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Structure of the Kakinada cyclone of 6 November 1996

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सार — चक्रवात की स्थिति, गति और उसके बढ़ने की दिशा तथा क्षैतिजीय और उर्ध्वाधर विस्तार का पता लगाने के लिए रडार एक अत्यंत शक्तिशाली उपकरण है। इसके अलावा, रडार के प्रेक्षणों से चक्रवात के केन्द्र के आकार, परिमाण और व्यवहार के विषय में और अधिक महत्वपूर्ण सूचनाएं प्राप्त की जा सकती हैं। चक्रवात का पूर्वानुमान लगाने, विशेष रूप से चक्रवात की तीव्रता के निर्धारण करने के लिए ये अभिलक्षण अत्यंत महत्वपूर्ण निवेश सूचना उपलब्ध कराते हैं। इस शोध-पत्र में, नवम्बर 1996 में गोदावरी के पूर्वी तट पर आए चक्रवात के उपरोक्त अभिलक्षणों को अभिलेखबद्ध करने का प्रयास किया गया है।

5 नवम्बर 1996 की दोपहर में बंगाल की खाड़ी के मध्य में एक चक्रवात बना अगले दिन केन्द्र में हरीकेन पवनों के साथ यह भीषण चक्रवातीय तूफान के रूप में परिवर्तित हो गया। विशाखापट्टनम के चक्रवात संसूचन रडार (सी. डी. आर.) द्वारा इस चक्रवात के बनने की आरम्भिक अवस्था से उसके काकीनाडा के निकट समुद्री तट को पार करने की अवस्था तक की सूचना एकत्र की गई है। इस शोध-पत्र में, समुद्र में चक्रवात के रडार पथ, रडार पर प्रेक्षित किए गए चक्रवात के केन्द्र के परिमाण, आकार और व्यवहार के विषय में चर्चा की गई है। चक्रवात के केन्द्र की भिति की चौड़ाई, अधिकतम परावर्तकता की त्रिज्या और भिति मेघ की ऊँचाई तथा केन्द्र के व्यास के बीच संबंध जैसे अन्य प्राचलों के परिवर्तनों की भी चर्चा की गई है।

ABSTRACT. Radar is a very powerful tool in determining the position, speed and direction of movement, horizontal and vertical extent of the cyclone. Besides, the radar observations can also be expected to provide more vital information on the shape, size and behaviour of the eye of a cyclone. These features are very important input information for cyclone forecasting, especially in assessing the intensity of the cyclone. An effort has been made here to document the above features of a cyclone that struck the east Godavari coast in November 1996.

The cyclone formed over central Bay of Bengal in the afternoon of 5 November 1996 and intensified into a severe cyclonic storm with a core of hurricane winds next day. The cyclone was tracked by Cyclone Detection Radar (CDR) Visakhapatnam from the initial stage of its formation till it crossed the coast near Kakinada. In this paper, the radar track of the cyclone over sea, along with the size, shape and behaviour of the eye as observed on radar have been discussed. The variation of other parameters like eyewall width, radius of maximum reflectivity and wall cloud height and relationship between eyewall width and eye diameter have also been discussed.

Key words—Cyclone, Spiral bands, Eyewall.

1. Introduction

The tropical cyclones forming in Arabian Sea and Bay of Bengal have been discussed by several authors and documented from time to time in various publications. Most of the literature on cyclones in these seas is available in "Mausam" the Journal published by India Meteorological Department. Raghavan and Veeraraghavan (1979) described radar-synoptic study of the Nagapattinam cyclone of 12 November 1977. Raghavan (1990) made detailed studies of the structures of a few tropical cyclones. He discussed core structure and wind and rainfall distribution of tropical cyclones forming in the Bay of Bengal. However, each cyclone differs in many respects from the documented behaviour of earlier cyclones.

The cyclone which developed in the central Bay of Bengal on 5 November 1996, intensified into a severe cyclonic storm with a core of hurricane winds on 6th afternoon. Throughout the day, it moved almost westward and struck the east Godavari coast of Andhra Pradesh by late evening of 6th itself. The cyclone caused a lot of damage to agricultural fields, coconut plants, pucca houses, roads, bridges and various infrastructure. Almost 1000 people lost

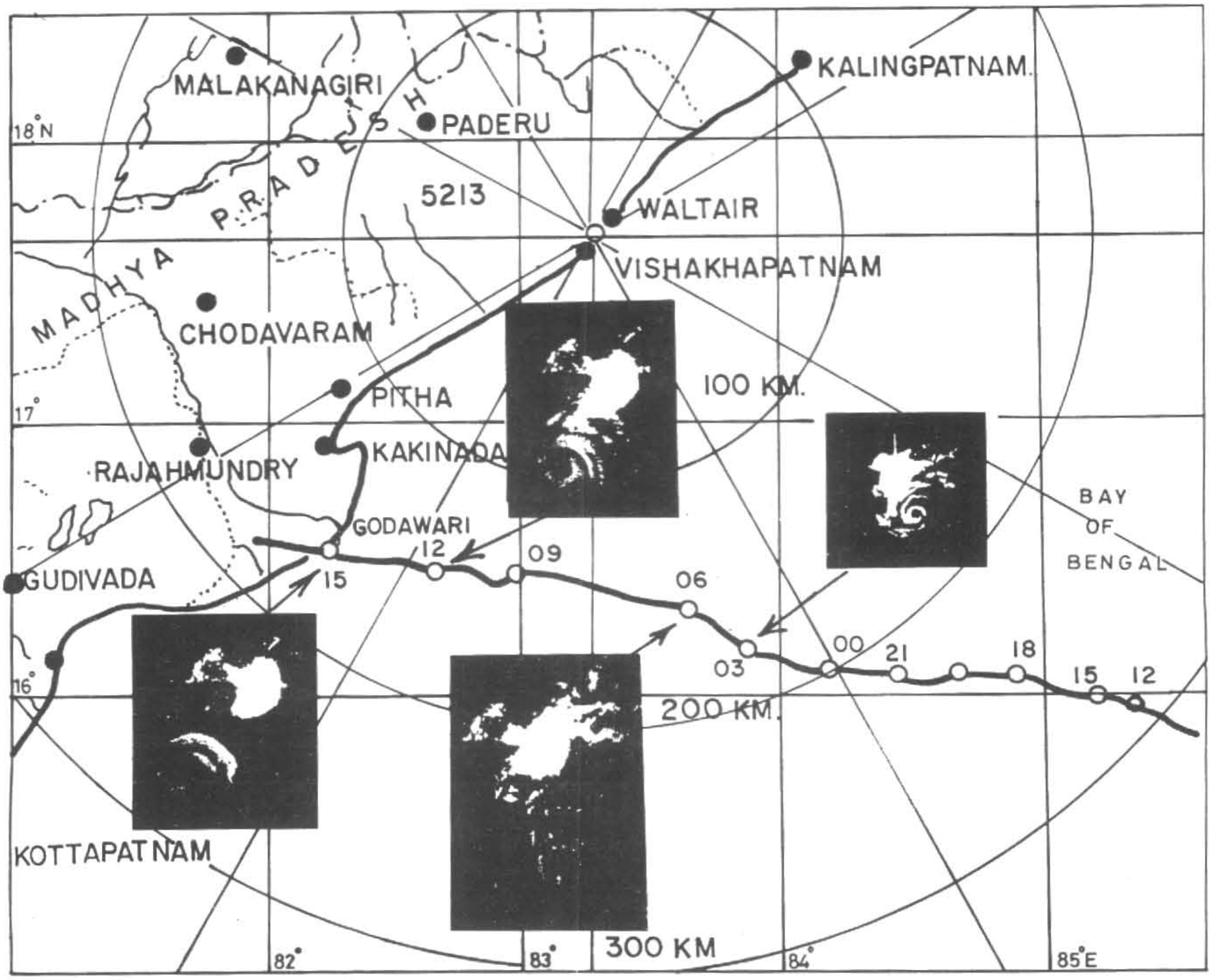


Fig.1. Radar track of Bay cyclone on 6 November 1996

their lives or were reported missing. Cattle also perished in large numbers.

The various features associated with the size, shape and behaviour of the eye of the devastating cyclone as monitored continuously on cyclone detection radar, Visakhapatnam from its formation till landfall, have been discussed and presented in this paper.

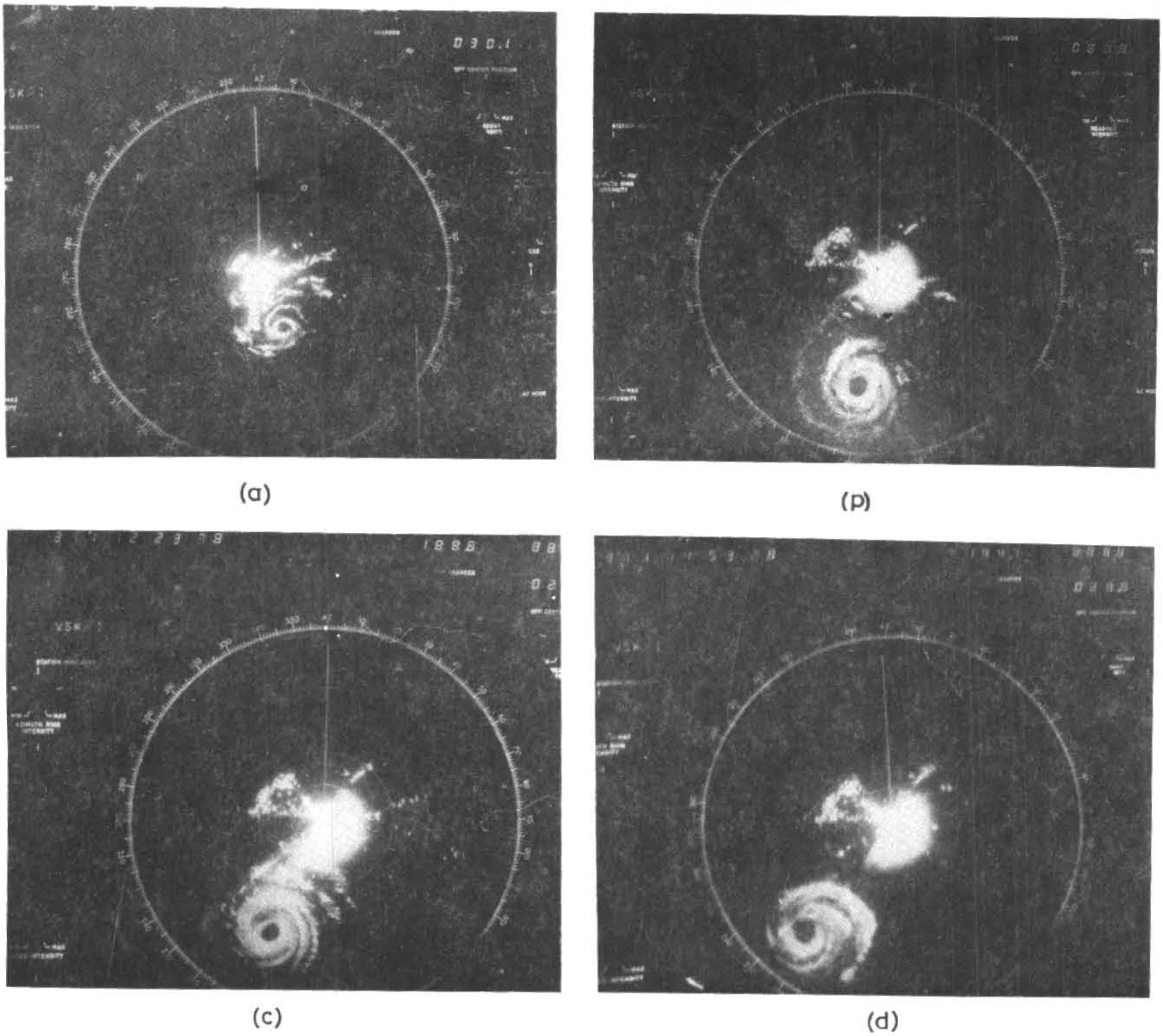
2. Radar observations of the system

In general, pre-cyclone squall lines, outer convection, rain shield area, inner spiral bands and eyewall clouds are associated with a well developed cyclone. It may be mentioned that all the above categories of echoes need not be necessarily present altogether in a cyclone. However, once an eyewall is seen on the radar screen, even partly, it can be easily assessed that the system is a severe cyclonic storm.

2.1. *Radar track*

Fig.1 shows the track of the cyclone determined from the radar observations from 12 UTC on 5 November 1996 to 15 UTC on 6 November 1996 when it crossed east Godavari coast of Andhra Pradesh at about 50 km south of Kakinada. The cyclone initially appeared on the radar screen at about 0900 UTC on 5th. Large convective clouds associated with the formative stage of the cyclone were seen. However, within two to three hours of observations, spiralling features were noticed and it became possible to fix the radar position of the cyclone more confidently at 1200 UTC at 15.9°N, Long. 85.3°E, about 280 km away from Visakhapatnam with the help of two spiral bands.

During 5th-6th night, the cyclone moved in a west-north westerly direction and spiral band features of the



Figs.2. (a-d). Sequence of cyclone photograph on 6 November 1996
(a) at 0254 UTC: Range marker interval 100 km
(b) at 0858 UTC: Range marker interval 40 km
(c) at 1223 UTC: Range marker interval 40 km and
(d) at 1453 UTC: Range marker interval 40 km

cyclone became well organized. The number of spiral bands also increased and a part of the eyewall could be seen at 0100 UTC of 6th at a distance of about 200 km from Visakhapatnam.

Figs. 2 (a -d) show the sequence of some radar pictures of the cyclone. At 0300 UTC of 6th (photograph at 0254 UTC), the eye formation was almost complete with closing of 95% eyewall clouds and inner spiral band of angular length more than 180 degrees. The inner spiral band consisted of almost continuous convective cells. This observation supports the earlier suggestion made by Raghavan (1990) that in Bay of Bengal, the eyewall and spiral band rainfall is almost entirely convective as against the stratiform precipitation just outside the eyewall reported in Atlantic ocean by Jorgensen (1984) and Marks (1985). Another spiral band of broken cells was also observed. The eyewall was thin (less than 10 km wide) but sharp-edged.

At 0600 UTC, the number of nearly closed spiral bands became two with the third one developing in the outer convective region. At this time, the thickness of eyewall became almost double (greater than 20 km) in the southwest sector. This indicated the development of strong convective cloud cells in southwest sector of the storm. The cyclone moved in a west/northwest direction from 0300 UTC and at 0600 UTC, it was located at Lat. 16.3° N, Long. 83.5°E.

At 0900 UTC [photograph at 0858 UTC, Fig.2(b)], spiralling bands became thicker. The inner spiral band made

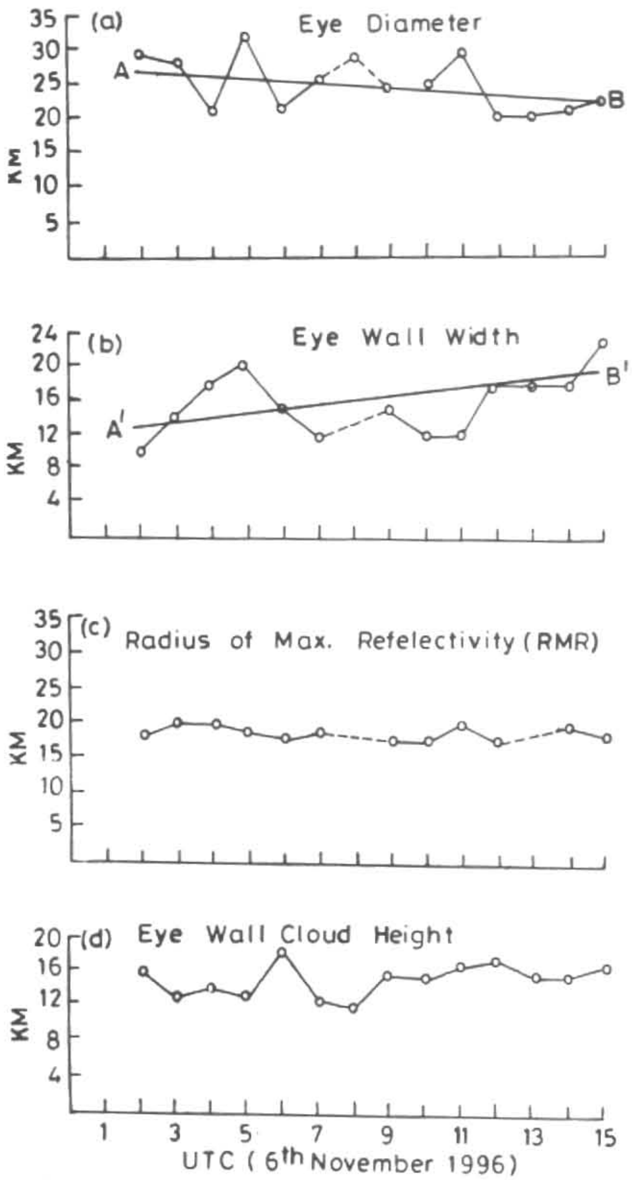


Fig.3. Hour to hour variation of: (a) eye diameter, (b) eyewall width, (c) radius of maximum reflectivity and (d) eyewall height

two continuous revolutions around the eye. In the outer field, another spiral band was also seen. The structure of the eye was nearly circular. The thickness of the eyewall was about 25 km and almost uniform around the centre. The cyclone moved almost westward and at 0900 UTC, was located at Lat. 16.4°N, Long. 83.0°E about 140 km away from Visakhapatnam.

At 1200 UTC [Photograph at 1223 UTC, Fig.2(c)], the spacing between the spiral bands reduced considerably indicating the increase in the angular momentum of the system. Beside the eye, the inner most spiral band was also circular indicating the smaller inflow angle which is expected in an intensified cyclone. The eyewall was thicker in the south sector.

At 1500 UTC [Photograph at 1453 UTC, Fig.2(d)], the outer convective band from west sector disorganized and the spiral band also became ragged. This was the time when the cyclone was in the process of crossing the coast. it was also noticed that total cyclone field became compact and associated clouds were not present even at Visakhapatnam which is about 150 km away from crossing position.

3. Eye diameter, eyewall width, radius of maximum reflectivity and wall cloud height

3.1. *Eye diameter*

Fig.3(a) indicates the variation of the eye diameter from 0200 UTC till 1500 UTC when the cyclone reached very close to the coast. It was seen that the eye diameter was between 25-30 km in the morning of 6th and reduced to 20 km in the late evening. Though hour -to-hour fluctuation in the eye diameter is observed, the apparent decreasing trend of the diameter is clearly visible. This decrease in the diameter, by angular momentum considerations, will result in increase in the wind speed around the eye. Thus, the decrease of the eye diameter as evident from the radar observations indicated intensification of the cyclone in the afternoon of 6th.

3.2. *Eyewall width*

Fig.3(b) depicts the variation of eyewall width from 6th morning till the cyclone struck the coast. It is apparently seen that the width of the eyewall at 0200 UTC was narrower (less than 10 km) and subsequently it became wider (about 15 km) at about 0500 UTC indicating development around the eyewall region. The eyewall width appears to decrease for a few hours (from 0500 UTC to 0700 UTC) but increased after 1100 UTC and became greater than 20 km at 1500 UTC.

3.3. *Radius of maximum reflectivity* (*RMR*)

Fig.3(c) depicts variation of the radius of maximum reflectivity (RMR) in the eyewall region. While the eye diameter can be easily measured, the structure of the eyewall is not clear until contours of different reflectivity within the eyewall are drawn. Further, the reflectivity may not be the same all along a closed ring but it is always possible to see an arc of maximum reflectivity within eyewall by using radar gain control. The radius of this arc can be measured by completing the circle and is referred to as RMR. From Fig.3(c), it is observed that in the present cyclone, the radius of maximum reflectivity was between 15 and 20 km.

Based on observational features, Marks and Houze (1984) and Jorgensen (1984) have established that the maximum radar reflectivity in the eyewall region and the maximum horizontal and vertical winds occur at about the same distance from the centre within a few km (3 to 5 km) from

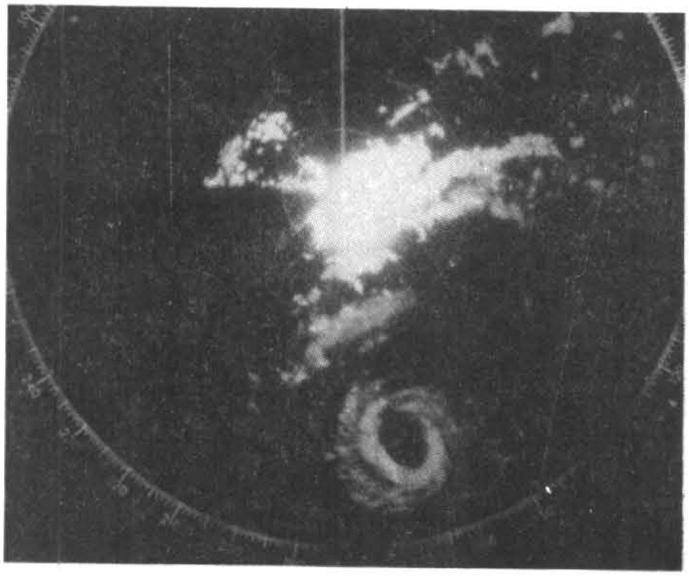


Fig. 4. Cyclone photograph at 0412 UTC on 6 November 1996 indicating ellipticity in the eye structure

each other. Hence, the radius of maximum reflectivity (RMR) can represent approximately the radius of maximum winds (RMW) in the cyclone field. Raghavan (1987) discussed the practical significance of the RMR for use in storm surge prediction.

3.4. *Eyewall height*

Fig.3(d) depicts variation of the eyewall cloud height from 0200 UTC to 1500 UTC on 6th. These heights have been recorded after applying radar beam width correction. The correction due to earth curvature is incorporated in the design of radar itself. Though, there appear to be fluctuations in the wall cloud height till 0900 UTC, later on it remains practically constant indicating maximum development of cloud height of about 16 km or so.

4. Shape of the eye

From the sequence of radar photographs as shown in Figs.2(a -d), it is seen that the eye of the cyclone was almost circular. However during the course of observations at about 0400 UTC on 6th, slight ellipticity of the eye was observed (photograph at 0412 UTC, Fig.4). It is noticed that the elongation of the eye diameter (major axis) is roughly coinciding with slightly changed direction of the cyclone over sea after 0300 UTC (Fig.1). Rao (1967) also observed in a Bay cyclone that the eye of the storm after crossing over land showed development of ellipticity before commencement of each stage of recurvature and after completion of recurvature, the eye appears to have regained its circular shape. However, he concluded that the development of the ellipticity in association with recurvature has no prognostic significance as it seems to occur in association with but not antecedent to recurvature. Dunn and Miller (1960) infer that as a cyclone passes overland, its eye often assumes an elongated shape in the direction of movement. Raghavan and Veeraraghavan (1979) reported slight distortion in the circularity of eye at large ranges due to radar characteristic (beam width effect). However, in the present case, the

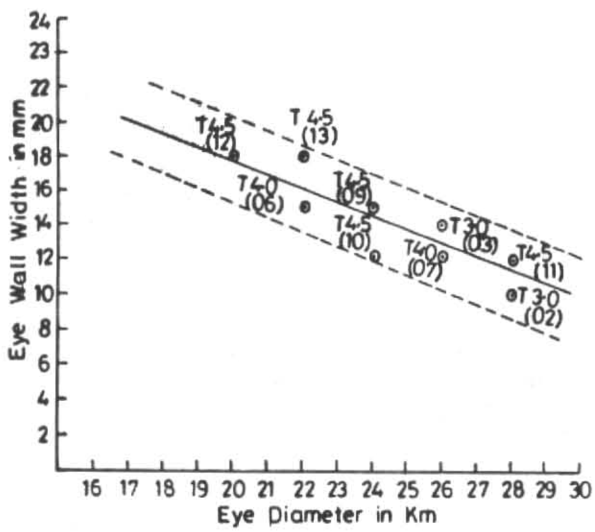


Fig.5. Variation of eye diameter *vs* eyewall width. Time of observation shown in brackets. Satellite T- numbers are also shown

ellipticity observed is over sea and is not significant and therefore the eye is considered more or less circular throughout its course of tracking. The ellipticity noticed in the eye structure for small duration can be considered as an observed feature in association with changed direction of cyclone for future study.

5. Relationship between eye diameter and eyewall width

During real time observation of the cyclone, eye diameter and eyewall width were measured with mobile marker facility available in the radar supplied by Enterprise Electronic Corporation (EEC) at CDR Visakhapatnam. The mobile marker on radar beam was moved to coincide with the inner and outer edges of the eyewall. As most of the time, eye was almost circular, the diameter was also measured by moving the mobile marker on radar beam fixed through the centre of the open space between eyewall. The values of eye diameter and eyewall width, thus obtained are plotted in Fig.5. The time of observation (in brackets) and the corresponding satellite T-numbers are indicated on the points.

From Fig.5, it is evident that the eye diameter and the eyewall width are negatively correlated, *i.e.*, as the eye diameter decreases, the eyewall width increases. The correlation coefficient between the eye diameter and eyewall width is - 0.87. It is well accepted that the decrease of eye diameter indicates intensification of the cyclone and thus the present result shows that the eyewall thickness is positively correlated with intensity. This agrees with the findings of Zhou Ducheng (1985) in case of typhoons affecting China. In some cases, week negative correlation has also been reported by Meighen (1985) and Raghavan (1985). As the cyclone intensifies, the enormous amount of latent heat released in the eyewall region may be utilized either in the process of increase of eyewall height or spreading of eyewall horizontally. In the mature stage when height becomes almost stagnated, there is a more likelihood of spreading of the eyewall in the horizontal scale. This may be a possible reasoning of negative correlation between eye diameter and eyewall width and positive between eyewall width and intensity of the cyclone.

6. Conclusions

From the observations presented here, the following conclusions can be drawn:

(*i*) The size of the eye (diameter) of the cyclone was between 25 and 30 km in the morning hours on 6th and reduced to about 20 km in the late evening when it crossed the coast.

(*ii*) The cyclone had gained the maximum intensity in the evening before crossing coast when the eye diameter decreased.

(*iii*) The eyewall of the cyclone which has caused heavy damage was within 15-20 km from the centre of the cyclone.

(*iv*) In the present cyclone, there appears to be negative correlation between eye diameter and eyewall width and positive between eyewall width and intensity of the cyclone.

The forecaster may find the utility of the above conclusions in assessing the intensity of a cyclone from the radar observations.

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