551·515·41(548·1) : 551·508·85·08

A radar study of the development and movement of thunderstorms in the vicinity of Madras in the monsoon season

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ABSTRACT. A study has been made of the favoured sectors and ranges at which thunderstorms developed around Madras during monsoon months (June-September) in 1959, with the help of a storm detecting radar, Decca Type 41. The favoured times of their formation as well as the speed and direction of movement have been examined. The relevant features observed are discussed in the paper.

1. Introduction

For a proper study of meso-meteorological phenomena like thunderstorm, the existing network of synoptic and current weather observatories with restricted hours of watch is totally inadequate. A large number of meso-scale phenomena escape observation and study by synoptic meteorologist. The storm detecting radar has helped largely to meet this deficiency.

Using one such radar, Decca Type 41, round-the-clock observation was made of all convective precipitation (thunderstorm) cells which developed around Madras during the monsoon season of 1959. The results of the study are presented in this paper.

2. Operational details

The radar was normally operated once every hour. Whenever formation of cells was detected, it was operated at more frequent intervals. Photographs of the echoes were also taken whenever they were conspicuous. The positions of the cells were plotted in all cases on polar diagrams from the time of detection till the time of dissipation.

The observations were made at various elevations but the majority of the positions plotted are based on observations at the angle, at which the cell is most prominently observed. Plotting of the cell positions at the best elevation implies successive increases in elevation with the approach of the cell, as the part of the cell having the highest radar reflectivity may be expected to be at about the same altitude during the life history of the cell. However, as the vertical beam-width of the radar is as large as 4° up to the half-power point, the actual positions of the point of maximum radar reflectivity would be virtually identical with the PPI positions, except in cases of exceptional wind-shear. Cases of such wind-shear in the lower troposphere are very rare at Madras.

The time of first detection of the cell is not strictly coincidental with the time of initial formation of the cells, which might have taken place at a greater distance before they became detectable by radar. Further, as the radar is not kept in continuous operation, some of these cells might have formed during the periods when scanning was suspended. However, in the discussion that follows, a broad period of two hours is taken as the unit for cataloguing the data of times of formation and first detection, with a view to minimising the error involved.

3. Discussion

The most important aspects of the thunderstorm development and movement unravelled by the radar, which the synoptic charts fail to reveal are (1) the source regions of thunderstorms in the vicinity of a radar station, (2) the favoured times of their formation and (3) the direction in which the cells move up to the point of dissipation. These aspects of the thunderstorms at Madras are discussed in the following paragraphs.

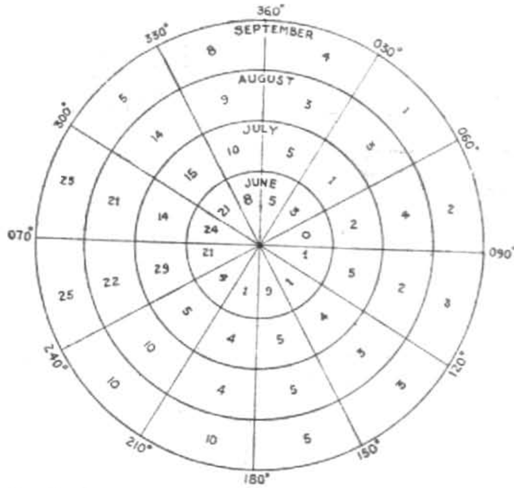


Fig. 1. Frequencies of thunderstorm development in the different sectors around Madras

3.1. *Preferred sectors of thunderstorms development*—To find out whether there are any particular favoured directions and distances of thunderstorm formation, the frequencies of thunderstorm formation have been worked out for sectors of 30° around the station and different intervals of range from the station upto a radius of 100 miles for each of the monsoon months from June to September 1959. There was only one case of thunderstorm in the month of May on 29 May 1959. This was included in the data for the month of June in view of the proximity of the date to the latter month. Table 1 shows the distances at which thunderstorms developed during different months. The percentage frequencies of thunderstorm development in each of the sectors around the station irrespective of the distance of formation are shown in the polar diagram reproduced in Fig. 1.

3.1.1. *Most favoured sector of cell development*—It is seen from Fig. 1 that in the monsoon months when westerlies prevail over the Peninsula upto 3·0 km or more, thunderstorms largely develop in the sector 240° to 300°, the frequency for this sector being 43 to 50 during each of the monsoon months. Next in order comes the sector 300° to 330° in which the percentage frequency declines from 21 in June to 14 in August becoming inconspicuous in September. It is of interest to mention that many hills forming part of the Eastern Ghats are located within the sector 240° to 330°.

3.1.2. *Favoured ranges of thunderstorm development*—The distances from Madras at which thunderstorms develop during different months also show certain characteristic features. Thunderstorms form on nearly a third of all occasions at distances of 16—20 miles as well as 25—50 miles in the month of June and on nearly a half of all occasions in the range 11—20 miles in the month of July. With the progressive southward displacement of the monsoon low, the range becomes restricted to 25—50 miles in the latter half of the monsoon period. Although the data for different months discussed in this paper relate to one season only, it does not appear improbable that the distance at which thunderstorms initially form with respect to the station is greater in the latter part of the monsoon than in the earlier part.

3.2. *Most favoured periods of thunderstorm development*—The thunderstorm frequencies in different months in various 2-hour intervals of the day have been worked out with a view to determining the most favoured period of thunderstorm activity in the different monsoon months. These results are displayed diagrammatically by the histograms in Fig. 2 (see also Table 1). Two well-marked features are disclosed by Fig. 2, *viz.*, (1) the shift of the peak of thunderstorm activity from the period 1400—1600 IST to the period 2000—2200 IST with the progress of the season and (2) the more even spread of thunderstorm activity into all hours of the night in the latter half of the season as compared to the earlier part of it.

As already remarked earlier, the lowering of the axis of the monsoon trough with the advance of the season and the consequent steadiness of the westerly flow across the Peninsula, leads to development of thunderstorm cells with longer life and trajectories of displacement in the later half of the monsoon than in the earlier part. Insolation being the main cause for the development of the cells and the cells of the early part of the monsoon being short-lived with short trajectories, the energy triggered off is released rapidly and the weather clears up early. The longer the life of the cells, the greater would naturally be the thunderstorm activity in the night.

3.3. *Direction of movement of the cells*—It is generally accepted that the direction of movement of a thunderstorm cell is in general agreement with that of the 3 km winds (Byers and Braham 1949, WMO 1959). This aspect of the thunderstorm at Madras has been studied individually in the case of every thunderstorm cell in the period of the study.

For following the course of any cell, it has often been the practice to choose some well-defined feature of its echo nearest to the station, in order to obviate the errors arising from shape distortion of the echo, owing to the attenuation of the radar beam within the cell itself (Hitschfeld and Bordan 1954). This has, however, not been found to be a satisfactory method, as the selected feature of the echo often disappears due to cell growth and the contours of the echo are themselves subject to modification with the motion of the cells. Further, the nearer edge is devoid of significance except in the case of those cells which move radially towards or away from station. In this study the authors have, therefore, plotted and followed the centres of the cells in investigating the direction and speed of movement of the cells.

The trajectories of the cells prepared in the above manner were compared with the rawin trajectories corresponding to the nearest hour of ascent by superposing the latter marked on a transparent overlay on the polar diagram showing the cell movement. The level at which the two trajectories were in agreement within 10° on either side was picked up from the rawin trajectory. The results are shown in Table 2. It is seen from the results that the

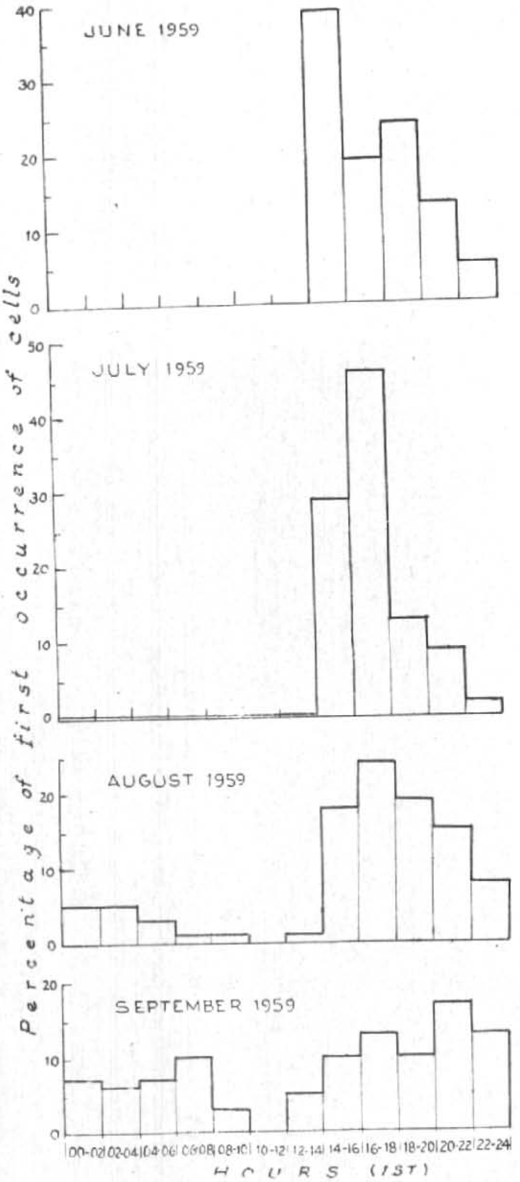


Fig. 2 Diurnal variation of thunderstorm frequency at Madras in the different monsoon months

TABLE 1

Number of cases of first occurrence of cells at different ranges

	Range in nautical miles								Total
	00-05	06-10	11-15	16-20	21-25	26-50	51-75	>75	
May-June 1959	1 (1)	6 (8)	12 (16)	23 (31)	10 (13)	23 (31)	—	—	75
July 1959	15 (9)	22 (13)	39 (22)	43 (25)	25 (14)	30 (17)	—	—	174
August 1959	11 (6)	29 (15)	32 (16)	31 (16)	31 (16)	48 (24)	15 (8)	—	197
September 1959	21 (8)	25 (10)	36 (14)	27 (11)	21 (8)	75 (30)	32 (13)	13 (5)	250

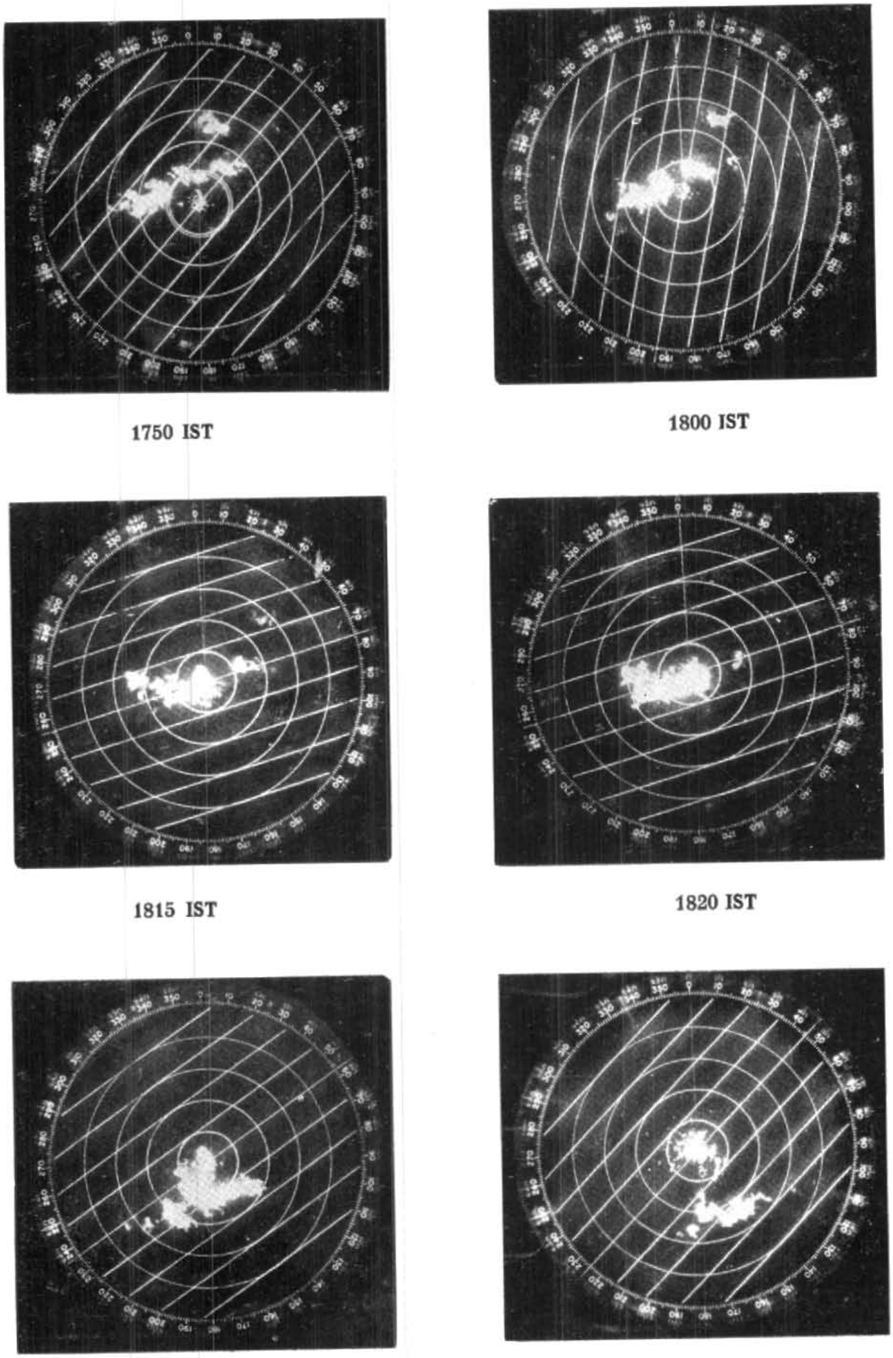
Figures in brackets are percentages

TABLE 2

Frequencies of cells moving from different directions and agreeing with wind in specified layers only in direction (±10° approximate) but may or may not agree in speed

Levels (ft)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-5000				1						1	4	4	9	2	4		25 (13)
5000-10,000			2							1		8	26	22	5		64 (34)
10,000-15,000		1	4							2	1	6	18	18	6		56 (30)
15,000-20,000					1							7	5	3	9	1	26 (14)
20,000-25,000				1						1		2	2	4	3		13 (7)
>25,000					1			2			1						4 (2)
Total		1	6	2	2			2		5	6	27	60	49	27	1	188

NOTE—Figures in brackets are percentages



1750 IST

1800 IST

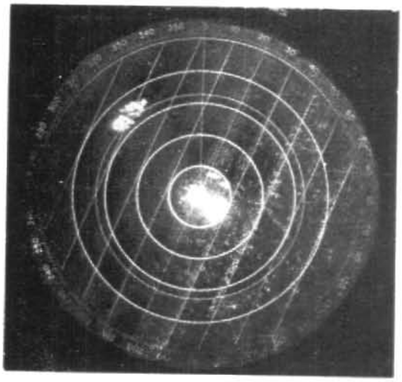
1815 IST

1820 IST

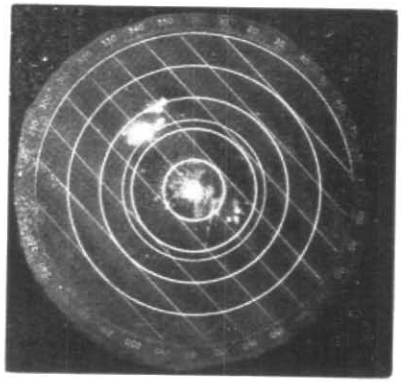
1840 IST

1905 IST

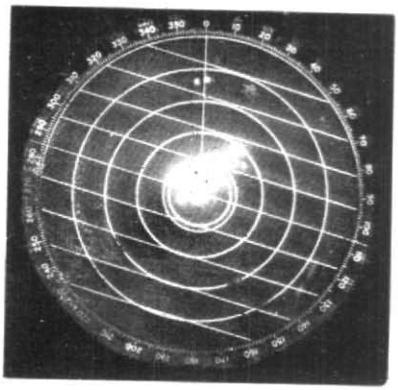
Fig 3. Example of thunderstorm Sequence I on 10 September 1959



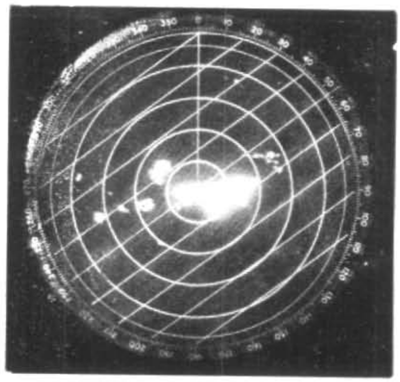
1655 IST



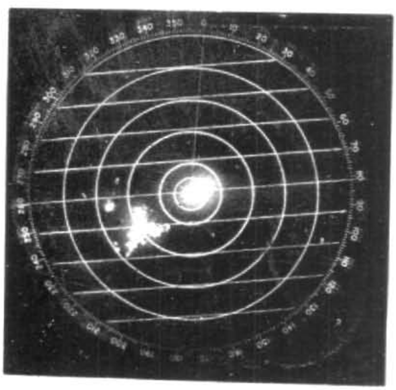
1710 IST



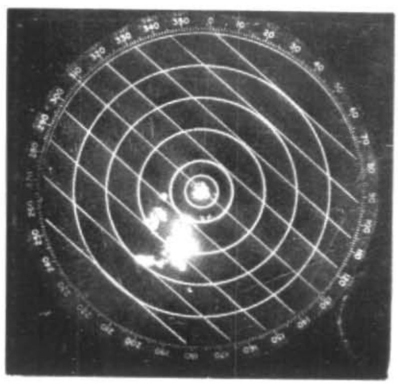
1740 IST



1755 IST



1815 IST



1830 IST

Fig. 4. Example of thunderstorm Sequence II on 2 July 1959

TABLE 3

Frequency of cells moving from different directions and agreeing with wind in specified layers both in direction and speed ($\pm$ 10° and $\pm$ 3 kt approx.)

Levels (ft)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-5000				1						3	2	2	7	4	1		20 (11)
5000-10,000			2									5	9	14	3		33 (17)
10,000-15,000		1	2									4	16	14	4		41 (22)
15,000-20,000					1							4	6	6	7	1	25 (13)
20,000-25,000										1	1	1	1	1	2		7 (3)
>25,000				1				1				1		1	1		5 (3)
Not agreeing with any level regarding speed			2		1			1		1	3	10	21	9	9		57 (30)
Total		1	6	2	2			2		5	6	27	60	49	27	1	188

NOTE—Figures in brackets are percentages

frequency of cases where the direction of translation of thunderstorm cells is in agreement with that of the average wind in the layer 15,000 to 20,000 ft is only 14 per cent as against 34 per cent for the 5000—10,000 ft layer and 30 per cent for the 10,000 to 15,000 ft layer. Thus, in 2 out of every 3 cases, the winds below the freezing level appear to be more effective in the translatory motion of the cell than those near or above the freezing level.

A typical example of the progressive linear displacement of a line of thunderstorm cells during the period 1750—1905 IST on 10 September 1959 is illustrated in Fig. 3.

3·4. *Speed of movement of cells*—The results shown in Table 2 are confined only to the directions of wind and cell motion. In view of the interesting results emerging from this study, it is worthwhile investigating whether similar inferences would result from a study of the wind vector levels, which correspond to the speed as well as direction of movement of the cells. Accordingly the translatory motion of the cells with well-defined trajectories was represented on polar diagrams as wind vectors and the layers in which the wind speed as well as direction was in agreement with the above, were picked out from the rawin trajectories. A close tolerance of $\pm$ 3 knots for speed and $\pm$ 10° for direction was allowed for this purpose. The results are shown in Table 3.

The results in Table 3 show that, in as many as 30 per cent of the cases studied, the cell motion appears to be unrelated to the wind at any level; while, in nearly 40 per cent of the cases, the cell motion is in close correspondence with the winds below 15,000 ft and in 13 per cent of cases the level of correspondence is 15,000—20,000 ft. The conclusion drawn earlier that thunderstorms are possibly steered by the winds below the freezing level is supported by this vectorial analysis.

3.5. *Apparent curvature of thunderstorm tracks*—As already mentioned earlier there have been several cases when the cell track on the polar diagram shows a sharp curvature at some point. In such cases the directions of movement on either side of the point of curvature agree with winds at different levels in most instances, in the rest, the movement in one part of the track does not agree at all with the wind at any level.

The most plausible explanation of such a curvature would be that the original cell had dissipated at that point and that the cold air released by it had triggered off a new cell, which subsequently moved in a different direction. Such a secondary formation may be particularly favoured by the presence of hills, lakes with large irrigation tanks (such tanks being in abundant in this district) or riverbeds or hills. This lends support to the explanation that the 'curvature' must be due to regenerative formation of new cells. The subsequent movement often coincides with the wind at a level other than that which the parent cell follows. The curved track is thus a composite trajectory, made up of the trajectories of the primary cell and the regenerated cells.

An example of thunderstorm cells, whose tracks apparently became curved from the northwest to the southeast at the station, covering the period 1655—1830 IST on 2 July 1959 is illustrated in the sequence reproduced in Fig. 4.

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