A Radar Study of Altocumulus cloud using 3-cm High Power Radar CPS-9

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ABSTRACT. Radar study of clouds has mostly been confined to that of convective clouds or precipitation-producing stratiform clouds. No such study appears to have been made of the non-precipitating clouds like altocumulus.

The high power radar CPS-9 at Safdarjung, New Delhi, has been receiving radar echoes from altocumulus clouds of cloudlet type and these have been under study. Two examples are presented here and discussed. Based on the radar parameters, the order of the *smallest* droplet size in altocumulus has been calculated and is found to be of the order of 6μ—8μ and to be fairly independent of concentration of droplets in the cloud. The cellular structure of the cloud as revealed by PPI and RHI photographs confirms the idea of existence of Benard Cells drawn earlier on the basis of laboratory experiments and aeroplane flights.

1. Introduction

In Meteorology, the study of clouds has always attracted a good deal of attention because in addition to being of practical use in forecasting, they yield valuable information about the thermal structure and movement of the layers in which they float. Numerous workers in the past have been engaged actually in this field using different techniques ranging from visual observations and upper air soundings to aeroplane flights. Many workers have also tried to study the same by simulating conditions in the laboratory.

During recent years, the advent of centimetric radars has provided the Cloud Physicist with a versatile and powerful new tool which, inspite of a number of limitations, has enabled him to obtain significant information on the fundamental physics of clouds apart from its use for storm-detection and even forecasting.

As the centimetric radars are most suitable for the study of precipitating clouds, most of the cloud studies by radar have been confined to the studies of distribution, movement, structure and development of convective clouds or precipitation-producing stratiform clouds and practically no attempt has been made to apply these radars to the study of the non-precipitating clouds like stratocumulus, altocumulus etc. This has been partly due to the impression that centimetric radars are incapable of detecting these clouds and that for this purpose millimetric radars are absolutely necessary.

In the present paper, some results of a radar study of altocumulus clouds by high power radar CPS-9 installed at New Delhi are presented.

2. Synoptic situation

On 13 June 1960, weather had been mainly dry over the northwest India. A steep pressure gradient existed over Rajasthan on the 0300 GMT chart causing gusty and dust-raising surface winds upto about 1200 IST. The winds weakened thereafter. Due to dust, the sky over the station was indiscernible but as no radar echoes were observed till 1430 IST, it can safely be assumed that the sky must have been clear. At about 1440 IST, radar echoes were observed. The eye observations showed that these were associated with altocumulus clouds which could now be seen as a result of the weakening of the winds and the consequent increase of the vertical visibility. These altocumulus
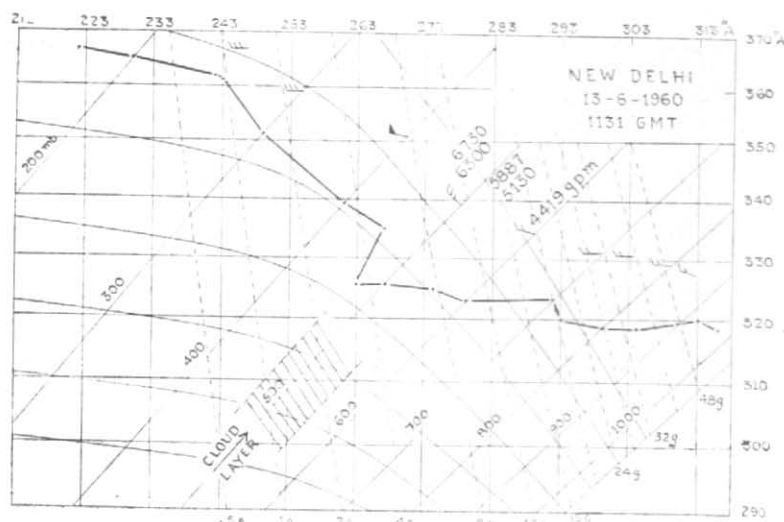
Fig. 1. 12 GMT Radiosonde—Rawin ascent of 13-6-1960

clouds consisted of small cloudlets, polygonal in shape, thick at the centre with clear sky around the margin and covered 5-6 oktas of the sky. The formation of altocumulus clouds continued upto about 1800 IST after which they dissolved.

3. Present knowledge about the structure of altocumulus clouds of the cloudlet type

The formation of altocumulus clouds of the cloudlet type (not the punch-hole type) has been studied both in laboratory as well as in nature and it has been shown that—

(i) such cloudlets are cellular in structure and are produced in nature in cloud sheets associated with vertical unstable temperature gradient and no shear,

(ii) the motion in each of these cloudlets resembles that in a Bénard Cell and is an ascending one in the centre of the cloudlet and descending one at the edges,

(iii) such a cloud layer is bound by very stable layers as shown by the presence of an inversion above and a stable gradient below it, and

(iv) the temperature gradient within the cloud sheet is adiabatic or superadiabatic.

4. Observed facts

Fig. 1 shows the 12 GMT radiosonde-rawin ascent for New Delhi. The height of altocumulus cloud as estimated from radar observations was about 5000 metres corresponding roughly to 550 mb. As the altocumulus clouds were present at the time of the ascent, the ascent gives the physical conditions under which altocumulus clouds of cloudlet type are formed in nature. It will be seen that the radiosonde-rawin ascent confirms the previous results completely in so far as (i) the temperature gradient in the cloud layer was adiabatic, (ii) stable temperature gradients prevailed both below and above this layer, and (iii) shear was practically absent in the cloud layer.

Figs. 2 to 6 and 9 give the PPI presentation of the altocumulus clouds at different elevations of the radar antenna and Figs. 7 and 8 RHI presentations of the same in different directions. These pictures were
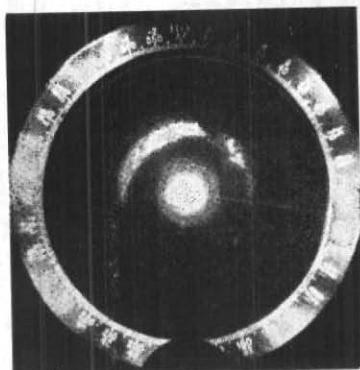
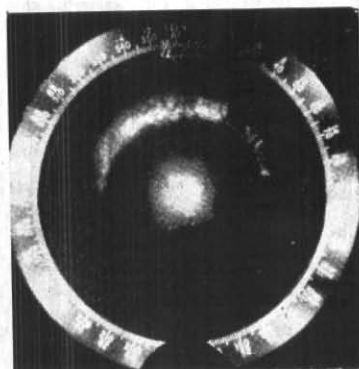13-6-1960
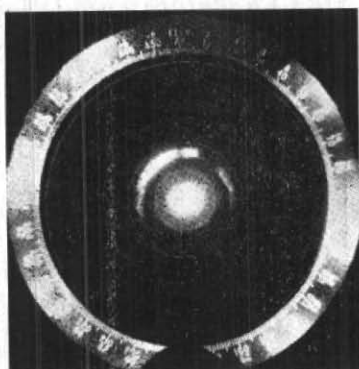
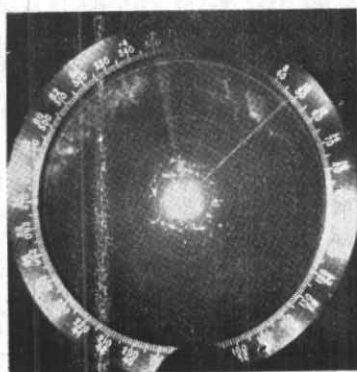1446   25   30°
Fig. 2

1448   25   25°
Fig. 3

13-6-1960

1450   25   20°
Fig. 4

1452   25   14°
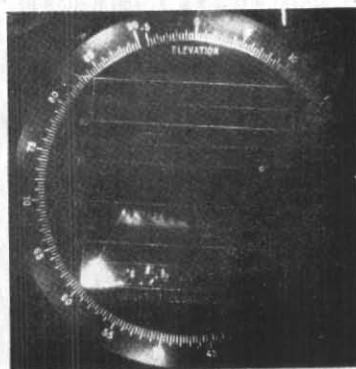**Fig. 5**

13-6-1960

1455   25   10°
Fig. 6

1502   25   341°
Fig. 7

Radarscope photographs of altocumulus clouds as observed on CPS-9 Radar, New Delhi
Figures given below the photographs indicate (from left to right)—Time (IST), Range in miles
and Elevation/Azimuth in degrees respectively

13-6-1960

1505   25   300°
          Fig. 8

1536   25   25°
          Fig. 9

22-6-1960

1204   10   230°
          Fig. 10

22-6-1960

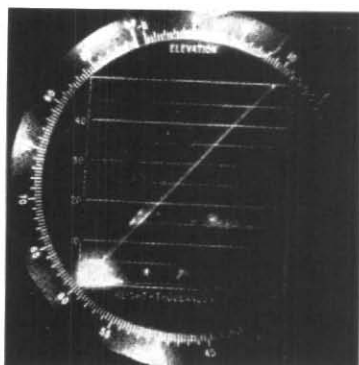1217   25   70°
          Fig. 11

1224   25   85°
          Fig. 12

Radarscope photographs of altocumulus clouds as observed on CPS-9 Radar, New Delhi
Figures given below the photographs indicate (from left to right)—Time (IST), Range in miles
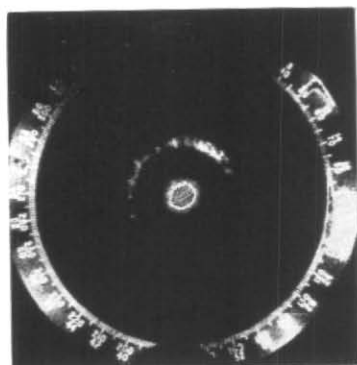and Elevation/Azimuth in degrees respectively

Fig. 13. 00 GMT Radiosonde-Rawin ascent of 22-6-1960
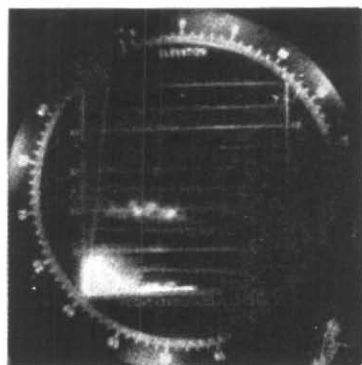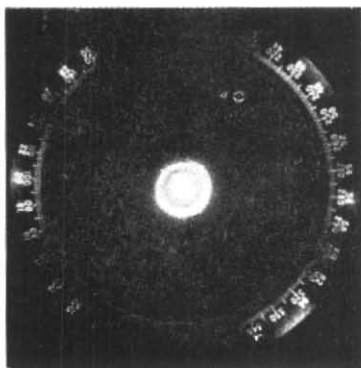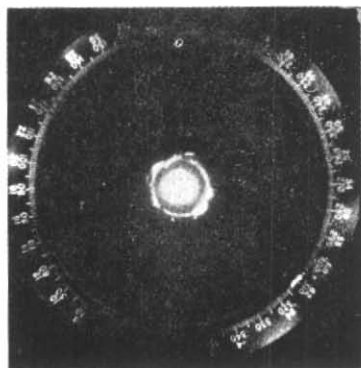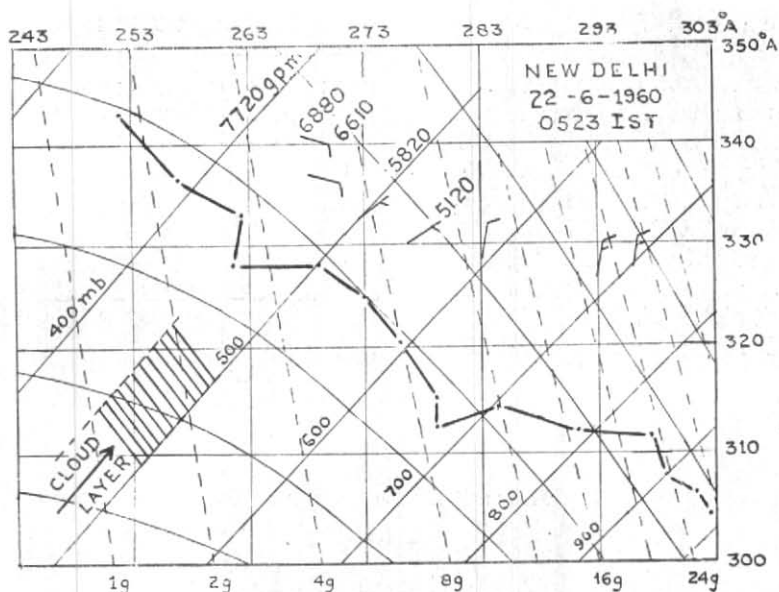
taken by the CPS-9, 3·2-cm radar with a pulse-width of 5·0 microseconds duration, peak power of 250 kw and 1° conical beam. All the PPI pictures clearly show cloud echoes as consisting of a large number of cores of echo of high intensity at a range of about 7 to 8 miles from the station in the western half. Although the radar echo gives an appearance of a more solid and continuous type in the PPI photographs taken at higher elevations (Figs. 2 and 3), the cellular nature of the cloud is very clearly brought out in the PPI pictures at lower elevations (Figs. 4 to 6). When seen in RHI scope, such an echo is seen between 14,000 and 18,000 feet. The cellular structure is again in evidence, the cores of high intensity now being revealed by the vertical columns of the echoes. The greater vertical thickness of the echo in the centre of the individual cell and a clear spacing in between the neighbouring cells also point to the vertical motion in the centre of the cell and descending motion at the edges of the cell. All these clearly confirm the inferences regarding cellular structure and the type of motion inside the cells as drawn on the basis of laboratory experiments and aeroplane flights.

PPI and RHI presentations (Figs. 10 to 12) taken on another day (22 June 1960) and the 00 GMT radiosonde-rawin ascent (Fig. 13) for this day again confirm the conclusions drawn above.

5. Suitability of a 3-cm radar for study of non-precipitating clouds

The application of radar to cloud studies has so far been confined mainly to U.S.A. and Europe. Even there, so far as known to the authors, no literature is available about the study of altocumulus clouds by a 3-cm radar. On the other hand, most of the authors on the subject are emphatic in asserting that the centimetric radars are useful *only for detection of precipitation elements and not cloud particles* as is clear from an extract from *WMO Technical Note No. 27* which reads: "It must be strongly emphasized that the phrase which is often used 'detection of *clouds* by radar' is very misleading when wave lengths from 3 cm

to 10 cm are employed since at the ranges usually used on these wavelengths only *precipitation* elements are detectable". In the two cases presented above, however, the radar echoes were definitely from the non-precipitating type altocumulus clouds which clearly shows that the above assertion is not wholly correct and cloud forms of the type of altocumulus can be detected by a 3-cm radar at reasonable ranges, at least in tropical latitudes. Whether, in these latitudes, it is due to the higher concentration of drops or due to the larger size of the droplets, it is not possible to say at this stage.

6. An estimate of the order of magnitude of the smallest droplet size of the cloud

Many direct measurements of droplet size have been made in stratified layers of clouds in the western countries by Diem (1942, 1948), Frith (1951) and Bricard (1943) using different techniques. In the tropics, however, such data are lacking. With the help of radar equation, the radar observations presented above can be made use of for estimating the order of magnitude of the smallest droplet size of a cloud which may be detected by a typical 3-cm radar like the CPS-9.

The radar equation for targets comprising an assemblage of spherical water particles is given by

$$\bar{P}_r = 284 \; \frac{\Sigma D^6}{\lambda^4} \; \frac{P_t \; h \; A_e}{8\pi r^2} \; F \; K \qquad (1)$$

where, P_t is transmitted power, $\bar{P}_r$ average power received, h pulse length, A_e the effective aerial aperture, r range, D diameter of the drop, the summation being over all the scattering particles in unit volume, F fraction of the radar beam intercepted by the target, K attenuation factor, and λ the wavelength.

For the CPS-9 radar working on long pulse, $\bar{P}_r = 10^{-13} \; W$ for minimum detectable signal, $P_t = 225 \times 10^3 W$, $h = 1500$ metres, $A_e = 2 \cdot 2 \, \text{m}^2$

TABLE 1

Serial No.	Concentration n (No. of drops per c.c.)	Estimated diameter D (μ)
1	100	12
2	500	9
3	1000	8
4	10000	6

(equivalent to a circular dish aerial of diameter $7 \cdot 75$ ft using a factor of about $0 \cdot 5$ between effective aerial aperture and true aerial aperture), $F=1$ (equivalent to the whole beam at range $r=5$ km being filled with cloud in which the distribution of droplets of all sizes is random), $K=1$ (*i.e.*, assuming no attenuation other than that caused by range), and $\lambda = 3 \cdot 2 \times 10^{-2}$ m. On substitution in equation (1), we get

$$\Sigma D^6 = 1 \cdot 248 \times 10^{-29} \, r^2 \qquad \text{m}^6/\text{m}^3 \qquad (2)$$

Taking the mean range of the echo under study as about 5000 metres (as revealed by the RHI pictures—see Fig. 7), we get,

$$\Sigma D^6 = 3 \cdot 1200 \times 10^{-22} \qquad \text{m}^6/\text{m}^3 \qquad (3)$$

If we assume all droplets to be of the same dimensions, equation (3) may be written as

$$nD^6 = 3 \cdot 1200 \times 10^{-22} \qquad \text{m}^6/\text{m}^3 \qquad (4)$$

where n is the number of particles per unit volume.

Although for middle latitudes, Best (1957) from the data collected by many workers, estimated the value of n for these clouds to be of the order of 1000 cm^{-3}; Diem, Frith and Bricard have assigned a value ranging between 300 to 500 cm^{-3} from their individual studies. Unfortunately, no such information is available for tropical latitudes. Table 1 gives the values of D, *i.e.*, the diameter of the smallest altocumulus droplet for a detectable echo on CPS-9

radar for different values of concentration. These have been calculated on the basis of equation (4) above.

It will be seen from Table 1 that the diameter of the smallest altocumulus droplet for a detectable echo varies very little with the value of n. Considering that the average liquid content in the tropics is very much higher than that in the middle latitudes, the value of n is likely to exceed the value of 1000 cm^{-3} found by Best. This would put the estimation of D between 6μ to 8μ even if an exaggerated value of 10,000 cm^{-3} for n is assumed. It would be worthwhile to verify this estimate by a more direct method like aeroplane flights through such clouds.

7. Conclusions

The conclusions arrived at as a result of this study can be briefly stated as follows—

(*i*) At least in tropics, radar echoes are recorded from non-precipitating altocumulus clouds even on 3 cm wavelength.

(*ii*) The radar photographs of cloudlet type altocumulus cloud show cellular structure with ascending motion in the centre and descending one at the edges.

The radar pictures reproduced here confirm completely the ideas about the structure of altocumulus clouds drawn earlier by Terada (1928) and Mull (1931) on the basis of laboratory experiments and aeroplane flights and are a fine illustration of the use to which weather radars can be put to confirm the long standing theories and hypotheses. The discussion above also shows how observations and analysis of radar presentations can prove valuable for getting estimates of certain parameters required in the study of Cloud Physics.

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