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A radar study of line-type thunderstorms over Bombay airport and surroundings

O. P. AGARWAL and G. KRISHNAMURTHY

Meteorological Office, Santacruz Airport, Bombay

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ABSTRACT. In this paper, the results of a radar study of two cases of squall line thunderstorms which occurred in the vicinity of Santacruz airport in the latter half of September 1966 are presented. The sequence of development from the formation to the decay stages has been examined on the basis of radar pictures obtained with the help of a 3-cm Decca-41 radar. The study reveals that the individual cells develop to form a line over land along the Western Ghats and move westwards. While the motion is in progress, the northern part of the line moves faster resulting in a cyclonic turn indicating a pivotal motion of the line of echoes.

1. Introduction

Thunderstorms of the squall line type of varying degree of violence occur during the second half of September when the monsoon starts withdrawing. The general occurrence of thunderstorms over Bombay has been studied by Narayanan and Krishnamurthy (1966). During the latter half of September 1966, when the monsoon began to withdraw from the country, isolated occurrence of thunderstorms were noticed and two typical cases of those occurred on 23 and 27 September 1966 are presented in the paper.

The equipment at Santacruz airport is a Decca type 41 storm detecting radar with a peak power of 20 KW operating at frequency 9375 Mc/s, beam width 4° vertical and 0·75° horizontal with PPI-scope.

2. The thunderstorm of 23 September 1966

Convective activity started around 0900 GMT and radar echoes were seen in SE near Poona, about 70 n. miles away and moved towards NW. At about 1100 GMT new cells formed and a line of cells along NNE/SSE was seen at a distance of 50 n. miles. The height of tops of various cells were mostly between 7 to 11 km. At 1200 GMT the movement of the line became faster and it was oriented ENE/S. The central portion of the line was at a range of 23 n. miles east of the radar site. At this stage the heights began to decrease. The speed of movement was estimated to be 6—7 kt. At 1300 GMT the line was at 13 n. miles away from the station and was moving towards the airport from E to W. Thunderstorms with strong gusty winds and rain occurred over the airport during the next one hour. Regeneration of cells occurred twice at 1600 and 2100 GMT; finally cells dissipated at 0200 GMT on 24 September 1966. The regeneration of cells over the sea, upto a distance of 120 n. miles was a remarkable feature.

The change in surface elements due to the passage of the thunderstorm over the airport are as follows —(1) A pressure 'Nose' of 3 mb, (2) A temperature fall of 5°C, (3) Rainfall of 8 mm, (4) Maximum intensity of rainfall 30 mm per hour, and (5) Winds gusty, from S/SE reaching a maximum of 28 knots.

3. The thunderstorm of 27 September 1966

Cells were seen on the radar-scope on this day at 0800 GMT at a distance of 90 to 105 n. miles SSW of the radar site. At 0900 GMT it extended upto 80 n. miles NE of the station. A line of cells developed in the next two hours and was oriented N-S at a distance of 30 n. miles. The heights of tops were estimated to be between 7-9 km. Initially the line moved slowly (5-6 kt) towards W, but when it was at a distance of 15 n. miles it moved fast and at 1500 GMT gave rain and thunder. Regeneration of cells was noticed at 1800 GMT upto 120 n. miles in the NW. Activity ceased at 2000 GMT. The changes in surface elements were —(1) Pressure rise of 5 mb, (2) Temperature fall of 60°C, (3) Squall from E/SE, speed 38 kt, (4) Rainfall amount 20 mm, and (5) Maximum intensity of rainfall 30 mm/hour.

4. Discussion

As the area, over which the Decca-41 radar in use at Santacruz is able to detect weather echoes, is only about 150 in. miles around only a very brief reference will be made to the general synoptic situation prevailing over the country on these days.

There was a shallow low pressure area over and around Bombay accompanied by upper air high pressure circulation upto 300-mb levels on both these days,. The tephigrams of 00 GMT and 12 GMT of both the days show that there was instability.

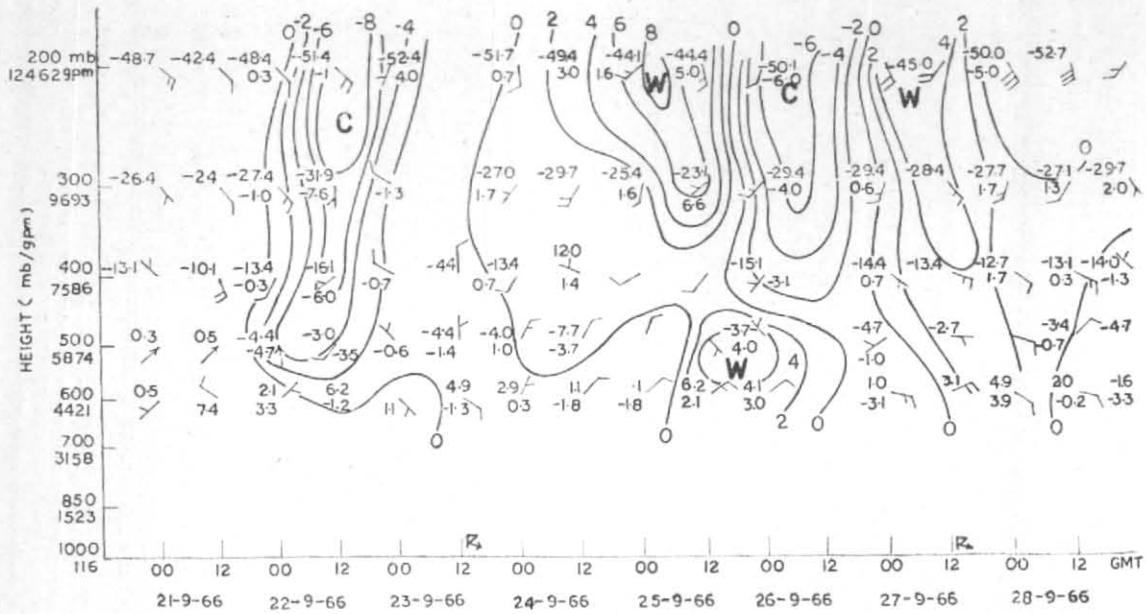


Fig. 1. Vertical time-section of winds and temperature over Santacruz during 21 to 28 September 1966

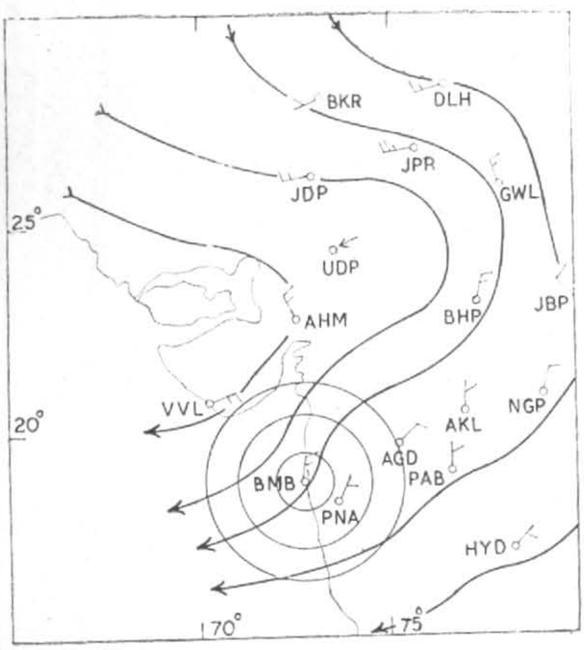


Fig. 2. 23 September 1966

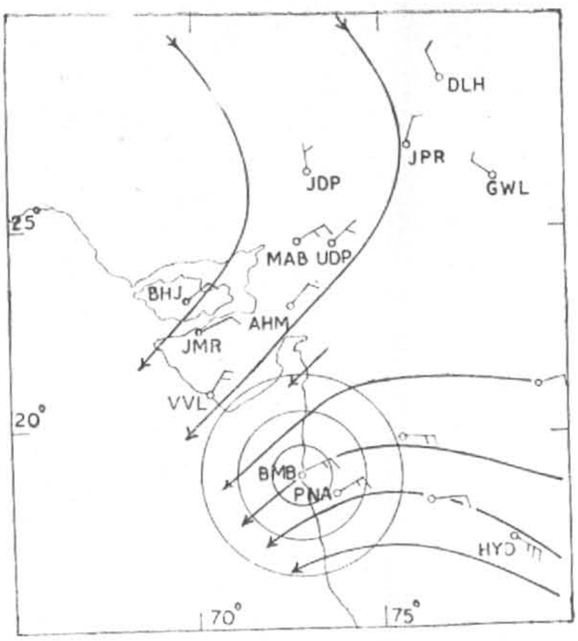


Fig. 3. 27 September 1966

Winds at 700 mb at 1200 GMT

(Rings at 50 n. miles interval)

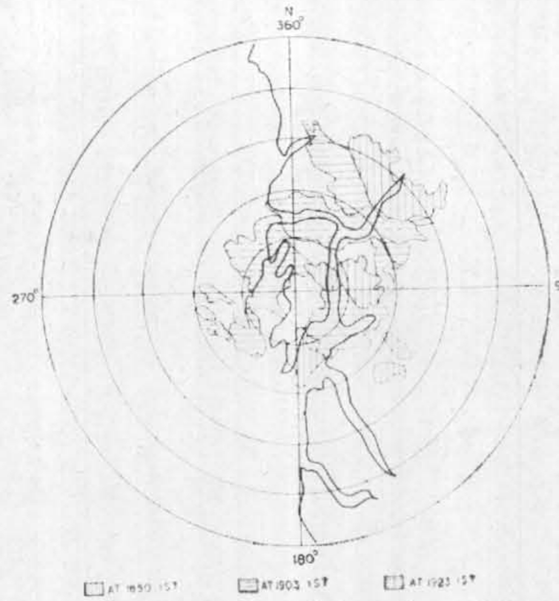


Fig. 4. Cells at different times of observation on 23 Sep 1966 at Santacruz showing pivotal motion
(Range 50 n. miles)

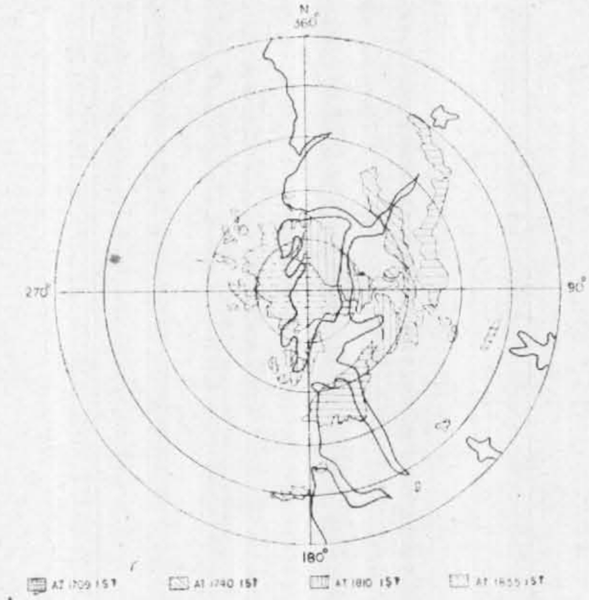
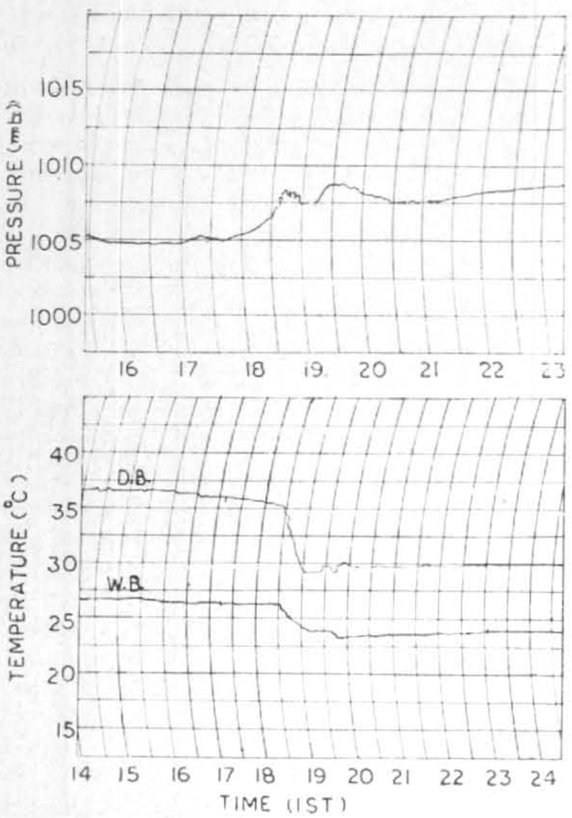


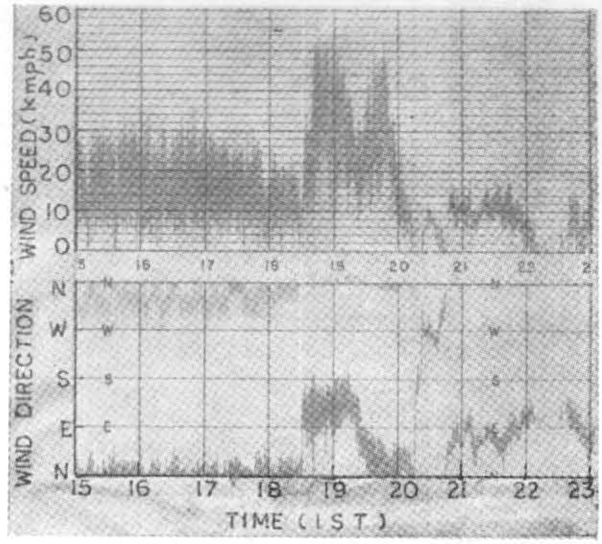
Fig. 5. Cells at different times of observation on 27 Sep 1966 at Santacruz showing pivotal motion
(Range 50 n. miles)

1. The vertical time section has been drawn (Fig. 1) showing winds, temperature and change of temperature for 24 hours. The 24-hour change in temperature has been plotted at the middle point of the period for purposes of analysis. Isoline of temperature change have been drawn. The diagram shows the maximum fall of temperature (as denoted by area marked C) centred at 00 GMT of 22nd and at 00 GMT of 26th whereas the thunderstorms occurred 36 hours later, *i.e.*, at 13 GMT of 23rd and 12 GMT of 27th respectively. Zero change line, *i.e.*, the transition from cold to warm takes place close to the time of occurrence of thunderstorms.

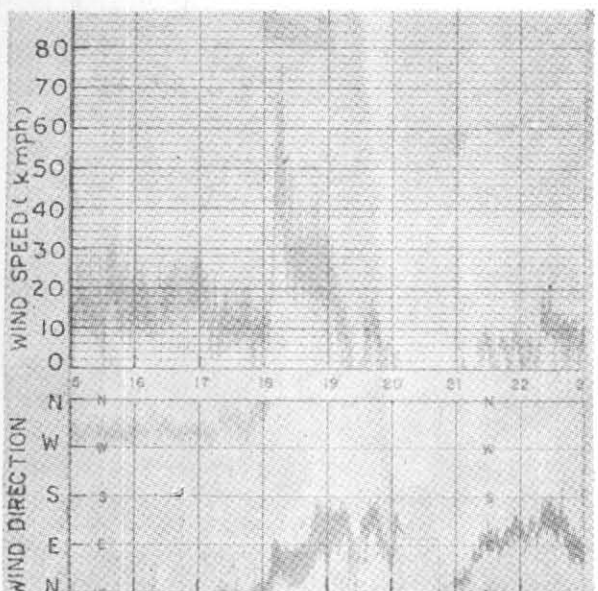
2. Figs. 2 and 3 show the wind field at 700 mb (10,000 ft) at 12 GMT on the days of thunderstorms under study, *i.e.*, on 23 and 27 September respectively. This shows a stronger N'ly component north of the site and NE'ly to the east and south over a distance of 150 n. miles around the radar site. The wind changes are not seen so markedly on synoptic map, but the winds north of the radar site have a large N'ly component



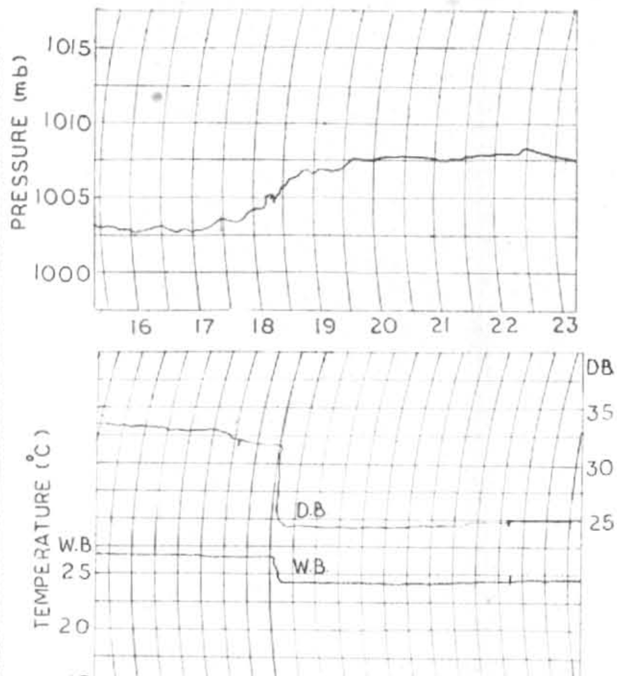
Dry & Wet Thermogram and Barogram on 23 September 1966



Dines P.T. Anemogram on 23 September 1966



Dines P.T. Anemogram on 27 September 1966



Dry & Wet Thermogram and Barogram on 27 September 1966

Fig. 6. Records of self-recording instruments at Santacruz during the thunderstorms on 23 and 27 September 1966

while those in the east and south have a larger E'ly component.

This is probably influenced by the change in the direction of movement of cells in the area. It has already been pointed out that the movement initially was from SE to NW and later E to W and finally NE to SW as seen from Fig. 3.

Byers *et al.* (1949) in 'The Thunderstorm Project' have stated that the path of movement of the radar echoes frequently curve to the right or left resulting in a change of direction upto 30° in a period of 10 minutes. Such curvature may be explained by the effects of vertical transport of horizontal momentum by strong vertical air currents found in thunderstorms. During the mature and dissipating stages the downdrafts initiated by the falling rain transport horizontal momentum downwards causing cloud particles in lower layers to be influenced by winds of the upper levels.

Movement of thunderstorm cells—Boucher (1963) has given the general procedure for forecasting the direction of motion of radar echoes and has found that 700-mb winds are highly correlated with the velocity of movement of echoes. Further he has recognised three types of echoes—(1) Line-type echo, (2) Echo area with leading edge (having clear cut leading edge), and (3) Amorphous echo area (without well defined boundaries—examples of such type are abundantly available over Bombay during monsoon season on both convective and stratiform type of cloud echoes).

After studying several cases he found, 'The lines generally move at a conservative rate of speed and in a direction which undergoes relatively small changes with time. This implies that radar data are sufficient for predicting by extrapolation of line motion for intervals of 1 to 3 hours with no additional echoes'. But the present study has shown that orography perhaps affects the direction and speed of motion of precipitation lines.

Pivotal motion—The movement of a group of cells or echo pattern is described as pivotal when one portion of the echo moves faster than another while other portion remains fixed or moves very slowly. A comparison of photographs which are traced at different time intervals in Figs. 4 and 5, for 23 and 27 September 1966 respectively, shows such a pivotal motion. The wind field at 700 mb (10,000 ft) over the area covered by the radar is shown in Figs. 2 and 3 for these dates respectively. The winds are NE'ly north of Bombay changing to E'ly in the eastern areas and the streamlines show that it again changes to NE'ly over the sea near the coast. The pattern of wind upto 600 mb on this day is similar to that of 700 mb.

Indications of localised strong convergence are provided by a study of the Dines P.T. Anemograms (Fig. 6). The wind direction suddenly veered from N'ly to SE'ly when the thunderstorm approached the station. The tracings of the photographs in Figs. 4 and 5 shows that the orientation of the line echoes of thunderstorm changes to E-W showing a wind force from N or NE. A study of the anemogram confirms that during this period the wind direction changed from SE to NNE. Such a change in wind direction can occur in a localised strong convergence zone.

The rate of movements for every half an hour has been calculated by measuring the displacement of the leading edges of the line along a direction parallel to the direction of movement. A practical operational difficulty experienced in predicting the time of arrival of the echoes over the airport may be mentioned. By observing the pattern of echo seen at 1740 IST (Fig. 5) and by noting the direction and speed of movement during past hour as towards W at 10 kt, the time of arrival of echoes over airport was estimated to be between 1830 to 1900 IST, but due to the pivotal motion of the line the echo came over station much earlier than expected, at 1800 IST itself. Hence it is necessary to keep in mind this possibility while estimating the movement of a line-echo as seen on the radarscope near an airport for purpose of issuing airfield warnings.

The instances cited above pertain to radar echoes of line-type squalls which originate over land and move towards sea. Such change of direction of movement of echoes may be due to any of the following reasons—(1) Change of friction or surface drag over sea and *vice versa* over land and sea, (2) Effects of orography and (3) Change in mean wind over the height to which the clouds are there or a change in steering wind.

5. Conclusion

Two cases of radar observations of thunderstorms at Bombay discussed above show that the echoes undergo pivotal motion while crossing from the mountainous terrain towards the coast. A systematic study of the movement of line-type of radar echoes over Bombay is being made by the authors in order to determine the relation between upper winds, the causes of change in direction of movement of echo patterns etc.

6. Acknowledgement

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