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Distribution of the areas and heights of the radar echoes from convective clouds around Delhi during monsoon season

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सार — छः मानसून ऋतुओं 1967–1972 के दौरान दिल्ली क्षेत्र में प्रेक्षित संवहनी मेघों से रडार प्रतिध्वनियों के क्षेत्रों तथा उंचाइयों के वितरण का अध्ययन किया गया। प्रतिध्वनियों का स्तरण अपने क्षेत्रों के अनुसार तीन विभिन्न मापक्रमों में नामत: डी मापक्रम (≤100 कि.मी.^{2}) सी मापक्रम (101–1000 कि.मी.^{2}) और बी/सी मापक्रम (>1000 कि.मी.^{2}), सी और बी/सी मापक्रमों में सापेक्षत: अल्प प्रतिशतों सहित, डी मापक्रम में प्रतिध्वनियों की पूर्वप्रभाविता को सूचित करता है। इन प्रतिध्वनियों के क्षेत्रों और ऊंचाइयों की बारम्बारता-बंटन, लघुगणक प्रसामान्यत: बंटन की ओर अग्रसर करती है।

ABSTRACT — Distributions of areas and heights of radar echoes from convective clouds, observed in Delhi region during six monsoon seasons, 1967-1972, were studied. Stratification of the echoes according to their areas into three different scales, namely D scale ($\leq$ 100 km^2), C scale (101-1000 km^2) and B/C scale (>1000 km^2) indicated predominance of the echoes in D scale, with relatively small percentages in C and B/C scales. Frequency distributions of areas and heights of these echoes tended to be lognormally distributed.

Key words — Distribution, Radar echoes, Convective clouds, Stratification, Lognormally.

1. Introduction

In the study of the characteristics of convective clouds over Florida, Biondini (1976) found that the frequency distributions of the duration and rainfall volume of their radar echoes follow lognormal distribution. That is, cumulative percentage frequency of durations of the echoes or their volumes when plotted on a logarithmic probability paper (the ordinate is plotted in logarithmic scale, while the abscissa is plotted in a normal probability scale), they appeared as a straight line showing that they are lognormally distributed [for a thorough discussion of the lognormal distribution, *see* the book by Aitchison and Brown (1957), Croxton *et al.* (1969)]. A similar feature was also observed by Lopez (1976) and Houze and Cheng (1977) in the frequency distributions of height, horizontal size and durations of the radar echoes of tropical cloud populations observed over the Atlantic Ocean during GARP's (Global Atmospheric Research Programme) Atlantic Tropical Experiment (GATE). In order to verify whether the observed lognormality is a general characteristic of cumulus cloud populations everywhere, Lopez (1977) further examined frequency distributions of heights, horizontal sizes and durations of convective clouds and convective echo populations in many different parts in the western hemisphere observed over a wide variety of convective situations. He found that it is generally so except for very large clouds. Based on the theory of lognormal distribution, Lopez (1977) attributed this observed phenomenon of lognormality due to the growth of cumulus clouds according to the law of proportionate effects [a variate as for example, height of a cloud, is said to obey the law of proportionate effects if the change in value of the variate at any step of a process is a random proportion of the previous value of the variate (Aitchison and Brown 1957)]. He suggested two hypotheses by which clouds could grow according to the law of proportionate effects. The first hypothesis assumes that the small convective elements which are produced by the large-scale features of flow (convergence field, thermal stability, etc) grow to their final size by the process of random entrainment of environmental air. The second hypothesis postulates a process by which clouds of a particular size are formed by the merger of smaller elements.

In order to see whether lognormal distribution also prevails in cumulus cloud populations in the Indian region, Raghavan *et al.* (1983) studied the frequency distributions of the areas of the radar echoes from convective clouds around Madras (13° 5′N, 80° 17′E). They found that smaller cells constituting 85-95 per cent of the total populations follow lognormal distribution. The objective of the present study is to see whether lognormality also prevails in radar echo populations from convective clouds in Delhi region (28° 37′N, 77° 12′E) of India.

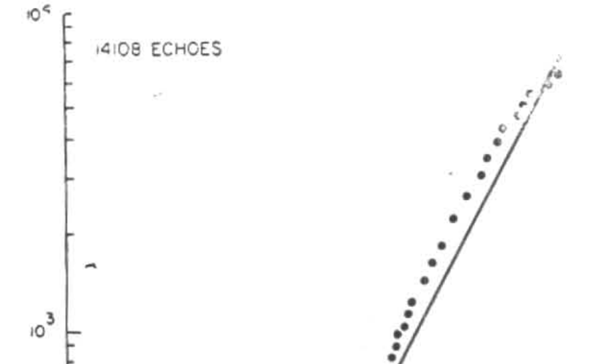

Fig. 1. Cumulative frequency distribution of the areas of radar echoes from convective clouds

2. Data used and method of analysis

The data used in the present study are based on the radar observations of precipitation echoes from convective clouds within 100 km around Delhi made during the monsoon season (July-September) of the 6-year period from 1967 to 1972. An X-band high power Japanese radar of type NMD-451A has been used for this purpose. Details of the radar set are :

Wavelength	3.2 cm
Peak power transmitted	250 KW
Pulse length	1 μ sec
Minimum detectable signal	—90 dBm
Pulse repetition frequency	300 Hz
Horizontal and vertical beamwidths	1.2°

Radar observations were taken every hour on a routine basis mainly between 1000 & 1700 IST (0430 & 1130 UTC). On each occasion the radar was first operated on PPI mode at low elevation angles (near 0°) to survey the precipitation occurrences and their general characteristics around Delhi on the PPI display. Photograph of each PPI observation was taken. Then some of the precipitation echoes were selected at random and their heights measured on the RHI or REI scope. From the radar data thus collected, frequency distributions of the areas and heights of the convective cells were compiled. In an earlier study, Chatterjee and Prem Prakash (1990) found that the average lifetime of a convective cell in this region is about 40 minutes during the monsoon season. Therefore, since the sampling interval was larger than the average lifetime of the individual cells, each echo was considered to be distinct. Areas of the echoes on PPI photographs were measured first in mm² using an overlay marked in mm² grids. Then the areas of the echoes were converted into km² by multiplying it with the scale factor. It may be mentioned here that because of the sampling procedure adopted, it has not been possible to determine the stage of development of the echoes at the time they were observed. Thus the areas (or heights) of the radar echoes considered in this study are not necessarily the maximum areas (or heights) that the echoes attained during their lifetimes. Nevertheless, they offer at least a semi-quantitative characterisation of the areas or heights of the echoes from convective clouds in the Delhi region.

TABLE 1

Distribution of radar echoes of convective clouds in different size scales

Year	Total population	Percentage of echoes in each scale		
		D	C	B/C
1967	2591	85.1	13.5	1.4
1968	1556	83.2	15.6	1.2
1969	2142	89.7	9.1	1.2
1970	3421	86.7	12.5	0.8
1971	2720	80.0	19.0	1.0
1972	1678	88.9	10.4	0.7
Total	14108	85.4	13.5	1.1

3. Results and discussion

3. 1. *Echo areas*

Following the nomenclature used in GATE (*e.g.*, Houze and Cheng 1977), radar echoes were classified into three scales according to their areas, namely, D scale (≤100 km²), C scale (101-1000 km²) and B/C scale (>1000 km²). The D scale is generally considered as cumulus scale while the latter two are generally considered as 'meso-scale'.

The relative frequency of the D, C and B/C scale echoes observed in each year is shown in Table 1. It is seen that during each year the radar echo population was dominated by D scale echoes. Percentage of such echoes varied between 80.0 and 89.7 per cent during different years. C scale echoes also accounted for an appreciable proportion in each year (9.1 to 19.0 per cent). B/C scale echoes accounted for only 0.7 to 1.4 per cent during different years. On the whole, out of the total number of 14108 echoes studied during the six years, 85.4 per cent of the echoes were of D scale, 13.5 per cent were of C scale and only 1.1 per cent were of B/C scale. The largest echo area observed was 7986 km². This type of distribution of the radar

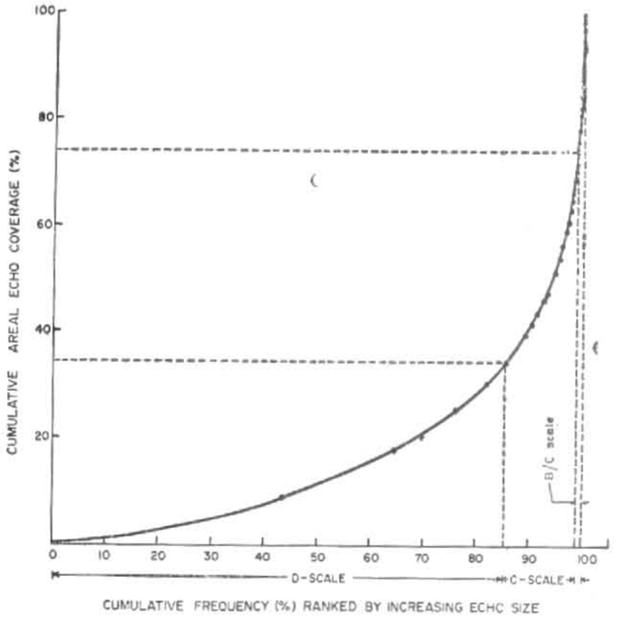

Fig. 2. Cumulative frequency distribution of accumulated areal coverage of radar echoes from convective clouds

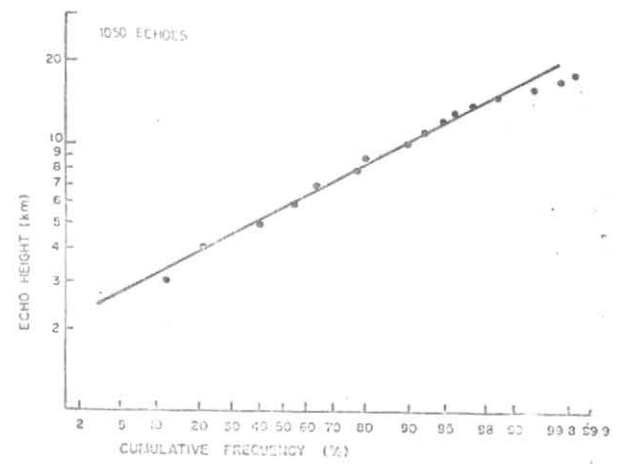

Fig. 3. Cumulative frequency distribution of heights of radar echoes from convective clouds

echoes, *i.e.*, D scale echoes dominated the total number of echoes has also been reported by Lopez (1976), Houze and Cheng (1977) and Raghavan *et al.* (1983) for radar echoes of cloud populations surveyed over western tropical Atlantic Ocean, eastern tropical Atlantic Ocean, and in Madras region in India respectively.

Fig.1 presents the cumulative percentage frequency distribution of the areas of the radar echoes for all the six years taken together. The distribution has been plotted on logprobability paper (the ordinate is plotted in a logarithmic scale, while the abscissa is plotted in a normal probability scale). It may be seen from the figure that 98.4 per cent of the total population representing echoes up to 600 km^2 in area closely followed lognormal distribution. Beyond that, the distribution of the echoes deviated above the lognormal straight line. Similar feature was also observed for echo populations studied by Raghavan *et al.* (1983) in Madras region. Studies by Lopez (1976, 1977) and Houze and Cheng (1977) have also shown that about 98 per cent of the radar echoes of tropical convection, observed in the Americas and in the Atlantic followed lognormal distributions. However, beyond that, the distribution was found to deviate below the lognormal line.

The physical significance of the deviation of the frequency distribution of the echo sizes above or below the lognormal line has been described nicely by Raghavan *et al.* (1983). According to that, if the growth of the cloud is limited — by whatever mechanisms— to some low upper limit, the distribution deviates below the lognormal line at largest size ranges. On the other hand, if the growth to very large sizes is frequent, the distribution deviates above the lognormal line. Thus in the western hemisphere very large echoes were found to be fewer than if the distribution were lognormal. Lopez (1977) attributed this due to the physical limit to the growth of the cloud. On the other hand in India, both in Madras and Delhi regions, number of very large echoes have been found to be more than would be the case if the growth had continued according to the law of proportionate effects. This is probably due to the reason that in both the regions, convective cells have been found to be accompanied by stratiform echoes (as inferred from the presence of melting band) as their extension on many occasions. This feature of large stable meso-scale extension accompanying convective cells may account for the substantial number of larger echoes and the observed deviation from the lognormal distribution in these two regions of India.

Fig. 2 presents the percentage of areas covered by different scales of echoes during the six-year period. It can be seen from the figure that D scale echoes, which accounted for 85 per cent of total number of echoes covered about 35 per cent of the total area covered, C scale echoes which accounted for 14 per cent of the total number of echoes covered 40 per cent and B/C scale echoes which accounted for only 1 per cent of the total number of echoes covered 25 per cent of the total covered area. It thus seems that both the small and large group of echoes contribute significantly each as a class, to the total volume of precipitation covered by the entire echo population. Similar feature was also observed by Lopez (1976) and Houze and Cheng (1977) for cloud populations observed over western and eastern tropical Atlantic Ocean respectively. However, percentages of the total number of echoes in each scale and the total area covered by the echoes in each scale varied from place to place. As pointed out by Houze and Cheng (1977), this can be due to the differences in meteorological conditions of different places under which clouds were sampled or more likely due to the differences in the sensitivity of the radar sets used in different experiments. The latter is due to the fact that strong echo cores connected with light precipitation would appear as one large echo on a highly sensitive radar, whereas it would appear as several smaller echoes on a less sensitive radar with the result that a large fraction of the total echo area would appear to be covered by smaller echoes.

3.2. *Echo height*

Out of the total number of 14108 radar echoes of convective clouds observed during the six years, only 1050 of them (about 8 per cent of the total number of echoes) were selected at random and their heights measured. Plotted on logprobability paper, Fig.3 shows the cumulative percentage frequency distribution of the heights of the radar echoes from convective clouds sampled during the six years. It may be seen from the figure that heights of 98.3 per cent of the total number of echoes also followed lognormal distribution. Also, deviation of the height distribution of the echoes from lognormality was noticed only for those echo categories whose heights were more than 15 km where the points lie below the lognormal line. The deviation from lognormality in the highest few per cent of the height categories below the lognormal line as seen in Fig. 3 indicated the presence of fewer clouds of such heights than expected in a lognormal distribution. Similar feature was also observed by Lopez (1976, 1977) and Houze and Cheng (1977) in the frequency distributions of the heights of the radar echoes of convective clouds studied in the regions mentioned earlier. Presence of fewer cloud of large echo heights than expected from lognormal distribution may, perhaps, be attributed to the effect of tropopause which acts as a barrier to the vertical growth of convective clouds.

4. Summary and conclusion

A large number of radar echoes from convective clouds observed in Delhi region in India during 6 monsoon seasons (1967 to 1972) have been studied in order to determine the characteristics of the distribution of areas and heights of such radar echoes in this region.

Using GATE nomenclature radar echoes have been classified into three scales according to the areas covered by the individual echoes, namely, D scale ($\leqslant 100$ km^2), C scale (101-1000 km^2) and B/C scale (>1000 km^2). It was found that out of the total number of 14108 echoes analysed, as much as 85 per cent of them were in the D scale while 14 and 1 per cent of the total number of echoes were in the C and B/C scale respectively. The largest echo area observed was 7986 km^2. Study of the relative contribution of the three scales of echoes to the total area covered by all the echoes showed that D, C and B/C scales of echoes accounted for 35, 40 and 25 per cent of the total echo covered area respectively.

The frequency distribution of the areas of the echoes showed that the smaller echoes (up to 600 km^2 in area) constituting about 98 per cent of the total echo population followed lognormal distribution. Echoes with larger areas deviated above the lognormal line indicating that very large echoes occur more frequently than a lognormal distribution would predict. This may be due to the development of quite a substantial number of stratiform mesoscale cloud as an extension to the main convective cell.

Frequency distribution of the heights of the echoes also tended to be lognormal except for very large heights (>15 km) where the distribution deviated below the lognormal line. This indicates that there were relatively less number of echoes of larger heights than a lognormal distribution would predict. Occurrence of less number of such echoes is attributed to the effect of tropopause which acts as a barrier to the vertical development of a cloud.

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