551.515.1 267) 551.508 57

On the ellipticity and gyration of the Radar Eye of a Bay Storm

D. VENKATESWARA RAO*

Meteorological Office, Calcutta Airport

(*Received 8 October 1965*)

ABSTRACT. The track followed by a tropical storm, which moved in the vicinity of Calcutta on 21 September 1962, as delineated from radar observations, is described and discussed with reference to the ellipticity of its radar eye in the course of its recurvature around the radar station. The gyration of the major axis of the elliptical eye during recurvature is compared with similar features of hurricanes in the Caribbean Sea discussed by Sadowski. His inference that the gyration of the major axis and its orientation with respect to the storm track may have prognostic significance is not supported by this study. The eye manifested even by a weak storm after it moved overland suggests the existence of sustained descending currents at the centres of weak tropical storms also.

1. Introduction

For want of sufficient ground and airborne radar observations in the vicinity of storm centres, factual information on the size and shape of the eyes of tropical storms is meagre. This is especially so in regard to storms in the Indian Seas. Riehl (1954) opines that the diameter of the eye averages 15 miles in mature storms and approaches 40 miles in large typhoons. Chakravortty (1950) infers that diameters of eyes of storms in the Bay of Bengal range from 7 to 16 miles. Deppermann (1939) expresses the view that weak storms have larger calms than more intense storms. Dunn and Miller (1960), however, report an eye of only 4 m diameter in a weak storm with a central pressure of 994·9 mb and hold that diameters of 20—25 miles are not unusual in mature storms. Simpson (1952) reports an eye of 10 miles diameter in a mature typhoon with a central surface pressure of 895 mb (26·43 in) in the West Pacific. As regards the configuration of the eye, Riehl says that, although it is usually described as circular, it sometimes becomes elongated, while Sadowski (1961) has reported that it displays considerable departure from circularity before and during recurvature over land. Donaldson and Atlas (1963) express the view that such changes may be caused entirely by the filling process. Imai (1963) finds that when a typhoon moves inland, its eye begins to shrink a couple of hours before landfall and complete filling occurs in the following hour. He also finds that, during the period of landfall, the shape of the eye becomes elliptic with the major axis parallel to the coastline. Dunn and Miller (1960) aver that, as a storm passes overland, frictional effects tend to increase the size of the eye and elongate it in the direction of its movement.

Dunn *et al.* (1955) emphasise the need for additional radar research to unravel the general relationships of radar, cloud, precipitation and wind eyes or centres and the physical processes, which go on in each with time. They also find that ground-based radars are useful for this purpose when storm centres pass close to their locations. In view of the diverse views on the eyes of storms held by various investigators, there is a presssing need for collection of documentary evidence on the size and shape of eyes of tropical storms as far as available facilities permit. In a lecture at a joint ICAO/WMO Seminar at Bangkok in 1962 the author described the structural features of the echo-free area on the PPI presentation of a post-monsoon storm of September 1962, which crossed coast close to Calcutta where a Japanese (NMD-451A) 3-cm radar with a peak power output of 225 KW is in operation round the clock. The author has ever since maintained a close watch on tropical storms, which formed in the Bay of Bengal during the period 1963—65 and crossed coast close to Calcutta. Such central echo-free areas were, however, not detectable in any subsequent storms that passed close to Calcutta. From combined aeroplane and surface radar observations, Dunn *et al.* (1955) observe that as hurricane *Dianne*, 16-17 August 1955, moved overland, there was a loosely defined squall eye of 45 to 50 miles diameter but the precipitation-free eye and wind eye were smaller. Although the echo-free area in the centre of the storm under study is patchy and cannot strictly connote an eye in the sense in which it is used with reference to mature hurricanes and typhoons, it suggests sustained subsidence throughout the career of the storm overland around the radar station during its decaying stages and defines the area of minimum return of radar energy with converging spiral bands around it. The expression "radar eye" is employed in this paper to signify the precipitation-free eye. As very few cases of radar echo patterns in monsoon depressions have been documented, it is felt worthwhile to

*We regret to announce the death of Shri D. Venkateswara Rao, Meteorologist at oona on 9 September 1967

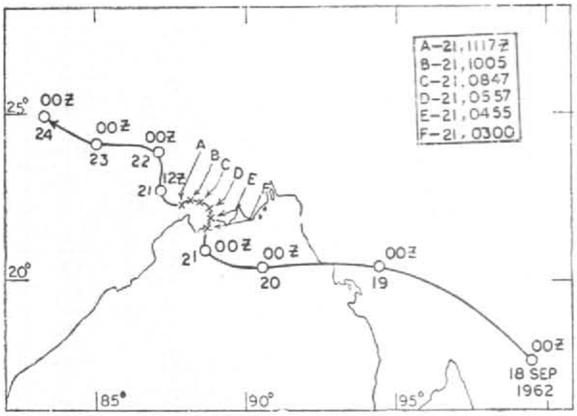

Fig. 1. Track of Bay storm of September 1962

describe and discuss the various features presented by the radar eye of this storm.

2. Synoptic features of the storm

The storm owed its origin to a typhoon in the south China Sea, which crossed Indo-China coast on 16 September 1962 near latitude $16\frac{1}{2}°$ N and subsequently moves as a depression in a westnorthwesterly direction, eventually emerging into the north Bay of Bengal on the afternoon of 19 September. After moving westnorthwestwards upto longitude 88°45′E, it rapidly recurved to the north and maintained its northerly course from 0000 to 0455 GMT when this phase of recurvature was completed. It subsequently recurved to the west and this phase of recurvature was completed by 1117 Z on 21 September. The storm was kept under continuous radar surveillance from 00 to 12 Z of 21 September. Half-hourly radar observations were continued later for the next 24 hours. The best-fit track of this storm following the locus of the radar eye centre is reproduced in Fig. 1.

A vertical time-section displaying the changes of height in gpm of different isobaric surfaces from 1000 to 200 mb for the corresponding period is reproduced in Fig. 2. Height-change values at 400 mb and above 200 mb were not available and the isopleths have been drawn subject to these deficiencies, keeping consistency in space, continuity in time and available wind data in mind. In this diagram are also shown the 24-hour sea level pressure changes in units and tenths of mb together with the surface observations recorded at Dum Dum Observatory at 00 and 12 Z. In Fig. 3 is shown a schematic diagram depicting the range and azimuth of the eye of the storm together with photographs of the radar PPI presentations of the storm during the period 0455 to 1117 GMT of 21 September when it lay closest to Calcutta. The radii or axes of the eye are shown in the figure on an exaggerated scale with respect to the radial distances of the centres of the eye, for convenience of discussion.

A brief description of the storm was given by Bhattacharjee and De (1965), who, however, read wind speed from autographic charts as knots instead of kmph, an obvious error.

The present discussion will be confined essentially to the variation of the size and shape of the eye, its distortion into an elliptical shape and the gyration of its major axis after distortion in relation to the recurvature of the storm track.

3. Discussion

3.1. *The track of the storm and its depth in relation to the radar eye*

The track of the storm as shown in Fig. 1 around the radar station could be identified only with the help of the radar photographs. The synoptic charts were too coarse to reveal it and but for the radar, the true path of the storm would have remained unknown.

The storm was not deep, the central pressure being approximately 986 mb and the pressure profile at Dum Dum showing a drop of only 15 mb. Its depth may have been greater than 20 mb before it moved inland. It is, therefore, of interest that the storm manifested on the PPI-scope a recognizable eye with characteristic spiral bands even after it moved inland. Dunn and Miller (1960) observe that storms in the Caribbean Sea and adjoining sea areas with central pressures of about 995·6 mb become sufficiently organised to possess recognizable eyes, although the wall cloud may not completely surround them. The echo-free region or the area of minimum return of radar energy is not sufficiently well organised in some of the overland radar photographs in Fig. 3, as the wall cloud does not fully surround it. The size of the eye and its range from the radar station cannot be gauged accurately with the radar photographs at the disposal of the author. These have, however, been estimated as objectively as possible, keeping in view the orientation of the spiral rain bands present around the storm centre as well as considerations of continuity based on several additional radar photographs at intervening times, not reproduced here. Dunn and Miller also infer that the frictional effects experienced as a storm passes overland tend to enlarge its eye and elongate it in the direction of its movement. They report several instances of the eye having become as large as 70-90 miles along the direction of motion after moving overland. Due to frictional effects and loss of supply of oceanic heat, storms decay and weaken after crossing coast. The disclosure of a recognizable radar eye even after the storm moved overland suggests that, even during decaying stages, tropical storms or

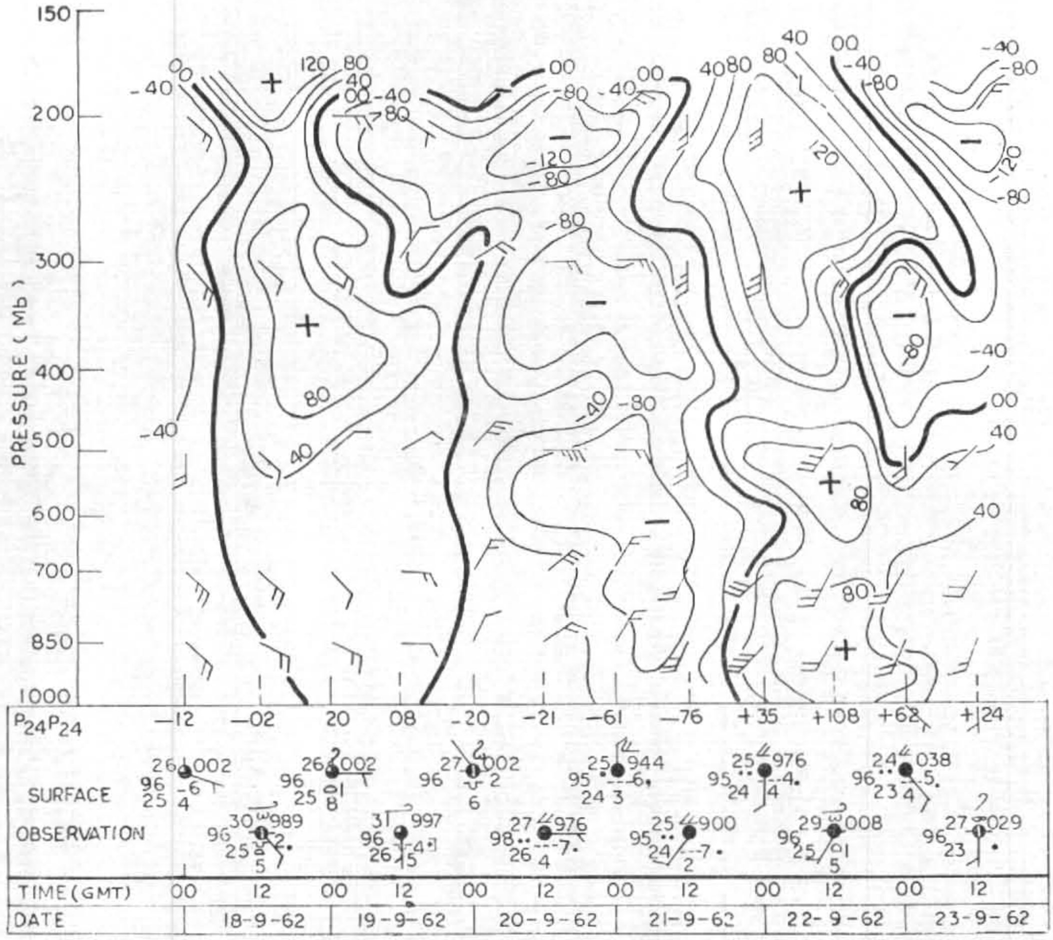

Fig. 2. Vertical time-section of Dum Dum

depressions are characterised by well-marked regions of subsidence at and around their centres. The largeness of the eye further suggests that the eye tends to vary in size inversely with the intensity of the storm.

From a study of several typhoons, Imai (1963) infers that the eye begins to shrink a couple of hours before landfall and complete filling occurs within an hour or so. In the case of the present storm, it was distinguishably present up to a distance of 170 km from the point at which it crossed coast and lasted for about an hour after landfall. Cases are also on record (1961) of the eyes of hurricanes being well-defined up to about the same distance inland from the coast. It is thus seen that tropical storms display identical behaviour after landfall, irrespective of the region where they develop.

The storms in the Bay of Bengal are not organised sufficiently well to display recognizable eyes when their central pressures are not less than 986 mb (29·40 in), which corresponds to a pressure anomaly of about 15 mb. In the case of the hurricanes in the Caribbean Sea also, Dunn and Miller (1960) find that eyes are noticed when the central

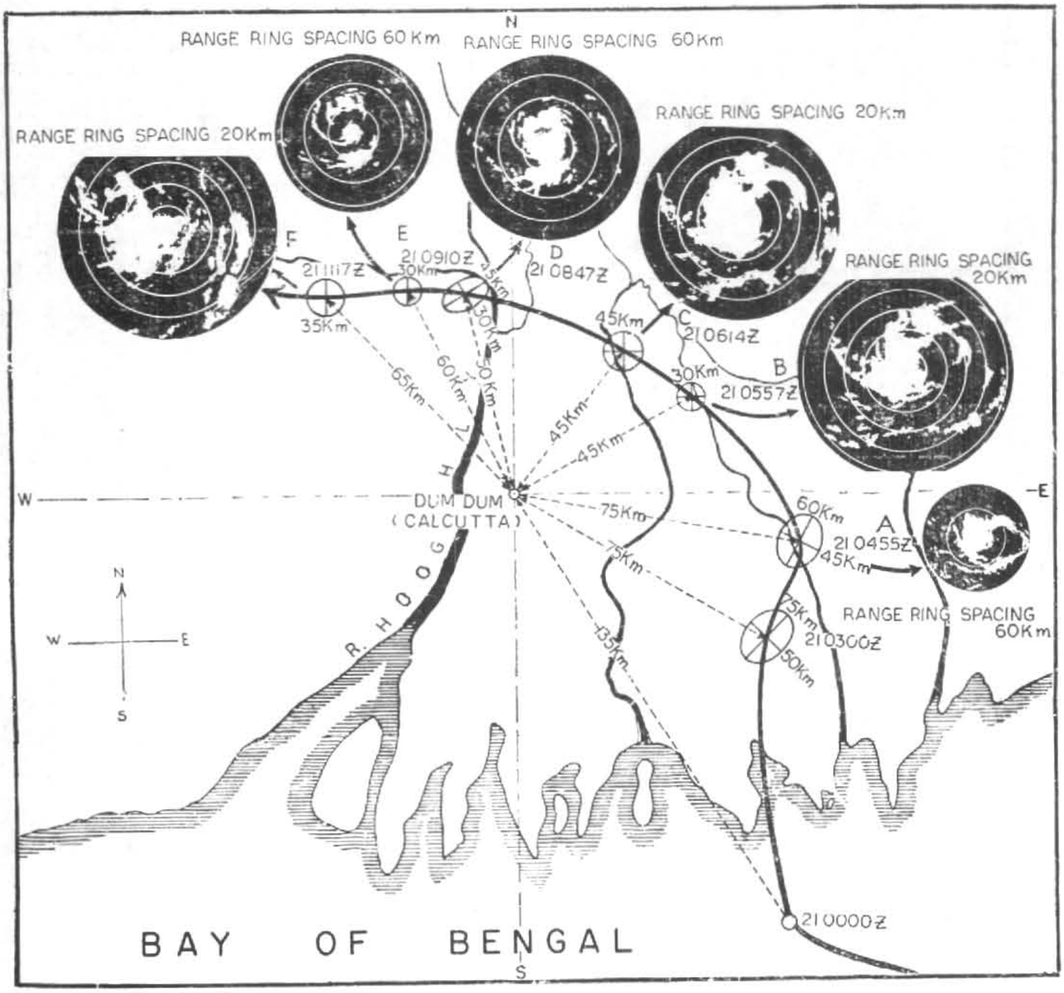

Fig. 3. Schematic diagram showing storm track and selected PPI radar presentations

pressures lie somewhere in the range of 995·6 mb (29·40 in) to 1000·7 mb (29·55 in), which yields about the same pressure defect from normal of 15 mb in the hurricane season. The present study thus demonstrates that when the central pressures in tropical depressions reduce to the extent of 15 mb below normal, both the typhoons and cyclones manifest detectable eyes. Once formed, eyes tend to persist even after moving overland. The concentration of radar echoes in the forward sector and their absence in the rear sector, however, suggests an asymmetrical distribution of vertical motion in the storm field.

3.2. *The development and disappearance of ellipticity of the radar eye*

The eye of the storm under study showed the development of ellipticity before commencement of each stage of recurvature — first to the north and then to the west. After completion of recurvature to the north the eye appears to have regained its circular shape, which it retained till it moved a point to the northeast of the radar station. With the commencement of the second stage of recurvature to the west later, the eye once again became elliptical. As soon as this stage of recurvature was completed, the eye regained circularity, which does not appear to have changed subsequently till the storm moved out of the range of the radar.

Aircraft reconnissance flights show that the eyes of hurricanes and typhoons are small and circular even though the wind field round them is not symmetrical. In the case of decaying storms over land, the eye can no longer maintain its circular shape on account of frictional forces, especially when its track is not straight.

While a storm is stationary or moving along a straight path at a slow speed, constant readjustment of the angular momentum may be presumed to be taking place on the periphery of the eye so as to maintain a persistent circular shape. When the track becomes curved, however, imbalances of momentum can develop, especially overland where frictional forces also become dominant. Such imbalances can distort the circular cross-section of the eye at any isobaric level in the lower troposphere into an ellipse with the major axis oriented parallel to the resultant of the superimposed shearing stresses. The author has made efforts to compute the actual ratios of the major to the minor axes of the distorted eye at different stages in the present case. It has, however, not been felt worthwhile to report the results of the computations as the wind data available were not of the quality or quantity required for the purpose.

3.3. *Gyration of the major axis of the elliptical eye*

A remarkable feature displayed by the elliptical eye of the storm is the orientation of its major axis at an angle ranging from 30° to 40° with respect to the track of the storm. Such features were also displayed by hurricane *Donna*, which moved across Florida during 10-11 September 1960 as well as hurricane *Ione*, which looped across southeast North Carolina, U.S.A. on 19 September 1955 (Sadowski 1961). Documentary evidence of the development of ellipticity and the orientation of the major axis of the eye with reference to the curvature of the storm track is meagre. The inference drawn by Sadowski that the orientation of the major axis may be indicative of the prospect of recurvature of the storm is not borne out by the present study. The gyration of the major axis of the elliptical eye with respect to the storm track appears not to precede but indeed to coincide with the curvature of the storm track and cannot therefore be considered to be invested with any prognostic value. The angle made by the major axis with respect to the storm track also appears to be a circumstance arising from the nature of the asymmetry of the wind field during the decaying stage overland and is, therefore, devoid of any prognostic significance. Dunn and Miller (1960) infer from their studies on tropical storm that, as a storm passes overland, its eye often assumes an elongated shape in the direction of storm movement. Further study of the synoptic-aerological characteristics of distorted eyes of tropical storms with the aid of radar data and satellite pictures is necessary to achieve a better understanding of the relationship between the gyration of the elliptical eye and the recurvature of tropical storms.

4. Conclusion

It is seen from the above discussion that the storms that form in the Bay of Bengal become sufficiently organised to disclose recognisable eyes when their central pressures reduce to 15 mb or less below normal as in the case of hurricanes in the Caribbean Sea. The asymmetrical distribution of radar echoes around the storm centre suggests that the vertical motion around the centre is non-uniform, especially after the storm has passed overland. The development of ellipticity in association with recurvature does not appear to be invested with any prognostic significance, as it seems to occur in association with but not antecedent to recurvature. The finding that the eye assumes an elongated shape in the direction of storm movement is in conformity with the results of study of this aspect of hurricanes by Dunn and Miller.

REFERENCES

Bhattacharjee, P. and De, A. C.	1965	*Indian J. Met. Geophys.*, **16**, 1, p. 81.
Chakravortty, K. C.	1950	*Ibid.*, **1**, 3, p. 252.
Deppermann, C. E.	1939	*Some Characteristics of Philippine Typhoons*, Philippine Weath. Bur., Manila, p. 18.
Donaldson, R. J. and Atlas, D.	1963	*Symposium on Tropical Meteorology, New Zealand*, New Zealand Met. Service, Wellington, p. 423.
Dunn, G. E. and Miller, B. I.	1960	*Atlantic Hurricanes*, Louisiana State University Press, p. 81.
Dunn, G. E., Davis, W. R. and Moore, P. L.	1955	*Mon. Weath. Rev.*, **83**, p. 315.
Imai, I.	1963	*Proceedings of the Tenth Weather Radar Conference*, Washington, D.C., p. 214.
Riehl, H.	1954	*Tropical Meteorology*, McGraw-Hill Book Co., p. 297.
Sadowski, A.	1961	Rep. 50, National Hurricane Research Project, Part I, p. 63.
Simpson, R. H.	1952	*Bull. Amer. met. Soc.*, **33**, p. 286.
—	1961	*Weatherwise*, **14**, 5, p. 193.