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Radar observations of rain at Poona

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1. Introduction

When radio waves are incident on rain drops, they are partly absorbed and partly scattered. The incident beam becomes attenuated, the effect increasing as the wave-length is reduced. The attenuation is not important for wave-lengths above one metre, but becomes appreciable at wave-lengths of 10 cm and below. A complete theoretical examination of the subject on both the aspects, *viz.*, attenuation and scattering, has been made by J. W. Ryde (1946, 1947) and others. The scattering by water drops or precipitation in frozen forms of the shorter radio-waves are observed as radar echoes and these provide the meteorologist with data on the distance of the region of precipitation as well as on the distribution of rain in the clouds.

According to Wexler and Swingle (1947) the ratio of P_r, the power received by the radar from a target, to P_t, the power transmitted is given by the formula

$$\frac{P_r}{P_t} = 0 \cdot 16\, \pi^6 \left(\frac{e-1}{e+2}\right)^2 \left(\frac{A_p\, d\, N\, a^6}{R^2\, \lambda^4}\right)$$

where, e = the dielectric constant of water

A_p = apertural area of the antenna

d = pulse-length in space

N = the number of drops per unit volume

a^6 = mean sixth power of the radii of the illuminated drops

R = range of the target

λ = radar wave-length

In order therefore, to obtain echoes at long range and to detect weak rain and cloud areas, a radar should operate at short wave-lengths, have a long pulse length, high peak power and a large antenna properly illuminated. For a particular radar, the above equation can be simplified as

$$\frac{P_r}{P_t} = K\, \frac{Na^6}{R^2}$$

where K is a constant.

Various attempts have been made to obtain information regarding the sizes of rain drops and cloud drops and their distribution per unit volume. Laws and Parsons (1943) have determined the mean frequency distribution of rain drop sizes and its relation to the rate of rainfall. Diem (1942) has observed the sizes and distribution of cloud drops from airplanes in Germany. The mean values of Na^6 for different cloud types and various rainfall intensities are given in Table 1.

It may be seen from Table 1, that even when the rate of rainfall is very small, the radar cross-section of the rain drops which depends upon Na^6 is 10^6 times that of the clouds. Thus, clouds in general, even if directly over the station are not detectable with radars operating at wave-lengths greater than one centimetre. Reflectivity from snow also has been observed to be much less than that of rain.

TABLE 1

	Median diameter	$N\,a^6$ (cm^3)
Cloud type		
Altostratus	9·0 μ	$2\cdot70\times10^{-17}$
Nimbostratus	9·1 μ	$14\cdot79\times10^{-17}$
Stratocumulus	6·3 μ	$9\cdot90\times10^{-17}$
Cumulus	6·4 μ	$6\cdot13\times10^{-17}$
Stratus	15·4 μ	$8\cdot57\times10^{-17}$
Rain intensity		
1·25 mm/hr	1·30 mm	$0\cdot07\times10^{-10}$
5 mm/hr	1·65 mm	$0\cdot7\times10^{-10}$
12·5 mm/hr	1·95 mm	$2\cdot2\times10^{-10}$

2. Description of the radar equipment SCR 717 C

By about the middle of 1953, the Instruments Division of the Meteorological Office at Poona was equipped with a search radar, type SCR 717 C operating on a wave-length of 9·1 cm. The peak power of the radar transmitter is approximately 40 kw and the pulse duration 1·25μ sec. It operates over five ranges, *viz.*, 4, 10, 20, 50 and 100 nautical miles. With this 10-cm radar, a precipitation rate of 0·02 inch per hour can be expected to be just detected at a range of 10,000 ft (Day 1953) if it is assumed that the rain storm completely fills the radar beam and has a size distribution, as given by Laws and Parsons (1943). Also, drops of 1 mm diameter and density 100 drops/m^3 would be just detected, while drops of 0·5 mm diameter would just be visible at the same range of 10,000 ft, if their density was 10^4 drops/m^3. It has to be noted that the intensity of the radar echo decreases rapidly with increase in range.

The radar antenna, which is a dipole fed paraboloid can rotate about its axis over the complete 360° sector at 23 r.p.m. It can also tilt over a range from 5 degrees below to 35 degrees above a line perpendicular to the axis of rotation. The antenna system of the radar was not unwieldy and was, therefore, mounted for rotation both about a horizontal or a vertical axis. In the former type of mounting first adapted by Bowen and his collaborators in Australia (see Day 1953), the radar beam scans a path from horizon to horizon through the zenith and this results in a representation on the cathode ray display unit of a vertical cross-section through the atmosphere about the point of observation (VPI). It has certain advantages over the conventional Range-Height tube presentation, since the range and height are maintained in true proportion, and an easier interpretation of the rain echoes immediately above the point of observation is possible.

The radar equipment could be easily converted from this type of mounting to one with the antenna rotating about a vertical axis and using both, the horizontal or vertical extent of a target could be easily estimated.

Fig. 1 shows the method of mounting adopted. An adjustable steel shelving 6′ high, 36″ wide, 18″ deep, was cut in the middle and hinged on the narrower side, so that it could be fixed in any of the two positions as in Fig. 1(a) or Fig. 1(b). The antenna could thus be made to rotate about a vertical or horizontal axis. The R. F. unit and the modulator were mounted suitably inside the shelving, and covered all round with metal sheets to protect them from sun and rain. The aerial radome consisted of an alkathene cover slipped over a light wooden frame. This cover could be easily removed or fixed when required.

To facilitate the location of the antenna in any azimuth while scanning about a horizontal axis, the whole antenna system was mounted on a base resting on steel balls. This arrangement is, however, not used when the radar is taken in a truck as the vehicle itself can be easily located in any azimuth as required.

The control unit, synchronizer, rectifier and the cathode ray display tube were mounted in a steel almirah (Fig. 2). The cathode ray tube was suspended from a swivel on an adjustable shelving, and when not in use, could be rotated to go inside the almirah which could then be locked. An extendable angle iron bracket was fitted to the CRT frame, to fix a Rolleiflex camera. Facilities were provided for taking 16 mm ciné pictures of the cathode ray display tube every minute (or half minute) with a 16 mm ciné-Kodak camera fitted with a cam arrangement (Fig. 3). The cam driven by a Haydon synchronous motor operating on 230 volts, 50 cycles, presses the exposure lever of the camera every minute (or half minute) for about 3 seconds, the period for a complete revolution of the antenna about its axis.

To study the variation in the intensity of echoes an A-scope presentation was also arranged in the radar display unit. This was facilitated by using the oscilloscope TS-34/AP supplied with the radar and could be conveniently connected to the second of the PPI channels available.

3. The mobile radar unit

Poona (1828 ft above sea level) is on the leeside of the Western Ghats and gets a total rainfall of 19 inches during the southwest monsoon months, June to September. However at Khandala (2000 ft a.s.l.) about 45 miles to the northwest of Poona the rainfall recorded during this season is about 150 inches. Here the ghats rise almost vertically from sea level, and the region is continuously inside the cloud during the monsoon. The monsoon on the Western Ghats is of long duration, extending to nearly 4 months with almost continuous precipitation in places like Khandala and frequent rainfall of all types and intensities to the east and west of the region.

Most of the radar observations of precipitation are generally made with ground installations located at a fixed site. A great disadvantage of this procedure is that the radar will not be at the right place with respect to the rain cloud under investigation. It was therefore decided that the radar should be mounted suitably for operation on a truck and thus made mobile so that it could be employed to study the mechanism of rain formation at any place in the neighbourhood of Poona. For the study of the thunderstorms which occur at Poona during the pre-monsoon months (April and May), and the post monsoon months (October and November), the radar could be located at a fixed site in Poona or in its immediate neighbourhood as required.

The truck available was a three ton Chevrolet with a floor space of about $9' \times 6'$. The cathode ray display tube and its accessories fitted in the steel almirah were clamped down to the flooring at one end. The antenna system mounted on wheels was also located inside the truck. To accommodate the unit during scanning, a platform consisting of two planks and extending from the truck was erected as shown in Fig. 1 (b). One end of the platform rested on the truck and the other on two supporting pipes with flanged bases. The planks were of sufficient length for the antenna system to be rolled completely outside the truck and the antenna could then be rotated either about the horizontal or vertical axis as required. The power unit for the radar, *viz.*, a petrol generator capable of giving 150 amperes at 28 volts was mounted on a trailer.

4. Some observations of radar echoes at Poona during the southwest monsoon in 1953

During the southwest monsoon the clouds always move steadily from some westerly direction. The mean wind speeds V_m (irrespective of direction), the resultant velocity (V_r) and direction (D_n) during the monsoon months, June to September, at Poona for levels upto 4·5 km are given in Table 2. The ratio of V_r and V_m will indicate the steadiness of the wind during this season at Poona. The temperature in centigrade (T_c) at these levels obtained from radiosonde ascents are also given.

The radar was fixed for VPI display, *i.e.*, with the antenna rotating about a horizontal axis and in the plane of the movement of the clouds so as to follow the movement of the cloud from horizon to horizon.

TABLE 2

	V_m	V_r	D_n	T_c	V_m	V_r	D_n	T_c
1953	*1 km a. s. l.*				*2 km a. s. l.*			
June	17·2	15·6	264	23·3	16·6	13·3	266	18·2
July	17·4	16·9	260	21·6	18·7	17·9	263	16·9
August	23·1	22·8	260	21·3	24·5	23·8	258	16·5
September	14·5	13·5	279	21·0	9·4	6·6	261	16·2
1953	*3 km a. s. l.*				*4·5 km a. s. l.*			
June	17·3	9·2	275	13·0	10·7	3·3	64	5·2
July	13·5	11·7	251	11·9	10·3	5·9	202	5·4
August	22·6	22·8	264	12·3	20·1	15·6	293	6·2
September	7·4	2·8	213	10·5	7·0	1·5	115	3·7

Radar observations of precipitation were made at Poona on a number of days during August and September 1953. Precipitation echoes were frequently observed in the clouds between the levels of 1·5 km a.s.l. and 2·5 km a.s.l. where the temperatures were about 16°C. One could also see that the tops of these clouds were very much below the freezing level. The echoes used to form very rapidly and disappear quickly. Fig. 4 shows one such series on 18 August 1953 from 1422 to 1428·30 IST. A rain cell moved at 1422 IST from the west at a height of about 1 km above ground. The wind at this level was estimated to be approximately 25 mph. More rain cells followed in succession and by 1424·30 IST there were 3 rain cells in the field of view. By 1426 IST these three cells of rain were dissipating, the earliest one being the least bright; a new one formed in front of the first cell. By 1427·15 IST this new rain cell intensified and moved forward and another formed behind it. Each of the rain cells was approximately 1 km wide and about 0·75 km thick.

Fig. 5 shows a series of radar photographs from 1600 to 1615·30 IST on 7 September 1953. The formation and dissipation of three rain cells can be clearly seen from these. At 1600 IST there is a rain cloud almost overhead with another just appearing on the west. By 1602 the rain patch overhead, which was about 2 km wide and 0·75 km deep at 1600 IST had increased to a width of 4 km (*i.e.* increase in size at the rate of about 1 km per minute) the thickness remaining almost the same. The second cell which was about 1·3 km wide and 1·3 km deep at 1602 IST was nearly 4 km wide and 1·6 km deep by 1605 IST the rate of growth in extent being again 1 km per min. A third cell just appears at about the same place where the second one appeared; the first cell has decreased in size. The succeeding pictures show how the three rain cells dissipated.

It may be noticed from the radar photographs of 18 August 1953 and 7 September 1953 that the level of formation of the rain was almost the same; this seems to be a seasonal characteristic.

In this connection, some observations made by J. H. Field (1908) at Belgaum in 1906, during the monsoon months, when discussing

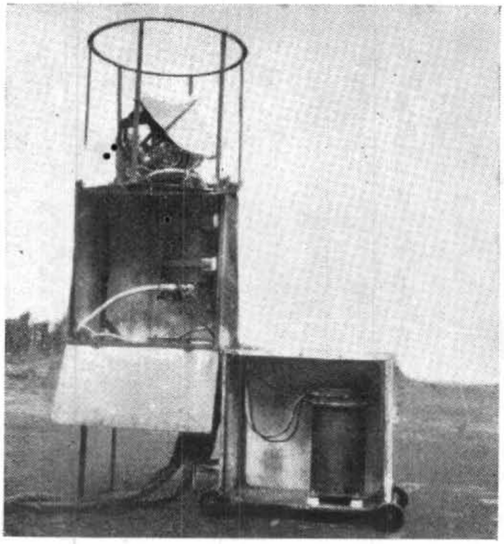

Fig. 1 (a)

Fig. 1 (b)

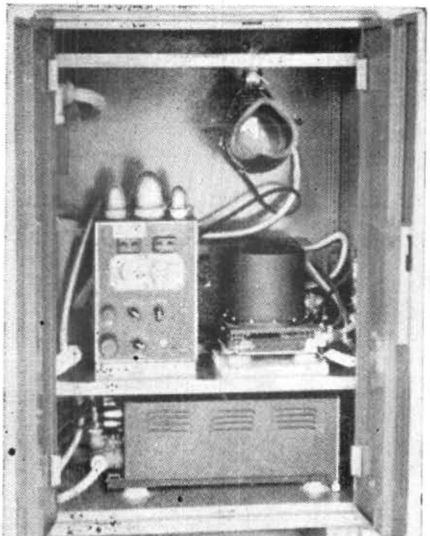

Fig. 2

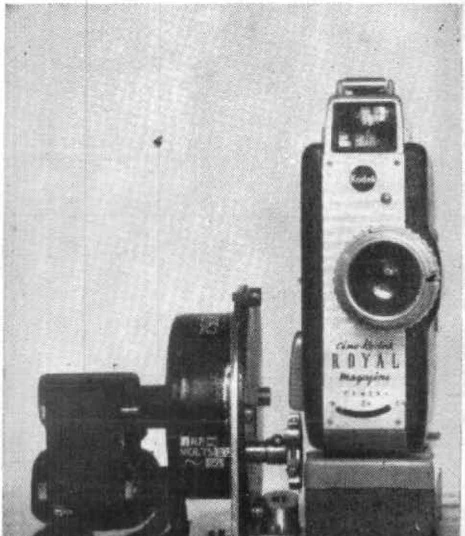

Fig. 3

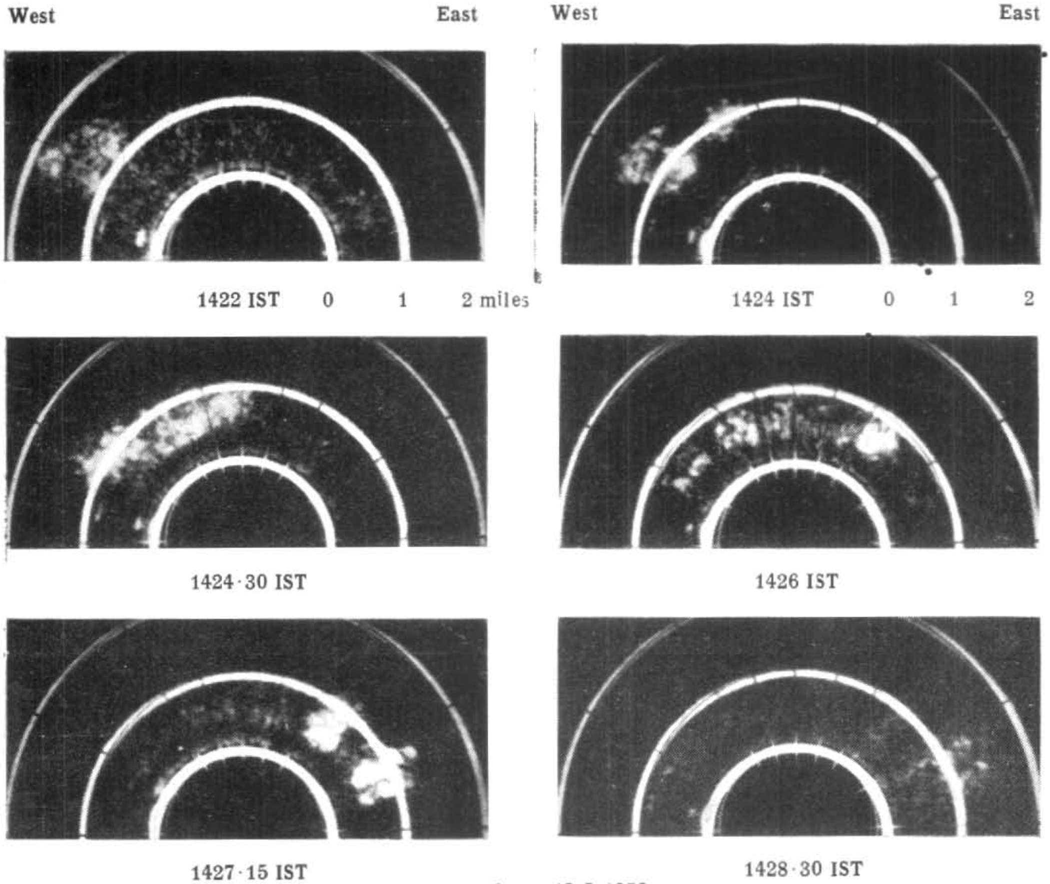

Fig. 4. Monsoon rain on 18-8-1953
(Scanning horizon to horizon, west to east; range markers at one mile intervals, with open centre, antenna tilt 0°)

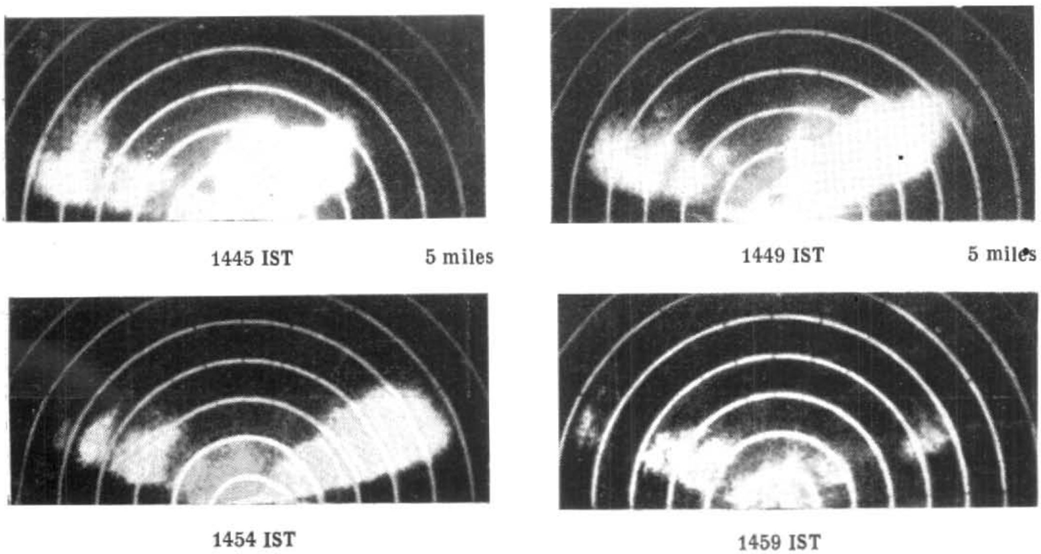

Fig. 6. Thunderstorm on 18-9-1953
(Scanning horizon to horizon, west to east; range markers at one mile intervals, antenna tilt 0°)

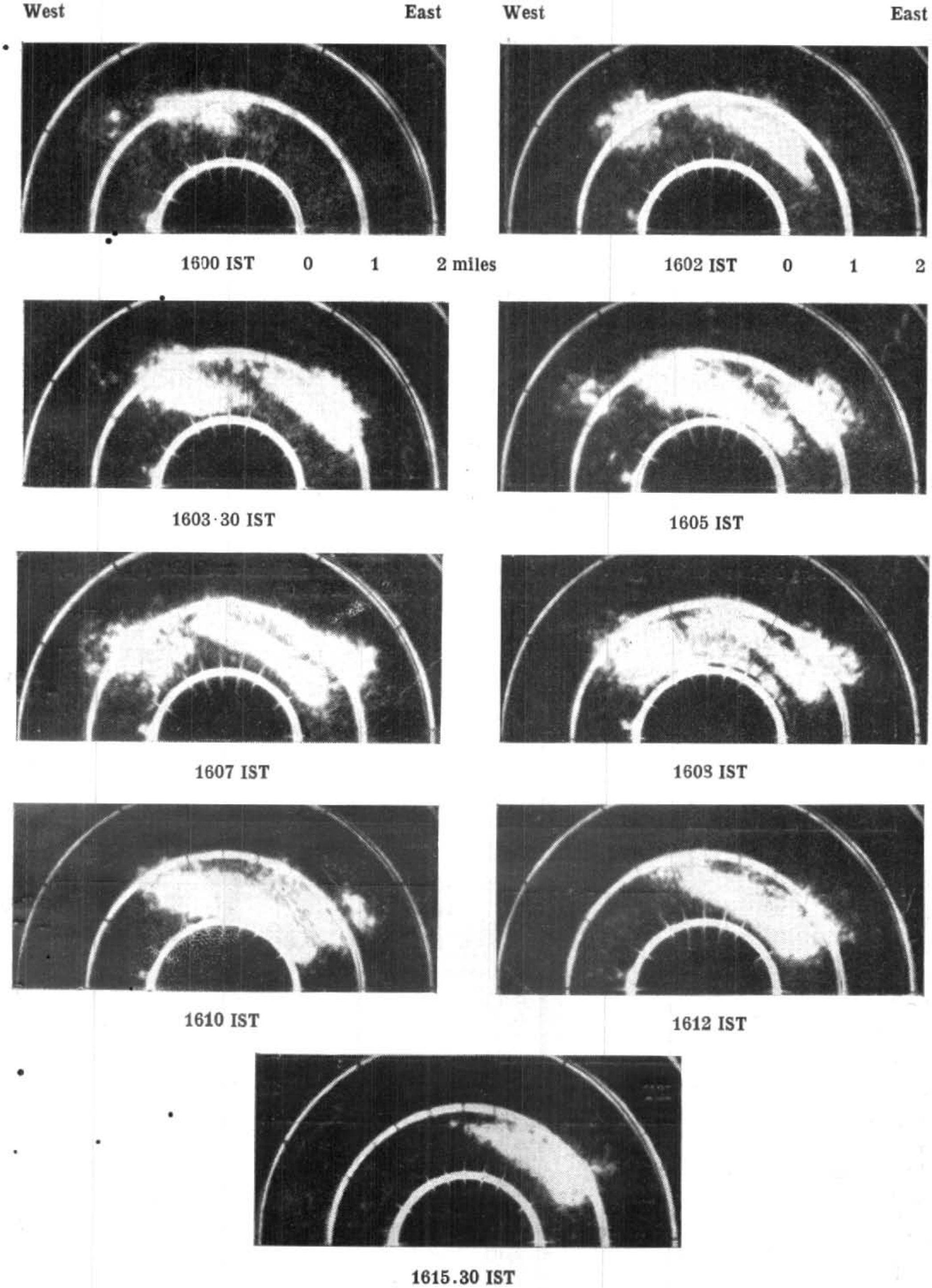

Fig. 5. Monsoon rain on 7-9-1953
(Scanning horizon to horizon, west to east; range markers at one mile intervals, with open centre, antenna tilt 0°)

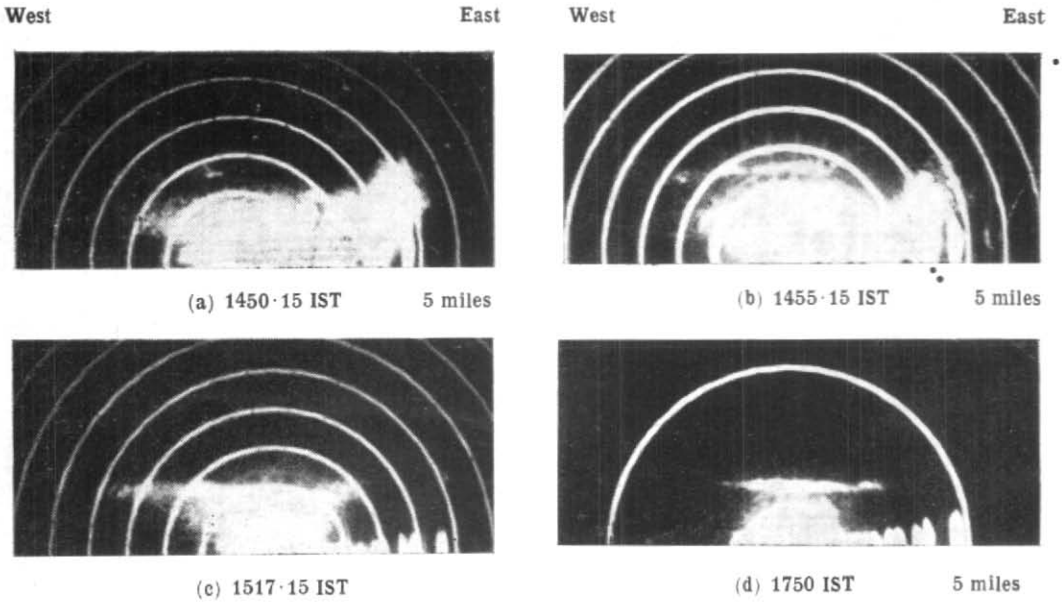

Fig. 7. **Thunderstorm on 7-9-1953**
(Scanning horizon to horizon, west to east; range markers at one mile intervals for (a), (b), (c) and at five mile interval for (d); antenna tilt 0°)

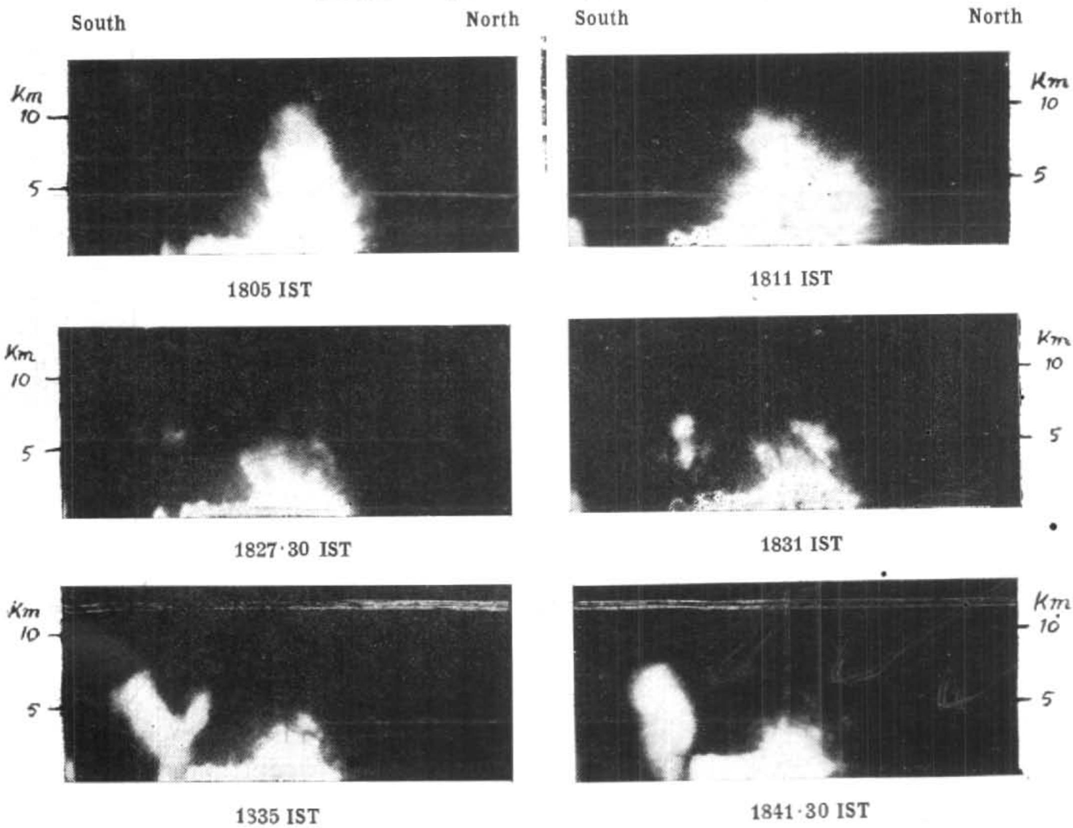

Fig. 8. **Thunderstorm on 16-3-1954**
(Scanning horizon to horizon, south to north, antenna tilt 0°)

the observations made with kites are relevant. Poona and Belgaum are almost similarly situated on the leeside of the Western Ghats. He has remarked that a very noticeable feature at Belgaum during the monsoon was the method of occurrence of rainfall. He observed that rainfall was seen to be concentrated in rain centres, "small drifting squalls of a diameter between one and three kilometres, travelling more or less in the wind direction with a velocity of probably between 5 and 10 metres per second. These rain centres were fairly numerous, as many as five or six being sometimes visible within the horizon at one time. Externally, they showed no indications of containing winds of very great velocity, but from observations of the behaviour of the kites where such rain squalls overtook them, it seems probable that the horizontal velocities within the squalls were much in excess of those outside, and that in many cases the kites had become involved in winds of 23 metres per second or more for short periods of time". The radar observations made at Poona seem to confirm this view and the formation of rain from the clouds seems to be related to the turbulence experienced.

5. Radar observations of thunderstorms at Poona

(a) Thunderstorm on 18 September 1953

Fig. 6 shows a series of photographs of a thunderstorm which came towards Poona from the west on 18 September 1953. It caused 0·26 inch of rain from 1437 to 1450 IST and dissipated rapidly. It can be seen from the radar pictures that the rain echo reached a height of nearly 19,000 ft above sea level where the temperature was about −6°C.

(b) Thunderstorm on 7 October 1953

A thunderstorm approached Poona from the east on 7 October 1953 and dissipated over the station. 0·63 inch of rain fell from 1310 to 1345 IST. From 1430 IST it was continuously drizzling over the station till 1810 IST. The drizzle over this period of over 3 hours added only 9 cents to the recorded precipitation. Fig. 7 shows the occurrence of a "bright band" during the dissipating stage of the thunderstorm. There was at first a stratification indicated on the radar echo at 1450·15 IST ; a bright band later formed at a height of about 4·6 km a.s.l. and by 1511 IST it lowered to a height of about 3·8 km a.s.l. where it remained stationary till it disappeared at about 1810 IST. The rate of descent of the bright band from the level of first formation to the level where it remained steady and dissipated was of the order of about 2·5 km hr^{-1}. The freezing level on this day was at about 4·4 km a.s.l.

(c) Thunderstorm with hail on 16 March 1954

A thunderstorm moved over the station from a northerly direction. This was associated with hail from 1800 to 1815 IST. Fig. 8 shows a series of radar photographs taken on this occasion. The range marking mechanism was not functioning in the equipment but the dimensions could be estimated. At the time the hail just started falling over the station, the radar echo reached a maximum height of 10·7 km a.s.l. and had a maximum width of about 9·0 km at the base. But from 1805 to 1827·30 IST it decreased in vertical extent from 10·7 km to 5·5 km (*i.e.*, 13·9 km per hour). By 1831 IST a new cell was forming to the south of the station. The rain echo in the new cell occurred first between the levels of nearly 6·7 km and 2·5 km and by 1841·30 IST increased in size as shown in Fig. 8. This thunderstorm was similar to the one on 18 September 1953 in that it also dissipated rapidly.

It is seen from the few thunderstorms over Poona described above that dissipation can occur in two forms. The thunderstorms of 18 September 1953 and 16 March 1954 dissipated rapidly. The thunderstorm on 7 October 1953 dissipated gradually and was associated with a bright band and light drizzle for a long time. It is possible that in the first two cases, the rapid dissipation was associated with the decrease in the supply of warm moist air from below and a rapid entraining of the colder surrounding air. This was not the case on 7 October 1953. On this day, after the up-draught was cut off due to rain cooled air on the ground, the entrainment was gradual, presumably due to difference in temperature between the cloud and the environments being small.

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