551.508.85 : 551.577 (541)

Vertical development of precipitation echoes from cumulus clouds near Calcutta during the post-monsoon season

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(*Received 13 February 1957*)

ABSTRACT. Vertical development of precipitation echoes from cumulus clouds near Calcutta during the post-monsoon season of 1956 was studied by using a Decca Type-41 3-cm radar installed at the Meteorological Office at Dum Dum airport. It has been shown that the origin of the first precipitation echoes were below the freezing level in most cases. The rate of growth of the precipitation echoes was found to be comparable with that found in USA. A condensation-coalescence mechanism has been suggested for the formation of rain from these clouds.

1. Introduction

In recent years, radar is being increasingly used for observation of clouds at a number of places in India. Studies in detection of precipitation cells, their horizontal movement and development have been made by a number of authors (Mathur *et al.* 1954, Gupta *et al.* 1955, Mitra 1955, De *et al.* 1957). Our knowledge of the vertical growth of convective clouds in the Indian areas, however, is still in a conjectural stage. This important aspect has been studied in detail by Battan in USA (1953 a). He examined the RHI scope presentations at intervals of 90 seconds, photographed with the aid of a 3-cm vertical scanning radar set located near Wellington, Ohio, during the USA Thunderstorm Project 1947 and got information of the rate of growth and decay of precipitation echoes from cumulus clouds as well as the most frequent locations within the clouds where the precipitation echo originates. An attempt has been made to obtain similar data with the aid of a Decca Type-41 radar installed at the Meteorological Office, Dum Dum airport and some of the observed features are described here.

2. Methods of observation

The radar operates on 3-cm waveband and has a peak power of 30 KW. The half power beam width is 4° in the vertical. This display is made on a PPI scope of a diameter of 12 inches on which there is a provision to read the plan position of echoes in miles of range and in degrees of azimuth with respect to true north. The antenna can be tilted in the vertical upto 12° from the horizontal. By rotating the antenna at various angles of tilt, precipitation echoes were detected almost at the time of their formations. Their vertical growth was studied by tilting the aerial in steps of one degree at a time and recording the elevation at which the precipitation echo just disappears. The process was repeated at intervals of a minute. From the slant range indicated in the PPI scope, the elevation angles were converted into altitudes. Fig. 1 illustrates the observational set up.

3. Limitations of the technique

If E/Et is the ratio of the back-scattered flux detected by the radar to that emitted initially, it can be shown that this quantity

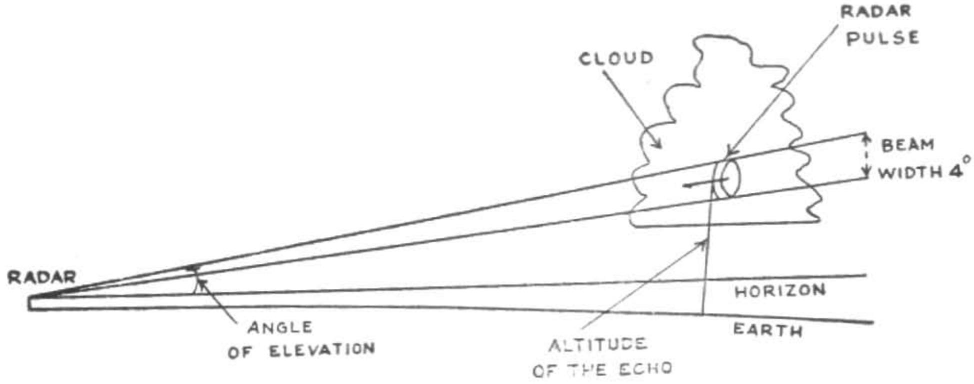

Fig. 1. Schematic diagram of the radar beam intercepted by the cloud

is a function of $\sum_{i=1}^{i=x} n_i a_i^6$ where the cloud contains scatterers of diameter a per unit volume and the summation sign indicates that more than one size of scatterers may be present (Johnson 1953). The power of return from the cloud drop is primarily dependant on the sixth power of its diameter. For a cloud assumed to contain, say 500 drops per cc of 10 microns in diameter in which the rainwater content is 2 drops per litre of 1 millimetre diameter, Johnson has computed that the ratio of the effect due to rainwater to that due to cloud drops is 4×10^6. It is, therefore, clear that the radar echo is almost entirely due to raindrops rather than cloud drops. When the raindrops however become larger ($a > \lambda/10$, where λ is the wavelength), 'Rayleigh scattering' is no longer applicable and the relation of the scattering cross section to λ is complex. Precipitation attenuation becomes appreciable at these large drop sizes. The 3-cm radar is subject to these limitations in the tropics due to the fact that large droplets are frequently present in convective showers. The 10-cm band is, however, free from such limitations due to rain attenuation.

It will be seen from Fig. 1 that the altitude of the precipitation echo detected by the radar is that of the centre of the radar beam intercepted by the cloud. A beam of half power width 4° would intercept quite a large slice of the cloud (7360 feet at a distance of 20 miles). The altitude at which the echo just disappears is the mean altitude of that portion of the cloud where the number of scatterers (rain drops) are just insufficient to produce an echo detectable by the radar. As such the maximum height of the echo cannot indicate the height of the top of the rainfall content of the cloud—much less that of the cloud itself. It should also be mentioned that the altitude determined by this method is subject to an error of about 900 feet at a distance of 10 miles due to the fact that the angle of tilt can be measured to an accuracy of 1°.

The errors mentioned above are not serious for measurement of growth rate of precipitation echoes which was the main purpose of this experiment. The determination of the altitude of the first appearance of precipitation echoes is also subject to these errors. A qualitative idea, however, can be obtained whether the first appearance of the echo is below or above the freezing level which is an important factor in determining the mechanism of rain formation.

4. Choice of precipitation cells

The investigation was mainly confined to the postmonsoon period of October-November 1956. A total of 22 clouds was studied. Since most of them were already in a developed stage when they were detected on the PPI scope, only their rates of dissipation could be observed by the technique described above. By a careful watch for the detection of a precipitation echo just at the instant of its formation it was possible to get at a picture of the complete life cycle in the case of 7 clouds.

One of the interesting phenomena observed on the PPI scope during the study of convective cells is clustering of precipitation echoes in the PPI screen. Secondary echoes form round primaries and after sometime, the secondary grows at the expense of the primary cell. This phenomenon has been observed during the USA Thunderstorm Project (1947) and has been discussed by various authors. In India the same was noted by Mitra (1955) who has made an investigation of the growth and movement of cells associated with a thunderstorm. Since the interaction of different primary and secondary cells introduces a complication in the cloud growth studies, it was considered desirable to eliminate such instances and take only cases where a single cell was observed to develop vertically. This further selection naturally limited the number of cases available for analysis.

5. Origin, growth and decay of precipitation echoes

The life history of the altitudes of the tops of precipitation echoes from the 7 cells mentioned above is given in Fig. 2. The average freezing level during the period which was about 15,000 ft a.s.l. has been indicated in the figure. The following features have been observed—

(*a*) The origin of the first precipitation echoes was below the freezing level in 5 cases. In one case it was near the freezing level and in another it was well above it.

(*b*) The tops of the precipitation echo grew beyond the freezing level in 4 cases and were confined below it on 3 occasions.

(*c*) The rate of development was more rapid in the case of cells growing to greater heights than in the case of smaller ones. The average rate of growth in the case of 4 cells was 2600 ft min^{-1}. This compares well with the rate of growth of 3000 ft min^{-1} observed by Battan (1953 b).

(*d*) The duration of growth is generally 3 to 6 minutes and there is a rapid decay thereafter, the rate of decay however being slower than the rate of growth.

(*e*) The decaying cell sometimes revives as in the case on 8 October 1956 (Fig. 2). The top of the precipitation echo which grew rapidly from 9000 to 25,000 ft in 4 minutes decayed to 15,000 ft in another 4 minutes but has another spurt of growth and decay during the next 8 minutes. It remained constant at about 19,000 ft for 22 minutes thereafter and it was observed that this cell ultimately developed into a thunderstorm.

On account of the rapid growth of these cells as can be inferred from the rate of growth of the tops of echoes, it has not been possible to make a similar study of the bottom of the echo pattern. It was, however, found that the echoes descended to the horizontal (0° elevation) within a minute or two of their detection at the higher levels. This aspect can be studied in greater detail only when a RHI scope is available.

The horizontal dimensions of the echo pattern at various altitudes have also been determined on the PPI scope. Fig. 3 gives a picture of the three dimensional growth of the precipitation echoes on 9 October 1956. The vertical scale in thousands of feet is marked on the Y-axis while the horizontal echoes on the PPI scope have generally an elliptical pattern with circumferential elongation due to distortion caused by finite beam width. The dimensions of these echoes

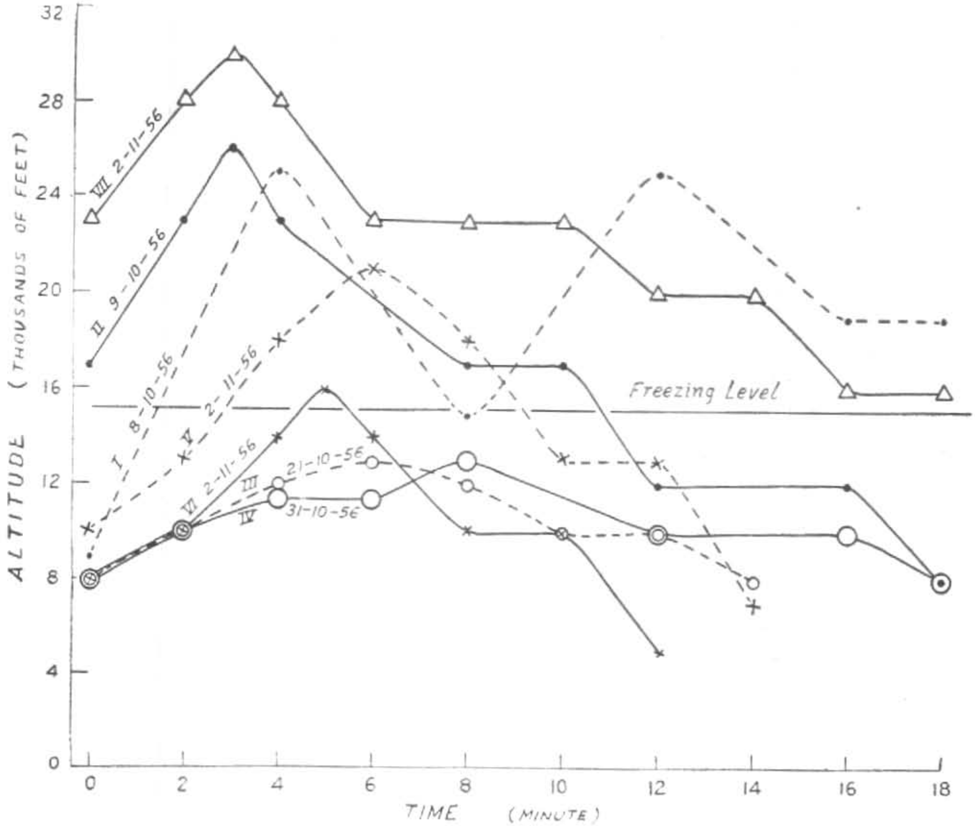

Fig. 2. Origin, growth and decay of precipitation echoes from cumulus clouds
Average freezing level marked by thick line

at each level are given in Fig. 3. It may be mentioned however, that the indicated diameters are also subject to errors due to attenuation and other factors but since we are interested in the time variations of the horizontal and vertical extent of these cells, the diagrams in Fig. 3 may be assumed to give an indication of this variation. It is generally observed that the echo patterns spread out at the lower levels during the decaying stage and cloud gradually thins out from the top.

It is interesting to observe that the pattern of development is almost identical with that noticed by Battan (1953 a) though the areas of location of the clouds were radically different and our sample was quite small. He found that in about 60 per cent of cases the entire first echo was at temperatures above freezing whereas in the present study the same result was otained in almost 70 per cent cases. In a recent study of convective showers over England, Feteris and Mason (1956) also noticed that on 13 days during the

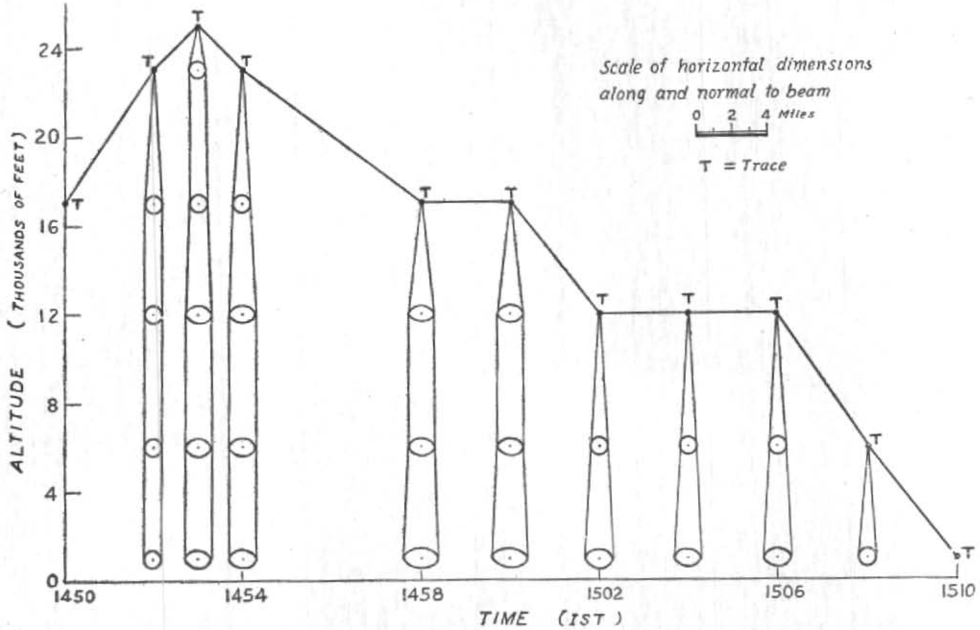

Fig. 3

summer of 1955, 48 echoes were observed to originate below–2°C level and 26 of them remained there during the whole life of the shower. The average echo diameter in the American study was 2·2 miles (Battan 1953 b) while in the present investigation it was 2·0 miles*.

6. Mechanism of rain formation

The data presented above would suggest that since in the majority of the cases the first precipitation echo was observed below the freezing level, the showers from these convective clouds were generally initiated by a condensation-coalescence process. Battan (1953 b) and Feteris and Mason (1956) also arrived at similar conclusions from their studies. Feteris and Mason point out that the appearance of the echo below 0°C need not necessarily indicate coalescence process since there is a possibility of their having originated from ice particles falling from above the freezing level, which remain undetected till they reach the freezing level. They have, however, produced strong arguments against such a possibility.

In our case, one of the most noteworthy features is the strong up-current (2600 ft min^{-1}) observed soon after the formation of the first echo. Strong currents should have existed even before the appearance of the echo and would preclude the descent of snowflakes or small graupel from above the freezing level for the initiation of the raindrops. A more plausible process would be a condensation-coalescence mechanism as suggested by Battan. When moisture ascends to higher levels cloud droplets form on condensation nuclei. The up-currents carry these droplets to a region of higher liquid water content, and some of the droplets grow more rapidly

* The most frequent echo diameters were 2–3 miles in both the investigations. The average rate of growth is also nearly the same as pointed out earlier.

than others. When these drops exceed a critical size, growth takes place by coalescence as shown by Langmuir (1948) and drops grow at an accelerated rate until rain is formed. Visual observation of monsoon clouds in India, particularly along the West Coast where heavy showers are seen to occur from clouds with tops below the freezing level (Pramanik and Koteswaram 1955) lends support to such a conclusion.

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