551·508·99 : 551.553.21(547·1)

Radar observation of a monsoon rain squall at Bombay

V. NARAYANAN

Rocket Meteorological Office, Thumba

(*Received 16 December 1966*)

ABSTRACT. During monsoon, a number of line type radar echoes developing over the Arabian Sea 40-60 nautical miles west of Bombay coast and moving in an eastward direction have been noticed on the radarscope of Decca type 41 storm detection radar installed at Santacruz airport. One such instance during June 1965 is studied and reported in this note.

The main features of the rain squall line — pivotal motion, bifurcation, deceleration in forward movement on reaching the coast line — are explained in the light of experience of radar observation of monsoon clouds at Bombay. A few suggestions for further investigation in order to get a better insight into the intricacies of the hitherto hidden phenomena of monsoon clouds with the help of weather radar, are indicated.

1. Introduction

From June to September Bombay experiences rain mainly of two types—(*a*) continuous rain of moderate intensity, and at times heavy, lasting for days together, (*b*) passing showers lasting for a few minutes. In the former case, the intensity of rainfall is usually less than an inch per hour, while in the latter type the intensity can be quite high of the order of 1–2 inches/hour or even more. It has been reported by Miller and Kesavamurthy (1965) that there are pockets of large towering cumulus and cumulonimbus above a layer of nimbostratus within 200-300 miles off the coast. The sudden increase in intensity in a steady continuous moderate rain from nimbostratus may be attributed to the passage of these *Cu* and *Cb* embedded in it. Mazumdar (1965) has pointed out that a weather radar may be useful for detecting and identifying these *Cu* and *Cb* hidden pockets which are beyond reach of visual observation.

The passing showers are caused by cumuliform convective clouds isolated or arranged in lines which can be detected by radar right from 60–80 nautical miles from the station. When it is raining over the station, the 3-cm weather radar (X-band) available at Bombay is not able to track distant precipitation convective cells quite satisfactorily, as the range of detection is limited to say 25 nautical miles due to attenuation. One interesting case of monsoon line echo tracked by Decca type 41 radar on 22 June 1965, is studied and the results are discussed.

2. Thundersquall line *versus* rain squall line

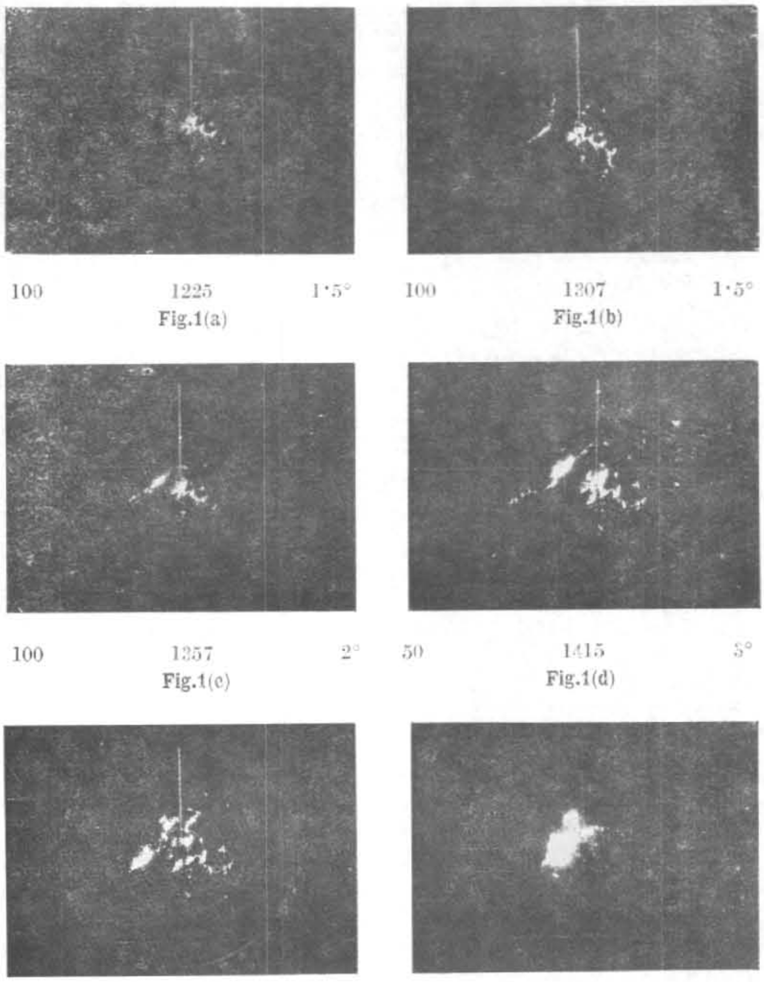
There are some standing instructions in the India Meteorological Department (Weather Radar Manual 1965) for reporting a squall line based on weather radar observation. A precipitation line echo is considered as a squall line if the following two conditions are satisfied simultaneously — (*i*) the length of the line echo is more than 60 km (36 miles), (*ii*) its length to breadth ratio is at least 10 : 1. In such a line echo a number of convective cells are arranged either in straight line or in curved line which may be again either concave, convex or both. The movement of the individual cells constituting the squall line may be different from each other and from that of the line as a whole. Due to this relative difference in movement, sometimes one end of the squall line may appear to move faster than the other end. Such a motion is called pivotal motion and that portion of the line which appeared to move with less speed is called the whip end. Pivotal motion of the line echo is usually associated with severe storms.

The squall line echo is invariably associated with local thunderstorm and frontal activity. Arakawa (1965) and Wexler (1947) have reported squall line echoes detected by weather radar in association with frontal storms.

It is questionable whether the squall lines detected at Bombay during monsoon are associated with frontal activity. There are two types of squall lines—(*a*) Thundersquall line and (*b*) Rain squall line. The former is a common feature during the break-monsoon, pre-monsoon and post-monsoon periods, due to the intense convective activity over the Western Ghats. The west coast squalls which occur frequently during active monsoon period may be called rain squalls. The mechanism of rain squall appears to be quite different from that of thundersquall. The changes associated with the passage of both type of squall lines in the surface meteorological elements are more or less similar with the exception that no appreciable change in wind direction is observed during rain squall. The synoptic situation plays an important part in distinguishing the rain squall from the thundersquall.

3. Synoptic situation on 22 June 1965

The monsoon had set over Bombay on 14 June 1965 and was quite active for about two weeks without any break. The axis of the monsoon



100 1225 1·5°
Fig.1(a)

100 1307 1·5°
Fig.1(b)

100 1357 2°
Fig.1(c)

50 1415 3°
Fig.1(d)

50 1455 4°
Fig.1(e)

25 1535 10°
Fig.1(f)

Figs. 1(a)—1(f). Sequence of radarscope photographs of the monsoon rain squall line observed on 22 June 1965

Figures below the photographs indicate (from left to right) range in nautical miles, time in IST and elevation in degrees respectively

trough on sea level chart on 22 June 1965 was passing through Ambala, Kanpur, Hazaribagh and Krishnagar. The northern limit of the monsoon current was located through Dahanu (about 60 miles north of Bombay), Khandwa, Raipur, Chandbali, Calcutta and Bagdogra. Monsoon had been quite active over Vidarbha. There were widespread thunderstorms in Kerala coast, Madhya Maharashtra, Konkan and Arabian Sea Islands. Bombay (Santacruz) had a rainfall of 3·5 cm mainly from passing showers.

4. Radarscope observations

During the 1230 IST routine hourly radar observation, a convex shaped broken line of precipitation echo was noticed at 40-60 nautical miles from 260° to 300°. Radarscope photograph (Fig. 1a) shows the broken line echo in the developing stage over the Arabian Sea. As all the echoes were in the developing stage, their heights of top were only of the order of 5 km. Within half an hour, the echoes strengthened, increased in number and aligned themselves in a curved line from 260°/64 nm to 330°/45 nm with its intense central portion at 280°/30 nm and moving towards east with a speed of 25 kts (Fig. 1b). The echoes were having heights of top of the order 8 km during their mature stage. By this time fresh echoes were found to appear on either ends of the line thus extending its length to about 80 nm.

After an hour it was observed that the convex line echo was changed to a straight line echo on account of its pivotal motion running from 260°/50 nm (whip end) to 330°/18 nm. The echoes were quite intense at this stage showing maximum convective activity (Fig. 1c). At 1415 IST,the line started dissipating with the breaking up of the same and the deceleration in forward movement. However, the middle portion of the line 280°/15 nm was still intense moving with a speed of 15 kts towards station (Fig. 1d).

At about 1500 IST, the line split up into two parts, one portion lying 250°/25 nm to 280°/15 nm and the other 300°/8 nm to 350°/15 nm (Fig. 1 e). The former was more intense and hit station at 1535 IST with a surface squall of 70 km/hr followed by a heavy showery rain for a few minutes.

Fig. 1(f) shows the rain squall echo right over the station. The effect of the passage of the rain squall line echo over Santacruz on surface temperature, relative humidity, surface wind direction and speed are shown in Figs. 2(a) and 2(b), respectively. A sharp fall in temperature of 5°C and abrupt rise in relative humidity of 20 per cent were recorded during the rain squall (Fig. 2a). No appreciable change in wind direction was noticed (Fig. *2b).

The positions of the line echo displayed in radarscope photographs Figs. 1(a) to 1(f) were marked in a 100 nm polar diagram (Fig. 3) with a view to study the movement, pivotal motion and splitting of the line on reaching closer to the coast. The movement and pivotal motion of the line are indicated by straight and curved arrows respectively in Fig. 3.

5. Discussion of the results

The main features of the rain squall line echo are discussed briefly below.

(*a*) *Movement* — The movement of the line echo is quite interesting in this case. The echoes in the initial developing stage over the sea moved faster with a speed of the order of 20–30 kts than in the dissipating stage on approaching the coast. They were decelerated in their forward movement near the coast and the speed was slowed down to 10–15 kts which is nearly half of its original speed. This reduction in speed is likely to be apparent in case it is raining over station. But in the case under study there was no precipitation over station prior to the hitting of the rain squall line cell. The decrease in speed may be attributed partly to the dissipation of the line. The movement of this rain squall line is opposite to the post-monsoon thunderstormsquall line echoes reported by Narayanan and Krishnamurty (1966).

(*b*) *Pivotal motion* — One of the main characteristics of a strong and intense convective storm is pivotal motion of the line echo. The squall line under study has shown pivotal motion in the clockwise direction as shown by the curved arrow in Fig. 3. The initial convex line echo was transformed to a straight line echo under the action of this pivotal motion (see radar photographs — Figs. 1a to 1d).

(*c*) *Bifurcation* — Another interesting feature of the rain squall is the bifurcation of the line echo into two parts and moving in a different direction. Fig. 1(e) clearly brings out this phenomenon. Similar cases have been noticed several times during the monsoon season. An example on 16 August 1964 is presented in Fig. 4. The leading edges of the line echoes are marked corresponding to each observation. It may be seen from Fig. 4 that the line on crossing the station has split up into three parts. The reduction in speed on reaching the station can also be noticed from the above diagram. Very often line echoes which are expected to cross over the station, were found to split into two or more pairs crossing south and north of Santacruz keeping the airport free of weather. This has been verified by visual observations from the Control Tower and confirmed by local telephone enquiries. A typical case more or less similar to the one already described was observed on 28 June 1965. No echo, one isolated cell, and then a group of cells at 80 nm in southwest sector were reported during 1130, 1230 and 1330 IST radar observations respectively. The group of cells aligned themselves along a concave line at 1530 IST at 40 nm northwest of Bombay moving with 15 kts speed in northeastward direction. At 1730 IST, the concave line approached the station, split up into two parts and passed over south and north of airport with practically nothing overhead of station. Slight drizzle occurred at the airport, but heavy rain could be noticed in the southeast portion of the aerodrome towards the Trombay hills. However in the case under review, the rain squall cell passed over airport (see Fig. 1f) and brought weather. It is yet to be established whether the shape of the line echo — convex or concave — has any bearing in bringing weather over airport. From the three instances cited above, it appears that the convex line echo is associated with more rain.

(*d*) *Vertical extent* — The vertical development of rain squall line echoes is of the order of 6–8 km. The thundersquall line echoes of break-monsoon, pre-monsoon and post-monsoon periods have greater vertical development which normally grow up to 12–15 km — just double that of rain squall line echoes. But whenever the rain squall line clouds are forced to move overhead of the Western Ghats greater vertical development is possible due to orographic lifting resulting in large *Cb* formation causing abundant precipitation, thunder and lightning on rare occasions.

TABLE 1

Upper winds nearest to the radar observation

	Height (km)	16 Aug 1964 1730 IST (DD/VV)	22 Jun 1965 1730 IST (DD/VV)	28 Jun 1965 1730 IST (DD/VV)
	Surface	225/08	270/08	270/10
Layer below the monsoon cloud	0·15	230/18	252/14	230/14
	0·3	230/21	249/18	225/10
	0·6	230/25	246/25	230/10
	0·9	240/25	245/25	245/10
Layer in which monsoon cloud is embedded	1·5	240/33	237/27	242/10
	2·1	245/29	237/18	247/14
	3·0	240/25	240/14	273/14
	3·6	255/29	312/14	287/08
	4·5	260/29	318/18	292/08
	5·4	255/23	276/10	262/06
Layer above monsoon clouds	6·0	250/21	252/10	155/04
	7·2	260/12	290/06	055/10
	9·0	265/10	066/10	090/14
	10·5	015/10	065/18	130/18
	12·0	065/29	068/35	094/43
	14·1	065/41	081/45	080/37
	16·2	085/72	082/54	—

DD — Direction in degrees VV — Speed in knots

TABLE 2

Relation between upper winds and movement of rain squall line

	Shape of rain squall line on radarscope	Mean observed movement	Vector mean wind in the layer 1 to 6 km	700-mb wind	Remarks
16 Aug 1964	Convex	NE/30 kt	250/28 kt	240/25 kt	No pivotal motion. Passed over airport with heavy rain
22 Jun 1965	Convex	E/13 kt	265/14 kt	240/14 kt	Pivotal motion noticed. Hit the station with a surface squall
28 Jun 1965	Concave	NE/15 kt	265/10 kt	273/14 kt	No pivotal motion, did not affect airport

(*e*) *Relation between rain squall movement and upper winds* — The relation between movement of the rain squall lines and upper winds has been studied on a similar method adopted by Atlas (1963), Browning and Ludlam (1962). The convective cells detected by radar during monsoon are found to be embedded in the layer 1–6 km and it is assumed that the movement of these convective cells are closely related to the vector mean wind in this layer. The most frequent direction of rain squall at Bombay is westerly; northwesterly and southwesterly squalls can also occur occasionally depending on the prevailing synoptic situation. Table 1 gives the upper wind data nearest to the radar observation of rain squall lines on 16 August 1964, 22 June and 28 June 1965. The actual movement and shape of rain squall line, vector mean wind in the layer 1–6 km and 700-mb wind in the three cases are shown in Table 2. There is a good agreement between the movement of the rain squall line and the vector mean wind in the layer 1–6 km. Incidentally this mean wind is nearly same as 700-mb wind, thus supporting the inference of Dakate and Bajaj (1966). This upper wind data also explain, to a certain extent, the pivotal motion observed on 22 June 1965. The high shear in the layer 3-4 km appears to be responsible for the pivotal motion.

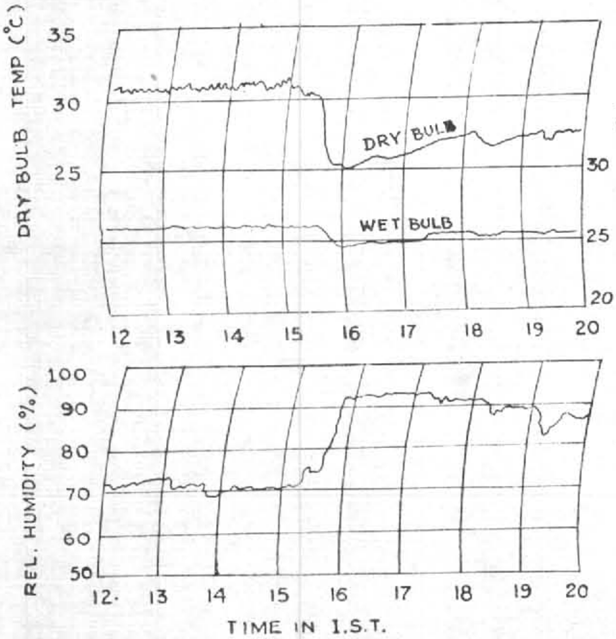


Fig. 2(a). Thermogram and hygrogram of Santacruz on 22 June 1965

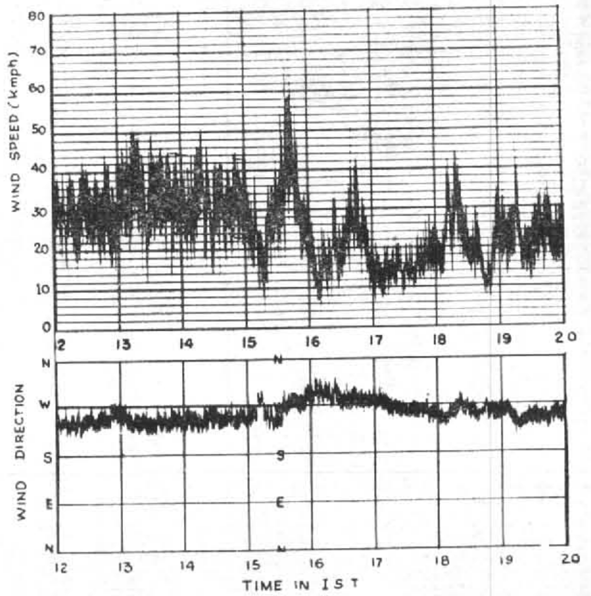


Fig. 2(b). P. T. Anemogram of Santacruz on 22 June 1965

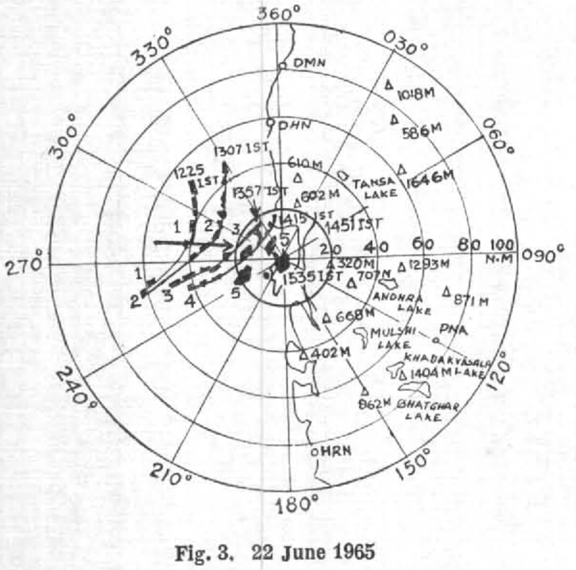


Fig. 3. 22 June 1965

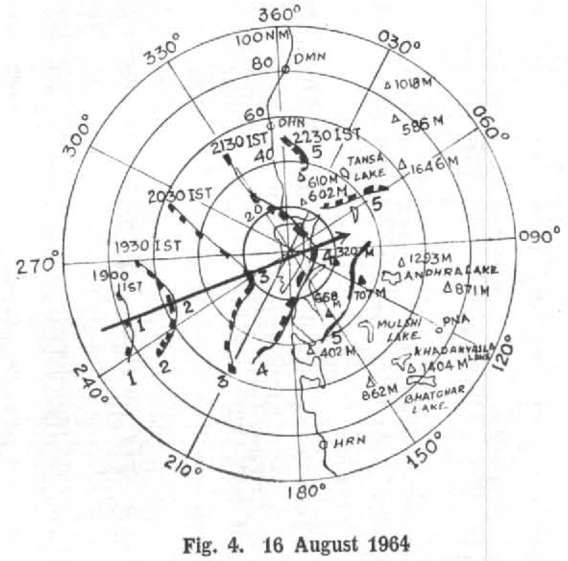


Fig. 4. 16 August 1964

Figs.3-4. 100 n.m. polar diagram showing the movement, pivotal motion and spliting of the rainfall echo on reaching closer to the Bombay coast

6. Concluding remarks

It is not possible to draw any general and definite conclusion based on this case study of monsoon rain squall. However, it gives us some hints for the better understanding of the intricacies of the hitherto hidden phenomena of monsoon clouds. The main features and results discussed will be useful to aviation and weather forecasters for guidance and for further research work on monsoon clouds with the help of weather radar at Bombay. A few suggestions for further investigation are given below—

(*i*) It will be interesting to investigate whether any anticlockwise pivotal motion is possible during the monsoon.

(*ii*) The mechanism by which the bifurcation of the line echo takes place on reaching closer to the coast requires further detailed investigation. Perhaps the local topography plays a major part in this phenomenon.

(*iii*) It is worthy to probe into the problem whether any frontal activity is associated with monsoon rain squall line formation. Detailed upper air analysis in juxtaposition with weather radar observation may reveal some useful results in this matter.

(*iv*) Collecting more such instances of rain squall lines, it will be possible to find out the exact relation between its movement and upper air circulation.

(*v*) Another point of interest would be to examine whether the line echoes have a tendency to be convex in shape while out at sea, as a general rule, and whether its shape has any definite bearing on bifurcation and the intensity of precipitation.

(*vi*) There is sufficient scope for a comparative study of the thundersquall line echoes of break-monsoon, pre-monsoon and post-monsoon periods and the rain squall line echoes of active monsoon period.

7. Acknowledgements

The author expresses his deep sense of gratitude to Dr. T. M. K. Nedungadi, Director, Regional Meteorological Centre, Bombay and Shri K.V. Rao, Senior Scientific Officer, Institute of Tropical Meteorology, Poona for suggesting the problem and for their guidance. He is thankful to the members of staff in Weather Radar Unit, Santacruz for the co-operation and help rendered in this work.

REFERENCES

Atlas, D.	1963	*Met. Monogr.*, Amer. met. Soc., 5, 27, p. 177.
Arakawa, H.	1965	Proc. Symp. Met. Results of IIOE, 22-26 July 1965.
Browning, U. A. and Ludlam, F. H.	1962	*Quart. J.R. met. Soc.*, **88**, p. 115.
Dakate, M. V. and Bajaj, K. K.	1966	*Indian J. Met. Geophys.*, **17**, 2, p. 217.
India met. Dep.	1965	Weather Radar Manual, Annex. I to Appendix II, p. 53.
Mathur, L. S. and Kulshrestha, S. M.	1966	*Indian J. Met. Geophys.*, **17**, 1, p. 1.
Mazumdar, S.	1965	*Ibid.*, **16**, 1, p. 136.
Miller, F. R. and Kesavamurthy, R. N.	1965	Proc. Symp. Met. Results of IIOE, 22-26 July 1965.
Narayanan, V. and Krishnamurty, G.	1966	*Indian J. Met. Geophys.*, **17**, 2, p. 237.
Wexler, R.	1947	*J. Met.*, **4**, 2, p. 69.