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Tracking of a cyclone over Arabian Sea by enhanced satellite pictures

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सार — उन्नत अतिउच्च विभेदन विकिरणमापी से नई दिल्ली में प्राप्त छायाचित्रों का उपयोग करके 1981 में हिन्दमहासागर में आए चक्रवात का अध्ययन किया गया। हमने देखा कि–65° सें० की तापमान परिरेखा से घिरा क्षेत्र केन्द्रीय सघन मेघाच्छन्नता (सी० डी० ओ०) को दर्शाता है। तूफान की तीव्रता के साथ केन्द्रीय सघन मेघाच्छन्नता के आकार में भी वृद्धि होती देखी गई। तीव्रीकरण के पूर्वानुमान में एक प्राचल के रूप में इसका उपयोग किया जा सकता है। तूफान, यद्यपि हरीकेन पवनों की क्रोड़ सहित भीषण चक्रवात की तीव्रता तक पहुंचा, पर उसमें कोई "आई" (केन्द्र) नहीं देखी गई। इससे स्पष्ट हो गया कि उपग्रह से प्राप्त चित्रों में बिना "आई" के भी हरीकेन पवनों की क्रोड़ वाला भीषण चक्रवाती तूफान विद्यमान रह सकता है। इनसैट के चालू होने पर आधे-आधे घंटे के अंतराल पर लिए गए चित्र उपलब्ध हो सकेंगे और तब "आई" के अभिलक्षणों पर और अधिक प्रकाश डाला जा सकेगा।

ABSTRACT. This is the study of a cyclone over the Indian seas in 1981 using enhanced Advanced Very High Resolution Radiometer (AVHRR) pictures received at New Delhi. We note that the area bounded by the temperature contour of —65 deg. C defines the Central Dense Overcast (CDO). The size of the CDO was seen to increase with the intensity of the storm. This could be used as a parameter to forecast intensification. Even though the storm attained the intensity of a severe cyclonic storm with a core of hurricane winds, there was no 'eye'. Thus a severe cyclonic storm with a core of hurricane winds may exist without an 'eye' in satellite pictures. With the advent of INSAT more frequent pictures at half hourly intervals will become available when more light can be thrown on the 'eye' characteristics.

1. Introduction

An AVHRR (Advanced Very High Resolution Radiometer) equipment was installed in New Delhi in February 1981. The facility of getting satellite pictures by introducing enhancement curves through a micro-computer became possible in September 1981. The post monsoon season (October to December) of 1981 was thus the first season, when these enhanced pictures were obtained on real time. In this study, the progress of a cyclone from its incipient stage has been studied using enhanced pictures. This provides brightness temperatures at the top of clouds.

2. Data

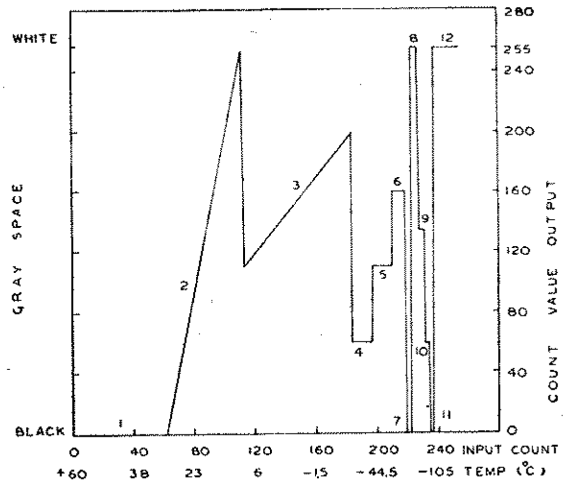
As there were two NOAA-6 and two NOAA-7 passes per day, this study uses 4 AVHRR pictures per day. Enhanced infrared pictures were obtained and used from 30 October when the system became a cyclone.

3. Discussion of the enhancement curve used

Utilisation of enhancement techniques in the study of cloud pictures is fairly well established in satellite meteorology. We know that when temperature gradients are small, it is difficult to recognise significant cloud features in the IR imagery. So to get a more detailed temperature definition in the IR imagery, the entire temperature range can be divided into a number of smaller segments and the input count values corresponding to these temperature ranges changed artificially into some suitable output count values. This is done by a suitable enhancement, the details of which are given in Table 1.

TABLE 1

Enhancement curve for the cyclonic storm



Segment No.	Temp. (°C)	Input count	output count	Remarks
1	51.5 to 33.6	0-52	0	No significant information
2	33.3 to 9.3	53-112	5-250	Low clouds
3	8.9 to—30.3	113-183	113-183	Cirrus outflow pattern
4	—31.3 to—41.3	184-197	60	Dark gray
5	—42.2 to—53.6	198-210	101	Medium gray
	—54.7 to—64.0	211-219	160	Light gray
7	—65.3 tc—69.5	220-223	0	Black
8	—71.0 tc—75.7	224-227	255	White
9	—77.4 to—83.0	228-231	135	Top medium
10	—85.0 to—89.5	232-234	60	Dark gray
11	—92.0 to—97.5	235-237	0	Black
12	—100.7 to—110.0	238-255	255	White

This is a modification of the enhancement used by us (Veeraraghavan *et al.* 1983) while studying the Bay of Bengal cyclone of September 1981. The advantages of the present enhancement are that very cold cloud tops of temperature —85 deg. C to —110 deg. C have been further divided into three segments and hence such areas, whenever present, are easily seen in the enhanced picture. The use of enhanced IR pictures in tropical cyclone analysis has been demonstrated by Dvorak & Wright (1977) and also referred to in WMO Technical Note No. 153.

4. Discussion

A low pressure area moved across south Peninsula and lay over east Arabian Sea on 28 October 1981. It intensified into a cyclonic storm on the morning of 30th as seen from the good comma shaped cloud with cirrus outflow in all sectors except southeast, as revealed by the NOAA-7 satellite picture. This cloud configuration (Fig. 1) will have a T-number of 3.0 in Dvorak's scale (Dvorak 1975). Enhanced infrared picture has shown an intense convective band to the northeast of the central dense overcast region (CDO), which is not apparent from the visible picture. A comparison of the visible and enhanced infrared pictures of 30 October shows that the area bounded by the temperature contour of —65 deg. C could define the central overcast region.

The infrared and the enhanced infrared pictures of 31 October (Figs. 2 & 3) show that the central region is better organised when compared with 30th. The area of very cold clouds of temperature less than —85 deg. C has almost doubled (figure not presented). Cirrus outflow is seen prominently in all sectors except northeast where intense convective clouds extend upto —98 deg. C.

The NOAA-6 enhanced IR picture of 31st morning (Fig. 4) shows that the central overcast region is almost circular indicating intensification. Dvorak's classification will assign it a T-number of 4.0. A small top medium gray area (marked by an arrow) seen within the colder dark gray denotes a warmer area, representing the beginning of 'eye' formation. However, 'eye' was not seen in the conventional VIS & IR pictures. This feature did not continue in subsequent pictures. It may be seen that the coldest temperature reached by the cloud tops was lower than —100 deg. C in the early morning of 31st whereas 6 hours later when the formation of 'eye' has started, the cloud top heights have considerably decreased, as seen by the absence of the coldest white (—100.7 to —110 deg. C).

There is a fairly large and intense convective mass to the northnortheast of the cyclone centre, dissociated from the main cloud mass. NOAA-7 afternoon enhanced picture (Fig. 5) shows that the central dense overcast is trying to lose its circularity and the temperature distribution is not uniform. The cloud top temperature has become colder by the appearance of 'coldest white' shade near the edge of the central overcast region. These features indicate the beginning of the weakening of the cyclone and it can now be assigned T No. 3.5. Narayanan and Rao (1981) have also pointed out that the coldest cloud tops shift to the southern edge when it starts weakening. NOAA-6

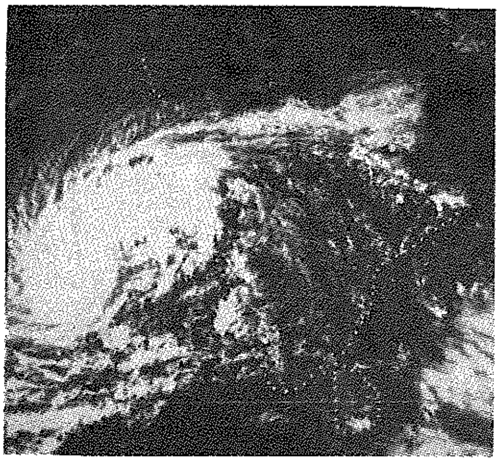


Fig. 1. NOAA-7 (vis) of 30 October 1981

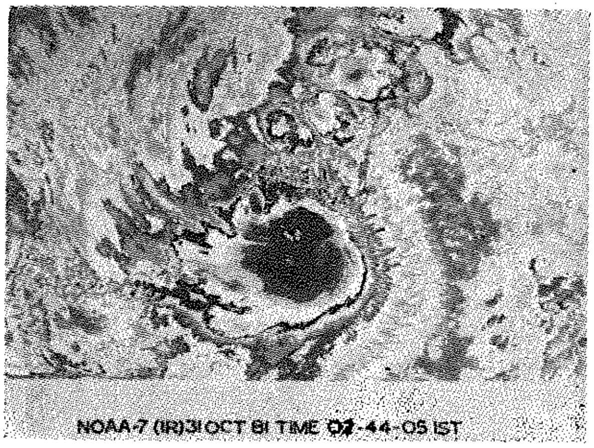


Fig. 2. NOAA-7 (enhanced IR) of 31 October 1981, time 02-44-05 IST

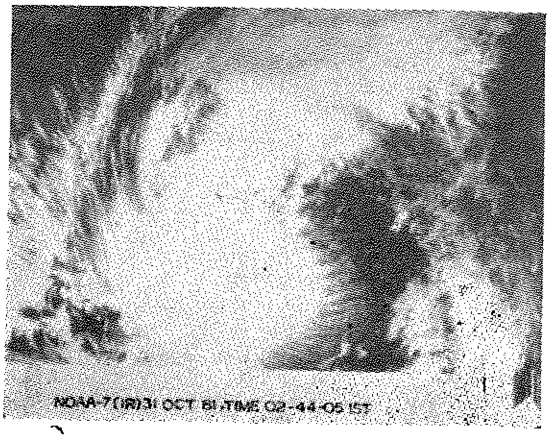


Fig. 3. NOAA-7 (infrared) of 31 October 1981, time 02-44-05 IST

Fig. 4. NOAA-6 (enhanced infrared) of 31 October 1981, time 08-15-30 IST

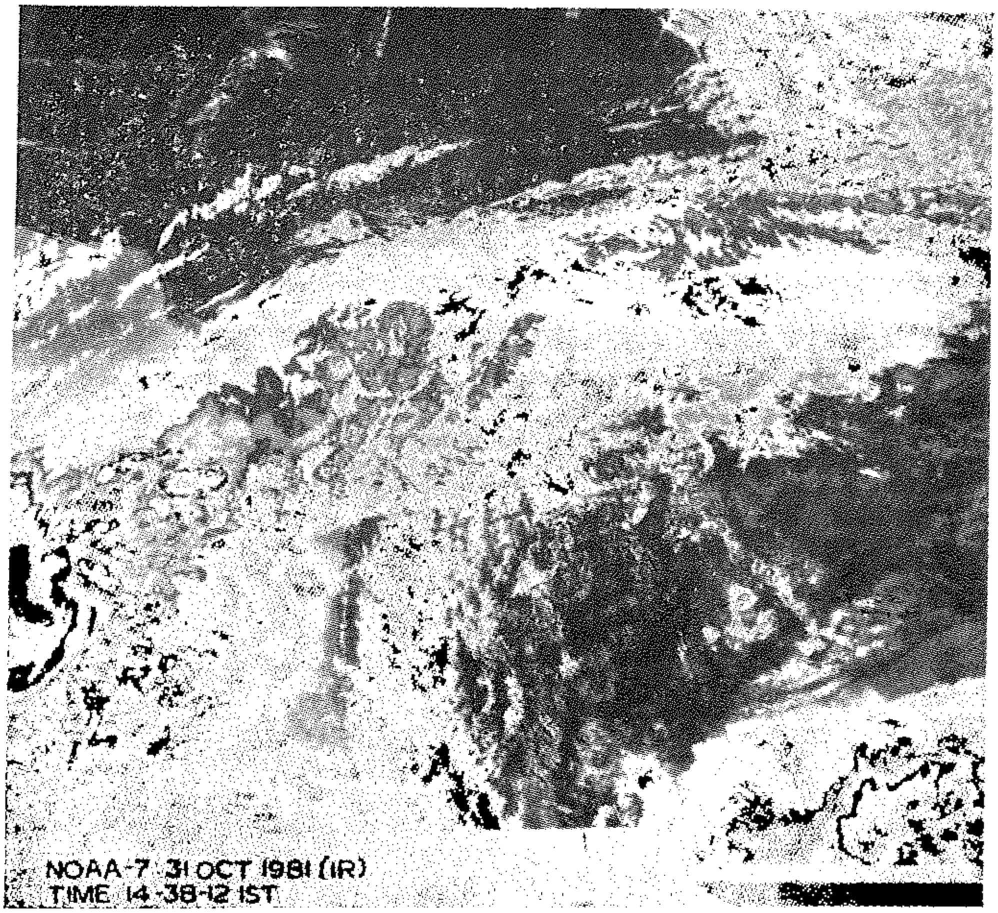


Fig. 5. NOAA-7 (infrared) of 31 October 1981, time 14-38-12 IST

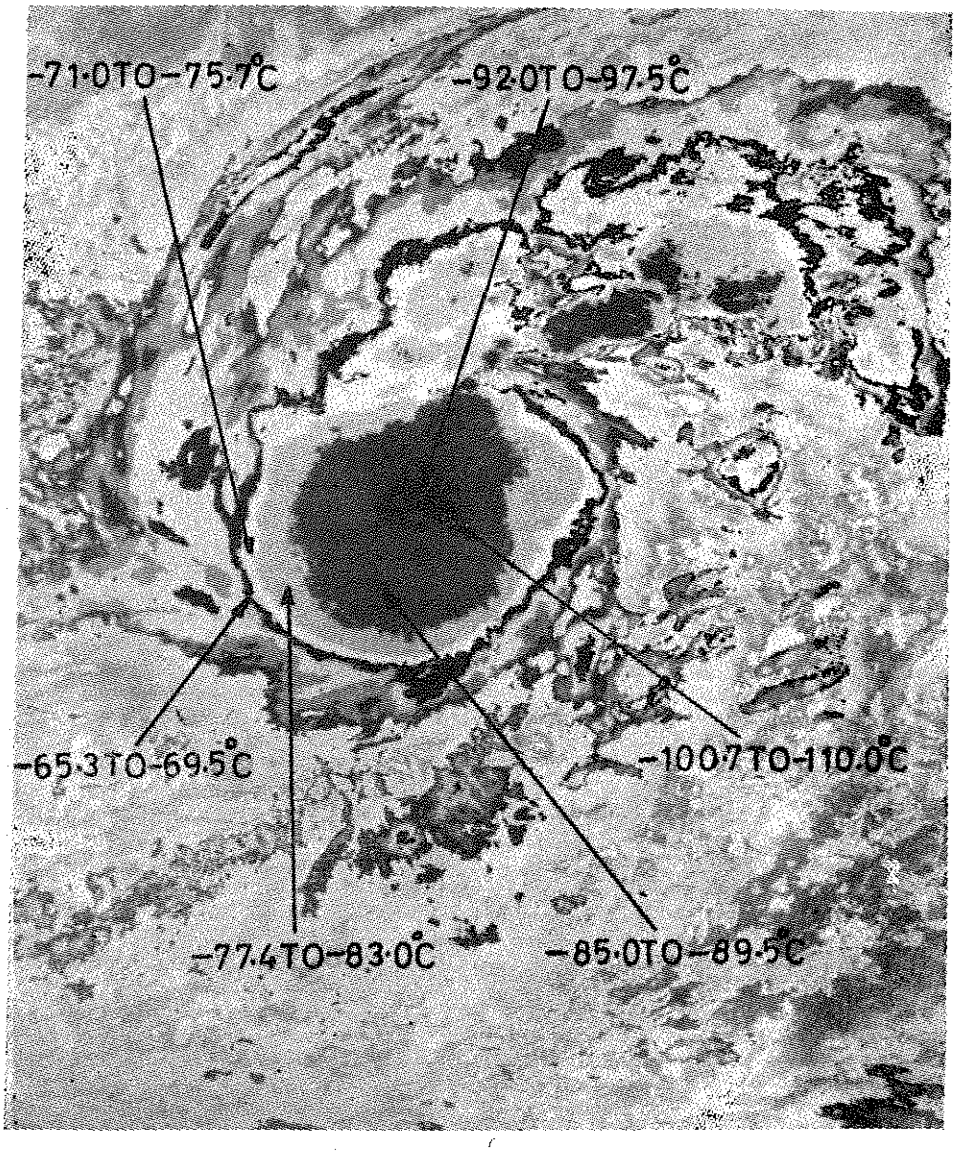


Fig. 6. NOAA-6 (enhanced infrared) of 31 October 1981, time 20-04-53 IST

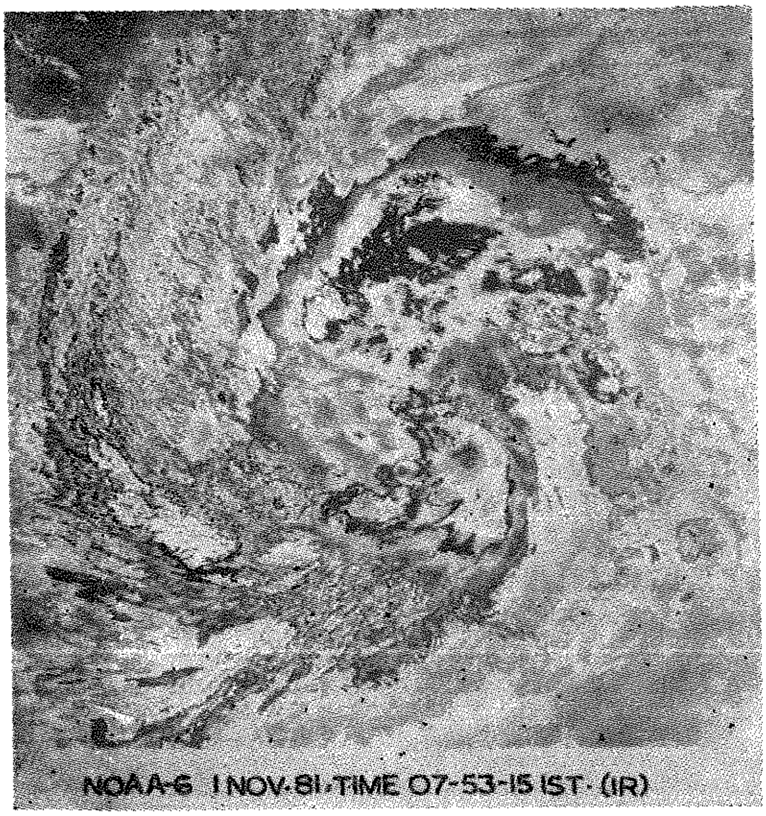


Fig. 7. NOAA-6 (infrared) of 1 November 1981, time 07-53-15 IST

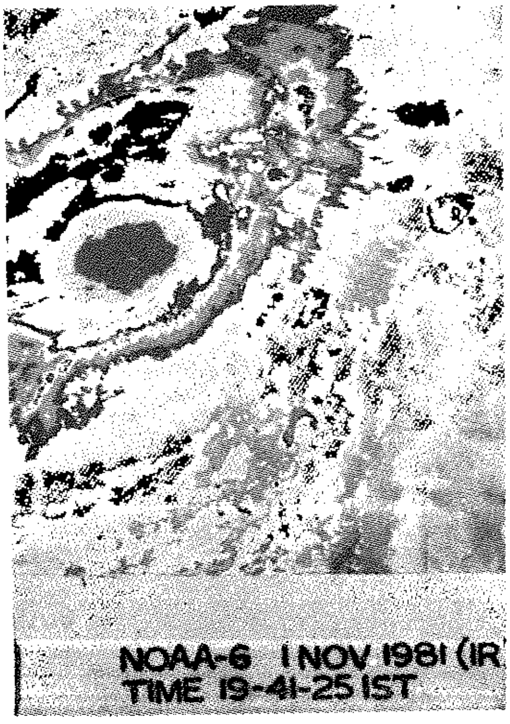


Fig. 8. NOAA-6 (infrared) of 1 November 1981, time 19-41-25 IST

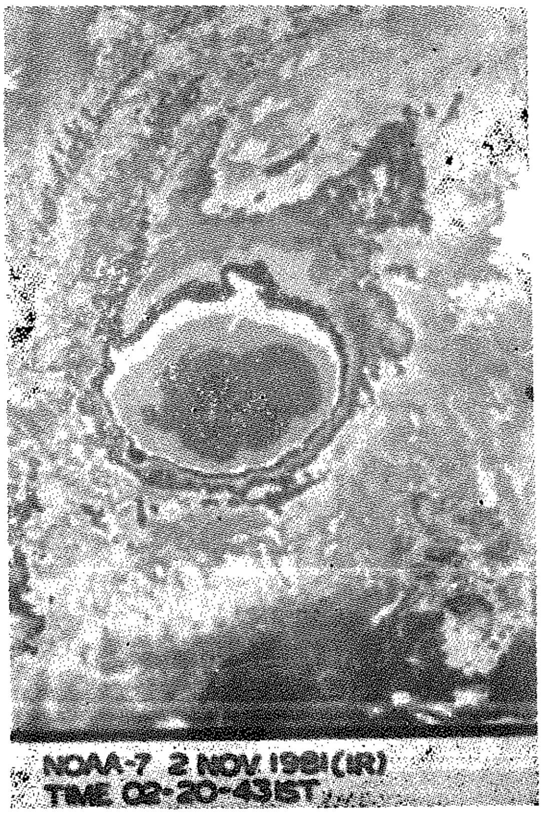


Fig. 9. NOAA-7 (infrared) of 2 November 1981, time 02-20-43 IST

TABLE 2

Size of central dense overcast (CDO) and central exhaust clouds (CEC)

Date	Average diameter of CDO (km) measured along		Average diameter of CEC (km) measured along	
	Lat.	Long.	Lat.	Long.
30 Oct 1981 (1449 IST)	423	570	153	240
31 Oct 1981 (0244 IST)	531	460	297	300
31 Oct 1981 (0815 IST)	405	410	243	230
31 Oct 1981 (1438 IST)	324	480	126	180
31 Oct 1981 (2004 IST)	387	350	234	250
01 Nov 1981 (1941 IST)	279	230	153	120
02 Nov 1981 (0256 IST)	477	400	288	220

night enhanced picture at Fig. 6 shows better organisation as compared to Fig. 5 and the disturbance intensity can be estimated as T 4.0. The coldest area represented by white has shifted nearer to the centre.

Fig. 7 gives the temperature distribution of the top of clouds on 1 November 1981. The area of very cold clouds has considerably decreased and the temperature distribution has become asymmetrical indicating a decrease in the intensity to T 3.0. From Fig. 7 we can also find out the height to which the cirrus outflow, seen in the northwest sector, extends.

From the afternoon of 1 November, the cyclone again showed signs of intensification as seen from Fig. 8. Compared to the absence of circularity and gradient seen in Fig. 7, the intensification of the cyclone can be noticed from the greater circularity and gradient seen in Fig. 8. A small area of top medium shade which is warmer than its surroundings could be seen on the evening of 1 November. The cyclone has further intensified to the hurricane level of T 4.0 as brought out in Fig. 9. The area of very cold clouds has considerably increased and the gradient has also become very steep. For quantification purposes measurements of the size of the central overcast region (CDO) were made with the original pictures. It was seen that the CDO size on the early morning of 2 November (Fig. 9) was nearly three times that of the evening of 1 November (Fig. 8). Also in Fig. 9, inside the coldest black, a very small area of dark gray representing a warmer area was seen in the original picture. This could not be reproduced in the photograph presented. The warmer areas seen inside relatively colder surroundings on 1st evening and 2nd morning were indicative of the reformation of the eye.

5. Estimate of maximum wind

In order to see whether our estimates of the cyclone intensity were correct, the maximum sustained wind has been computed using Fletcher's formula. The lowest sea level pressure recorded during the cyclone was at Porbandar, *viz.*, 985.3 mb at 00 GMT of 2 November and the cyclone has passed close to Porbandar. Hence it is reasonable to use this pressure as the central pressure to give an estimate of maximum wind. Natarajan and Ramamurty (1975) have modified Fletcher's formula to suit the cyclones in the Indian seas. They have proposed the relation $V_{max} = 13.6\sqrt{P_n - P_c}$ where P_n is the peripheral pressure and P_c is the central pressure in mb. Some workers have opined that instead of the actual value of the outermost isobar, a constant value of 1010 mb can be used with good results. Thus the modified form of Fletcher's formula becomes

$$V_{max} = 13.6\sqrt{1010 - P_c}$$

where P_c is the central pressure.

This wind speed agrees with the maximum wind speed of 102 kmph recorded at Jamnagar. Dvorak (1975) has given a table relating mean sea level pressure with cyclone intensity in the form of T-numbers. In this table T4 corresponds to 987 mb which also more or less coincides with the lowest pressure recorded at Porbandar. Thus the estimation of intensity of the system as T4 seems to be fairly in agreement with the actual.

6. Size of central dense overcast

Table 2 gives the size of the central overcast region (the almost circular area bounded by the black shade corresponding to the temperature range —65 to —69 deg. C in the infrared enhanced picture) from day to day based on original pictures. The central overcast region had reached a maximum of 4.8 degree on the early morning of 31st. This incidentally was the time where the cyclone was at its peak intensity of T4 as seen in the preceding discussions. The size of the overcast region had started decreasing from 31st afternoon and reached a minimum on the morning of 1 November (not shown in the table as it has lost its circularity). Thereafter the size has again started increasing and reached an average diameter of about 3.7 deg. on the early morning of 2 November. Thus the increase or decrease in the intensity of the cyclone seems to be directly related to the size of the central dense overcast region as derived from the enhanced IR picture.

7. Reason for intensification

The reason for the intensification from 1st morning (Fig. 7) to 2nd early morning (Fig. 9) is perhaps due to the concentration of the kinetic energy in one area as in Fig. 9 unlike its spread out as seen in Fig. 5 due to the presence of very high convective cloud areas to the north and northeast of the main cloud mass. In other words, the increased intensity of the disturbance to the level of a severe cyclone with a core of hurricane winds on 2nd morning is probably due to the merger of the convective cloud masses to the north with the main cloud mass of the system. Incidentally it may be seen that Fig. 9 is more or less similar to that of Fig. 4 confirming to the intensification that has taken place in the course of 1 November 1981.

8. Area of coldest clouds

While discussing some aspects of tropical storm structure revealed by photographs obtained from hand held camera from space, Black (1977) has said that the circular exhaust clouds (CEC) which is a large dome protruding to the stratosphere, extends nearly 3 km above the undisturbed cirrus level with smaller scale convective turrets extending another 1 to 1.5 km higher. He has also said that for hurricane *Ellen* of September 1973 in the Atlantic the circular cloud was nearly 200 km in diameter. The temperature near the tropopause in tropical latitudes is of the order of —75 to —80 deg. C, which is represented by 'top medium' shade in our enhancement. As the CEC is protruding into the stratosphere, we can infer that the colder cloud contours within the top medium gray shade (defined by dark gray, black & white shades) will adequately define the CEC. In the enhanced pictures presented the diameter of CEC which contains the overshooting tops is roughly of the order of 200-250 km, the maximum being 300 km as shown in Table 2.

It is also observed that the temperature gradient is very steep on the eastern side (especially in the north-east quadrant) of the central overcast region of the tropical storm on almost all days, as seen from the packing of the temperature contours consistently on the eastern side. Figs. 2, 4, 5, 6 & 9 bring out this fact clearly. This will mean that most intense convection is taking place on the right semi-circle of the direction of motion. This is supported by the observation that in tropical storms, maximum winds are generally observed in the right semi-circle of the direction of motion (Dunn & Miller 1964). Black (1977) has also pointed out that maximum winds occur in the area of most intense convection and overshooting turrets. Dvorak has observed that steep temperature gradient was most often seen on the western side of the pattern in the case of Atlantic storms where the upper level flow was strong from west. On the same analogy, the temperature gradient for Arabian Sea storm is steepest on the eastern side due to the upper level flow over the storm being from the east.

9. Absence of eye

It is interesting to note that this hurricane did not show clear cut eye formation on any day, especially on 31 October when it reached peak intensity of T4. As 'eye' of a cyclone is an area of practically no clouds, in the enhanced picture it should have shown itself as the warmest area and hence of shade, black or near black, corresponding to segment 1 or the beginning of segment 2 of the enhancement curve (Table 1). Malkus (1958) has said that wind speed in the circulation of a tropical disturbance cannot exceed 45 mph (40 knots) without the formation of an eye. Thus the absence of clear cut eye in this case is probably due to the non-availability of continuous satellite imageries. With the advent of INSAT, more frequent pictures at half hourly intervals will become available and hence more light can be thrown on 'eye' characteristics.

10. Conclusion

This study brings out the importance of enhanced satellite imagery in estimating the intensity of tropical cyclones. In the enhanced picture the circular area bounded by the black contour corresponding to the cloud top temperature of —65 deg. C and lower can be taken to represent the central overcast region of the storm. The size of the central dense overcast region appears to be directly related to the intensity of storm and hence its growth as defined above can be used to forecast the intensity of a cyclone in the early stages when eye is not formed. The area of most intense convection occurred in the E/NE sector of this cyclonic storm and this incidently was the area of maximum winds on the ground. This study further indicates that the wall cloud of the cyclonic storm extends to temperatures much beyond —85 deg. C. Further, a tropical disturbance can reach severe cyclone intensity with a core of hurricane winds without showing an eye in the satellite imageries. The steepest gradient in the temperature pattern on the eastern side is probably due to the strong upper level flow from the east.

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