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THE RADAR FIXES OF TROPICAL CYCLONIC STORMS

1. A study of the position difference in two radar fixes of two cyclonic storms is made. The two severe cyclonic storms of November 1989 any May 1990 over Bay of Bengal are chosen for the study where, the eye was clearly seen on the radar scope in both the cases and more than two radars could track them simultaneously.

2. The tracking of a tropical cyclone by a Cyclone Detection Radar (CDR) is possible whenever the eye or the spiral band pattern is seen on the radar scope. The S-Band (10 cm wavelength) radars which are used by the India Meteorological Department to track the cyclonic storms by monitoring the position of the eye or using the spiral overlay technique, have an useful range of 400 km.

3. Generally, whenever the eye is identifiable the centre can be fixed to an accuracy of 10 km (Raghavan 1985). But the fast changing characteristics of the eye pose problems in fixing the centre at any time of observation. Also, in viewing the storm by the radars located at different ranges and at different azimuths lead to some uncertainty in fixing the storm centre. In a previous investigation with the data of the three CDRs at Karaikal, Madras and Machilipatnam, Raghavan *et al.* (1985) found that the cyclone centres determined by Karaikal and Machilipatnam radar differed by 15 to 52 km from that of Madras radars, for Sriharikota cyclone of 1982.

4. The eye, sometimes seen partially takes various shapes and sizes. Each storm is unique in its characteristics. The eye, sometimes with its irregular shapes poses problems in identifying the centre (Meighen 1985). But whenever the system is approaching the station even small precipitation echoes become prominent and the eye appears distinct. Besides this, the radiowave propagation characteristics, observational and gridding errors add to the uncertainty in locating the storm centre. Thus, various errors exist in identifying the centre of the storm from a single radar observation itself. So there would be differences in locating the centres by two different radars. Hence attempt is made in the present paper to study the maximum

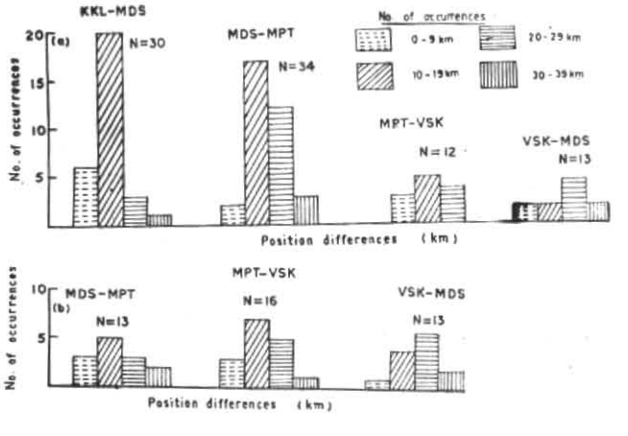

Fig. 1. Histograms for : (a) Machilipatnam cyclone of May 1990, and (b) Kavali cyclone of Nov 1989 for various pairs of radar data. N gives the total number of simultaneous observations compared for the corresponding pairs of the radar data shown in the diagram

deviation in radar fixes of the storm by two radars which simultaneously tracked from two different stations.

5. The type of errors in location of the storm centres can be viewed broadly as instrumental, observational and analytical, given in the following way:

5.1. *Instrumental errors* — The instrumental errors arise out of the electronic circuitry and functioning. Also due to the transmission by a dish antenna which normally has a beam width of about 2 deg. makes the distant echoes seen as overlapping than distinct, introduces additional error. For example, two cloud cells at 200 km range unless they are separated by more than 3 km cannot be located on the radar scope as two distinct cells.

The propagation paths of the transmitted pulse introduces some error in ranging. If there were no atmosphere the radiowave would suffer no banding and hence there is the time delay between transmitted pulse and the echo corresponds to the line of sight distance between the radar and the target. But as the atmosphere becomes rarified with height, the transmitted pulse undergoes refraction with downward curvature. As such the path of the transmitted pulse will not be in a straight line but slightly curved with its concave surface facing earth. This results in two effects, *viz.*, (*i*) locating a target which is slightly of lower height to that calculated from the straight path, and (*ii*) the additional path covered, which is not shown in the range evaluation. The latter part causes more difference between two radar positions of the storm centres at different ranges. So normally the location given by nearer radar gives an accurate position.

One more error is the one arising out of the different propagation velocities due to different air masses along the line of propagation. But this is almost insignificant at closer ranges compared to other errors.

5.2. *Observational errors* — In locating the centre of the storm normally two methods are followed. One is estimating centre by the spiral overlays and other by monitoring the eye of a storm whenever it is identifiable on the radar screen. The eye is seen either partially or fully depending on the intensity and the range of the storms. The radar meteorologist is likely to commit some error in locating the centre depending on the observed echo pattern. When the storm is weak or farther away from radar the irregular eye pattern poses considerable difficulty for the observer to fix the centre.

5.3. *Analytical errors* — This error crops up in scaling on the cyclone tracking chart. Once the centre is located in terms of azimuth and range from the PPI scope, the same is plotted on cyclone tracking chart. The position relocated is transformed in to coordinates as latitudes/longitudes are reported to the first place of decimal for operational use. At this stage the error is limited to 0.1° Lat./Long. which is about 11 km in tropics.

Thus, when various errors are added up there are bound to be some differences between the storm centres given by two radars which are viewing the storm at different azimuthal and range values.

6. *Data* — In the present analysis the data of the severe cyclonic storms with a core of hurricane winds of November 1989 and May 1990 that crossed Andhra coast near Kavali and Machilipatnam respectively were chosen. The former cyclone was located first by Visakhapatnam radar and tracked from a range of 408 km. Subsequently, Machilipatnam and Madras radars followed. Similarly in the case of Machilipatnam storm the positions were first given by CDR Karaikal. Later on, Madras, Machilipatnam and Visakhapatnam CDRs successively tracked the storm.

The eye was distinct in both the stroms although it was open at times. They were simultaneously tracked by more than two radars for several hours thus making the present study possible.

7. The distance of separation in the location of the storm centre by any two radars which is hereafter called as position difference is evaluated in kilometres from the tracking chart on an hourly basis. The number of occurrences of the position difference at various ranges of 0-9, 10-19, 20-29 and 30-39 km are shown in histograms.

8. For the Machilipatnam cyclone of May 1990 the histograms are plotted (Fig.1) for Karaikal-Madras, Madras-Machilipatnam, Machilipatnam-Visakhapatnam and Madras-Visakhapatnam pairs of radar data. Similarly, histograms for Kavali cyclone of November 1989 are shown in Fig. 1 (b).

Table 1 shows the mean, median and modal values of position difference. The results clearly show that the mean position difference ranges from 14.2 to 19.2 km for nearby radars. This value increases to 21.4 km when compared between two distant radars. The median and modal values were found to be below 19.1 km for nearby radars and below 25 0 km for distant radars.

TABLE 1

Statistical distribution of position difference from simultaneous radar observations of storm centre

Storm particulars	Between two adjacent radars (km)			Average (km)	Between two distinct radars (km) VSK-MDS
	KKL-MDS	MDS-MPT	MPT-VSK		
		Machilipatnam cyclone : May 1990			
Mean	14.2	19.2	15.3	16.3	21.4
Median	14.4	19.1	17.0	16.8	24.3
Mode	14.5	17.5	16.7	16.2	25.0
		Kavali cyclone : Nov 1989			
Mean	—	17.6	17.0	17.3	21.4
Median	—	18.0	17.9	17.9	23.3
Mode	—	15.0	16.7	15.9	23.3

From the eye diameters reported by Madras and Machilipatnam radars based on 45 and 27 observations, the average values were found to be 28.7 and 29.1 km respectively for the May 1990 storm. Thus average diameter of the eye from both radars was 28.9 km.

When two radars are tracking the farther one from the storm is likely to commit more error due to the bent propagation paths instead of line of sight propagation. This range uncertainty introduced by this become dominant compared to the other errors contributing for position difference although the individual radar estimate depends on the dimensions and echo pattern of the eye also.

9. Since the instrumental, observational and analytical errors put together can account for an uucertainty of more than 11 km the present values of the position differences appear resonable. The maximum value of position difference below 40 km [Fig. 1(a)] now seen follows a similar observation of Raghavan *et al.* (1985) who observed a maximum deviation of 52 km for the storm in Bay of Bengal. Hence average position differences of 16.3 and 17.3 km for May 1990 and November 1989 storms respectively are within tolerable limits, which is of the order of one radius of the eye.

10. It can be concluded that the position differences in locating the storm centres by two radars viewing the storm eye in different azimuthal directions are of the order of about 20 km.

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