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Comparative analysis of subjective/advanced objective technique of tropical cyclone intensity estimation

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सार – उष्णकटिबंधीय चक्रवात की तीव्रता का आकलन करने के लिए समूचे विश्व में व्यावहारिक रूप से उपयोग की जाने वाली ड्वोरक तकनीक में उपग्रह से प्राप्त चित्रों का उपयोग किया जाता है। इसमें व्यवस्थित संवहन के संबंध में विश्लेषक द्वारा किए गए विवेचन सहित कुछ प्रायोगिक मानदंडों के आधार पर उपग्रह से प्राप्त चित्र के पैटर्न की पहचान की जाती है। विभिन्न विश्लेषण केन्द्रों द्वारा किसी एक चक्रवात का आकलन करने में होने वाली विषयपरक विवेचन संबंधी विसंगतियाँ कंप्यूटर पर आधारित एलगोरिथ्म के माध्यम से कम हुई। इस संशोधित तकनीक को विकसित विषयपरक ड्वोरक तकनीक (ए. ओ. डी. टी.) कहा गया और यह पूर्ण विकसित उष्ण कटिबंधीय चक्रवातों के लिए उपयुक्त है। इस शोध–पत्र में वर्ष 2004 में आए तीन उष्णकटिबंधीय चक्रवातों के संबंध में ए. ओ. डी. टी. के कार्य – निष्पादन का मूल्याकंन किया गया है। इनके तुल्नात्मक विश्लेषण से यह पता चला कि ए. ओ. डी. टी. तकनीक ड्वोरक तकनीक के आधार पर किए गए चक्रवात की तीव्रता के आकलनों, जो उष्णकटिबंधीय विश्लेषण केन्द्रों के उपग्रह से प्राप्त चित्रों के विश्लेषकों द्वारा व्यावहारिक रूप से तैयार किए गए, के मुकाबले की रही।

ABSTRACT. Dvorak technique operationally used all over the world for estimating the tropical cyclone intensity is based on satellite observations. It involves image pattern recognition based on certain empirical rules along with the analyst interpretation of organized convection. The computer-based algorithm can minimize these subjective judgement discrepancies between different analysis centers estimating the same storm. This modified version is called Advanced Objective Dvorak Technique (AODT) and which is applicable for well-developed tropical cyclones. In this paper the performance of the AODT is evaluated on three cases of the year 2004 tropical cyclones. Comparative analysis indicates the technique to be competitive with, the Dvorak-based intensity estimates produced operationally by satellite analysts from tropical analysis centers.

Key words – Tropical cyclone (TC), Advanced objective technique (AODT) and Subjective Dvorak technique (SDT).

1. Introduction

Infrared (IR) and Visible imagery from geostationary satellites is a fundamental tool for diagnosing and forecasting tropical cyclones (TC) because the temporal and spatial regularity of sampling allows for continuous and timely global monitoring of TCs. However, IR imagery is often severely limited at giving direct information about TC inner core structure and evolution because upper level cirrus clouds are opaque at typical IR wavelengths. This is especially problematic in TC scenes, which often display a central dense overcast (CDO) aloft, and much of the structure of the eyewall and surrounding rain bands becomes obscured. In the visible imagery the low level clouds are clearly seen and due to better resolution it is easier to recognize the cloud pattern type. This method of analyzing cloud patterns using visible images is called the Dvorak VIS technique (Dvorak and Wright 1977). For the past 30 years, the Dvorak (1973, 1975, 1984) technique has served as the benchmark for tropical cyclone (TC) intensity estimation using satellite data. The method relates TC minimum sea level pressure (MSLP) and maximum near-surface wind (*V*max) to satellite-measured cloud features. The Dvorak technique yields intensity estimates in terms of *T* numbers (short for tropical numbers). The *T* numbers are then related to current intensity (CI) numbers that are then directly related to MSLP and *V*max using a simple table (with greater *T* numbers associated with greater intensity). With improvements in satellite infrared (IR) imagery, the Dvorak technique was modified to include the enhanced IR (EIR) technique, which utilizes this new data (Kalsi, S. R., 2002).

The Advanced Objective Dvorak Technique (AODT) algorithm (Olander *et al*., 2002, 2004) is a computer-based technique, developed at the University of Wisconsin-Madison/Cooperative Institute for Meteorological Satellite Studies (UW/CIMSS), to objectively determine tropical cyclone intensity using Geo-stationary

TABLE 1

Comparative analysis of NHAC, Satmet & AODT for the cyclone during 05-10 May 2004

Date/Time (UTC)	NHAC (N)			Satmet (S)			Diff. (N-S)		AODT (A)			Diff (A-S)	
	Lat.	Long.	Intensity (T.N/C.I)	Lat.	Long.	Intensity (T.N/C.I)	Distance (km)	Intensity (T.N)	Lat.	Long.	Intensity (T.N)	Distance (Km)	Intensity (T.N)
05 May/0300	11.5	73.5	1.5	11.5	73.5	2.0	0.00	-0.5	11.50	74.40	2.0	99.00	0.0
06 May/0300	11.5	73.0	2.5/3.0	11.0	73.2	3.0	59.24	0.0	11.35	73.16	3.7	38.75	0.7
07 May/0300	12.5	72.0	3.5	12.2	72.1	3.5	34.79	0.0	12.51	72.61	3.4	65.65	-0.1
07 May/1200	13.0	71.5	3.5	13.1	70.8	3.5	77.78	0.0	13.24	71.80	3.1	111.07	-0.4
08 May/0300	13.5	71.0	3.5	14.1	70.0	3.5	128.28	0.0	12.41	72.45	2.8	327.40	-0.7
08 May/1200	13.5	71.0	2.5/3.0	14.1	70.0	3.0/3.5	128.28	0.0	13.81	73.56	2.8	392.90	-0.2
09 May/0300	15.0	70.5	2.5/3.0	15.0	69.9	3.0/3.5	66.00	0.0	14.54	72.32	2.8	270.97	-0.2
09 May/1200	16.5	70.0	2.5/3.0	17.7	69.1	3.0/3.5	165.00	0.0	15.19	71.66	2.8	394.37	-0.2
10 May/0300	19.0	70.0	2.0	18.8	69.8	2.5/3.0	31.11	-0.5	18.72	68.69	2.8	122.42	0.3
10 May/1200	19.5	70.0	1.5	19.8	70.4	2.0	55.00	-0.5	19.23	68.07	2.2	263.86	0.2

TABLE 2

Comparative analysis of NHAC, Satmet & AODT for the cyclone during 30 September - 03 October 2004

Date/Time (UTC)	NHAC (N)			Satmet (S)			Diff. (N-S)		AODT (A)			Diff (A-S)	
	Lat.	Long.	Intensity (T.N/C.I)	Lat.	Long.	Intensity (T.N/C.I)	Distance (km)	Intensity (T.N)	Lat.	Long.	Intensity (T.N)	Distance (km)	Intensity (T.N)
30 Sep/0900	16.0	69.0	1.5	15.5	68.5	1.5	77.78	0.0					
30 Sep/1200	16.5	68.5	2.0	16.5	68.5	2.0	0.00	0.0					
01Oct/0300	19.0	67.0	2.0	19.0	67.0	2.5	0.00	-0.5					
01Oct/0900	19.5	66.5	2.5/3.0	19.8	66.2	3.0	46.67	0.0					
01Oct/1200	20.0	66.5	2.5/3.0	20.0	66.2	3.0	33.00	0.0					
02Oct/0300	21.0	66.5	2.5/3.0	21.2	66.5	3.0	22.00	0.0	21.35	67.17	2.6	75.52	-0.4
02Oct/0900	21.5	67.0	3.5	21.8	67.3	3.5	46.67	0.0	22.08	67.46	3.5	35.47	0.0
02Oct/1200	22.0	67.5	3.5	22.2	67.5	3.5	22.00	0.0	22.31	67.56	3.5	13.78	0.0
03Oct/0000	23.0	68.5	3.0	23.0	68.5	1.5	00.00	1.5	23.61	68.59	2.4	67.83	0.9
03Oct/0300	23.0	68.5	2.0	23.0	68.5	1.5	00.00	0.5	23.93	68.75	2.0	105.93	0.5

TABLE 3

Comparative analysis of NHAC, Satmet & AODT for the cyclone during 05-07 November 2004

Date/Time (UTC)	NHAC (N)			Satmet (S)			Diff. (N-S)		AODT (A)			Diff (A-S)	
	Lat.	Long.	Intensity (T.N/C.I)	Lat.	Long.	Intensity (T.N/C.I)	Distance (km)	Intensity (T.N)	Lat.	Long.	Intensity (T.N)	Distance (km)	Intensity (T.N)
05 Nov/0300	14.0	67.0	1.5	14.0	67.0	2.0	0.00	-0.5	13.73	65.04	3.2	217.64	1.2
05 Nov/0900	14.0	66.5	2.0	14.5	67.0	2.0	77.78	0.0	14.04	64.34	3.3	296.94	1.3
05 Nov/1200	14.5	66.0	2.0	14.5	67.0	2.0	110.00	0.0	14.13	63.97	2.8	335.78	0.8
06 Nov/0300	15.0	65.0	2.0	15.5	66.0	2.0	122.98	0.0	14.61	62.97	3.0	347.38	1.0
06 Nov/1200	15.0	62.5	2.0	15.7	62.0	1.5	94.63	0.5	14.85	61.42	2.7	113.19	1.2
07 Nov/0300	15.0	59.0	2.0	15.7	59.0	1.5	77.00	0.5	15.07	58.24	2.5	108.59	1.0
07 Nov/1200	13.5	56.5	1.5	13.5	56.5	1.0	0.00	0.5	13.69	56.63	2.2	25.32	1.2

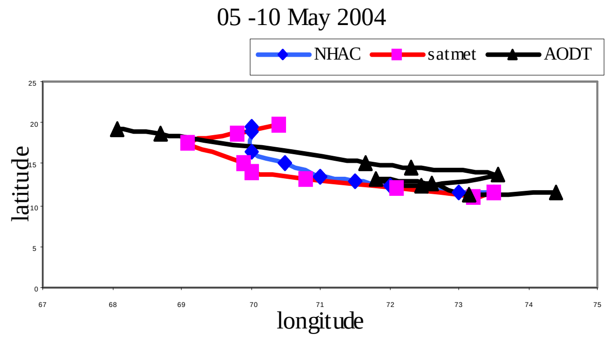


Fig. 1. Position and intensity of 05-10 May 2004 cyclone

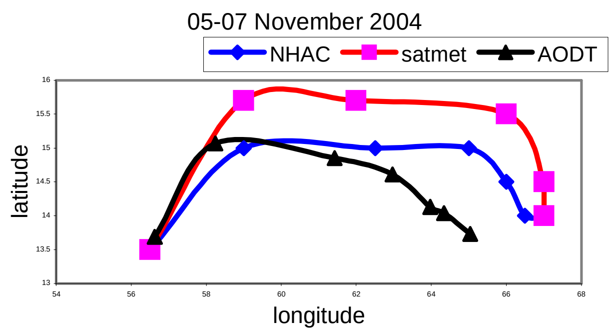


Fig. 2. Position and intensity of 05-07 November 2004

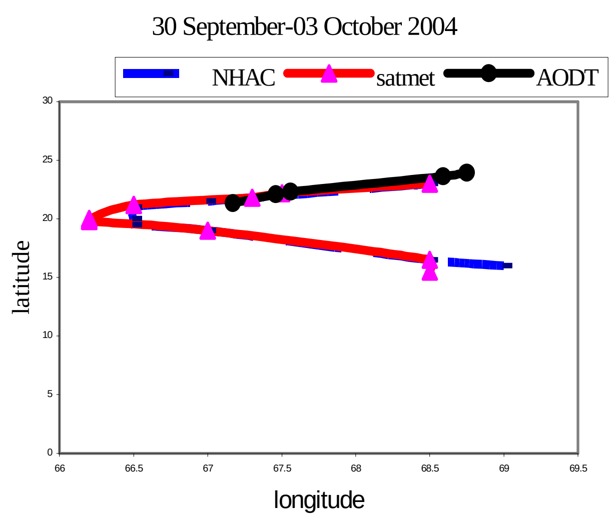


Fig. 3. Position and Intensity of 30 September-03 October 2004 cyclone

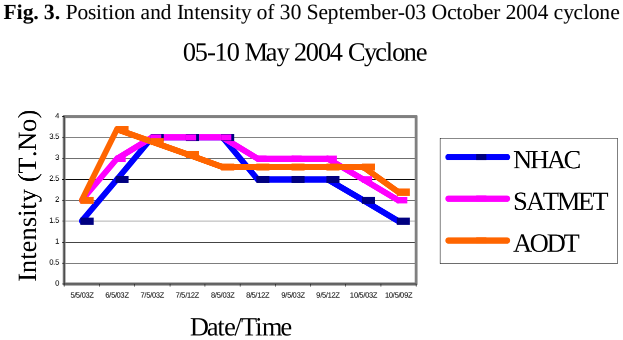


Fig. 4. Intensity of 05-10 May 2004 cyclone

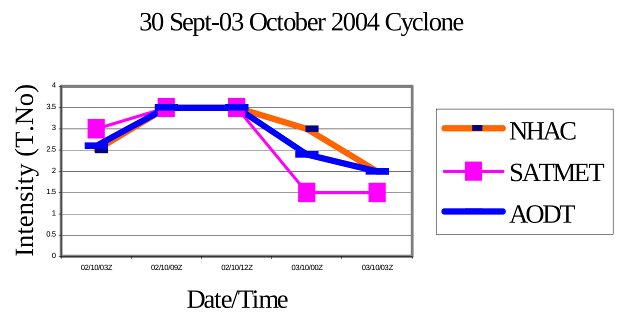


Fig. 5. Intensity of 30 September – 03 October 2004

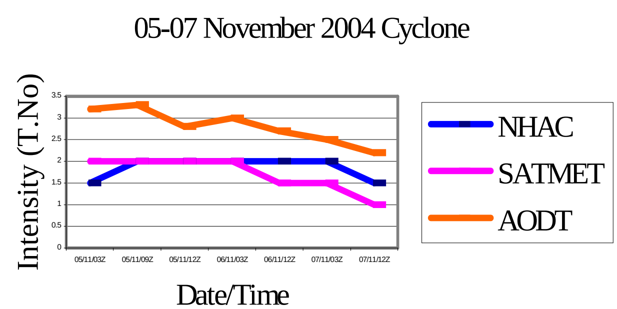


Fig. 6. Intensity of 05-07 November 2004 cyclone

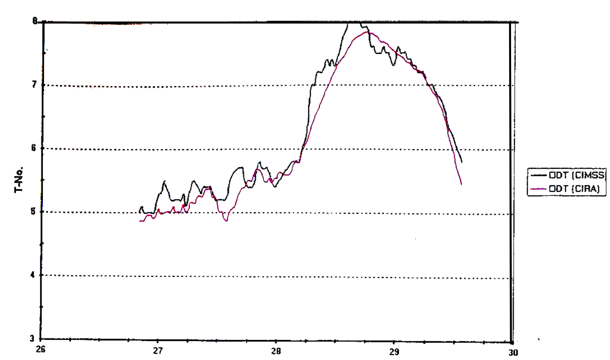


Fig. 7. Intensity of Orissa 1999 super cycle by ODT analysis

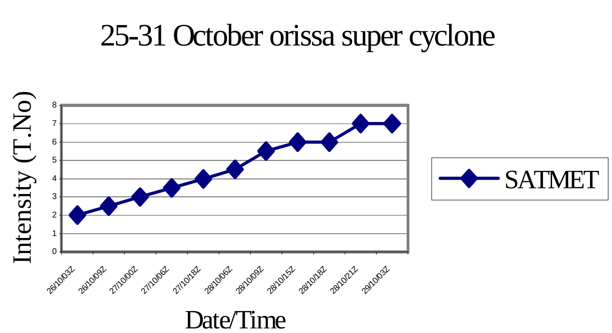


Fig. 8. Intensity of Orissa 1999 super cycle by Synoptic unit analysis

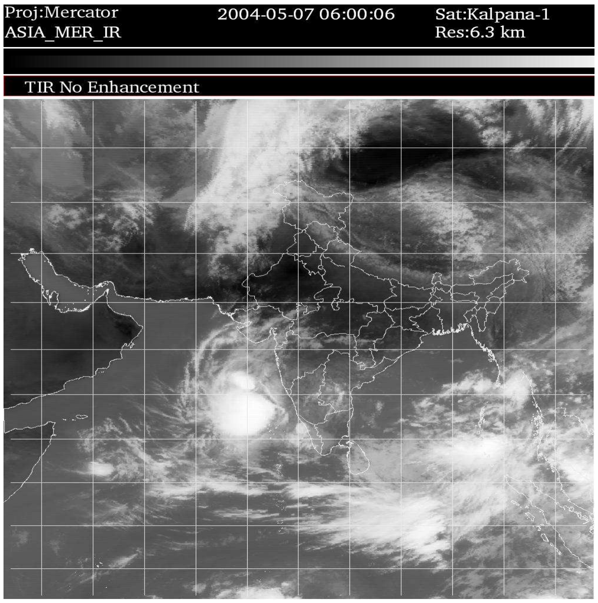


Fig. 9. Kalpana-1 satellite Infrared (IR) image of 07 May 2004 cyclone showing shear type of pattern

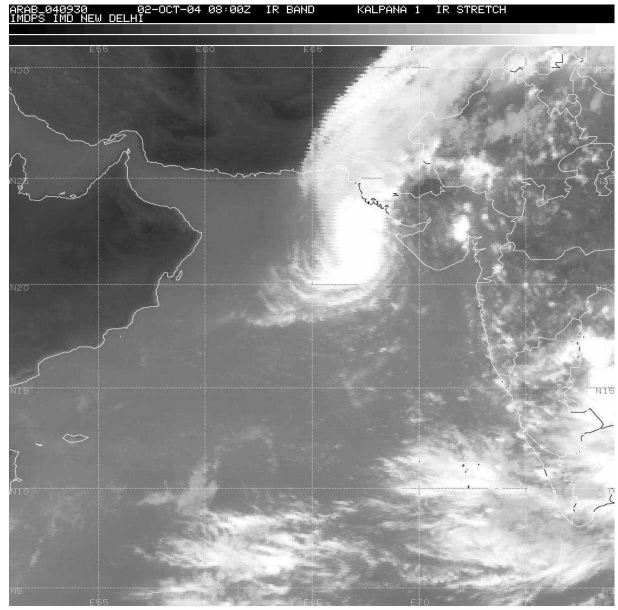


Fig. 10. Kalpana-1 satellite Infrared (IR) image showing irregular CDO pattern of 02 October 2004 cyclone

satellite infrared imagery. The AODT can be used to classify storm intensity beginning from storm formation from development to dissipation.

2. Data and methodology

The AODT data for the three cyclone cases 05 - 10 May 2004, 05-07 November 2004 and 30 September – 03 October 2004 is taken from, Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin - Madison, U.S.A. The INSAT satellite imageries used in subjective Dvorak technique (SDT) is taken from Satmet division India Meteorological Department (IMD). The AODT package is mainly developed for Man Computer Interaction Data Access System (McIDAS) software system. In satellite division we have McIDAS software but we do not have AODT package in it. Because it is automated computerized way to determine the intensity of tropical cyclone so the aim of the present study to determine the accuracy in the prediction of Intensity of tropical cyclones in the tropical Indian ocean. So we have taken this data from University of Wisconsin - Madison, U.S.A. for testing purpose.

The enhanced infrared technique (EJR technique), developed in 1978 (Dvorak and Wright, 1977), when applied to storms of hurricane strength, rely almost entirely on measurements of the “eye” temperature and the temperature of the clouds around the eye for the intensity determination. The method uses IR images that display the cloud features related to cyclone intensity in discreet gray shades representing known temperature ranges. This enables the analyst to use the temperatures of the features as objective measures of intensity. This is an objective technique whose accuracy increases as the intensity of the tropical cyclone increases.

Objective Dvorak Technique (ODT) is an automatic technique based on previous objective satellite estimation algorithms with the modifications in SDT rules, which are responsible for the variability of the intensity estimates. These changes have led to more stable and statistically sound estimates of intensity. In AODT technique objective scene identification is performed using Fast Fourier Transform (FFT) / log spiral analysis or statistical analysis techniques and the patterns are identified with almost the same threshold as in the subjective Dvorak EIR technique. The eye scene type and surrounding cloud region are examined by the FFT harmonics and their categorical differences in temperature values. Log spiral analysis is used to determine the curvature extent of the convective cloud region around the selected center position. After the scene type determination (automatically or manually) this value is used in conjunction with the eye and surrounding cloud top temperatures, oceanic basin type, and other history file (Software module utility stores all the past information) to calculate the intensity estimate for the image being investigated. The algorithm is quite sensitive to the effects of upper level shear in IR imagery, leading to center estimates driven by patterns in the cirrus clouds rather than low-level clouds. Recently the AODT method is

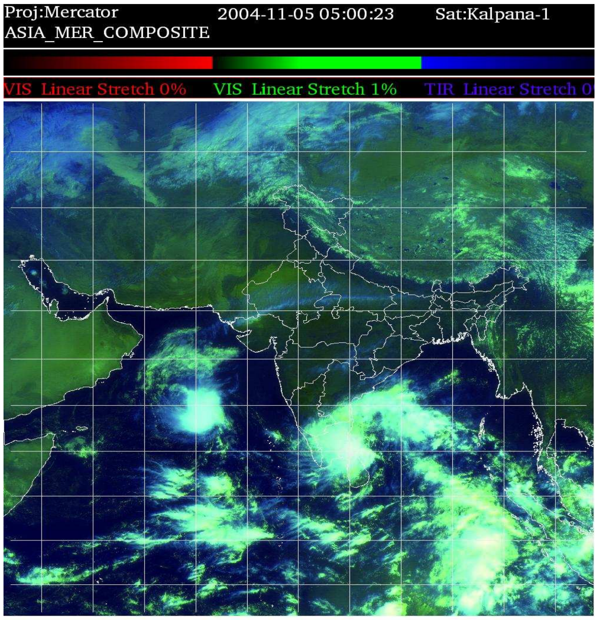
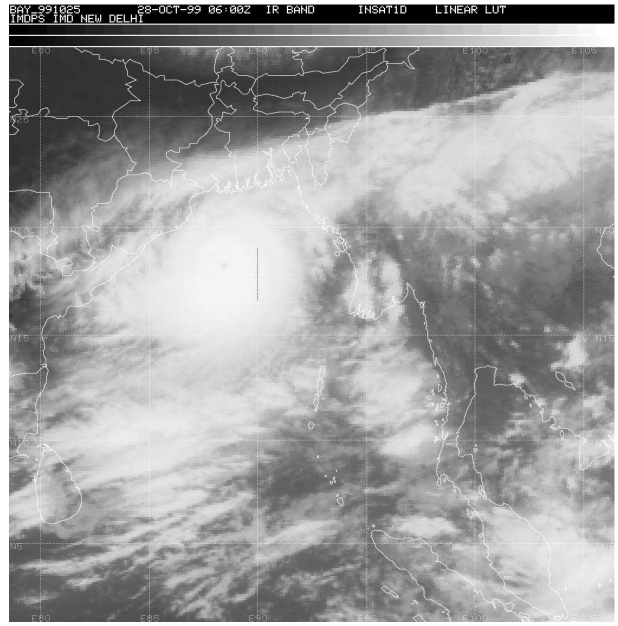


Fig. 11. Kalpana-1 satellite image showing CDO type of pattern 05 November 2004 at 0500 UTC



Figs. 12. INSAT-1D Satellite IR image showing irregular CDO pattern of Orissa super cyclone of 28 October, 1999 at 0600 UTC

integrated with multi sensor microwave (TRMM, SSM/I) and additional geostationary satellite channels such as the water vapor channel and visible and short wave infrared imagery (Velden *et al*., 2004).

3. Result and discussion

The comparative analysis of three cases of year 2004 cyclones (05 - 10 May 2004, 30 September - 03 October 2004 and 05 - 07 November 2004) with Northern Hemisphere Analysis Center (NHAC), Satellite Meteorology Division SATMET) and AODT are given in Tables (1, 2 & 3). Their graphical plots are also shown in the Figs. (1, 2 & 3). Figs. (4, 5, & 6) shows the comparative graphs of all the above said year 2004 cyclones. It is evident from the table as well as graphs that in the third case (05 - 07 November 2004) the deviation in position and intensity of the cyclones by AODT technique are shown in four cases. The position and the intensity of the super cyclone (Orissa 1999) are shown in Sikka's paper in this volume. Similarly Fig. 7 represents the ODT analysis by two approaches one is from Cooperative Institute for Meteorological Satellite Studies (CIMSS) and other Cooperative Institute for Research in the Atmosphere (CIRA) shows higher value than satmet synoptic analysis unit graph (Fig. 8). This is probably due to that ODT technique not always good in tropical region. And other very important factor of AODT more variation than conventional SDT technique is latitudinal bias in tropical cyclone MSLP determination. The bias can be approximated as a linear function of latitude and is caused by the dependence of tropopause temperature on latitude. The final major upgrade to the algorithm involves the inclusion of a bias adjustment to the AODT estimate of MSLP based upon storm latitude position (Kossin and Velden, 2004). Due to the problems of latitudinal bias, scene identification and complex nature of tropical dynamics the AODT technique does not produce good results in many cases of tropical cyclones. The other problem of the technique is that it is not plateform independent it requires Man Computer Interaction Data Access System (McIDAS) architecture, utilizing the McIDAS text and graphics/image windows for command line input, data access and image analysis. Runtime status and final analysis text output are displayed within the McIDAS text window, with image display and graphical output displayed within the McIDAS graphics/image window. In this way we can say that this technique is more suitable in Atlantic/Pacific Ocean storms Fig. 9 shows the SDT analysis from satellite imagery for cyclone of 07 May 2004 which was of shear type of pattern and its center was defined by low cloud lines in the south of main cloud cluster. In the second case, 02 October 2004 cyclone case shown in Fig. 10 it was an irregular Central Dense Overcast (CDO) pattern and its centre was within the convective cloud mass. Similarly, for the third case (Fig. 11), 05 November 2004 it was an irregular CDO pattern. In the fourth case, 28 October 1999 (Fig. 12) it was regular CDO pattern and its centre was in the centre of the convective cloud mass.

4. Conclusions

(*i*) The results derived from AODT of all the three cases of tropical cyclones are not so encouraging in the tropical region; it may be due to the complex nature of various types of interactions acting on the system. It may be recalled that the Dvorak technique was originally developed for cloud patterns associated with tropical cyclones in the Atlantic Ocean. The cloud pattern associated with an actual cyclone for the Indian Ocean Basin is likely to be somewhat different. Experienced forecasters take this bias into account while actually denoting the *T* numbers of tropical cyclones.

(*ii*) Sudden change of the intensity of the tropical storm is not very well accounted for, by the AODT as compared to the SDT, it is because precisely the automatic scene estimation is very difficult. On the average AOD estimate slightly higher than Satmet estimate. The maximum intensity estimated in AOD techniques is also higher by about 1 T. No. in two cases and is the same in the other two cases. It may be due to fact that if some error occurs in the past history file than this error will automatically propagate further analysis.

(*iii*) The position and intensity variation is more pronounced in all the three tropical cyclone cases which may be due to MSLP bias and a systematic inconsistency in the relationship between MSLP and *V*max.

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