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A radar study of squall lines affecting Nagpur airport

A. CHOWDHURY, K. G. S. NAIR and A. K. BANERJEE

Regional Meteorological Centre, Nagpur

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ABSTRACT. The paper presents results of detailed study of squall lines that formed and affected Nagpur airport during 1961-1970. Some characteristic features of these lines have been discussed. The rough terrain of Satpura mountain range appears to be favourable for initial formation of echoes resulting in the organisation of line. Relation between computed normal motion of the line from 700 mb and the actual motion has been brought out.

1. Introduction

Recent investigations of organised radar echoes such as echo-lines, precursor lines, edged sheets have directly contributed in improving local forecasting techniques. Pioneering work in this field has been done by Boucher and Wexler (1961) and Reed and Pranter (1961), who proposed mechanism of formation of squall lines and studied their movements. Boucher (1963) found that the convective cells which make up the radar line, have short life-time but new cells are generated successively along it. In India, De (1963) and Chaudhury and Rakshit (1970) studied occurrence and life-cycles of squall lines over Gangetic West Bengal, whereas De and Kundu (1966) and Ray and De (1971), respectively made similar investigations around Agartala and Gauhati airfields.

Attempts have been made in this paper to study prominent characteristics of the squall lines that affected Nagpur airfield during the period 1961—1970. Synoptic situations that favour formation of the lines have also been studied.

2. Collection of data

A Decca radar is functioning at Nagpur airport since 1959. This radar is operated regularly in all seasons except winter, when it is operated only in cases of anticipated or actual bad weather situations. The monthly distribution of 93 such lines found in the investigation, is depicted in Fig. 1. It is evident from the figure that these lines form predominantly during premonsoon and monsoon months.

3. Initial formation

It is well known that the convective cells which organise themselves into broken or solid lines, are initially observed as scattered or isolated oval shaped, amorphous echoes. Alignment of the scattered echoes is perhaps the consequence of instability, insolation and downdrafts from cells present in the vicinity. However, regardless of their origin the organisation of cells into persistent line implies a localised updraft motion. Thus, there generally is a time lag between the first appearance of random echoes and their alignment. This lag is shown in Table 1(a). It may be seen that around Nagpur, the echoes may take 2 to 4 hour in premonsoon and 1-3 hours in monsoon for organising into line.

Table 1(b) gives the life-period of these lines. According to Boucher (1963), convective cells which make up the radar line have limited life time of the order of one hour, the line system persists and new system is sucessively generated along it. Around Nagpur, the life-time of squall lines was generally 2 to 3 hours and a few of them retained their identity as line even beyond 4 hours. Over Assam, Ray and De (1971) found a large number of lines having span upto 5 to 6 hours.

4. Time of first detection

Seasonwise break-up of the time when these lines were first detected is shown in Table 2. In the premonsoon and monsoon seasons, which together account over 90 per cent of cases studied, nearly 70 per cent of lines formed between 08 and 12 GMT.

5. Length of lines

The length of the echo-lines observed in this study has been shown in Table 3. It was noticed that majority of the squall lines had length between 50-100 nautical miles (n.m.). Interestingly,

TABLE 1 (a)

Distribution of time-lag between first appearance of radar echoes and their orientattion into line

Season	Duration (hr)			
	<1	1—2	2—3	3—4
Winter		1		1
Pre-monsoon	6	8	13	11
Monsoon	7	22	16	5
Post monsoon		2		1

TABLE 1(b)

(b) Distribution of life-span of the echo-lines

Season	Duration (hr)				
	<1	1—2	2—3	3—4	>4
Winter				1	1
Pre-monsoon		4	17	8	9
Monsoon	3	7	23	6	11
Post monsoon		2			1

TABLE 2

Time of first detection (GMT) of the lines

Seasons	Hours (GMT)													
	06—07	07—08	08—09	09—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—20
Pre-monsoon		1	10	16	12	11	6	3	6	5	2	2	3	1
Monsoon	3	3	17	17	14	17	8	1	4	3	1	1		1
post monsoon			5	6	1									
Winter						1		1						

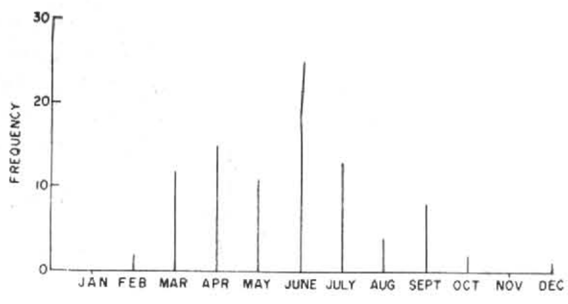


Fig. 1. Monthly distribution of squall lines around Nagpur

it may be seen that a good number of squall lines reached 200 and a few among them even exceeded 200 n.m. in length. From the study of squall lines over Gangetic West Bengal, De (1963) found lines reaching 75 to 120 nautical miles. Battan (1966) also reported squall lines having length greater than 200 miles.

6. Favourable regions of formation

The topography around Nagpur is uneven with Gawilgarh hills in westnorthwest and Satpura range in the northwest extending to northnorthwest as Mahadeo hills (*see*, Fig. 2). The distance of the

TABLE 3

Seasonal distribution of length of the squall lines (n. m.)

Season	Length (n. m.)			
	Upto 50	50—100	100—200	>200
Winter		2		
Pre-monsoon	9	17	8	4
Monsoon	14	26	8	2
Post monsoon	1		2	

mountain ranges vary from 65 to 150 n.m. In the northwest about 120 n.m. from Nagpur, the Vindhya range is situated beyond the Satpuras.

The location of initial formation of the squall lines has been depicted in Fig. 2. Preponderance in the formation in the northern zone can be easily seen. Then, within that zone, the northwest sector seems to be the more favourable region. Squall lines, as may be seen from the figure, have a greater tendency to form within 80 n.m. of Nagpur with larger concentration between 20 to 60 n.m.

7. Movement of the squall lines

An attempt was made to correlate the movement

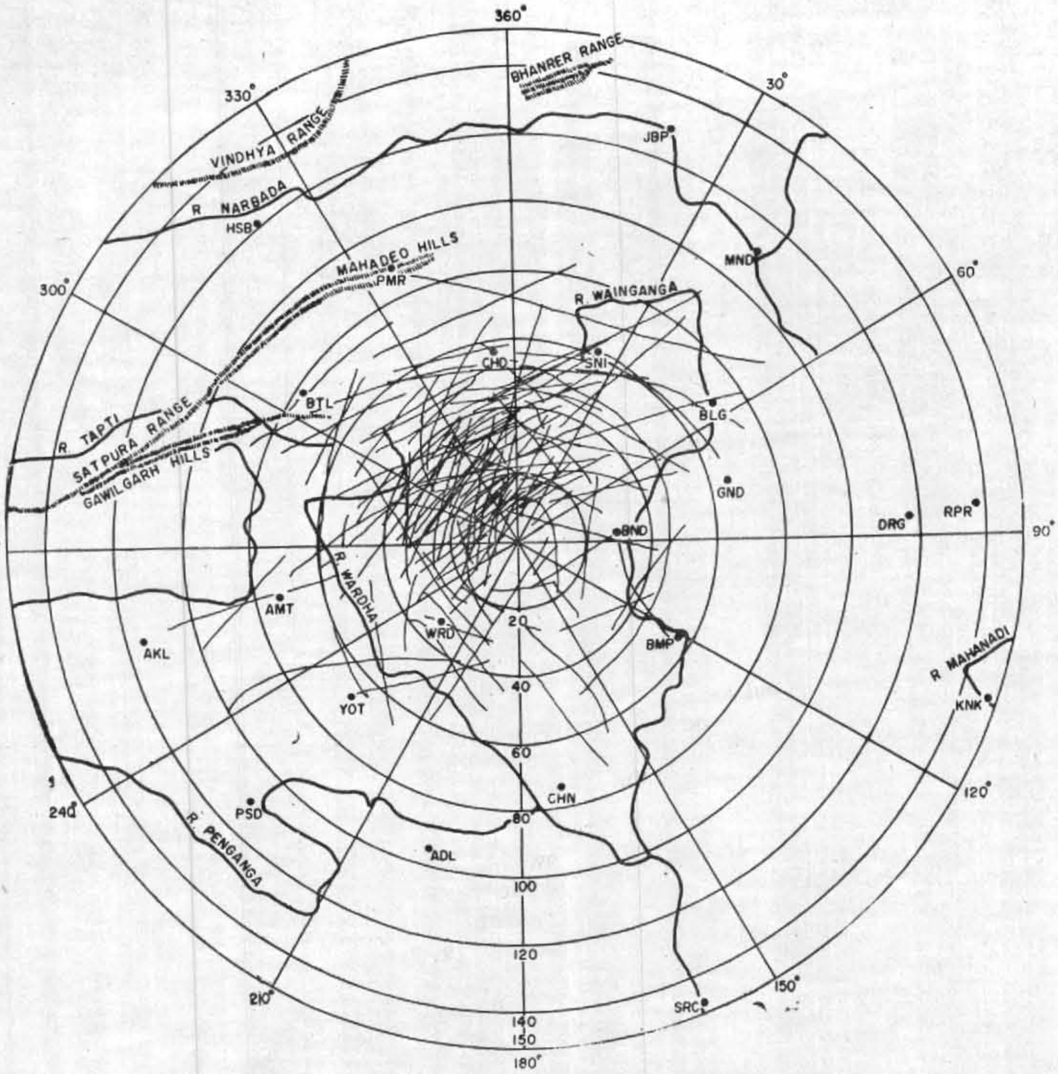


Fig. 2. Favourable regions of initial formation of the squall line

of the lines with the upper winds over the regions of formation. For this purpose upper air charts nearest to the time of formation/movements were considered.

Firstly, an attempt was made to correlate the mean resultant wind of levels 1·5 to 5 km, and the motion of the echo-line. It was noticed that the mean resultant wind does not bear significant relationship with the motion of the lines. Efforts were then made, through correlation analysis to determine if the squall line follow wind at any level. The linear correlation were computed between the different levels and the squall line motion. It was found that correlation coefficient with wind at 3·0 km (700 mb) and 3·6 km were respectively 0·96 and 0·49. At no other levels, the wind bore any correlation whatsoever with the line motion.

On subjecting the coefficients to Students' *t*-test the correlation with wind at 3·0 km was found highly significant, even at 0·001 per cent level of significance, whereas the other coefficient was not significant at the mandatory 0·05 per cent level. Thus it is clear that the 700-mb level is generally the steering level for squall line motion around Nagpur airport.

Although the steering level depends upon the size of the storm and other factors (Brooks 1946), Newton and Kartz (1958) confirmed that the movement of radar echoes are highly correlated with winds at 700 mb. Ligda and Mayhow (1954) also found high correlation between the velocity of echoes from frontal precipitation and winds at 700 mb.

From the available data, the speed of propogation of the lines was computed. The average speed

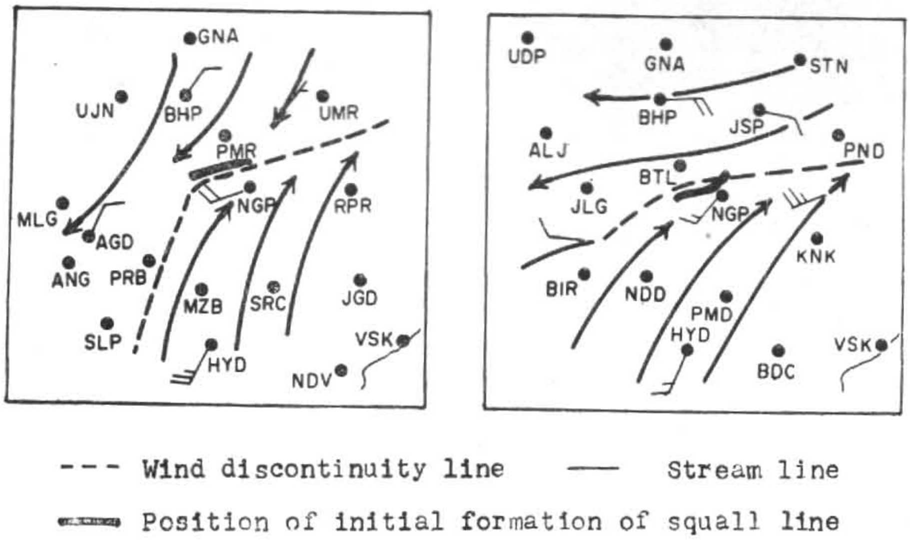


Fig. 3 (a) . Flow pattern at 1·5 km a. s. l. on 18 Mar 1967 at 00 GMT

Fig. 3 (b) . Flow pattern at 0·9 km a. s. l. on 15 Mar 1969 at 00 GMT

of movement was found to be 17 n.m. with a wide range varying from 10 to 30 n.m.

8. Synoptic situations favourable for line formation

With a view to determine the extent to which different synoptic features contribute towards the organisation of echoes into line, the available daily weather charts for days when squall lines formed, were studied and the result presented in Table 4. In the preparation of the table, surface low pressure areas not associated with any upper air circulations were taken separately from these lows (including depressions) which had cyclonic circulations associated with it.

It is worthwhile to point out that during all seasons, low level wind discontinuity or lower tropospheric troughs contribute most towards the development of instability or the echo line. A study of correspondence between the positions of the formation of the lines and line of low level wind discontinuity revealed that in nearly all cases, the orientation of the echo-elements was within 80 to 100 nautical miles from the position of wind discontinuity at 0·9 or 1·5 km a.s.l. Two such instances have been depicted in Figs. 3(a) and 3(b) which clearly demonstrate the importance of low level wind discontinuity in the formation of squall line. The convergence taking place along the discontinuity line perhaps contribute for the alignment of the "squall lines".

Rhea (1966) while defining a 'dry-line' as the surface boundary between maritime tropical air masses and dry air masses, concluded that the immediate vicinity of the dry line is a highly preferred zone of thunderstorms development and squall line formation.

TABLE 4

Contribution of different synoptic features towards formation of squall lines

Synoptic situations	Season			
	Winter	Pre-monsoon	Monsoon	Post monsoon
Surface lows not associated with low level cyclonic circulations		8	5	
Low with cyclonic circulations or depressions		7	15	
Low level wind discontinuity or lower tropospheric troughs	2	22	18	3
High level W'ly trough		1		
No. synoptic situation seen			12	

There appear to be little possibility of line formation exclusively due to upper tropospheric westerly troughs.

9. Squalls at Nagpur and the squall lines

A comparison was made between general direction of movement of squall lines and the direction of the associated squall. The results are presented in Fig. 4. On 33 out of 61 occasions, the two directions coincided; in 16 cases they were within $22\frac{1}{2}°$ and together they accounted for 80 per cent of the cases. The difference exceeded $22\frac{1}{2}°$ in the

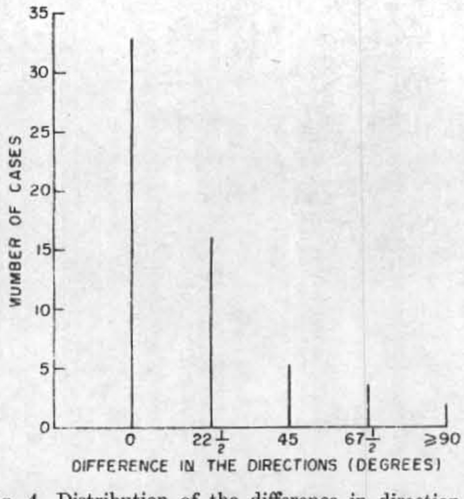


Fig. 4. Distribution of the difference in direction of squall and squall lines

remaining 12 cases, and in a few cases, was as large as 90°. Thus, it appears, the direction of squall, in general, coincides with the average direction of movement of squall line.

10. Forecasting of echo-line motion

The motion (speed and direction) as determined by tracking on radar is perhaps the best indicator of its future movement. As the short term motion may be erratic, any method to forecast radar motion of the squall line should be applied only when the line is under observation for at least an hour. Keeping this in view and noting that the 700-mb wind is a fair indicator of the possible movement as shown elsewhere in this study, the following procedure was adopted for forecasting the arrival of the line :

(*i*) Best possible estimate of the 700 mb wind in the vicinity of the line was obtained from the latest chart.

(*ii*) The component of the wind normal to the smoothed forward edge of the echo-line, *i.e.*, $u \cos \theta$ was computed where u is the estimated 700 mb wind and θ is the angle between 700 mb wind direction and the normal. This computed value is the forecast value of the line.

The forecast values were then compared with the actual normal motion of the squall line. Remarkably, in a substantially high number of cases (57 out of 75) the actual position was within ± 5 km of the forecast position while in 89 per cent of the cases, the actual and computed positions were within ± 10 km. This result, in terms of probability, is significantly large to merit consideration for forecasting. The maximum duration of forecast was of 6 hours.

11. Illustrative example

Squall on 18 May 1962

On this date a low pressure area lay over northwest Madhya Pradesh with a trough aloft upto 1·5 km a s l. At 2·1 km asl, a wind discontinuity passed through Ujjain, Sagar and Sidhi.

Radar observations showed that at 1443 IST (Fig. 5a) isolated cells appeared northwest of Nagpur and showed signs of organisation by 1522 IST (Fig. 5b). By 1605 IST the echoes had not only developed into a line but also moved southeastward and were 25 n.m. from the station (Fig. 5c). As can be seen from observations at 1645 and 1705 IST (Fig. 5d and 5e), the line continued to move towards Nagpur. Nagpur was affected by NW/75 kmph squall at 1721 IST.

Fig. 5f demonstrates that the squall line was definitely not over the station when it was affected by the squall.

12. Concluding remarks

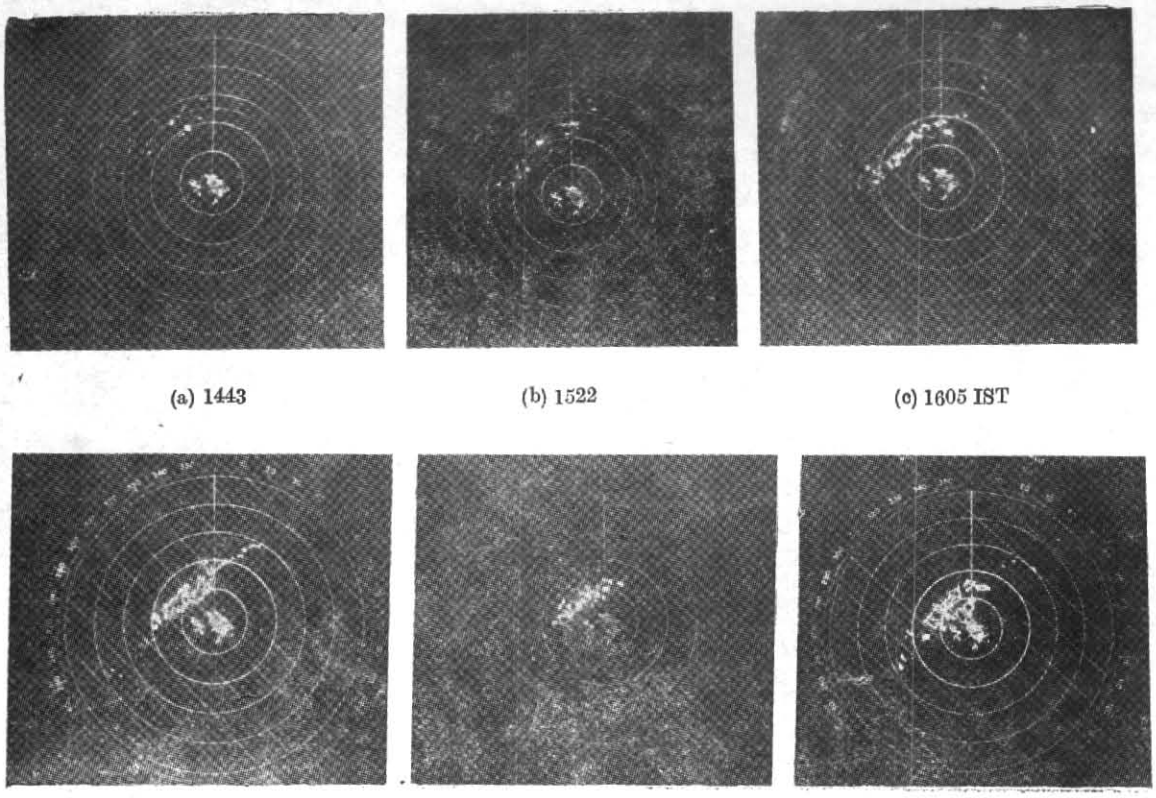
From forecasting point of view, the study brings forth the following interesting results :

(*i*) Squall lines organise from the initial isolated or scattered echoes and take 3-4 hours for alignment. In majority of cases their life period varies from 2-3 hours.

(*ii*) They generally formed between 08 and 12 GMT and between 20 to 60 n.m. northwest of Nagpur.

(*iii*) A fairly high correspondence exist between the movement of squall lines and winds at 700 mb.

(*iv*) The direction in which the squall line



(a) 1443 (b) 1522 (c) 1605 IST

(d) 1645 (e) 1705 (f) 1721 IST

Fig. 5. Sequence showing formation and movement of squall lines of 18 May 1962
(Range : 100 n. miles, tilt : 1° and antenna gain : 4)

approached and the direction of the resultant squall over the station, generally agreed.

(*v*) Wind discontinuity at 0·9 km or 1·5 km asl appear to be a major contributory situation for the formation of squall lines.

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