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Secondary convective rings in an intense asymmetric cyclone of the Bay of Bengal

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सार — उत्तरी हिन्द महासागर के बंगाल की खाड़ी वाले क्षेत्र में 4 से 11 मई 1990 की अवधि में जो भीषण चक्रवातीय तूफान आया उसने मछलीपट्टनम (आंध्रप्रदेश) के निकट भारत के पूर्वी तट को पार किया था। इस चक्रवात के आंतरिक भाग में प्रबल हरीकेन पवनें थी। यह चक्रवाती तूफान हाल ही के वर्षों में इस क्षेत्र में आए सबसे अधिक प्रचण्ड चक्रवातों में से एक था। यह पता चला है कि इस चक्रवात का न्यूनतम समुद्र तल दाब 912 हैक्टोपास्कल था, जो कि इस क्षेत्र में आए किसी भी चक्रवात का निम्नतम प्रेक्षित मान रहा है। इस चक्रवात में कुछ अदभुत संरचनात्मक विशेषताएँ थीं। इस चक्रवात की प्राइमरी 'आईवॉल' के चारों ओर बने सैकेण्डरी संवहनी छल्ले इसकी सबसे अधिक आश्चर्यजनक विशेषता है। भारत के पूर्वी तट पर लगे चार चक्रवात संसूचन रेडारों द्वारा लगभग दो दिन तक ये विशेषताएँ देखी गई। इस शोध पत्र में इन विशेषताओं का विश्लेषण प्रस्तुत किया गया है। इस बात का पता चला है कि चक्रवात के सक्रिय रहने की अवधि में इसकी दोहरी 'आईवॉल' संरचना में आवृतिमय चक्र विद्यमान था, जिसका कारण इसकी बाहरी 'आईवाल' का संकुचन और अन्दर की 'आईवॉल' का क्षीण होना था। इस तरह की अद्‌भुत विशेषताएँ उत्तरी हिन्द महासागर क्षेत्र में आए किसी भी चक्रवात में पहली बार देखी गई। दोहरी 'आईवॉल' वाली अद्‌भुत विशेषताओं से सम्बद्ध कुछ पहलुओं, जैसे, चक्रवात के पुनः मुड़ने अथवा मुड़ने में दोहरी 'आईवॉल' संरचना का योगदान तथा सैकेण्डरी 'आईवॉल' के विकास में भू-अवरोध प्रभाव की चर्चा की गई है।

ABSTRACT. The severe cyclonic storm with a core of hurricane winds of 4-11 May 1990, which crossed the Indian east coast near Machilipatnam (Andhra Pradesh), was one of the most intense cyclones in recent years over the Bay of Bengal region of the north Indian Ocean. The storm reported the minimum sea level pressure of 912 hPa, the lowest observed value for any cyclone in the region. The storm exhibited certain interesting structural characteristics. The most striking feature observed was the formation of secondary convective rings wrapped around the primary eyewall. These features were observed for nearly two days by four cyclone detection radars (CDR) located on the east coast of India. The paper presents an analysis of these features. We find that the double eyewall structure of the storm has undergone a repetitive cycle characterised by the contraction of the outer eyewall and the weakening of the inner eyewall during the life of the cyclone. These interesting characteristics are observed for the first time in the north Indian Ocean for any cyclone. Some of the related aspects of double eyewall features, such as, the possible role of double eyewall structure on the recurvature or turning of the storm and the effect of land obstacle in the development of a secondary eyewall are discussed.

Key words — Tropical cyclone, Double eyewall, Convective rings, Structure, Radar, Eyewall, Bay of Bengal.

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1. Introduction

Convective rings are generally prevalent in very intense axisymmetric tropical cyclones. They are not observed in tropical storms of low intensities. Highly asymmetric and not so intense hurricanes are dominated by spiral bands rather than rings. In most intense storms, the radius of maximum wind (RMW) lies within the eyewall. For a very intense cyclonic storm, the RMW sometimes shifts to the outer periphery of the eyewall. This forces the eyewall to contract. The RMW then shifts just outside the eyewall. At this stage an outer eyewall often forms completely separated from the inner eyewall. Some investigators believe that the appearance of double eyewall marks the end of an episode of intensification, and the storm either weakens or maintains a constant intensity after the formation of this secondary eyewall (Willoughby *et al.* 1982). The inner eyewall slowly weakens and decays as the outer eyewall contracts. This entire process undergoes repetition a few times during the life of the tropical cyclone.

Fortner (1958) was the first to document this feature for typhoon *Sarah* of 1956. Hoose and Colon (1970) and Holliday (1977) also observed a similar cycle in hurricane *Beulah* of 1967 and typhoon *Gloria* of 1974 respectively. Willoughby *et al.* (1982) studied in detail the evolution of various features of the double eyewall cycle observed in hurricanes *Anita* of 1977, *David* of 1979 and *Allen* of 1980. Dvorak (1975) describes circular Central Dense Overcast (CDO) regions surrounded by rings of convective clouds in super typhoons (Vmax > 65 m/s). Rodgers *et al.* (1994) describe outer eyewalls in satellite-borne special Sensor Micro-wave Imager (SSM/I) observations of Atlantic hurricanes. Willoughby (1990) analysed aircraft observations of 19 Atlantic hurricanes during the 1977-88 period and confirmed that the contracting convective rings are common in intense hurricanes, and when the maximum sustained wind exceeds 45 m/s, a secondary eyewall often forms leading to a repetitive cycle of the eyewalls. In the Indian region, there were a few studies on the double eyewall aspects for tropical cyclones of the Bay of Bengal. Raghavan *et al.* (1980, 1989) reported double eyewall characteristics in the Bay of Bengal cyclones of 1977 and 1984. Kalsi (1993) studied double eyewall features in the Bay of Bengal hurricanes of May 1990 and April 1991 in satellite imageries.

The present paper deals with some of the interesting aspects of the double eyewall features observed in the Bay of Bengal cyclone of May 1990. The cyclone gave an excellent opportunity, for the first time in the north Indian Ocean (NIO), to study the double walled eye features observed over a period of two days.

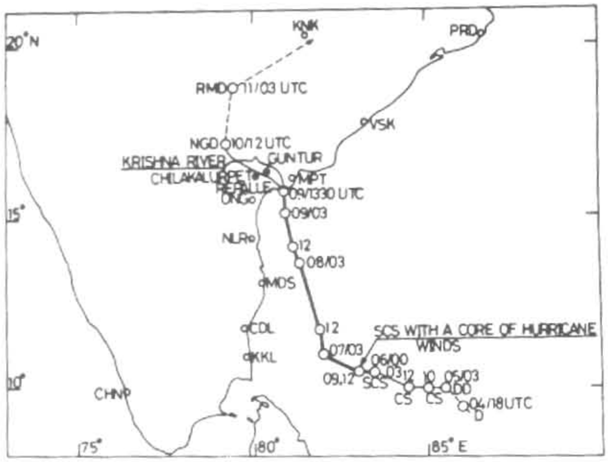


Fig. 1. Best-fit track of the cyclonic storm of 4-11 May, 1990.

2. A brief history of the cyclone

A low pressure area concentrated into a depression in south Bay of Bengal around 2100 UTC of 4 May 1990 and intensified into a deep depression by 0300 UTC of 5 May. Moving westwards it became a cyclonic storm by 1000 UTC of 5 May. Moving in a northwesterly direction it further intensified into a Severe Cyclonic Storm with a core of hurricane winds [SCS (CHW)] by 0300 UTC of 6 May and by 7th morning it was located 250 km east of Karaikal. From this position onwards it moved north-northwestwards and was located about 150 km northeast of Madras on 8th morning when it reached its peak intensity (T-6.5). The system maintained hurricane intensity, from 6th morning onwards till it crossed the coast of Andhra Pradesh at Krishna river estuary about 45 km south of Machilipatnam around 1330 UTC of 9 May 1990. On land it moved northwestwards and weakened into a cyclonic storm by 10th morning. It moved further north and weakened into a depression the next day. Fig. 1 gives the best-fit track of the cyclone.

3. The Data

Radar observations of the May 1990 cyclone reported by the cyclone detection radar (CDR), Madras, have been utilised in addition to the Indian National Satellite (INSAT)-1B data, and the synoptic observations.

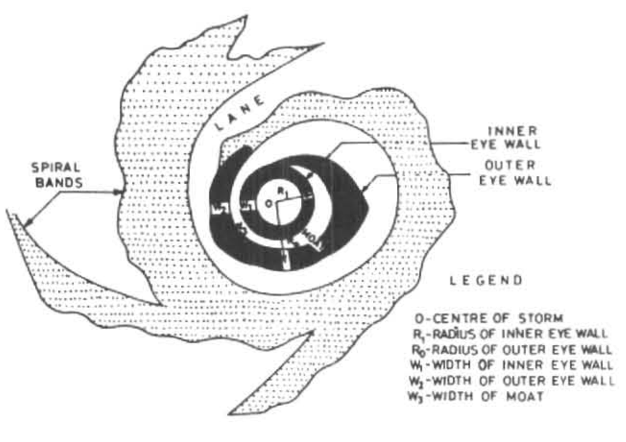
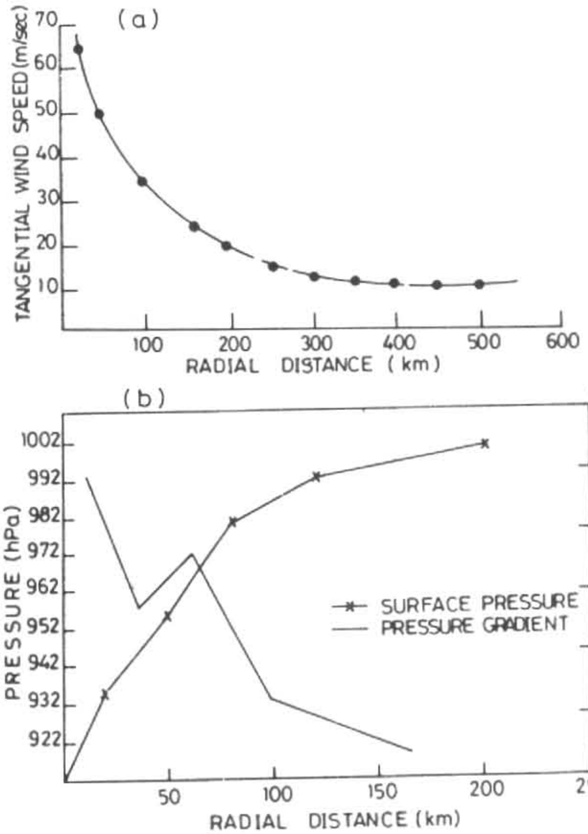


Fig. 2. Depiction of double-eyewall features in the May, 1990 cyclone observed on the PPI scope of CDR, Madras

To study the different characteristics of the double eyewall features in the storm, hourly observations in different modes, such as, the Plan Position Indicator (PPI), the Range Height Indicator (RHI) and the Iso-echo modes have been carefully analysed. The diameters of eyewalls, their widths and the width of moat (the clear region between the two eyewalls) have been measured from the hourly PPI photographs. The diameter of the eyewall is taken as the mean of major and minor axes of its inner-most periphery. Similarly, the mean width of eyewall or moat is taken as the mean of the broadest and the thinnest widths. All the PPI photographs of CDR Madras and Machilipatnam presented in this paper are taken with a range of 200 km and the range marker interval of 40 km. The RHI photographs are taken with 200 km range and 20 km height. The height and range markers in RHI photographs are separated by 5 km and 40 km respectively. Iso-echo mode photographs of CDR Madras are taken with 500 km range. These are obtained by applying approximately 37 dBz reflectivity attenuation at the receiver. Fig. 2 shows a depiction of various features of double eyewall structure observed on PPI scope of CDR, Madras.

4. Surface wind and pressure observations

With the advent of technological advancement in terms of the geostationary satellite and coastal radars in the north Indian Ocean, there has been considerable improvement in the accuracy of cyclone positioning and tracking. This has led to improved warnings which, in turn, resulted in significant reduction in ship observations in the area close to storm's inner core.



Figs. 3(a&b). (a) Composited surface wind profile based on ship data and (b) surface pressure and pressure gradient profiles based on the data from the ship "Vishwamohini" and other ships in the neighbourhood of cyclone's centre.

During the course of movement of the May 1990 cyclone over the Bay of Bengal, a ship called "Vishwamohini" was caught in the cyclone's inner core due to the failure of the telecommunications with the coastal radio station. The ship was reported to have crossed through the centre of the storm nearly at the same time when the latter was at its peak intensity, but miraculously escaped severe damage and loss of life. The ship provided invaluable data of surface wind and pressure within the cyclone's inner core.

Figs. 3 (a&b) are the profiles of composited surface wind and pressure reported by the above ship and other ships in the vicinity of the cyclone. A total of 27 ships observations were available in the region within 300 km from the storm's centre for the composited profiles. The ship "Vishwamohini" reported minimum sea level pressure of 912 hPa, which was the lowest value ever recorded by any cyclone of the north Indian Ocean, and the estimated maximum sustained surface winds were 135 kt. The cyclone size taken as radius of 17 m/s gale force

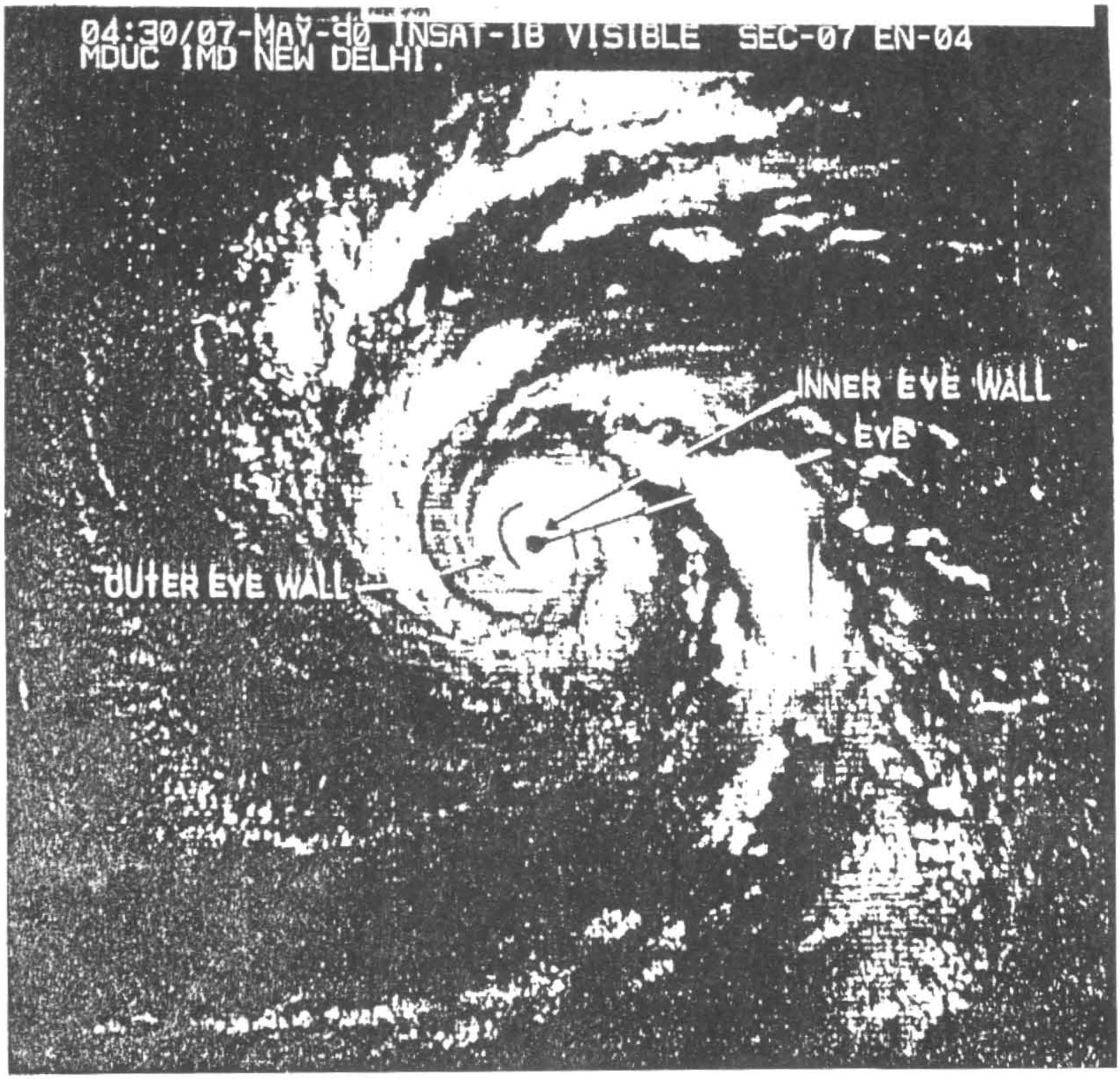


Fig. 4. INSAT-IB visible imagery at 0430 UTC of 7 May, 1990

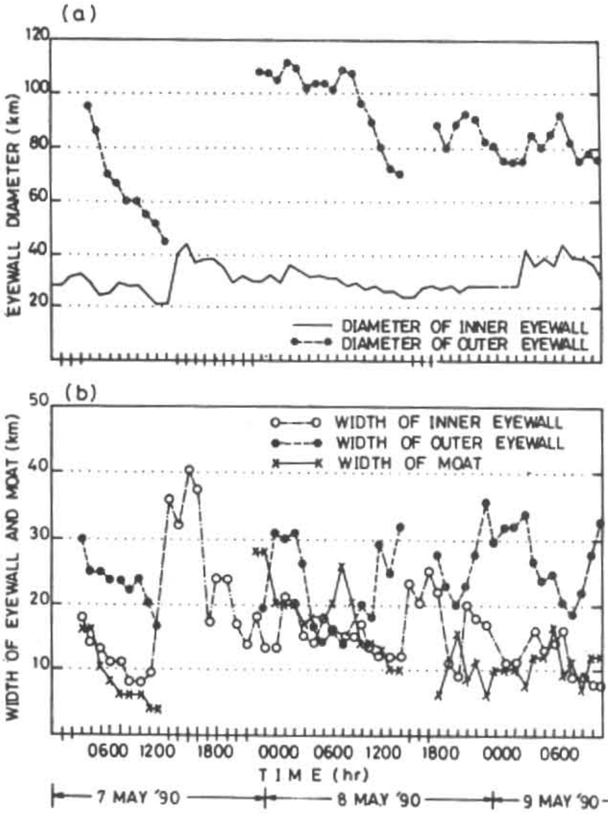
wind (Merrill 1984) was of the order of 225 km. The Outer Core Strength (OCS) defined as the average gale fore winds within the radii of 100 and 300 km from the storm's centre (Merrill 1984) was of the order of 20 m/s. A steep fall in the surface pressure was observed in the inner core region from a value of 980 hPa at 80 km to 912 hPa at the centre (Fig. 3 b), indicating a mean pressure gradient of 0.85 hPa/km. The maximum pressure gradient of 1.12 hPa/km was seen within the inner eyewall region. Beyond 80 km distance the pressure gradient decreases to the value of about 0.16 hPa/km.

5. Radar observations

Although, the system was tracked by the four cyclone detction radars located at Karaikal, Madras, Machilipatnam and Visakhapatnam as and when the storm came under their survillance, the CDR, Madras tracked the storm for the longest period, starting from the morning of 7 May to a little after its landfall in the evening of 9th. The CDR, Machilipatnam also monitored the cyclone for more than 24 hours from the forenoon of 8th to the evening of 9 May 1990. The radar observations reported by the CDRs, Madras and Machilipatnam alone are discussed here. The double eyewall characteristics shown by the storm, have been much better captured by these radars compared to other two. However, these features have been independently confirmed from observations reported by other two CDRs also.

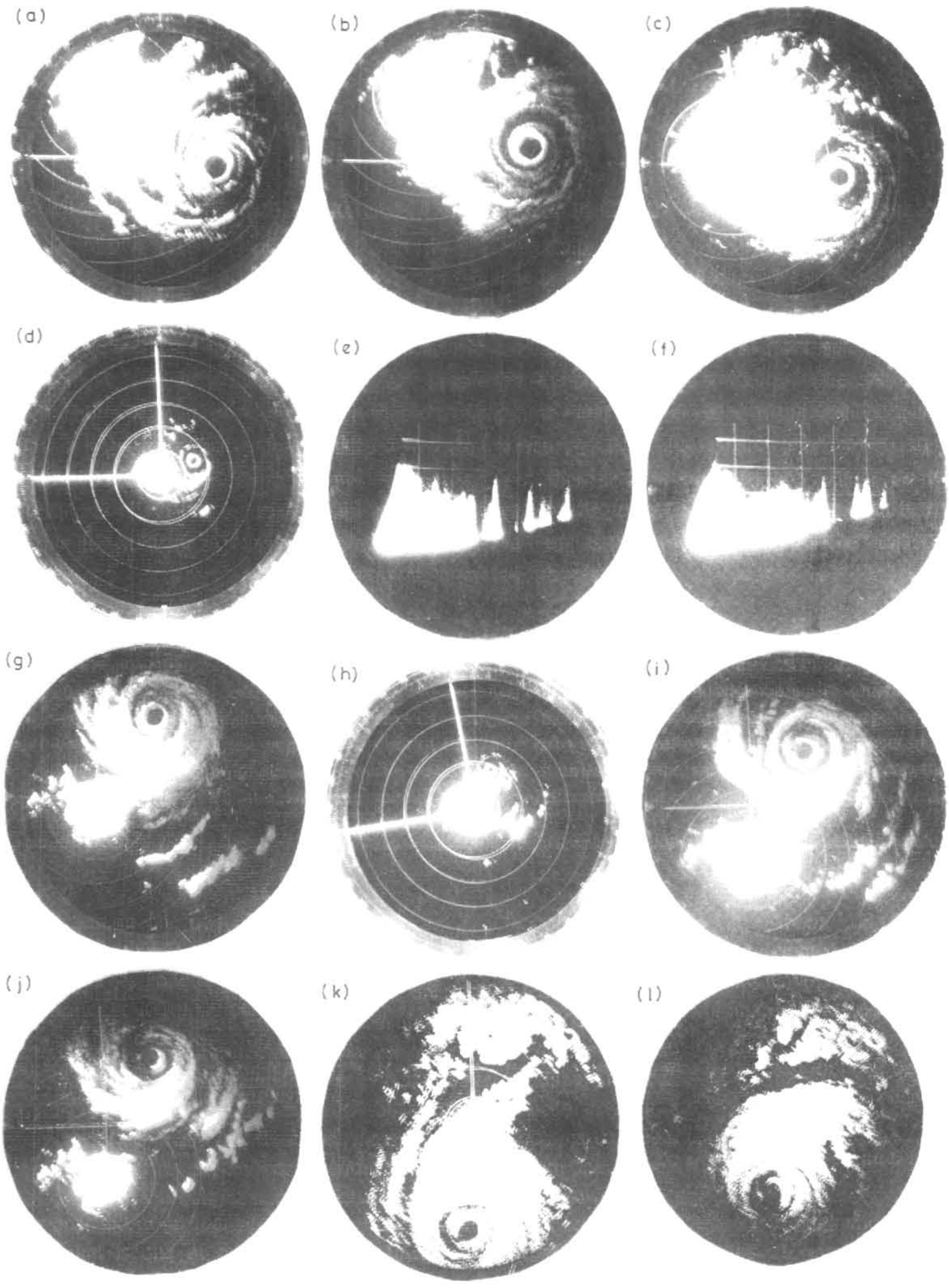
5.1. *Observed changes in the eyewall characteristics*

From its genesis on 4 May till the morning of 6 May, the storm has shown gradual intensification from T-1.5 to T-4.5. During 0600 UTC to 1900 UTC of 6 May, the cyclone maintained a constant intensity (T-4.5). From then onwards the storm has shown rapid intensifiation of T-1.5 in just $9^1/_2$ hours between 1900 UTC of 6th (T-4.5) and 0430 UTC of 7th (T-6.0). It was after this episode of rapid intensification that the cyclone detection radar stations at Karaikal and Madras observed the double eyewall more or less simultaneously on the morning of 7th. The two eyewalls, though not seen completely on the PPI scope due to range limitation, yet were found to be well separated and distinct. The observations from the Indian National Satellite (INSAT)-1B also confirmed the presence of two distinct eyewalls in the cyclone. Fig. 4 is the INSAT-1B imagery (visible) at 0430 UTC of 7 May 1990.



Figs. 5(a&b). Variation in (a) the eyewall diameters and (b) the width of eyewalls with time during 7-9 May 1990.

Subsequently, the inner eyewall showed partial decay and was undergoing fragmentation while the outer eyewall was moving closer towards the inner one from 0800 UTC to 1400 UTC. By 1400 UTC the outer and the inner ones almost merged with each other. This agrees well with the satellite observations indicating merger of the two eyewalls around 0900 UTC of 7 May (Kalsi 1993). The CDR, Karaikal's observations also confirm this. Fig. 5 (a) depicts the hourly variation of the diameters of inner and outer eyewalls. The break in the outer eyewall graph shows absence of this eyewall during that period. Fig. 5(b) shows the hourly variation in the widths of the two eyewalls and the moat area during the same period. It may be seen from the Figs. 5 (a&b) that the diameters of both the eyewalls have decreased considerably during this period. The widths of inner eyewall and the moat also decreased during the above period. The diameters of inner and outer eyewalls decreased from 29 and 95 km at 0500 UTC to 21 and 45 km at 1300 UTC respectively. Widths of inner and outer eyewalls and the moat decreased from 18, 30 and 16 km at 0500 UTC to 4, 17 and 4 km at 1300 UTC respectively. It is important to note that the storm



Figs. 6(a-l). PPI photograph of CDR, Madras at (a) 1753 UTC of 7 May 1990; (b) 2044 UTC of 7 May 1990; (c) 0041 UTC of 8 May 1990 [Range=200 km, Range marker interval = 40 km]; (d) Iso/Echo (37 dBz reflectivity attenuation) photograph of CDR, Madras at 0546 UTC of 8 May 1990 [Range = 500 km, Range marker interval = 100 km]; RHI photograph of CDR, Madras at (e) 1155 UTC of 8 May 1990; (f) 1459 UTC of 8 May 1990; (g) 1748 UTC of 8 May 1990; (h) 1741 UTC of 8 May 1990; (i) 2051 UTC of 8 May 1990; (j) 0113 UTC of 9 May 1990; [Range = 200 km, Height marker interval = 5 km, Range marker interval = 40 km]. PPI Photograph of CDR, Machilipatnam at (k) 0003 UTC of 9 May 1990 and (l) 0602 UTC of 9 May 1990 [Range = 200 km, Range marker interval = 40 km].

maintained a constant intensity of T-6.0 during the period of $17\frac{1}{2}$ hours from 0430 UTC to 2100 UTC.

Subsequent to the merger of inner eyewall, however, the storm showed intensification as the intensity increased to T-6.5 at 2200 UTC of 7th. This is in close agreement with Willoughby *et al.* (1982)'s findings that while the formation of the double eyewall arrests further intensification of the storm, the intensification may resume once the inner eyewall has dissipated or weakened. After the weakening/merger of the inner eyewall, the second eyewall contracted inwards rather rapidly and took the position of the inner one. The width of this eyewall (outer one) increased progressively to 36 km at 1700 UTC from 17 km at 1300 UTC. Thereafter , the inner most spiral band has shown some tendency of its detachment from the eyewall. Around 1800 UTC the width of the eyewall reduced to about 17 km and the clear region outside the eyewall has shown slight widening. These developments indicate that the formation of a secondary eyewall is in the offing. The diameter of the inner eyewall, although practically unchanged till 1800 UTC, has shown gradual contraction. Figs. 6 (a&b) are the PPI photographs at 1753 and 2044 UTC of 7th depicting the formation of an asymmetric double eyewall. By 2200 UTC, the first outer spiral-band is seen to have separated from the inner eyewall and by 0041 UTC of 8th more or less two separate but asymmetric eyewalls could be identified [Fig. 6 (c)]. The 0548 UTC photograph shows that both the eyewalls are very well formed. Iso-echo photograph (with 37 dBz reflectivity) of 0546 UTC of 8 May clearly shows presence of two well formed eyewalls [Fig. 6 (d)].

After the formation of secondary eyewall, there was a sequential contraction of both the inner and the outer eyewalls. Alongwith such a contraction the width of the moat also decreased. While the width of the inner eyewall showed a decrease perhaps due to isolation and lack of adequate moisture feed, the width of outer one has initially shown sharp decrease but later on shot up to the original value. These developments took place between 0200 UTC and 1400 UTC of 8 May. This is shown in Fig. 5 (b). Fig. 5 (a) shows that the inner eyewall diameter of the storm decreased from 36 to 24 km and, correspondingly, the outer eyewall diameter decreased from 112 to 70 km. Simultaneously, the width of the inner eyewall shrank from 21 to 12 km while the width of the outer eyewall initially decreased from 30 km, at 0200 UTC to 14 km at 0800 UTC; but subsequently increased to 32 km by 1400 UTC. By 1500 UTC, the two eyewalls are seen to have come closer to each other at least in the southern sector. The RHI photographs of 1155 and 1459 UTC [Figs. 6 (e&f)] also show these changes. While the two eyewalls were seen to be well separated at 1155 UTC, the RHI photograph of 1459 UTC clearly shows that the two eyewalls have moved close to each other at least on the near side.

From 1500 UTC onwards the inner eyewall grew more significantly and became well formed. The second eyewall was also seen but was not very prominent at least upto 1700 UTC. Even subsequently, the secondary eyewall did not form completely but was seen as an extension of the inner-most spiral band wrapping around the inner eyewall, giving an impression of a secondary eyewall formation. The PPI photograph of 1748 UTC [Fig. 6 (g)] and Iso-echo /37 dBz reflectivity photograph of 1741 UTC [Fig. 6 (h)] show this feature. Dominance of spiral bands rather than secondary eyewall around the inner eyewall denotes asymmetric character of a hurricane which, in turn, indicates weakening of inner core circulation of the system (Willoughby *et al.* 1982). It is important to note that the storm's intensity got reduced to T-5.5 by 1800 UTC and then further reduced to T-5.0 by 2100 UTC of 8 May. It is noteworthy that from 1800 UTC onwards the inner eyewall has undergone rapid weakening and is seen as an incomplete disk at 2051 UTC [Fig. 6 (i)]. This eyewall has further weakened and is seen as an arc by 0113 UTC of 9th [Fig. 6 (j)].

The observations from CDR, Machilipathnam which was closer to the storm's centre as compared to CDR Madras, have also shown these developments. Figs. 6 (k&l) are the PPI photographs of CDR, Machilipatnam at 0003 and 0602 UTC respectively of 9th which clearly support the weakening of inner eyewall observed by CDR, Madras.

6. Discussion

From the above analysis of the evolution of the structure of the May 1990 cyclone, we find that the storm has shown a double eyewall feature almost continuously for a period of two days during 7-9 May. It has also shown at least one complete cycle of contraction of outer eyewall accompanied by the contraction and weakening of the inner eyewall. This phenomenon appears to be similar to the one observed by several authors for axisymmetric intense cyclones of the Atlantic and north-west Pacific Oceans in recent years.

A detailed examination of the cyclone's overall evolution and structural features led us to conclude that the storm appears to have exhibited largely asymmetrical structure except on a few occasions when it did show nearly concentric eyewall. The secondary eyewall in most of the observations is an extension of the innermost spiral band wrapping around the inner eyewall. While a clear distinction between a band wrapping the inner eyewall and a convective ring is often difficult, radar and satellite observations indicate the dominance of spiral bands rather than the convective ring throughout the life span of the cyclone. However, unlike radars, the satellite could not observe double eyewall features continuously for such a prolonged period as the stratified cloud layer comprising of cirrus clouds obscured the inner core region of the storm for quite some time (Kalsi 1993). The radar observations on a few occasions have shown detachment of the principal spiral band from the inner eyewall to form a distinct secondary eyewall.

The characteristics of double eyewall features observed for the present storm are, therefore, in contrast with those observed by previous workers for other intense storms of the Bay of Bengal. Other intense cyclones of this region seemed to have developed an extremely short lived 'asymmetric double eye' consisting of the formation of an outer convective band wrapped around the inner eyewall which obviously did not exhibit any repetitive process of contraction or dissipation of eyewalls. The analysis of the May 1990 storm as described in this section revealed that although the storm seems to have exhibited an 'asymmetric double eye' structure, it did show the so-called repetitive double eyewall cycle shown by 'axisymmetric storms' of other basins. It is important to mention that none of the 'asymmetric double eye' storms observed in any part of the world are reported to have shown repetitive cycle of contraction and dissipation of eyewalls. The May 1990 cyclone is, therefore, a unique case of an asymmetric storm exhibiting these characteristics.

7. Some other interesting aspects of concentric eye-wall features

Chen (1986) analysed data collected during the TOPEX experiment and other data of 38 years (1949-86) over northwest Pacific. He found that about 72% of the typhoons with concentric eyewall had shown recurvature or sudden turning.

In the Bay of Bengal very few cyclones attain the intensity of severe cyclonic storms with a core of hurricane winds. During the last twenty years, when the S-Band Radar network was established in stages over the coastal belt of the country, the number of such occasions have been very few. Out of these cyclones, on record, we have only four storms over the Bay of Bengal which developed a double eyewall (Raghavan *et al.* 1980, 1989; Kalsi, 1993). In the November 1977 cyclone of the Bay of Bengal, the double eyewall structure was observed in the cyclone nearly 48 hours after recurvature (Raghavan *et al.* 1980). The double eye wall features, however, disappeared after a few hours and subsequently there was a gradual decrease in the intensity of the storm. The double eyewall possibly existed even a few hours earlier but could not be seen by CDR Madras due to range limitations of the radar. In another intense cyclone of November 1984 in the Bay of Bengal the double eyewall first appeared in the morning of 12 November. This happened a little less than 24 hours after the storm took a northward turn in the afternoon of 11th. The double eyewall feature was observed quite unexpectedly once again after the cyclone had crossed the coast (Raghavan 1989). Kalsi (1993) observed double eyewall features in Bay of Bengal hurricanes of May 1990 and April 1991. Incidently, both these cyclones have shown recurvature preceded by a double eyewall formation. For the May 1990 cyclone, it is observed that the system had earlier remained nearly stationary for some time in its westward course towards the east coast of India around mid-night of 6-7 May. It intensified and then recurved by 7th morning. Following this the double eyewall was noticed by CDRs at Karaikal and Madras. The intensification and the recurvature followed by the appearance of a double eyewall, occurred in a sequence. With fewer cases available for analysis, it is difficult to draw any definite conclusion on whether recurvature followed by stagnation of the storm led to the formation of a secondary eyewall.

It is interesting to note that the above four intense cyclones over the Bay of Bengal exhibiting double eye-wall characteristics, moved close to the land area (within 200 to 300 km range). It is possible that some other intense cyclones over the Bay of Bengal might have also developed a double eye-wall but this could not be detected or documented due to the non-availability of necessary facilities, such as cyclone detection radars or aircraft observations over the sea outside the detection range of coastal radars. Similarly, there were a few intense systems which did not show these characteristics, though they moved close to the coast for considerable length of time before landfall. Hawkins (1983) has shown that the land interruptions may have an important role to play in the occurrence of a double eyewall, although there have been a few cases of this phenomenon occurring over the open ocean.

Willoughby (1990), also found that three, out of four hurricanes during 1983 to 1989 over the Atlantic developed double eye-wall when they came close to the land mass. Although the sample is admittedly biased towards the landfalling storms, there appears to be frequent coincidence of outer eyewalls with the landfall indicating an apparent relation of land-induced effects with the formation of a double eyewall.

8. Conclusions

Based on the results and discussion the following conclusions may be drawn:

(*i*) The Bay of Bengal Cyclone of May 1990 has shown double eyewall characteristics continuously for nearly two days.

(*ii*) The observations made by the cyclone detection radards at Madras and Machilipatnam provided indications that there was a repetitive cycle of contraction of the outer eyewall, weakening of the inner eyewall and the reformation of another outer eyewall, similar to the one reported by several workers for many axisymmetric intense cyclones of the northwest Pacific and Atlantic oceans.

(*iii*) The observations from these radars show that the structure of the cyclone has been largely asymmetric rather than axisymmetric. Moreover, the eyewall cycle was not distinctly brought out by these observations when compared to the ones reported elsewhere. This could be due to the limitations of the ground-based radars.

(*v*) In general, the repetitive cycle is said to have a close relation with the corresponding changes in the intensity value (central pressure or maximum wind). The intensity changes as observed by the INSAT-IB have to some extent, shown good agreement with the structural changes observed by the CDRs. However, there was no distinct one-to-one relation between the two.

(*vi*) Several other related features, such as, the role of land obstacle and the effect of sudden recurvature on the development of secondary eyewall discussed in the paper require further study by taking a good number of such cases.

(*vii*) Though qualitative, the double eywall features presented here may go a long way to make further study to establish the role of structural changes in the inner core of the cyclone in modulating the intensity changes in the cyclone. The advent of Doppler radar facility and the aircraft reconnaissance programme in the north Indian Ocean would greatly help in establishing the occurrence of such characteristics in other intense cyclones in the years to come.

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