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Radar observations of cyclones in the Arabian Sea and the Bay of Bengal*

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ABSTRACT. The paper presents features observed on radar, of tropical cyclones in the Arabian Sea and Bay of Bengal. The features discussed are the differences in the organisation of cloud bands, the structure of the central eye, and the distribution of coastal rainfall. Qualitative explanations are offered. Evidence of trochoidal movement of the storm is also presented.

1. Introduction

A network of several S-band radars has been set up on the Indian coastline for tracking cyclones in the Bay of Bengal and the Arabian Sea. The purpose of this paper is to discuss some features of the cyclones tracked by the radars at Bombay and Madras.

Three severe storms were selected for study, of which two were in the Bay of Bengal and one over the Arabian Sea. Fig. 1 shows the locations of the S-Band radars on the Indian coastline, and the tracks of the three cyclones.

2. Synoptic features of the tropical cyclones

2.1. *Severe cyclonic storm over the Arabian Sea (31 May to 4 June 1976)*

This storm developed during the onset phase of the monsoon over the Laccadives islands in the Arabian Sea. Moving north, it gradually deepened and became a severe cyclonic storm on the afternoon of 31 May with its centre at 14.5 deg. N, 71.5 deg. E. Its subsequent track was approximately towards the north with a few undulations (Fig. 1).

The radar echoes are shown in Fig. 2(a)-(c). The track of the cyclone lay between three oil drilling ships off the coast near Bombay on 2 June. The ships were able to provide valuable weather data. A maximum wind of 90 kt and a minimum pressure of 980 mb were reported by the ship *Haakon Magnus* (Fig. 2b). The cyclone ultimately crossed the coast near south Gujarat.

2.2. *Severe cyclonic over the Bay of Bengal (15-19 November 1976)*

The origin of this cyclone could be traced to a low pressure area which moved westwards from the South China Sea into the Andaman Sea on 14 November 1976. Subsequently, it concentrated into a depression on the morning of 15 November with its centre at 10.5 deg. N, 87.0 deg. E. It intensified into a severe cyclonic storm on the morning of 16th with a centre at 13.8 deg. N, 82.5 deg. E. The radar echoes are shown on Fig. 3(a)-(c).

The cyclone had its landfall at a point nearly 200 km north of Madras around mid-night of 16 November. Thereafter, it weakened. Widespread rain was recorded over the coastal areas to the right of the track on 17 and 18 November. Considerable damage due to high winds was reported over a narrow path of width approximately 40 km along the track of the storm after landfall. The maximum winds were estimated to be between 120 and 140 kt.

2.3. *Severe cyclonic storm of Bay of Bengal (11-12 May 1979)*

In its initial stages this severe cyclonic storm was located as a depression on southwest Bay of Bengal near 7 deg. N, 89 deg. E on 5 May 1979. The formation of a depression of this type, at

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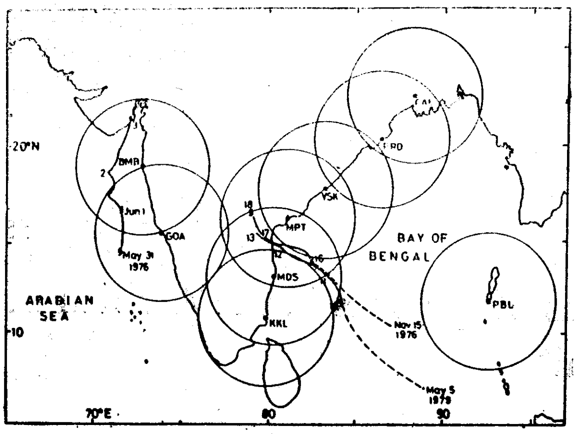

Fig. 1. S-Band radar network of the India Met. Dep. for cyclone warning, and the tracks of the three cyclones

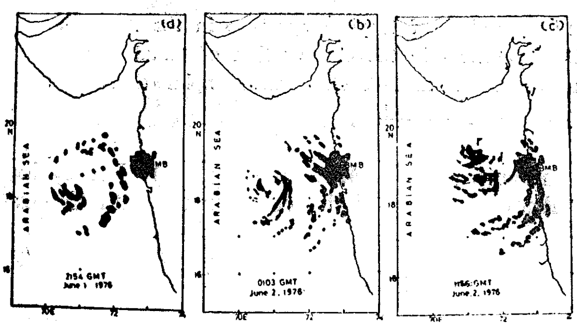

Fig. 2 (a-c). Severe cyclone over the Arabian Sea as seen from Bombay radar (18.8°N, 72.8°E) on 1 & 2 June 1976; winds from oil-drilling ships and coastal observatories for the appropriate hours are indicated

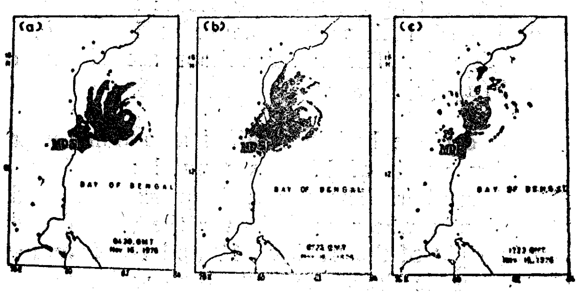

Fig. 3 (a-c). Severe cyclone over the Bay of Bengal as seen from Madras radar (13.2° N, 80.3° E) on 16 November 1976

such a southerly latitude in the beginning of May was unusual. The depression subsequently moved into northwest and developed into a cyclonic storm on 11 May. It intensified further during the day with a core of hurricane winds and moved northwest [Fig. 4(a)-(d)]. Its landfall was at a place near Kavali on the mid-day of 12 May. Although it weakened after landfall, it was severe enough to be a cyclonic storm even 24 hr after crossing the coast.

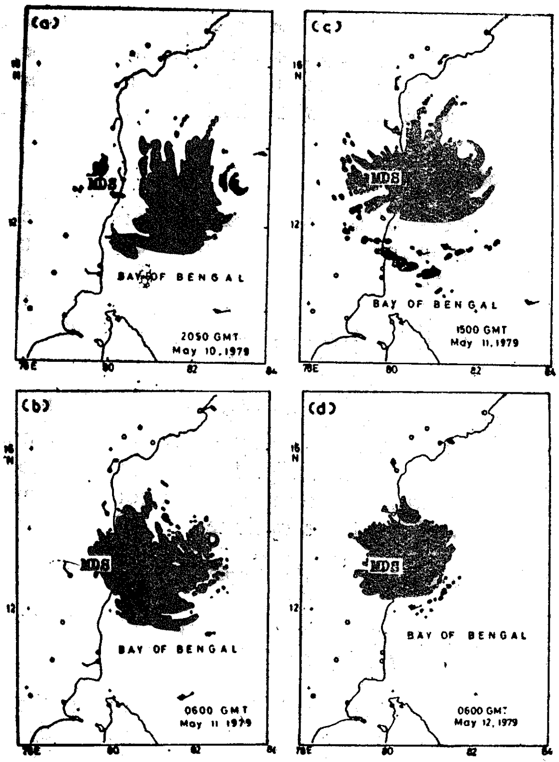

Fig. 4 (a-d). Severe cyclone over the Bay as seen from Madras radar on 10—12 May 1979; winds from ships and a coastal observatories for the appropriate hours are indicated

3. Characteristics of radar echoes

3.1. *Main radar features*

The main radar features normally associated with cyclonic storms (Rockney 1956, Senn & Hiser 1957) are:

(*i*) A pre-hurricane squall line,

(*ii*) Bands of outer convective cells showing cyclonic inflow of air,

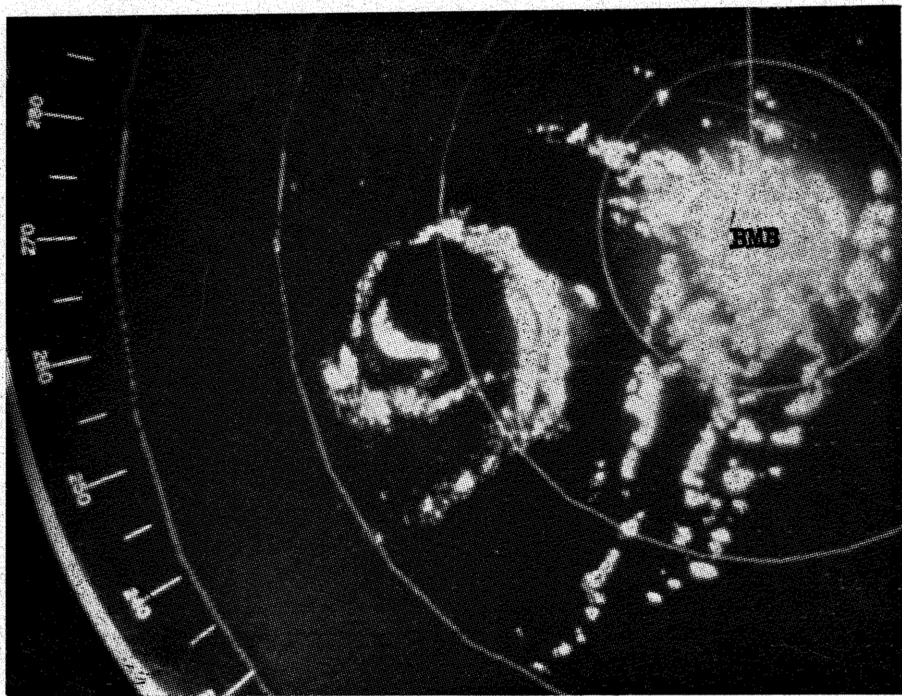

Fig. 5(a). Central region of the Arabian Sea cyclone at 2154 GMT on 1 June 1976

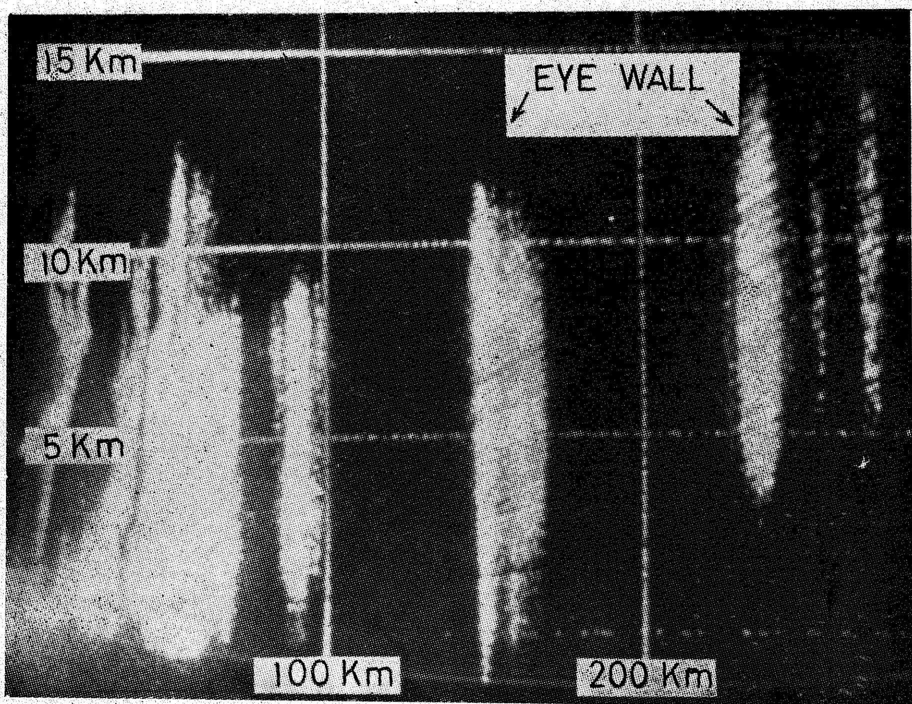

Fig. 5(b). RHI picture of the central region along azimuth 253° at 0111 GMT on 2 June 1976
(Range markers at 100 km intervals and height markers at 5 km intervals)

TABLE 1

Dimensions of the central region or the eye, and the eyewall cloud heights in cyclonic storms

Cyclonic storm	Date (1976)	Time (GMT)	Average dia. of central region/ eye (km)	Maximum heights of wall clouds (km)	
				Nearer side	Farther side
Arabian Sea cyclone of 31 May-4 Jun 1976	01	2205	40	16	15
	02 Jun	0018	47.5	10	13.5
		0111	58	12	14.5
		0215	52	10	12.5
		0314	95	10	14
		1200	—	—	15
Bay of Bengal cyclone of 15-16 Nov 1976	16 Nov	0300	30	9	
		0430	32	18	
		0630	30	16	
		0830	40	12	
		0930	35	—	
		1130	30	21	
		1215	20	20	
		1315	26	20	
		1415	15	21	
		1515	25	17	
		1615	—	12	
		1800	—	9	

TABLE 2

A comparison of the maximum wind speeds and lowest mean sea level pressure as estimated from the satellite picture and actual reported values near the centres

Cyclonic system	Wind speed (kt)		Pressure (mb)	
	Max. estimated from sat. picture	Max. reported by nearest ship or island obsy.	Estimated lowest msl pressure at the centre	Lowest msl pressure reported from nearest ship or island obsy.
(1) Arabian Sea cyclone (June)	70 (2 Jun)	90	970 (2 Jun)	980
(2) Bay of Bengal cyclone (15-17 Nov 1976)	60 (16 Nov)	40	992	—
(3) Bay of Bengal cyclone (11-12 May 1979)	102 (11 May)	40	954	994

(*iii*) A rain shield with spiral bands,

(*iv*) The central eye and eye wall.

The main feature to which attention is drawn here, is the lack of organisation of the cloud bands as far as the Arabian Sea cyclone was concerned. A short sea travel of only 700 km, and the cyclone's proximity to the coast are believed to be the main reasons for lack of organisation [Fig. 2(a)-(c)]. It is well recognised that the structure of the boundary layer above the sea surface determines the vertical transport of momentum into the body of the cyclone. As the cyclone was located very near to the coast, it is felt that the boundary layer could not be so well formed, as was the case for the other two cyclones over the Bay of Bengal (Figs. 3 & 4).

3.2. *The eye and eye-wall clouds*

Table 1 provides the dimensions of the eye and eye-wall clouds observed for two of these three cyclones.

A closed eye was not observed for the Arabian Sea cyclones, but the boundary of the central cloud free zone had the characteristics of a wall-cloud [Figs. 5(a) & (b)]. Although the diameter of the central region was relatively larger than that of the Bay of Bengal cyclone, the Arabian Sea cyclone was no less severe. The observations recorded by an oil drilling ship *Haakon Magnus* are shown in Table 2.

A number of severe cyclones of the Bay of Bengal were studied by Raghavan *et al.* (1980). He did not find any relation between the diameter of the eye and the intensity of the cyclone. In a few cyclones a reduction in the diameter of the eye was observed as they approach the coast (Fig. 3). This is a little surprising, because as the cyclone approaches the coast, there should be a reduction in the absolute angular momentum lost to the sea. In this context, a distinction has to be drawn between the radar observed eye, and a "wind-eye". The latter is determined by the point at which the inflowing spiral winds begin to decelerate and rise upwards. This distinction is relevant, because subsequent examination of the damage after the passage of a cyclone indicates, on a few occasions, that the wind eye continued to be active for a considerable period after the landfall even though the radar observed eye had become indistinguishable. Therefore, it would appear that there is need for caution in inferring a decrease in intensity (Imai 1963) of a cyclone merely because of a reduction in diameter of its eye or its apparent collapse as seen on radar, as the cyclone approaches landfall.

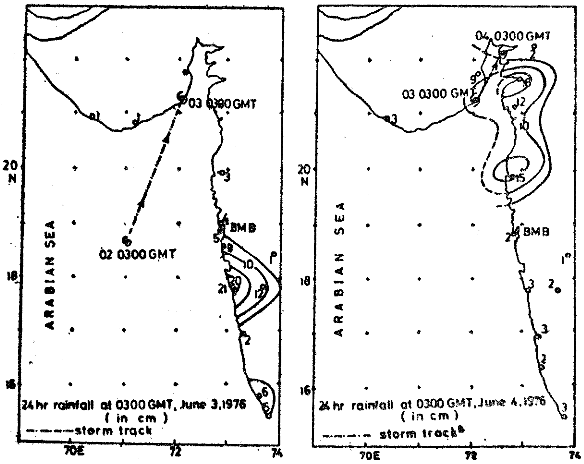

Fig. 6(a-b). Distribution of precipitation along the coast with the passage of the Arabian Sea cyclone (3 & 4 June 1976)

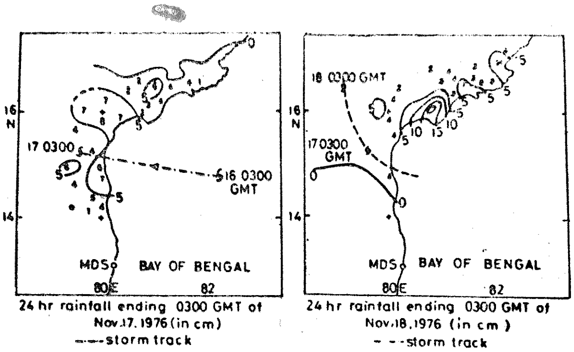

Fig. 8. Distribution of precipitation along the coast with the passage of Bay of Bengal cyclone (17 & 18 November 1976)

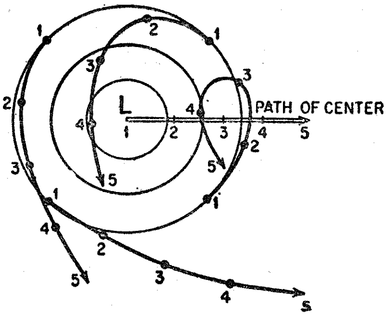

Fig. 7. Typical trajectories in the storm field over an extended interval of time

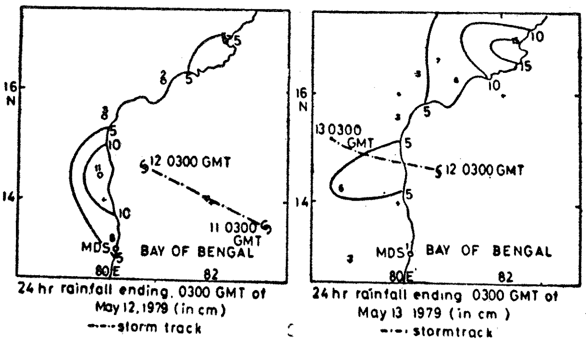

Fig. 9. Distribution of precipitation along the coast with the passage of Bay of Bengal cyclone (12 & 13 May 1979)

3.3. *Distribution of precipitation*

An interesting feature which was observed for the Arabian Sea cyclone (Fig. 6) was that there was little precipitation in the forward sectors, but the main precipitation appeared to be concentrated on its right rear quadrant. These observations were based on raingauges located near the coast. It is possible to seek an explanation for this phenomenon in the trajectories of air parcels in the storm field as idealised by Petterssen (1956) over an extended interval of time (Fig. 7).

Accordingly one could visualise the trajectories of the highly moist air from rear quadrants of the cyclone field meeting the north-south coastline where they suffered orographic ascent in the Western Ghats producing the heavy precipitation.

Figs. 8 and 9 refer to the rainfall distribution on the east coast for the two Bay of Bengal cyclones. Here, the rainfall was slightly more in the right front than in the left front quadrant while the storm made the landfall but with the movement of the system inland, the rainfall maximum shifted to the right rear quadrant. Here again it is possible to visualise the trajectories of moist air released from the rear of the cyclone field causing heavy precipitation at the rear of the system, due to increased frictional drag over land (Mukherjee *et al.* 1966).

3.4. *Movement of the cyclone*

The movement of tropical storms is influenced by internal forces besides an interaction between the cyclonic storm and its external steering current. Discussing one such internal force, Yeh (1950) believes that a storm in the form of a Rankine Vortex will describe a circular path in the absence of steering current. When the latter is present, the interaction between the vortex and the steering current will tend to make the cyclonic vortex move along a trochoidal track with a net progression along the steering current. The amplitude and period of the resulting oscillations will

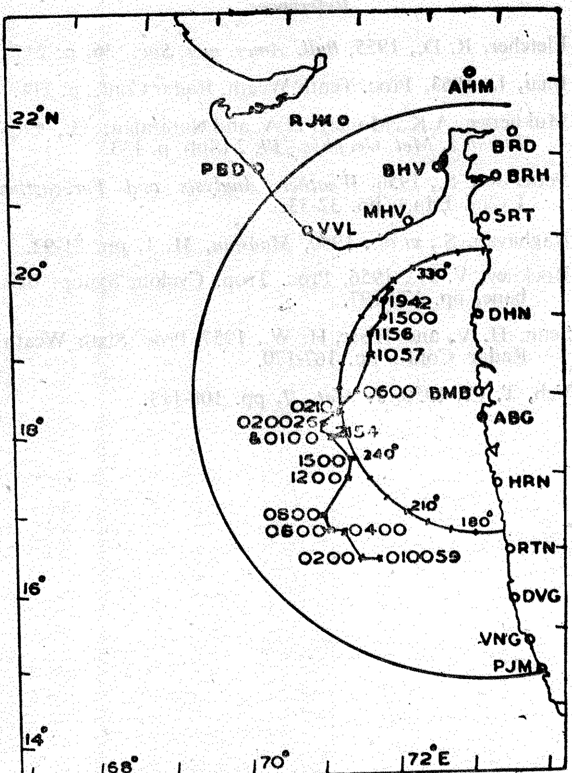

Fig. 10. Radar track of the Arabian Sea cyclone (1 & 2 June 1976)

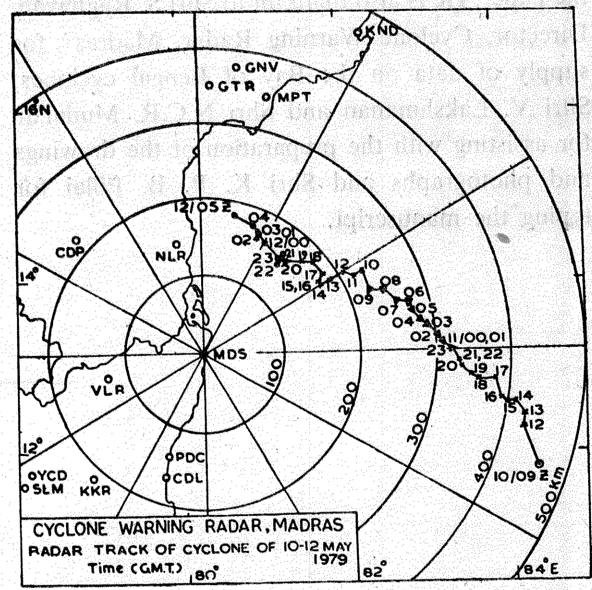

Fig. 11. Radar track of the Bay of Bengal cyclone (10-12 May 1979)

depend upon the basic current as well as the size and intensity of the storm. Small oscillations of the storm centre with an amplitude of 1 deg.-2 deg. (Lat./Long.) and periods of 12 to 48 hours may be expected.

Detection of such oscillating motion has become possible with the advent of cyclone tracking radars. The Arabian Sea cyclone which was tracked with radar for nearly 45 hours (Fig. 10) was found to describe this type of motion. An amplitude of about 1/2 deg. and a period ranging from 17 to 12 hours was observed. The Bay of Bengal cyclone of 12 May 1979 discussed in this paper also exhibits an oscillatory movement (Fig. 11).

4. Conclusions

(1) Arabian Sea cyclones taking a northerly track near and parallel to the west coast appear to have a less organised cloud sructure than the westward moving Bay of Bengal cyclones; however the wind structure is equally severe.

(2) Comparisons of the dimensions of the eye, eye-wall heights and their variation from storm to storm do not lead to any definite conclusion on their relative severity. Studies with finer time scale resolution from ground radar with simultaneous reconnaissance aircraft observations of the inner cyclone field might probably lead to useful conclusions.

(3) The relatively heavy rainfall on the coast in the right rear quadrants of a moving cyclone appears to be due to the long trajectories of the moist air of the cyclone field arriving to the right of the track after a delay of the order of 24 hours and interacting with local topographic features. This information is useful for forecasting of heavy precipitation before and after landfall.

(4) Rare cases of movement of the storm along a trochoidal track, have been observed in this region.

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References

Fletcher, R. D., 1955, *Bull. Amer. met. Soc.*, **36**, p. 247.

Imai, I., 1963, Proc. Tenth Weath. Radar Conf., p. 214.

Mukherjee, A.K., Mooley, D.A. and Natarajan, G., 1966, *Indian J. Met. Geophys*., **17**, 2 (Spl), p. 133.

Petterssen, S., 1956, *Weather Analysis and Forecasting*, I (2nd Edn.), pp. 32-33.

Raghavan, S., *et al.*, 1980, *Mausam,* **31**, 1, pp. 81-92.

Rockney, V. D., 1956, Proc. Trop. Cyclone Synop. Brisbane, pp. 179-197.

Senn, H. V. and Hiser, H. W., 1957, Proc. Sixth Weath. Radar Conf., pp. 167-170.

Yeh, T. C., 1950, *J. Met.*, **7**, pp. 108-113.