.5-5.0	0.5-6.0
Mean depth of the first layer echo (km)	2.3	2.2	2.8
Range of variation of the maximum horizontal extent of the layer (km)	12-100	20-200	15-180
Mean horizontal extent (km)	48.0	50.0	64.0
Rate of vertical spread (m s^{-1})	0.7-2.0	0.5-2.1	0.5-1.7
Mean rate of vertical spread (m s^{-1})	1.3	1.3	0.6
Percentage of cases when precipitation from layer clouds reached ground	58.0	78.0	57.0
Mean height of the melting band (km)	3.9	5.1	2.7
Mean height of the freezing level (km)	4.3	5.5	3.0

Table 4—Contribution of rainfall from layer type cloud days towards seasons total rainfall

Season	Total no. of case studies	Amount of rainfall recorded per station on layer type cloud days (A)	Amount of rainfall recorded per station in the season (B)	Percentage contribution of rainfall by layer type cloud days towards seasons' total rainfall (A/B) × 100
Summer (Apr.-June)	12	42.0	98.0	42.9
Monsoon (July-Sep.)	36	562.0	1436.0	39.1
Winter (Nov.-Mar.)	30	33.0	172.0	19.2
For the complete period	78	637.0	1706.0	37.2

km in monsoon and between 15 and 180 km in winter. Mean horizontal extents of the layer echoes in the above three seasons were 48.0, 50.0 and 64.0 km, respectively.

Rate of vertical spread of the layer echoes varied between 0.7 and 2.0 m s^{-1} in summer, between 0.5 and 2.1 m s^{-1} in monsoon and 0.5 and 1.7 m s^{-1} in winter season, respectively. The mean rates of vertical spread in the above three seasons were, respectively, 1.3, 1.3 and 0.6 m s^{-1}. Earlier, Chatterjee and Prem Prakash[3] studied the vertical growth rates of radar echoes from convective clouds in this region and found that the vertical growth rates of such clouds varied between 1.0 and 25.0 m s^{-1} in summer and between 0.9 and 12.8 m s^{-1} in monsoon season respectively. The average growth rates in the above seasons were 4.3 and 4.1 m s^{-1}, respectively. It is, therefore, clear that the growth rates of layer echoes are much smaller as compared to the growth rates of convective echoes.

Number of cases, when precipitation from layer clouds reached ground, have been found to be maximum during monsoon (in 78% cases). In the other two seasons such cases are comparatively low (in about 58% cases).

Table 4 shows the percentage contributions to the total rainfall by layer type clouds in Delhi region in different seasons as well as for the complete period. For this purpose, rainfall data obtained from a raingauge network consisting of 25 raingauge stations within 25 km around Delhi have been considered and the total of mean rainfall per raingauge station on layer type cloud days has been compared with the total amount of mean rainfall per station for the entire season. It may be seen from Table 4 that about 43, 39 and 19% of the seasons total rainfall are contributed by layer type clouds during summer, monsoon and winter seasons, respectively. For the entire period, i.e., summer, monsoon and winter seasons taken together, about 37% of the total rainfall is contributed by layer type clouds in this region.

Attempts have also been made to measure rainfall rate and liquid water contents of the layers from the radar reflectivity measurements. The radar reflectivity was determined by the pre-calibrated radar receiver sensitivity which was checked from time to time. For computing the rainfall rate and liquid water content, the following empirical relations given by Kutty and Shirvaikar[18] have been used.

$$Z = 345.8\ R^{1.618}$$

$$M = 67.8\ R^{0.85}$$

where, the rainfall rate, R, is expressed in mm h^{-1}, liquid water content, M; in mg m^{-3} and radar reflectivity, Z, in $mm^6\ m^{-3}$. Table 5 shows the mean values of rainfall rate and liquid water content in layer echoes for the days when radar reflectivities were measured for layer echoes in different seasons. Although the data presented are very small, nevertheless it would give an idea regarding the range of variations of rainfall rates and liquid water contents in precipitation from layer clouds. It is seen from Table 5 that the mean value of the rainfall rate of layer clouds observed on different days varied from day to day between 8.4 and 12.1 mm h^{-1} in summer, between 0.9 and 23.9 mm h^{-1} in monsoon and between 0.6 and 13.1 mm h^{-1} in winter season. When mean rainfall rate of individual seasons is considered, it has been found that rainfall rate of layer clouds was maximum during monsoon (11.3 mm h^{-1}) and minimum in winter (5.4 mm h^{-1}). In summer, it was 10.3 mm h^{-1} which is comparable to that obtained in monsoon season. Similar to the rainfall rate, there was marked day-to-day variations in mean liquid water contents of the layer clouds also. It varied between 413.8 and 564.4 mg m^{-3} in summer, between 62.0 and 1006.6 mg m^{-3} in monsoon, and between 44.4 and 603.8 mg m^{-3} in winter seasons. Similarly mean liquid water content obtained for different seasons has been found to be maximum during monsoon season and minimum during winter season. The mean values in different seasons were 489.1, 510.5 and 271.7 mg m^{-3} in summer, monsoon and winter, respectively.

Table 5—Rainfall rate and liquid water content of layer clouds in different seasons

Date	Mean height of layer echo km	Rainfall rate mm h^{-1}	Liquid water content mg m^{-3}
	Summer		
16 Apr. 60	5.6	8.4	413.8
22 June 60	7.5	12.1	564.4
Mean	6.6	10.3	489.1
	Monsoon		
14 July 60	6.0	2.5	147.7
25 July 60	10.5	0.9	62.0
26 Aug. 60	7.5	6.5	333.0
15 July 61	9.5	3.6	201.4
21 July 61	8.0	18.4	806.0
22 July 61	11.0	9.1	442.2
25 July 61	12.5	13.0	600.0
6 Aug. 61	10.0	23.9	1006.6
8 Aug. 61	7.3	23.6	995.9
Mean	9.1	11.3	510.5
	Winter		
6 Jan. 60	6.0	4.0	220.3
12 Jan. 60	6.0	3.8	210.9
20 Jan. 60	4.9	11.7	548.5
4 Mar. 60	4.2	10.7	508.4
17 Mar. 60	5.5	7.9	392.8
30 Dec. 60	7.0	3.4	191.9
17 Jan. 61	5.4	5.2	275.3
25 Jan. 61	6.3	13.1	603.8
28 Jan. 61	5.3	2.2	132.5
31 Jan. 61	5.5	2.2	132.5
17 Mar. 61	7.8	1.3	83.3
23 Mar. 61	5.0	3.4	187.0
1 Feb. 62	4.0	11.5	540.5
3 Feb. 62	7.5	0.6	44.4
15 Feb. 62	5.0	1.9	117.0
1 Mar. 62	5.2	2.7	158.0
Mean	5.7	5.4	271.7

4 Special characteristics in different seasons

In winter, on days of extensive layer situation, a definite slope was generally observed depending

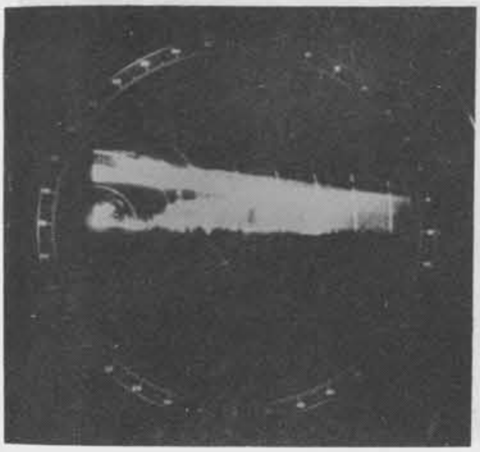
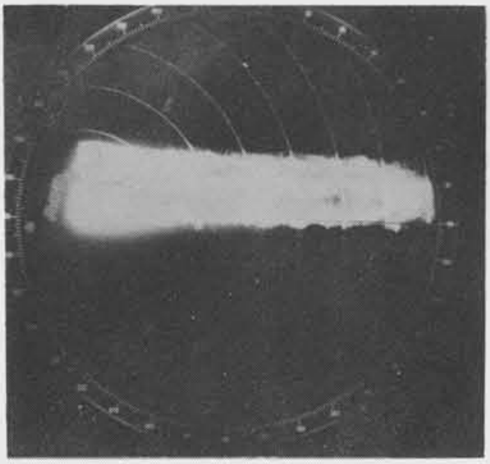

Fig. 2—REI pictures showing slope in layer echoes

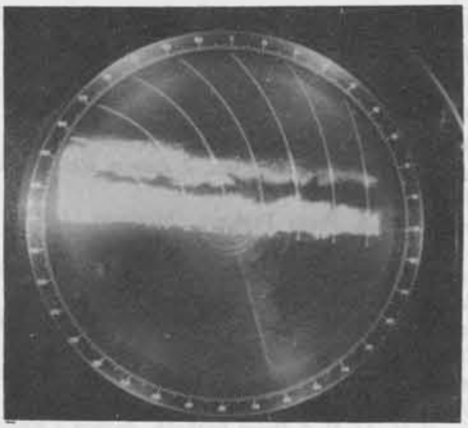
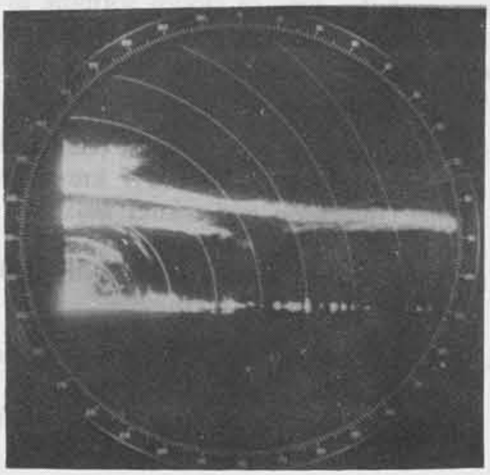

Fig. 3—REI pictures showing multiple layer features

on the movement of the front. These types of days were generally associated with western disturbances. Radar REI pictures in Fig. 2 show examples of such situation.

On a number of days, multiple layer features as shown in Fig. 3 have been observed. Table 6 shows the percentage frequency of occurrence of layer echoes displaying different number of significant layers in different seasons. It is seen from Table 6 that multiple layer feature is more predominant in monsoon season although the same is not very rare in winter season but are very few in summer.

Lastly, it may also be mentioned that there were occasions when convective activities were seen through the layer (Fig. 4). In winter, this type of feature was generally noticed in isolated cases, whereas in monsoon it appeared on a number of occasions on days of widespread activity.

Table 6—Frequency distribution (%) of layer echoes showing indicated number of significant layers

Season	No. of significant layers			Total no. of cases
	1	2	3	
Summer (Apr.-June)	83.4	8.3	8.3	12
Monsoon (July-Sep.)	66.7	20.0	13.3	30
Winter (Nov.-Mar.)	80.6	16.6	2.8	36
Combined	75.6	16.7	7.7	78

5 Summary

Radar data of precipitation echoes from layer type clouds, within 300 km around Delhi collected during the three year period from 1960 to 1962 have been analysed in order to study some

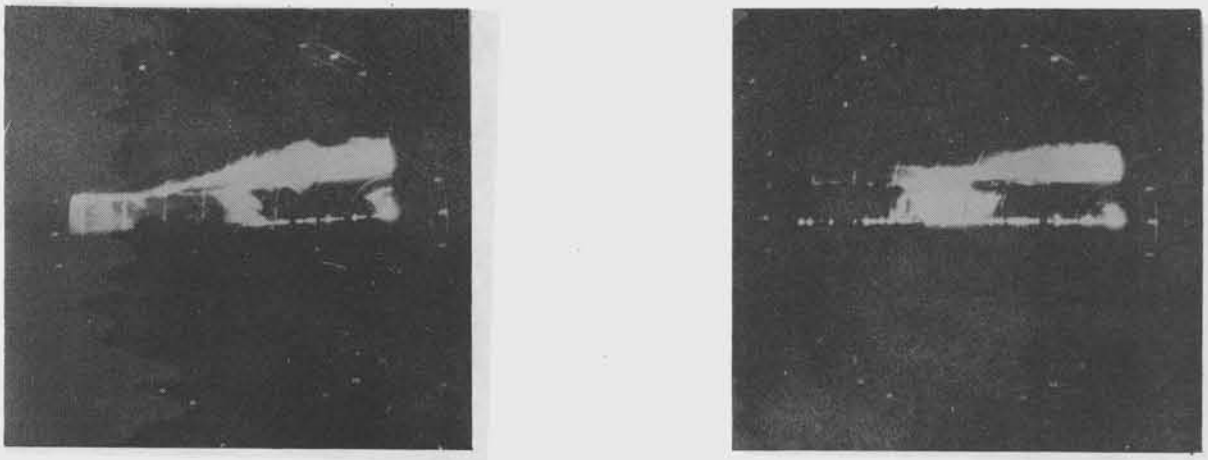

Fig. 4—REI pictures showing convective activity through layer echoes

features of this type of clouds forming in this region during the summer (April-June), monsoon (July-September) and winter (November-March). Following broad features have been noticed:

(i) Layer echoes in this region commonly occur at a height of 8, 10 and 7 km during summer, monsoon and winter seasons, respectively.

(ii) Thickness of the initial layer normally varies between 1.5 and 3.0 km.

(iii) Horizontal extent of the layer varies between wide limits ranging from 12 to 200 km. Average horizontal extent of the layer echo observed was 50 km.

(iv) During summer, about 75% of the layer echoes appear towards the end phase of convective activity.

(v) Melting band feature in layer echoes appears more frequently in monsoon as compared to the occurrence of such feature in the other two seasons. Percentages of layer echoes which show melting band feature in different seasons are 50% in monsoon, 27% in winter and only 17% in summer.

(vi) In monsoon, precipitations from layer reach the ground in about 80% cases. In the other two seasons, precipitations from such clouds reach the ground in about 60% cases.

(vii) Rate of vertical spread of layer clouds is much smaller than that of convective clouds.

(viii) Multiple layer feature also occurs sometimes. Occurrence of such feature is maximum in monsoon and minimum in summer.

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