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A radar study of post monsoon thunderstorms over Bombay airport

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ABSTRACT. The paper deals with the radar echoes of post monsoon thunderstorms observed over Bombay airport during the past few years with a Decca type 41 Radar operating on 3 cm wave length. The post monsoon thunderstorm activity is confined to certain areas, over the Western Ghats and lakes on the eastern side of Bombay. The time of occurrence is during late afternoon and night. The speed of movement of these thunderstorms is quite slow when compared to that of monsoon radar echoes. The direction of movement is from land to sea, generally from NE to SW. Most of the thunderstorms do not affect the Bombay airport. They usually dissipate over the land itself, or over the sea near the coast.

1. Introduction

Bombay experiences thundershowers both during the premonsoon and post monsoon seasons, *i.e.*, during the transitional periods before and after the southwest monsoon. The present paper is confined to a study of the post monsoon thunderstorms observed over Bombay airport, with a Decca type 41 storm detecting radar.

At present the only available weather radar on the western coast of India is at Bombay where a Decca type 41 radar has been in operation since 1958. After the withdrawal of the southwest monsoon and before winter conditions set in, *i.e.*, during the first week of October and the last week of November, Bombay experiences a few thundershowers of moderate intensity, whenever synoptic conditions become favourable for their development; for example, appearance of a low or trough in the vicinity of Maharashtra or instability brought about by the passage of a depression over the peninsula. Once the synoptic conditions become favourable, thunderstorms often recur for two or three successive days generally and in some cases even longer, in the month of October.

The post monsoon thunderstorms detected in the months of October and November during the last six years have been studied and their frequency of occurrence over Bombay airport has been worked out. Table 1 gives the dates on which post monsoon thunderstorm echoes were detected by the radar and the dates on which the thunderstorms actually reached the airport during the years 1959-64. It will be seen from Table 1 that (*i*) the frequency of development of thunderstorm in October is more than that in November and (*ii*) the number of thunderstorms which actually pass through the airport is very much less than the number of thunderstorms that develop within the radar range during October and November.

The mean frequency of development of thunderstorms for the month of October is fifteen and only four out of these reach the airport. The mean frequency of thunderstorm development for November is four which is only about 25 per cent of the mean frequency for October. Only one or at times none of the thunderstorms reaches the airport during November. In general, the probability of a post monsoon thunderstorm reaching the airport is only about 22 per cent.

In the following paragraphs, the main features of these post monsoon thunderstorms, namely, their time of occurrence, location, character, movement and speed have been described in detail. These are shown in Table 2 for the years 1961 to 1964.

2. Observed features of the radar echoes from thunderstorms

A study of the radar data regarding the post monsoon thunderstorms during the past four years, *i.e.*, 1961 to 1964 shows some interesting features. The post monsoon thunderstorms have a preferred area and time of development. They develop in the afternoon (cumulus stage), reach the mature stage in the evening, and dissipate in the night. Occasionally regeneration occurs. The average life of the echoes as seen on the radarscope is about eight hours, usually from 0900 to 1700 GMT. Convective cells begin to appear on the radarscope by about 0900 GMT. The preferred time of occurrence, namely in the afternoon after the maximum temperature has been reached, is significant. These are local thunderstorms and insolation plays an important role in initiating convective activity.

The location of the echoes is over the Ghats, the lakes in the mainland and near the creeks on the coast of the mainland south of Bombay island. Within an hour of initial detection, the echoes strengthen and sometimes extend upto 100 nautical miles arranged in line formation (see radarscope photographs — Figs. 5 a to 5 d).

The influence of topography on the distribution of convective clouds has been investigated by Byers and Braham (1949) in the Thunderstorm

TABLE 1

Frequency of development (within the radar range) and occurrence of post monsoon thunderstorms over Bombay airport as observed by Decca Radar type 41 (1959 to 1964)

	Dates of development	Freqency of development	Dates of reaching airport	Frequency of occurrence over the airport	Remarks
1959					
October	1 to 5, 7 to 18, 21 to 25 and 27	23	1 to 4, 8, 13 to 15	8	3 recurrences, one lasting 12 successive days
November	10 to 14	5	Nil	Nil	Only one recurrence
1960					
October	3 to 7, 12 to 16	10	13	1	2 recurrences lasting for 5 days
November	7 to 9	3	Nil	Nil	Only one recurrence in 3 successive days
1961					
October	1, 4 to 11, 14 to 16	16	5, 8, 9, 11	4	3 recurrences, one lasting 8 successive days.
November	5 to 8	4	5	1	Only one recurrence lasting 4 successive days
1962					
October	8 to 10, 18 to 20, 29 and 30	8	18, 19 and 20	3	3 recurrences in 2-3 successive days
November	1 to 6	6	Nil	Nil	Only one recurrence lasting 6 days
1963					
October	1, 12 to 23	13	1, 12, 19, 20	4	Only one recurrence lasting for 12 days
November	21, 22, 25	3	Nil	Nil	Only one recurrence lasting 2 days
1964					
October	1 to 15, 17, 18, 24, 30 and 31	20	1, 2, 30, 31	4	3 recurrences, one lasting for 2 weeks
November	9 to 12	4	10	1	Only one recurrence lasting 4 days
	Total	115		26	
			Percentage of frequency:	22	

Total No. of days of thunderstorm development in October : 90, in November : 25
Total No. of days of thunderstorm occurrence over the airport in October : 24, in November : 2
Average No. of days of thunderstorm development in October : 15, in November : 4
Average No. of days of thunderstorm occurrence over airport in October : 4, in November : 1

Project and their report mentions "Air blowing up the slopes receives a forced impetus upward which is conducive to the formation of clouds of marked vertical development, *i.e.*, cumulus or cumulonimbus .... Temperature contrasts between water bodies and the adjacent land also determine preferred areas for cumulus and cumulonimbus development". With a view to study the formation of convective clouds in relation to terrain features, a method similar to that adopted by Byers and Braham in the Thunderstorm Project, was adopted, but no correction for wind transport of cells was applied as the winds were weak.

The main topographical features of the area covered by the Decca Radar in Bombay, can be seen marked on the 150 nautical miles polar diagram (see Fig. 1). The area in the western half is almost entirely sea and the eastern half entirely land comprising of Bombay island and the mainland. The Western Ghats are situated close to the coast and small hills of heights varying from 300 to 700 metres are seen in the NE to SE through E at distances varying between 20 to 40 nautical miles. A few more hills are also situated close to the coast in the SE very near a creek in the direction 150 degrees at a range of 20 to 40 nautical miles. The height of ground increased rather sharply on the windward side of the Ghats, and forms a plateau with a slight slope on the leeward side of the Ghats. On this plateau, are situated a few lakes namely, Tansa, Andhra, Mulshi, Khadakvasla and Bhatghar. The southern coast is broken and a number of creeks are formed in this area. The Western Ghats are closer to the coast in this region when compared to the northern coast.

TABLE 2

Main features of the post monsoon thunderstorms which reached Bombay airport during the years 1961—1964

	Date and Time (GMT) of occurrence of thunder-storm over the air port	Character of echoes	Area of development w.r.t. radar station	Movement: Direction (towards which movement took place)/Speed in kts	Synoptic situation	Remarks
October 1961	5	Scattered and widely scattered	E and SE	S/less than 10	Trough in low level westerlies extending from Punjab to NE Arabian sea	Activity was persisting from 1-12 October. Conditions were favourable for the withdrawal of monsoon
	8	Line of *Cb*	E, SE and NE	SSW/less than 10	Feeble trough and high level westerlies lie over West Pakistan	
	9	Scattered and line of *Cb* North to South	S and SE	S/less than 10	A low over Vidarbha	
	11	Line	N	SSW/less than 5	No movement, but intensified	
November 1961	5(9—15)	Isolated and scattered	E	No movement	Trough associated upper air cyclonic circulation extending from Kutch to west U.P.	
October 1962	18 (12—24) 19(9—17) 20 (9—15)	Broken line Line Scattered	NE and SE NE and SE NE and E	W/10 W/15 W/15	A low over Laccadive islands moving westwards and an upper trough persisting on 18, 19 and 20 October	
November 1962	Nil					
October 1963	1 (9—15)	Broken line	E and SE	NE/10	A feeble upper air cyclonic circulation extending to 6 km in East Arabian Sea off Konkan. A feeble trough in east central Arabian Sea. A low over peninsula and adjoining sea moving westwards. Passage of depression over the peninsula	Monsoon weak over Arabian sea and Bay of Bengal. SE'ly 32 kts surface squall. Rain 25 mm
	12(11—24)	Scattered, broken line and solid	E and SE	NW/16		
	19 (10—01)	Scattered and broken line	NE	No movement		
	20 (7—1630)	Do.	E and SE	SW/20	Do.	SE'ly 27 kts surface squall
November 1963	Nil					
October 1964	1 (1130—17)	Isolated	SE	SW/15	Continuation of thunderstorm activity of 30 September 1964	Occurred early in the morning
	2(04—16)	Scattered and isolated	SE	No movement	Do.	Activity was persisting throughout for 2 weeks
	30 (9—03)	Scattered and broken line	E and SE	WSW/15	A well marked trough of low pressure off Kerala and Mysore coasts, the associated upper air cyclonic circulation extends upto 5 km	NE'ly 26 Kts surface squall at Colaba
	31(9—21)	Broken line	NE and E	WSW/15	Do.	E'ly 35 kts surface squall
November 1264	10 (9—15)	Broken line	NE and SE	SSW/22	A low in east central Arabian Sea off Mysore and Maharashtra coast with associated upper air cyclonic circulation extending upto 3 km	E'ly 26 kts, surface squall

Note — Figures within brackets indicate the time in GMT

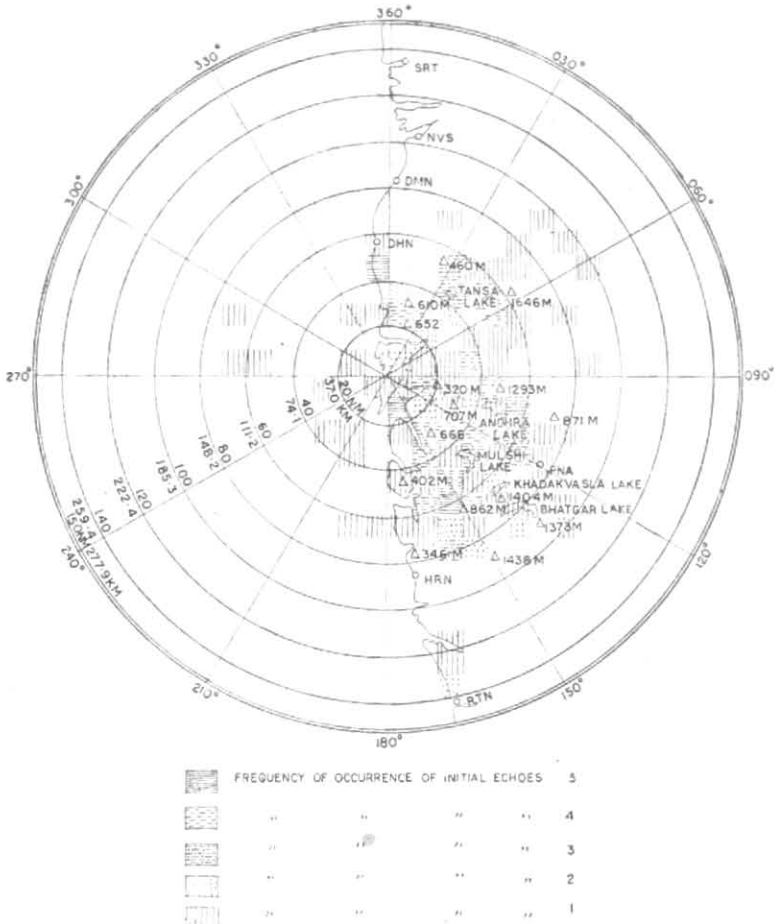
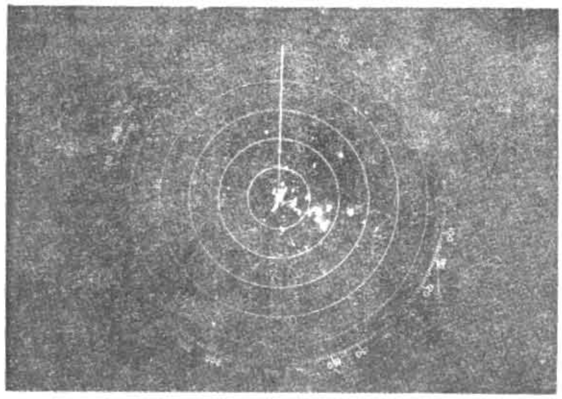


Fig.1. Polar diagram showing the region covered by PPI scope of Decca-41 Radar at Santacruz airport and indicating the frequency of occurrence of the first detected radar echo during the post monsoon season of the years 1962, 1963 and 1964. The shaded areas are the preferred locations of cell development



1047 20

Fig. 2. Radarscope photograph of the thunderstorm in the formation stage on 31 December 1964, Convective cells may be seen in the NE, E and SE sectors, upto 85 n. miles range

(Figures in the left and right hand bottom corners indicate time in GMT and range rings in nautical miles respectively)

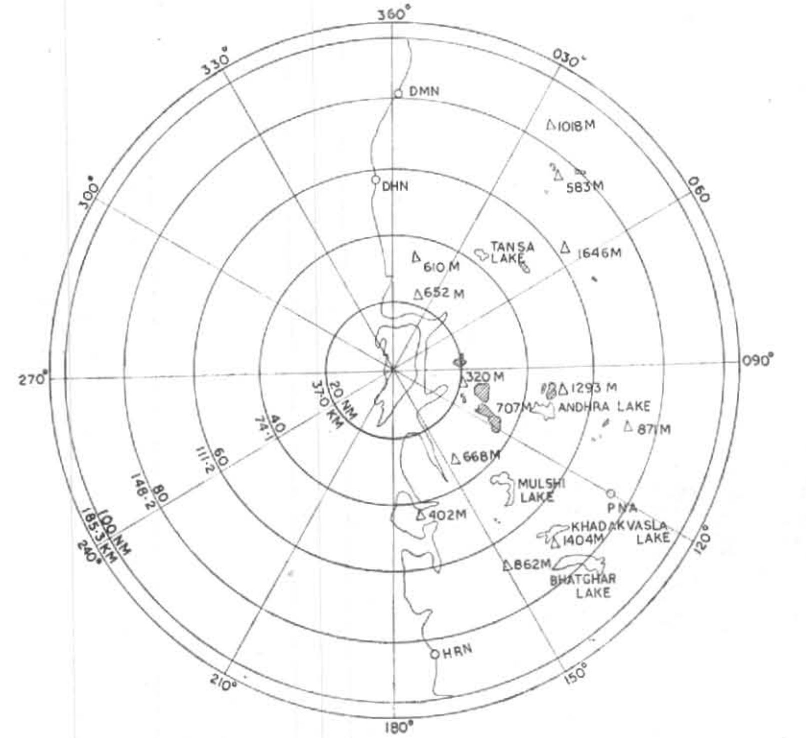


Fig. 3. The echoes from the projected photograph of the radarscope (Range 100 n. miles) is plotted on a 100 nautical miles polar diagram, showing the location of the echoes in the cumulus stage on 31 October 1964 at 1047 GMT. The location of these echoes (shaded) may be seen very close to the hills and adjoining lakes which are not shaded

For the purpose of locating the preferred areas of cloud development, the area covered by the radar, as marked in the polar diagram, was divided into squares of 10 nautical miles square and the first echoes observed on the radarscope during each day (after a period of 'no echo'), for the months of October and November for the years 1962, 1963 and 1964, were plotted in azimuth and range on this polar diagram and the number of initial echoes in each square was counted. As only the first echoes to appear on the scope for each day were noted and subsequent developments were not taken into account, the total number of instances are low, but a definite area in which convective cells develop frequently can be located. Such areas are shown in Fig. 1. Regions of 3 instances of initial echoes and more can be taken as preferred areas within say 60 nautical miles range. At further ranges beyond 60 nautical miles, areas of 2 instances are also taken as preferred areas in order to allow for the effect of range attenuation.

It may be seen from Fig. 1 that these preferred areas are close to the several lakes on the plateau on the leeward side of the Western Ghats and creeks on the southern coast on the mainland. The presence of hills and lakes appears to help the formation of convective clouds. The number of echoes around Khadakvasla and Bhatghar lakes is fewer, probably due to the effect of range attenuation. The first echoes in this region are not 'seen' on the scope until they have developed sufficiently to give a detectable echo and moved away from the position of initial formation.

Radar photograph (Fig. 2) shows the convective cells in the developing stage observed in the NE, E and SE sectors at 1047 GMT on 31 October 1964. Fig. 3 shows the echoes plotted on a 100 nautical miles polar diagram, giving their location on the map of Bombay and surroundings. It may be seen that these echoes are very close to the hills and adjoining lakes.

The echoes are most intense in the late afternoon and evening. Sometimes reintensification occurs in the night. The probability of regeneration of cells is found to be more on the first day of thunderstorm development. On subsequent days the intensity of the thunderstorms is reduced.

3. Movement

To study the movement of the post monsoon thunderstorms, a diagram was prepared on polar

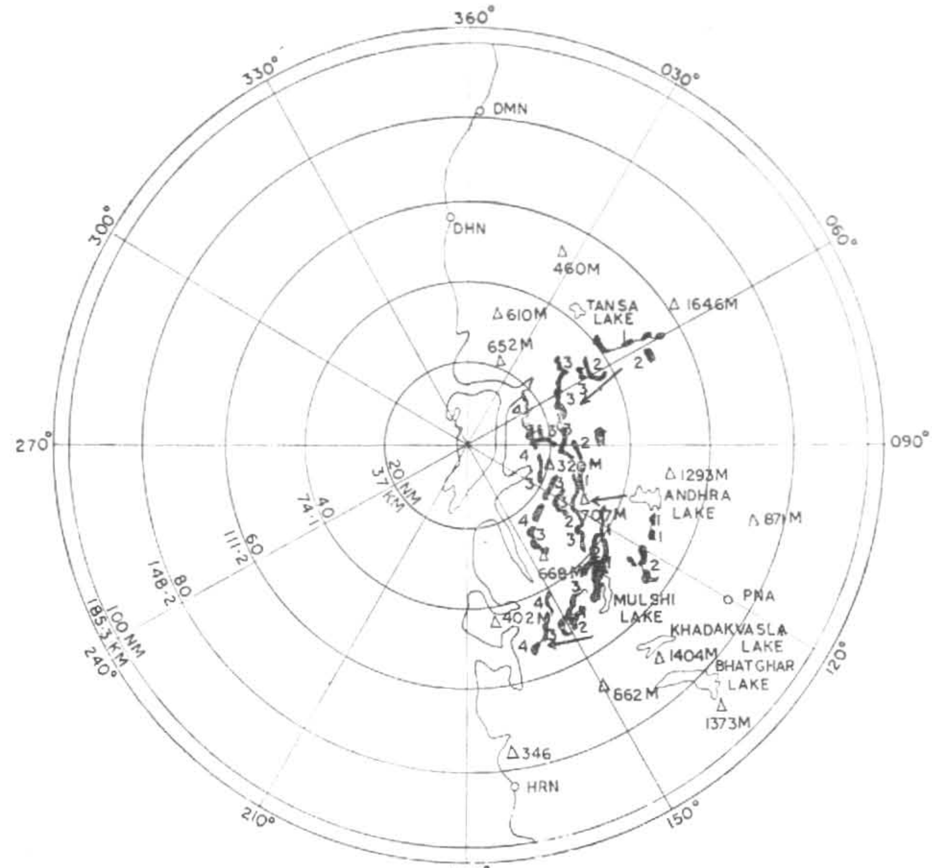


Fig. 4. The leading edges of the line echoes from the projected photographs of radarscope (Range 100 n. miles) are marked and their successive positions are numbered serially. The movement is shown by arrows

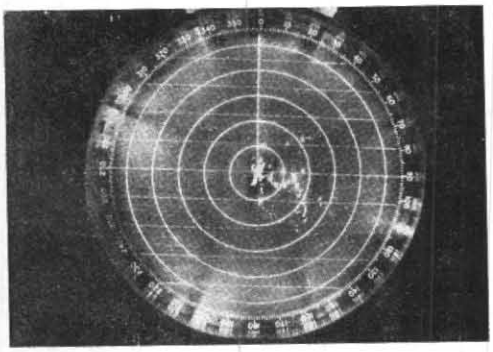
1. Position of the leading edges of the line echoes at 1109 GMT on 12 November 1964
2. Position of the leading edges of the line echoes at 1126 GMT on 12 November 1964
3. Position of the leading edges of the line echoes at 1152 GMT on 12 November 1964
4. Position of the leading edges of the line echoes at 1247 GMT on 12 November 1964

chart by projecting enlarged pictures of 35 mm photographs of the radarscope and tracing the outlines of the echoes other than the permanent echoes. As the polar diagram has the same dimensions as the radarscope (approximately 30 cm diameter), the enlarged photo gives a reconstructed picture of the PPI scope during the actual observation. The successive positions of the leading edges of the cells were traced for the four different observations at 1109, 1126, 1152 and 1247 GMT on 12 November 1964. The resulting diagram shows the progress of the echoes around the station. Fig. 4 gives such a sequence for the thunderstorm of 12 November 1964. This corresponds to the radarscope photographs shown in Figs. 5(a) to 5(d).

While studying the movement of line formations Boucher and Wexler (1961) have adopted a similar method in their paper on 'the motion and predictability of precipitation lines'. A smoothed echo line showing the leading forward edges was drawn and the displacement was marked perpendicular to the centre of the forward edges. Fig. 4 shows the movement of echoes seen on the scope during a thunderstorm that occurred on 12 November 1964. The movement is from NE to SW with a speed of 15 knots and it is slow when compared with monsoon echoes which move at a rate of 30 to 40 knots usually from WSW to ENE.

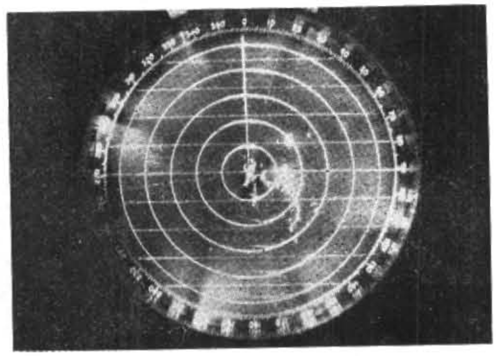
With a view to compare the movement of the post monsoon thunderstorms with that of the (southwest) monsoon radar echoes, a similar diagram was prepared for a typical monsoon day. Fig. 6 presents such a sequence of the monsoon echoes of 16 August 1964. The routine radar observation polar diagrams from 1330 to 1800 GMT of 16 August 1964 were used for preparing this diagram. The line formation and movement are apparent in Fig. 6. The speed of movement is of the order of 40 knots. The direction of movement is from WSW to ENE, *i.e.*, from the sea to the land while post monsoon thunderstorms move from land to sea.

Another feature of the post monsoon thunderstorms is that most of them dissipate over the land



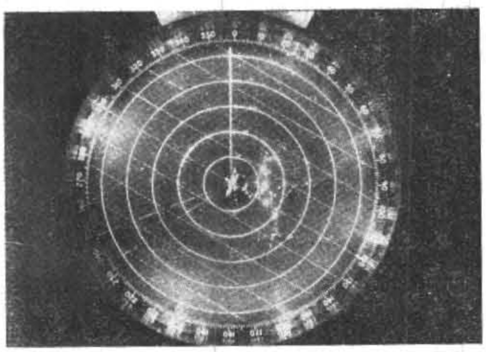
1109 20

Fig. 5(a)



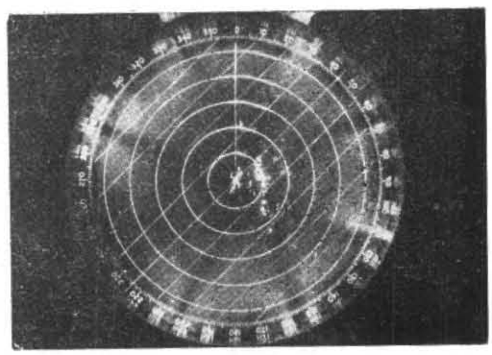
1126 20

Fig. 5(b)



1152 20

Fig. 5(c)



1247 20

Fig. 5(d)

Figs. 5(a) to 5(d). Radarscope photographs of the thunderstorm on 12 November 1964 showing the line formation and its movement

(Figures in the left and right hand bottom corners indicate time in GMT and range in nautical miles respectively)

itself without crossing the coast and sometimes near the coast, over the sea. Boucher and Wexler (1961) have pointed out that the dissipation of the lines near the coast may be due to the relatively stable cool sea air inhibiting convection and hastening the deterioration of convective lines, as they move into these areas, by preventing development of new cells. This influence of the sea air is evident in the case of post monsoon thunderstorms observed over Bombay also.

4. Conclusions

This preliminary study of the post monsoon thunderstorms over Bombay leads to the following conclusions —

(1) The thunderstorm activity has a preferred time of occurrence usually between 0800 to 1700 GMT and a place of origin as shown in Fig. 1. Probably the proximity of the lakes and the Ghats provides the necessary differential heating for the formation of convective cell and the relatively cooler region of the Arabian Sea inhibits convective activity.

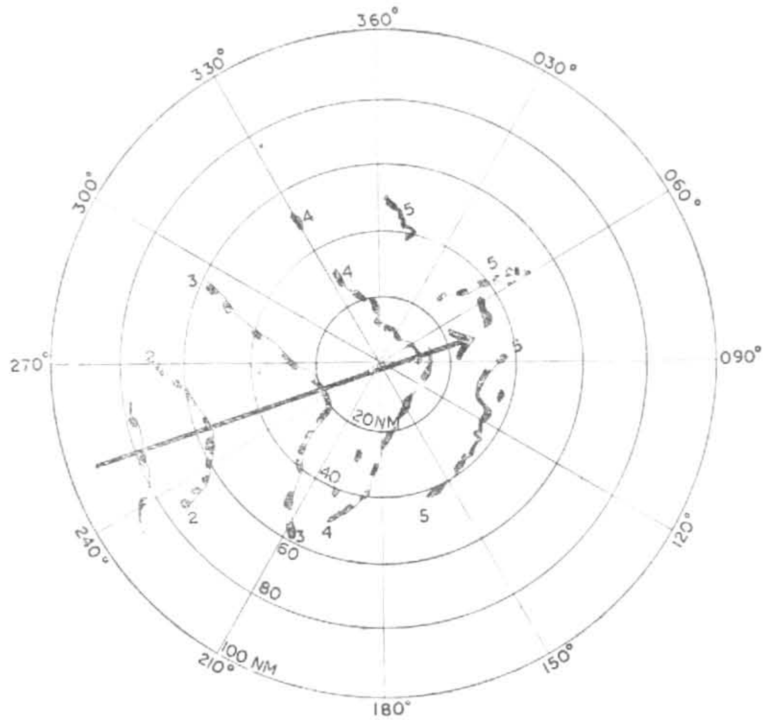


Fig. 6. The leading edges of the line echoes of a typical SW monsoon radar echoes marked and their successive positions traced to study the movement. The direction of motion is shown by the arrow. The 100 n. miles polar diagrams of the routine observations of 16 August 1964 were used for preparing this diagram

1. Position of the leading edges of the line echoes at 1330 GMT on 16 August 1964
2. Position of the leading edges of the line echoes at 1400 GMT on 16 August 1964
3. Position of the leading edges of the line echoes at 1500 GMT on 16 August 1964
4. Position of the leading edges of the line echoes at 1600 GMT on 16 August 1964
5. Position of the leading edges of the line echoes at 1700 GMT on 16 August 1964

(2) During November, the frequency of development of thunderstorms is only 25 per cent of that during October, and the probability of the thunderstorm occurring over the airport during the post monsoon season October—November is only 22 per cent. During October they persist for a longer time and regeneration is also possible during this period.

(3) The movement of the post monsoon thunderstorms is generally from land to sea with a speed less than 20 knots. They usually dissipate over the land itself or over the sea, near the coast.

5. Acknowledgement

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