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# Radar studies of rain with special reference to initial release of precipitation in clouds over Poona*

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## 1. Introduction

The temperature at which the first precipitation echo appears on radar-scope and the thickness of the cloud at the time are considered to be an indication of the nature of the processes involved in the initial release of precipitation in clouds. Several workers in the United States, Australia and England have tried to analyse the evidence of first precipitation radar echoes in their study of the contribution of ice-crystal and coalescence processes to the formation of rain. Most of these observations have, however, been made in the extra-tropical regions. Koteswaram and De (1959) have recently reported radar observations of first precipitation echoes over Calcutta. Radar observations have been made at Poona using a 10-cm radar since 1953. The present paper summarises the results of the study of the radar echoes, their first appearance, development and decay over Poona for the years 1953—58.

## 2. Equipment and observational procedure

The radar used was a search radar type SCR-717C, operating on a wavelength of 9·1 cm, with a peak power of 40 KW and a pulse duration of 1·125 μ secs. The antenna is a dipole-fed paraboloid mounted for rotation about a horizontal axis, so that the radar beam scans the sky from horizon to horizon, through the zenith giving a vertical cross-section through the atmosphere about the point of observations. The radar was installed on the observatory tower about 120 ft above ground level, from where an unobstructed view of the sky was available all round and visual observations could be made and the clouds photographed whenever necessary. Single celled convective echoes or the first cell of complex storms were selected for the study. The cloud was observed from the growth to decay stages and photographs of the display tube taken at suitable time intervals, from the moment of the first appearance of the radar echo, till after the decay of the cell. The heights of the echo base and top were determined from the range marks on the display tube. The temperatures were obtained from radiosonde ascents at Poona taken at 2000 IST the same day or from mean values when radiosonde data for the day were not available. While the heights of the radar clouds obtained from the radar photographs are subject to uncertainty of the order of 500 ft increasing to 1000 ft where the range was large, uncertainties of the same order exist in the determination of the freezing level from the radiosonde data. The technique used for study of the initial stages of precipitation development has, as pointed out by Feteris and Mason (1956), also other limitations, since the stage at which a radar echo will first appear depends obviously on the range and reflectivity of the cloud and the performance characteristics of the particular radar used. In order to obtain really conclusive information, radar observations must be closely co-ordinated with measurements of the visual cloud.

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**TABLE 1**

**Melting band observations during the monsoon**

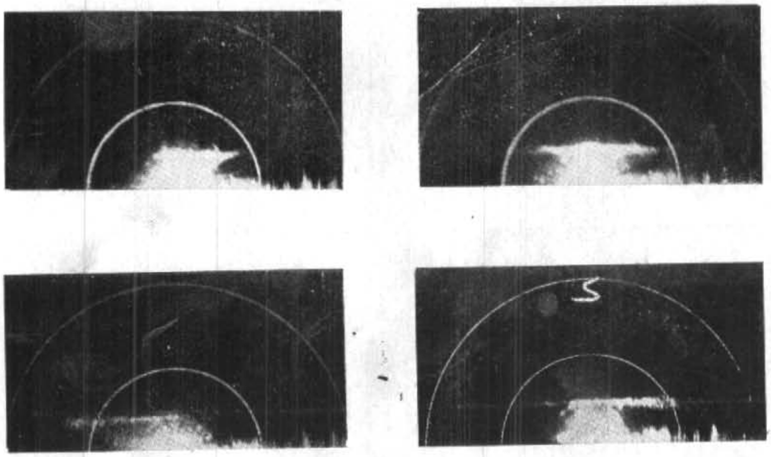
| No. | Date | Time (IST) | Ht. of 0°C isotherm (km a.s.l.) | Ht. of bright band (km a.s.l.) | Thickness of bright band (km) | Distance of band below 0°C (km) |
|---|---|---|---|---|---|---|
| 1 | 18-6-54 | 1127 | 5·2 | 4·3 | 0·3 | 0·9 |
| 2 | 15-7-54 | 1033 | 5·2 | 4·5 | 0·8 | 0·7 |
| 3 | 7-8-54 | 1530 | 6·0 | 4·6 | 0·7 | 1·4 |
| 4 | 9-8-54 | 1247 | 5·6 | 4·5 | 0·6 | 1·1 |
| 5 | 1-9-54 | 1650 | 5·3 | 4·2 | — | 1·1 |
| 6 | 2-9-54 | 1115 | 5·4 | 4·6 | 0·5 | 0·8 |
| 7 | 16-6-55 | 1650 | 5·1 | 4·1 | 0·8 | 1·0 |
| 8 | 28-6-55 | 1052 | 5·1 | 4·4 | 0·5 | 0·7 |
| 9 | 17-8-55 | 1142 | 5·0 | 4·4 | 0·5 | 0·6 |
| 10 | 30-8-55 | 1630 | 5·1 | 4·1 | 0·8 | 1·0 |
| 11 | 21-9-55 | 1430 | 4·8 | 3·8 | 0·7 | 1·0 |
| 12 | 22-9-55 | 1510 | 5·3 | 4·1 | 1·0 | 1·2 |
| 13 | 11-7-56 | 1122 | 5·3 | 4·1 | 0·5 | 1·2 |
| 14 | 13-7-56 | 1230 | 4·6 | 4·5 | 0·9 | 0·1 |
| 15 | 20-7-56 | 1145 | 5·6 | 4·5 | 0·5 | 1·1 |
| 16 | 2-8-56 | 1052 | 5·5 | 4·5 | 1·1 | 1·0 |
| 17 | 6-7-57 | 1118 | 5·7 | 4·8 | 0·4 | 0·9 |
| 18 | 26-7-57 | 1306 | 5·5 | 4·0 | 0·5 | 1·5 |
| 19 | 12-9-57 | 1441 | 5·4 | 4·3 | 0·7 | 1·1 |

## 3. Results of observations

Radar observations of clouds were made at Poona on 166 days during the period 1953-58, on 119 of which radar echoes were observed and photographed. 51 of these were of cumulonimbus clouds during the thunderstorm season March to May and October to November and the remaining 68 of monsoon clouds during the months June to September. The winter season December to February was generally clear.

(*a*) *Radar echoes from monsoon clouds*—Some features of radar echoes observed at Poona during the end of the monsoon season in September 1953 have been described in an earlier paper by the authors (1955). During the height of the monsoon, in July and August, bright bands were generally observed in radar echoes, suggesting that the origin of the precipitation was from snow above the freezing level. This was associated with steady rain or drizzle occurring for long stretches during the day. In Fig. 1 are shown two sets of photographs of the bands on two typical days during the monsoon. The band persisted almost throughout the day on 15 July 1954, continuously reforming at the same level and light rain fell throughout. The range markers are for 5 nautical miles and the freezing level was about 16,000 ft. a.s.l. In Table 1 are summarised measurements of the heights and thickness of the bright bands, on 19 occasions they were observed in monsoon clouds. The heights of the 0°C isotherm obtained from radiosonde ascents and the distances of the bands below the 0°C isotherm are also given. It will be observed that the band forms well below the freezing level, the distance varying on most of the occasions from 0·6 to about 1·1 km, in sharp contrast to observations in the extra-tropical regions.

(*b*) *Initial radar echoes in shower clouds*—A series of photographs showing the growth and decay of radar clouds, from the moment of their first appearance on the radarscope are reproduced in Figs. 2 and 3. In the



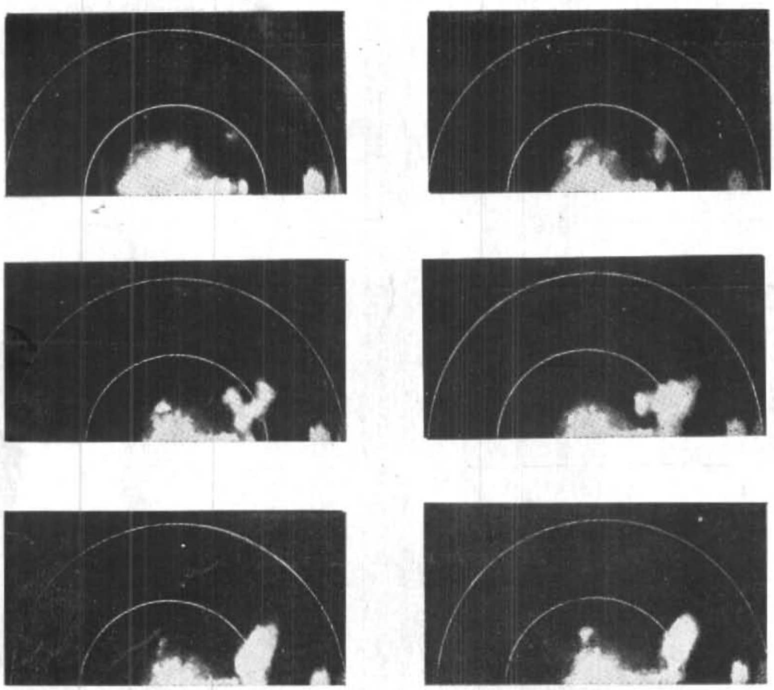
1235 IST 15-7-1954

1531 IST 15-7-1954

1515 IST 7-8-1954

1721 IST 7-8-1954

**Fig. 1. Radar echoes from monsoon clouds**



1827 IST

1831 IST

1834 IST

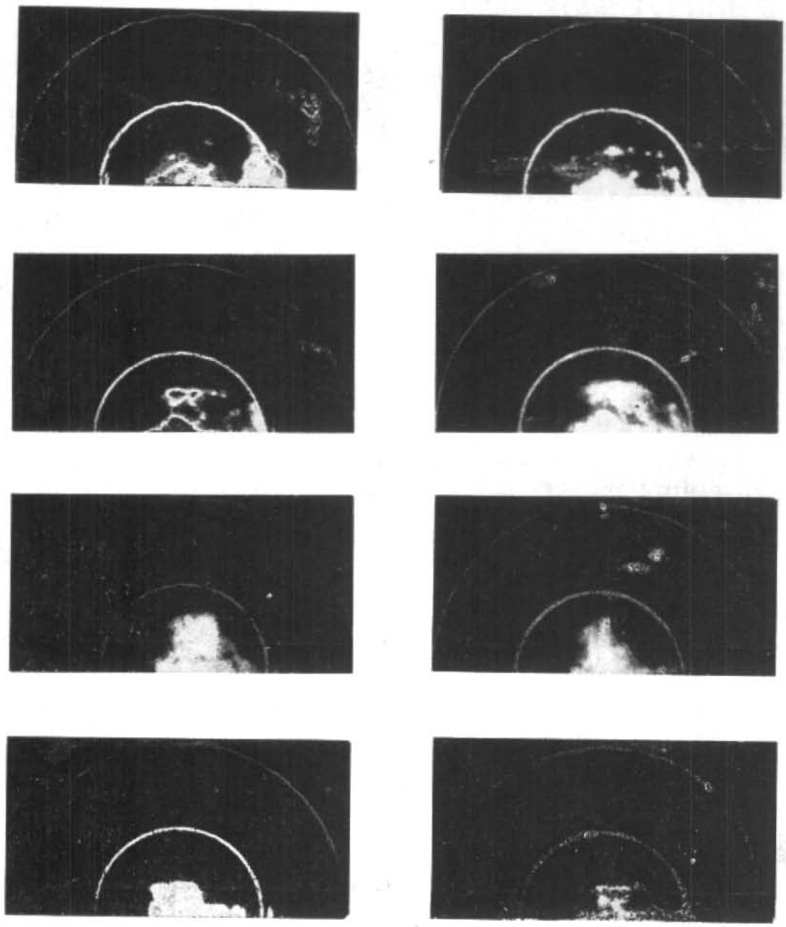
1837 IST

1844 IST

1847 IST

**Fig. 2. Thunderstorm on 16 March 1954**

(Range markers are for 5 nautical miles)



1817 IST
1825 IST
1827 IST
1829 IST
1833 IST
1839 IST
1849 IST
1918 IST

**Fig. 3. Thunderstorm on 21 April 1954**
(Range markers are for 5 nautical miles)

first series the thunderstorm dissipated rapidly, while in the second a melting band formed during the dissipating stage and persisted for over two hours.

(*i*) *Thunderstorm on 16 March 1954*—This was the day of a hailstorm at Poona, when the radar echo reached a maximum height of 10·7 km. The first appearance of the echo associated with the hailstorm could not be observed. A number of new cells, however, appeared after the dissipation of the main cumulonimbus cell and these were also associated with heavy rain though the maximum heights reached were much less and only of the order of 7 km. The complete sequence is illustrated in Fig. 2 for the period 1827—1847 IST. The first radar echo made its appearance at 1827 IST at a height of 5·5 km and was relatively shallow in extent, being less than 1 km thick. It grew rapidly both upwards and downwards, the rate of growth being of the order of 3 and 10 m/sec respectively. It developed two turrets reaching heights of 7·6 km; the two merged and later descended to lower levels. A fresh echo appeared at 1841 IST at a height of 4·8 km. It did not develop upwards, but extended towards the ground, reaching it by 1848 IST. Tha rate of growth of this cell was much slower than that of the first. No bright band was observed in the dissipating stage of the storm.

(*ii*) *Thunderstorm on 21 April 1954* (*Fig. 3*)—A number of *Cb* cells developed over and around the station, giving rise to heavy rain. The first radar echo of the sequence illustrated in Fig. 3 appeared at 1817 IST at a height of 6 km. It did not grow upwards, the top of the echo even at its stage of maximum development at 1833 IST being only 6·3 km. The first echo was sharp and shallow in extent being only 0·5 km thick. It did not develop till 1824 IST when it brightened and its depth increased to 1 km. A number of similar cells appeared to the SE at the same level at 1825 IST. These merged into a band at 1827 IST, intensified and later rapidly grew downwards reaching the ground by 1833 IST. The top of the echo remained stratified at the original level at which it formed. The echo began so dissipate after 1833 IST, the melting band making its first appearance at 1835 IST at a height of 4·0 km. The echo above the band decayed rapidly till by 1845 IST only the band remained. The rate of descent of the echo was of the order of 4 m/sec. The band persisted at 3·8 km till 1848 IST, when it began to dissipate and by 1900 IST only one small echo was present at this height. Two new echoes made their appearance to the NW at 1905 IST and one more to the SE at the same level. All merged into a band at 1916 IST, and they persisted as such, till 2011 IST, when it disappeared from the radarscope.

It is seen that (1) the first echo always makes its appearance suddenly, suggesting a sudden release of considerable quantities of large water drops and (2) numerous small echoes appear around an active thunderstorm cell. (3) The maximum horizontal and vertical extents of the echo are generally of the same order of magnitude. (4) The rates of ascent and descent of the echo were of the same order.

Table 2 summarises the characteristics of the first detectable echoes from 26 convective clouds observed over Poona during the years 1953—58. The heights and temperatures of both the base and top of the initial echo, the heights of the 0°C isotherm obtained from radiosonde ascents, the rates of growth of the echo, the maximum heights reached by the echoes and the temperatures in the free air corresponding to the maximum height reached are also given.

In 15 of the 26 cases studied, the base of the initial echo appeared below the 0°C isotherm and on the remaining 11 occasions at or above it. On 6 occasions, both the base and the top of the initial radar echo were at temperatures above 0°C. Only in

TABLE 2

**Details of initial radar echoes from convective clouds**

| No. | Date | Time (IST) | Height of 0°C level (km a.s.l.) | Ht. of base of initial echo (km a.s.l.) | Temp. of base of initial echo (°C) | Ht. of top of initial echo (km a.s.l.) | Temp. of top of initial echo (°C) | Max. ht. of echo (km a.s.l.) | Temp. at max. ht. of echo (°C) | Rate of growth of echo (m/s) Up | Rate of growth of echo (m/s) Down |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6-10-53 | 1522 | | 4·6 | 1·5 | 6·8 | —11·4 | 9·6 | —32·5 | .. | 10 |
| 2 | 6-10-53 | 1525 | 5·2 | 7·6 | —16·5 | 9·6 | —32·5 | | | .. | .. |
| 3 | 6-10-53 | 1547 | | 6·1 | — 7·4 | 7·1 | —14·0 | 7·6 | —16·5 | .. | .. |
| 4 | 8-10-53 | 1413 | 4·1 | 4·1 | 0 | 4·6 | — 3·0 | 5·6 | — 8·0 | 5 | 10 |
| 5 | 8-10-53 | 1414 | | 3·6 | 2·7 | 4·6 | — 3·0 | 5·6 | — 8·0 | 3 | 7 |
| 6 | 16-3-54 | 1827 | 4·3 | 5·1 | — 7·0 | 6·1 | —14·6 | 7·6 | —18·0 | 3 | 10 |
| 7 | 16-3-54 | 1841 | | 4·6 | — 2·0 | 5·1 | — 7·0 | 5·6 | —11·6 | 2 | 5 |
| 8 | 21-4-54 | 1817 | 4·9 | 5·8 | — 4·9 | 6·3 | — 8·0 | 6·3 | — 8·0 | .. | 9 |
| 9 | 22-4-54 | 1509 | | 4·8 | 4·0 | 5·9 | — 3·5 | 5·9 | — 3·5 | .. | 14 |
| 10 | 22-4-54 | 1525 | 5·3 | 4·3 | 8·2 | 4·9 | 3·3 | 5·9 | — 3·5 | .. | .. |
| 11 | 22-4-54 | 1743 | | 3·8 | 12·0 | 5·9 | — 3·5 | 6·5 | 2·5 | .. | .. |
| 12 | 22-4-54 | 1808 | | 2·2 | 20·6 | 4·9 | 3·3 | 4·9 | 3·3 | .. | .. |
| 13 | 5-6-54 | 1530 | 5·9 | 5·1 | 5·0 | 7·4 | — 7·5 | 9·7 | —21·0 | 8 | 4 |
| 14 | 19-10-54 | 1452 | 5·2 | 3·6 | 6·5 | 6·1 | — 5·2 | 6·1 | — 5·2 | .. | .. |
| 15 | 19-10-54 | 1743 | | 3·3 | 8·2 | 5·6 | — 3·5 | 5·6 | — 3·5 | .. | .. |
| 16 | 16-3-55 | 1745 | 4·9 | 3·8 | 7·5 | 6·0 | — 5·0 | 6·0 | — 5·0 | .. | .. |
| 17 | 22-3-55 | 1651 | | 2·8 | 11·0 | 3·7 | 5·2 | 6·8 | 15·6 | 5 | 6 |
| 18 | 22-3-55 | 1742 | 4·6 | 3·3 | 8·5 | 4·4 | 0·5 | 4·9 | — 3·5 | 2 | 5 |
| 19 | 22-3-55 | 1748 | | 2·7 | 12·0 | 5·1 | — 1·9 | 5·1 | — 4·4 | .. | 3 |
| 20 | 27-9-55 | 1654 | 5·0 | 4·3 | 6·6 | 5·9 | — 1·5 | 7·6 | —13·3 | 7 | .. |
| 21 | 17-4-56 | 1600 | 4·5 | 5·5 | — 2·5 | 6·8 | —16·0 | | | 3 | .. |
| 22 | 18-4-57 | 1607 | 4·7 | 6·5 | —10·2 | 8·1 | —19·8 | 11·8 | —45·0 | 11 | .. |
| 23 | 23-5-57 | 1644 | 5·9 | 6·0 | — 1·5 | 8·1 | —13·5 | 12·8 | —44·0 | 22 | .. |
| 24 | 26-5-58 | 1444 | | 3·3 | 10·0 | 4·8 | 2·0 | 7·3 | —13·0 | 6 | 12 |
| 25 | 26-5-58 | 1447 | 5·4 | 2·4 | 16·0 | 3·9 | 7·0 | 4·8 | 2·0 | 5 | 5 |
| 26 | 26-5-58 | 1522 | | 6·6 | — 8·0 | 8·5 | —20·0 | 8·5 | —20·0 | .. | 10 |

7 cases was the bright band observed in the dissipating stages.

The vertical depths of the first detectable echoes ranged from 500—2700 m, with a mean vertical thickness of about 1·5 km. As the echoes were not photographed for every sweep of the antenna and the rate of growth of the echo in convective clouds is very rapid, there may be a certain amount of uncertainty in the estimation of the thickness of the first echoes given in Table 2.

The rates of ascent of the echo varied from 2-22 m/sec and of descent from 4-14 m/sec. The mean maximum height reached by the radar echo was about 8 km, the maximum height recorded being 13 km. The minimum temperatures reached by the echoes varied from 2° to —45°C, with a mean value of about —18°C.

#### 4. Discussion

A radar cloud usually indicates the presence of elements larger than 10$\mu g$ in considerable numbers, so that its first appearance can be taken as a sign that the release of precipitation has begun. But the occurrence of the initial radar echo above or below the 0°C isotherm is not conclusive proof that the release of precipitation is by either the Bergeron or the coalescence process, since the radar detects drops only after they attain precipitation size and not earlier 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. In clouds, the tops of which are below the freezing level, it is clear that rain can form only by the coalescence process. And in clouds where the melting band is present from the beginning, this is evidence of the absence of updraughts necessary for the formation of cloud drops by coalescence. In other clouds, however, the location of the initial radar echo below 0°C by itself does not provide unmistakable proof that only coalescence plays a part in the initial release of precipitation. It must, however, be conceded that in convective clouds in which the radar echo appears below the freezing level, the existence of updraughts of several metres per second precludes any suggestion that they might have been formed from snow flakes or single ice crystals melting and growing by accretion into large drops to give the first radar echo. Ice crystals have fall speeds usually less than 0·5 m/sec while the updraughts in the clouds studied exceed 2—22 m/sec.

The melting band on the other hand, is a common phenomenon observed in the monsoon rain clouds over Poona and it is quite likely that much of the rain over Poona during the monsoon is initiated by the Bergeron process. Monsoon clouds advancing along the West Coast of India (Pramanik and Koteswaram 1955) are, however, known to have tops at about 10,000 ft well below the freezing level. The analysis of the heights of tops of low clouds over India by Pramanik and Koteswaram (1955) is of interest in this connection. They found that more than 90 per cent of the reported heights of low cloud tops lie below the freezing level during the year, the percentage frequency of clouds reaching heights above freezing level being least in the southwest monsoon season and highest in summer. The freezing level over India in the monsoon season is about 16,000 to 18,000 ft while in winter it falls to 10,000 ft over north India and slopes upwards to 15,000 ft in south India. They found that the tops of low clouds lie most frequently between 6000 and 10,000 ft during the year and nearly 98 per cent of low clouds in the monsoon season over the states of Bombay and Hyderabad are below the freezing level and along the West Coast of India and in Bengal where heavy falls of monsoon rain occur, the heights of the cloud tops are predominantly below the freezing level. Whether the occurrence of bright bands in monsoon rain over Poona is a special feature associated with its location on the lee side of the Western Ghats has to be confirmed by radar observations to the west of the Ghats, as for example at Bombay.

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