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Validation of Advanced Dvorak Technique (ADT) over north Indian Ocean

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सार - भारत मौसम विज्ञान विभाग में 2014 से प्रयोगात्मक रूप से उन्नत ड्वोर्क तकनीक स्थापित की गई है। प्रचालानात्मक रूप में लाने से पहले इस तकनीक की वैद्यता की आवश्यकता है। इसलिए 2014 और 2015 (कुल नम्बर 7) के दौरान उत्तरी हिंद महासागर में सभी उष्णकटिबंधीय चक्रवातों पर (34 नॉट्स से ऊपर) आधारित उन्नत ड्वोर्क तकनीक (V8.1.313) और उन्नत ड्वोर्क तकनीक (V8.2.1) की वैद्यता का अध्ययन किया गया है। उन्नत ड्वोर्क तकनीक की तुलना नियम पुस्तक T नम्बर के निष्पादन से की गई है। इससे यह पता चलता है कि उन्नत ड्वोर्क तकनीक (V8.2.1) 1.0 से 2.5 के नियम पुस्तक T नम्बर की तुलना में लगभग 1 T नम्बर अधिक अनुमानित की गई और 4.0 से 5.5 के नियम पुस्तक T नम्बर की तुलना में 0.5 से 1 T नम्बर कम अनुमानित की गई। आगे CIMSS उन्नत ड्वोर्क तकनीक के साथ तुलना से संकेत मिलता है कि आई एम डी उन्नत ड्वोर्क तकनीक CIMSS ADT पर आधारित T नम्बर की तुलना में लगभग 1 T नम्बर कम अनुमानित की गई।

ABSTRACT. The Advanced Dvorak Technique (ADT) has been installed in India Meteorological Department experimentally since 2014. There is a need to validate this technique before it's used operationally. Hence a study has undertaken to validate ADT (V8.1.3B) & ADT (V8.2.1) based on all the TCs (34 Knots & above) over the North Indian Ocean during 2014 & 2015 (total 7 no.). The performance of ADT has been compared with manual T number. It indicates that ADT (V8.2.1) overestimates by about 1 T number as compared to manual T number of 1.0 to 2.5 and underestimates by about 0.5 to 1 T number as compared to manual T number of 4.0 to 5.5. Further comparison with CIMSS ADT indicates that IMD ADT underestimates by about 1 T number compared to T number based on CIMSS ADT.

Key words – Tropical cyclone, Satellite, Advanced Dvorak Technique (ADT), Intensity, Arabian Sea and Bay of Bengal.

1. Introduction

The advent of satellites enabled researchers to determine the organization and intensity of tropical cyclones (TCs) to estimate its intensity. The appearance of a storm's eye, the presence of banding structures and the size of the cloud pattern were all used in the early 1960s as a first-guess for storm intensity. By the 1970s, however, the temporal interval between successive images decreased substantially. Access to multiple satellite images per day allowed scientists to empirically derive relationships between cloud patterns typically seen with TCs and the intensity associated with said patterns. For the first time, Dvorak (1975) developed an empirical method based on pattern recognition technique for estimating intensity of TC using pattern of cloud as observed in satellite imagery. For the past 40 years, the Dvorak (1975, 1984) technique has served as the benchmark for tropical cyclone (TC) intensity estimation using satellite data. The Dvorak technique uses geostationary satellite imagery to estimate TC intensity at all stages of its lifetime. The earliest documented versions of the technique (Dvorak, 1973 and 1975) relied heavily on visible imagery to extract intensity information by subjectively analysing tropical cyclone cloud patterns (*e.g.*, eye and eye wall patterns, referred to collectively as "central features" and "spiral band patterns"). The Dvorak technique yields intensity estimates in terms of *T* numbers (tropical numbers). The T numbers are then related to current intensity (CI) numbers that are then directly related to mean sea level pressure (MSLP) and maximum sustained wind speed (V_{max}).

Dvorak (1984) noted four cloud patterns that are observed throughout the evolution of a tropical cyclone: curved band, central dense overcast (CDO), eye and shear. Each scene type is assigned a T number throughout the tropical cyclone's lifespan, with higher

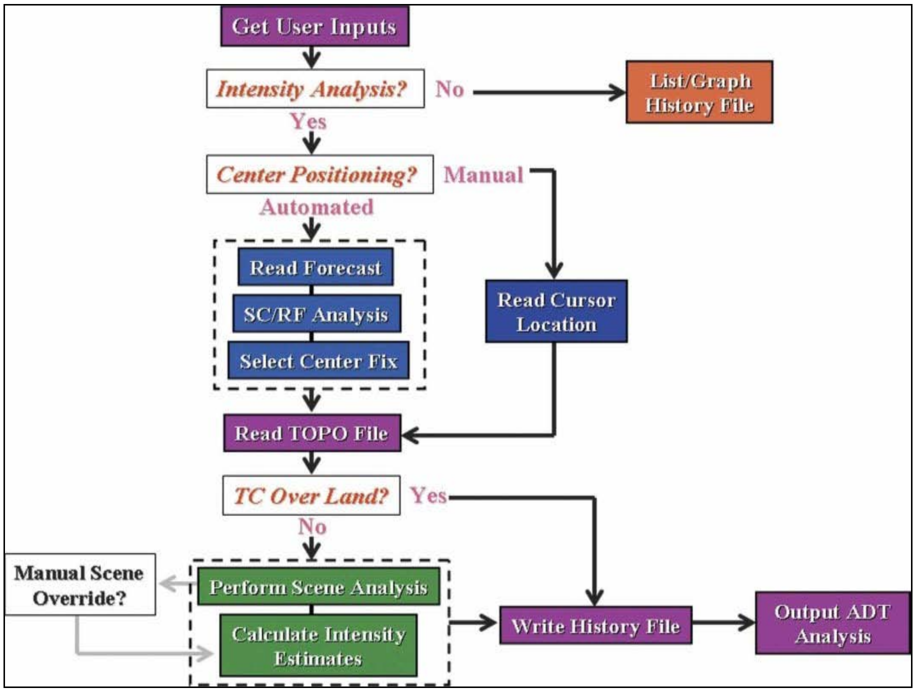


Fig. 1. ADT algorithm for satellite image analysis to estimate tropical cyclone intensity

TABLE 1

Characteristics of cyclones considered in the study

S. No.	Cyclone name	Basin	Season	Maximum intensity (wind) as per IMD best track	Classification
1.	Nanauk	Arabian Sea	Monsoon	T3.0	CS
2.	Hudhud	Bay of Bengal	Post-monsoon	T5.0	ESCS
3.	Nilofar	Arabian Sea	Post-monsoon	T5.5	ESCS
4.	Ashobaa	Arabian Sea	Monsoon	T3.0	CS
5.	Komen	Bay of Bengal	Monsoon	T2.5	CS
6.	Chapala	Arabian Sea	Post-monsoon	T6.0	ESCS
7.	Megh	Arabian Sea	Post-monsoon	T5.0	ESCS

T numbers corresponding to greater intensity values. The Dvorak technique has two primary shortcomings. First, the storm center has to be manually determined by the user. If an eye has not developed, or is too small to be observed by satellite, the user may incorrectly identify a storm's center, resulting in an erroneous T number given that most scene type-based intensity estimates are highly dependent upon the amount of curvature around the storm center location. Secondly, infrared imagery may reflect an obscured eye due to the presence of a broad area of light cirrus clouds (with cold cloud-top brightness temperatures) over the storm center. Such clouds are usually transparent, or nearly so, in visible satellite imagery. This may result in the user incorrectly determining a CDO scene type instead of an eye scene type, resulting in an underestimation of storm intensity. Consequently, a fair amount of subjectivity is inherent to each Dvorak technique analysis, as user expertise can vary substantially (Velden *et al*., 2006).

The main shortcoming of the Dvorak technique is its inherent subjectivity and the widely varying expertise levels of the TC forecasters who utilize it. In the late 1980s, Zehr (1989), Velden *et al*. (1998) developed an initial computer-based objective routine based on the analysis technique outlined by Dvorak (1984) using

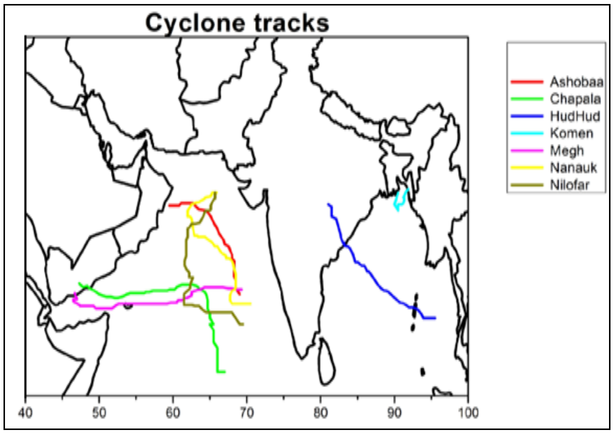


Fig. 2. Best tracks of TCs considered in the study

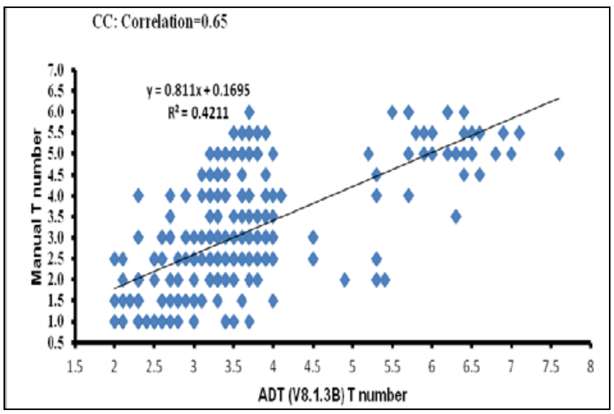


Fig. 3. Scattered plot of T numbers based on ADT (V8.1.3B) and Manual analysis for TCs over North Indian Ocean during 2014-2015

TABLE 2

Number of cases of T. No. of TCs considered in the Study during 2014-15

Manual T. No.	No. of cases considered in the study
1	71
1.5	44
2	28
2.5	48
3	44
3.5	17
4	23
4.5	11
5	27
5.5	21
6	5
Total	339

enhanced infrared satellite data. An objective Dvorak Technique reduced the subjectivity promoted uniformity and accuracy. Few technical modifications are done in objective Dvorak Technique and it developed in the form of Advanced Objective Dvorak Technique. The Advanced Dvorak Technique (ADT) utilizes long wave-infrared, temperature measurements from geostationary satellites to estimate tropical cyclone (TC) intensity. The ADT is based upon the operational Dvorak Technique developed by Vernon Dvorak of NOAA over 30 years ago. This step-by-step technique relies upon the user to determine a primary cloud pattern and measure various TC cloud top parameters in order to derive an initial intensity estimate. Various rules regarding TC development and intensity change over time are employed to guide the user in the scene selection process and govern the rate in intensity change over a given time period.

The Advanced Objective Dvorak Technique an objective application of the empirical Dvorak Technique that lessens subjectivity due to analyst judgment, but also it employs an automated storm centering determination processes and a variety of new rules, constraints and scene types to produce intensity estimates that are competitive with Dvorak Technique estimates (Olander *et al*., 2004). The ADT is also being run locally in a research mode at University of Wisconsin Madison's Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) in a completely automated environment, for all global TC systems. The real-time ADT intensity estimates are performed at a 30-min or hourly frequency (depending on image acquisition availability) and are accessible from the UW-CIMSS Tropical Cyclone Web site (http://cimss.ssec.wisc. edu/tropic/adt). The ADT has been installed in India Meteorological Department (IMD) for operational determination of intensity of TCs over the North Indian Ocean (NIO).

The objective of this study is to evaluate the performance of ADT in estimation of intensity of TCs over the NIO.

2. Data and methodology

The steps involved in ADT for estimation of intensity of TC are shown in Fig. 1 (Velden *et al*., 2006). The initial step in determining a storm center within Advanced Objective Dvorak Technique involves using an interpolation of an official tropical cyclone warning center short-term track forecast as a first guess for the storm center location. Next, the Advanced Objective Dvorak Technique centring method is employed as followed: If the previous final T number intensity lies between 3.5 and

TABLE 3

Root mean square difference, actual mean difference and absolute mean difference of T Number based on ADT (V8.1.3B) and Manual_Tnumber for all TCs during 2014-15

Manual T. No. (A)	Total No. of cases	Avg. T.No. of ADT(V8.1.3B) (B)	Actual mean difference (B-A)	Absolute mean difference	RMS Difference
1	82	2.46	**1.46**	1.46	1.58
1.5	49	2.67	**1.17**	1.17	1.35
2	28	3.25	**1.25**	1.29	1.52
2.5	49	3.28	**0.78**	0.86	1.00
3	44	3.36	**0.36**	0.48	0.57
3.5	17	3.77	0.27	0.45	0.76
4	23	3.66	**-0.34**	0.63	0.80
4.5	11	4.13	-0.37	1.25	1.31
5	27	4.83	-0.17	1.36	1.43
5.5	21	4.96	**-0.54**	1.34	1.45
6	5	5.5	-0.50	0.74	1.08

The difference in T number significant at 95% level of confidence is highlighted

TABLE 4

Root mean square difference, actual mean difference and absolute mean difference of T Number based on ADT(V8.2.1) and Manual_T number for all TCs during 2014-15

Manual T. No. (A)	Total No. of cases	Average T. No. of ADT(V8.2.1) (B)	Actual mean difference (Bias) (B-A)	Absolute mean difference	RMS Difference
1.0	57	2.39	**1.39**	1.39	1.51
1.5	46	2.70	**1.20**	1.20	1.35
2.0	17	3.05	**1.05**	1.05	1.15
2.5	27	3.07	**0.57**	0.98	1.09
3.0	31	3.12	0.12	0.68	0.80
3.5	16	3.26	-0.24	0.58	0.81
4.0	20	2.95	**-1.05**	1.20	1.51
4.5	11	3.82	**-0.68**	1.46	1.68
5.0	23	4.37	**-0.63**	1.53	1.71
5.5	23	4.44	**-1.06**	1.56	1.93
6.0	6	4.05	**-1.95**	2.02	2.77

The difference in T number significant at 95% level of confidence is highlighted

4.5 and three or more eye or embedded scene types have been previously identified, the Spiral Centering and Eye Ring Fitting methods will be used. Once the final T Number value has exceeded 4.5, both auto-centering techniques will be utilized. Otherwise, the first guess center location is used as the Advanced Objective Dvorak Technique center point.

The Advanced Dvorak technique is a "living" algorithm (continually being boosted). Various versions are currently operating in real time. At present Advanced Dvorak Technique version "ADT (V8.1.3B)"and "ADT (V8.2.1)" (Velden *et al*., 2006; Olander and Velden, 2007) are installed in automated environment and validation process is in progress for all TC system in the North

TABLE 5

Root mean square difference, actual mean difference and absolute mean difference between T number based on ADT (V8.1.3B) and ADT (V8.2.1) of IMD for all TCs during 2014-15

ADT(V8.1.3 B) T of IMD	Total No. of cases	Average T.No. based on ADT(V8.1.3B) (A)	Average T.No. based on ADT(V8.2.1) (B)	Actual mean difference (A-B)	Absolute mean difference	RMS Difference
1.5-2.0	12	1.60	1.97	**-0.36**	0.38	0.64
2.1-3.0	93	2.59	2.37	**0.22**	0.32	0.45
3.1-4.0	162	3.52	3.25	**0.27**	0.33	0.72
4.1-5.0	5	4.42	4.04	0.38	0.38	0.76
5.1-6.0	13	5.68	4.17	**1.51**	1.51	2.38
6.1-7.0	16	6.5	5.99	**0.51**	0.51	0.95
7.1-8.0	2	7.35	7.05	0.30	0.3	0.3

The difference in T number significant at 95% level of confidence is highlighted

Indian Ocean using INSAT-3D data (HDF5) in the Satellite Division, IMD. For this analysis, all the systems that occurred in the North Indian Ocean during 2014 and 2015 are considered (Table 1). The number of case of TCs considered for the study is presented in the Table 2. The best tracks of these TC's are shown in Fig. 2 (IMD, 2008).

To determine the efficiency of ADT (V8.1.3B) and ADT (V8.2.1), various parameters like root mean square (RMS) difference, actual mean difference (bias) and mean absolute difference are calculated for (*i*) individual TCs, (*ii*) different stages of T number as par manual estimation of IMD for all TCs taken together. The student's '*t*' test has been applied to find out the significant difference, if any.

We assess the average difference between manually estimated T number by IMD and T number based on ADT (V8.1.3) and ADT (V8.2.1).Also the T number based on ADT have been compared with IMD's best track based CI number and the ADT derived by CIMSS based on RMS difference, actual mean difference and absolute mean difference for different T numbers.

3. Results and discussion

3.1. *Comparison of ADT (V8.1.3B) with manual T number estimated by IMD*

The comparison of T number based on ADT (V8.1.3B) with the manually estimated T number of IMD is given in Table 3. According to Table 3, there is overestimation of intensity by ADT (V8.1.3B) in the initial stage of development of TC (up to T3.0) as compared to manual T. The estimation in ADT (V8.1.3B) is about one T number higher than manual T. There is underestimation of intensity for T ≥ 4.0. According to one

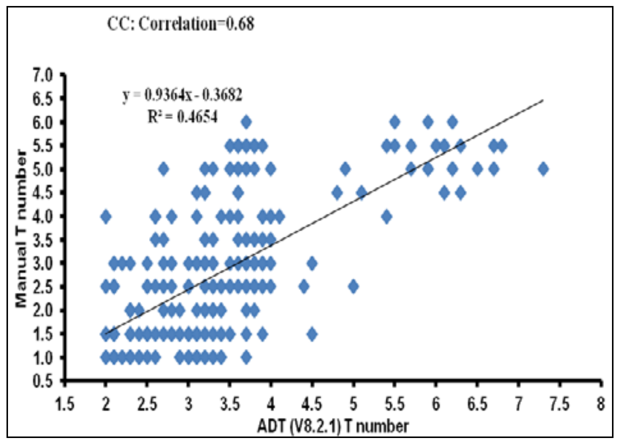
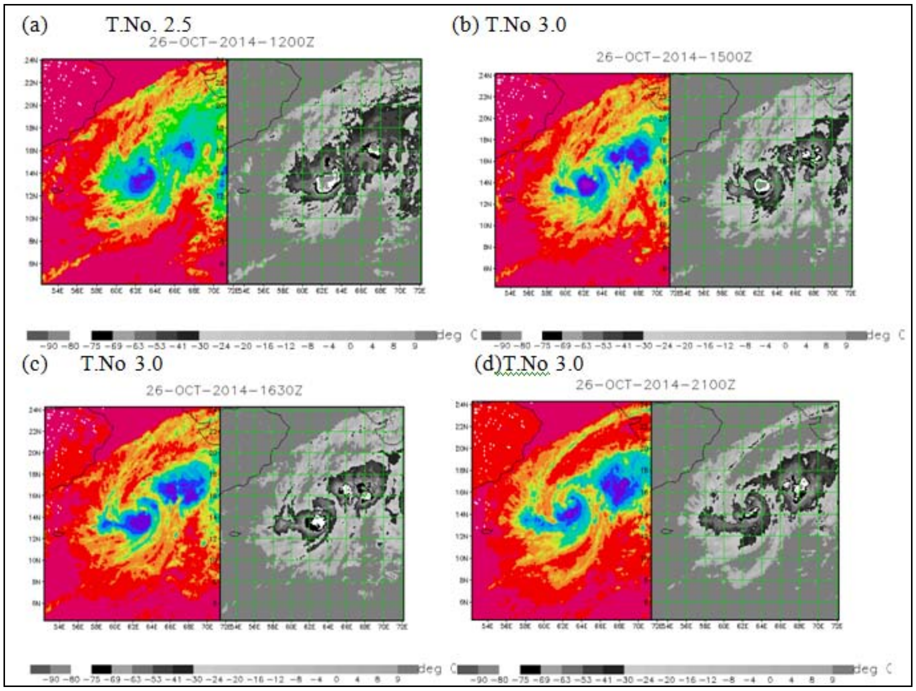


Fig. 4. Scattered plot of T number based on ADT (V8.2.1) and manual analysis for TCs over North Indian Ocean during 2014-2015

tailed Student's 't' test the difference in T number is significant at 95% level of confidence in the above two cases.

The scattered plot of T number based on ADT (V8.1.3B) and manual analysis is presented in Fig. 3. It also indicates that there is overestimation in initial stages and underestimation in higher intensity stage. The correlation coefficient (CC) between manual T and ADT (V8.1.3B) is about 0.65.

One of the limitation of this study is the comparison of ADT with manual T instead of validation of ADT with real time observed data like the data from aircraft reconnaissance, buoys, ships and scatterometer based satellites etc. For North Atlantic Ocean it is validated against the actual observations of aircraft (Olander *et al.*, 2007) which are not available



Figs. 5(a-d). Enhanced IR Images of TC Nilofar on 26th Oct. 2014 over the Arabian Sea generated by using ADT (V8.2.1)

over North Indian Ocean. For low intensity systems (<T3.0). The ADT can be validated to a large extent with the scatterometer derived winds. However during the study period the scatterometric data was not available for OSCAT II. The other source was ASCAT derived winds however due to its limited swath area (around 600 Km), the observations are limited for validation during the period of study. There is limited number of buoys over BOB and Arabian Sea for validation purpose (Mohapatra *et al*. 2012; Goyal *et al*., 2013) have demonstrated that manually derived T number agrees very well with the best intensity estimates of RSMC, New Delhi with intensity difference of -0.5 to 1.0 T number. Manually derived T number is underestimated in 9.5% cases and overestimated in about 5% cases over the North Indian Ocean (NIO).

3.2. *Comparison of ADT (V8.2.1) with manual T number estimated by IMD*

The comparison of *T* number based on ADT (V8.2.1) with the manually estimated T number of IMD is presented in the Table 4. Like ADT (V8.1.3B), there is overestimation in intensity by ADT (V8.2.1) up to T 2.5 and under estimation in intensity by ADT (V8.2.1) for T 4.0 and above at 95% level of confidence as per student's '*t*' test for comparison of two means. It almost agrees with the manual *T* for *T* 3.0 to T 3.5. Actual mean difference of ADT (V8.2.1) from Manual T (underestimation) is about 1.5 to 1 T number for T 1.0 to T 2.0 and is about 0.5 for T 2.5. Similarly the overestimation is about 1 T number for T 4.0 to T 5.5 and about 2 T number for T 6.0. It is again noted that the intensity estimates in this validation study were obtained using a completely automated version of the ADT algorithm. However, as mentioned previously, the ADT possesses a manual override functionality that can be applied by an analyst to adjust the initial position or scene type. Comparisons between intensity estimates obtained from the ADT using manual (provided by an experienced analyst) versus automated storm center positioning demonstrate an improvement in the overall accuracy (Olander and Velden, 2007).

The scattered plot of ADT (V8.2.1) and manual T is shown in Fig. 4. It also endorses the earlier findings of overestimation in low intensity stage and underestimation in high intensity stage by ADT (V8.2.1).

The same findings are given by Velden *et al*. (2006) in case of stronger systems ADT is underestimated. Olander *et al*. (2007), Herndon (2014) provides comparison between operational forecasting centers (OFC) manual intensity estimates and ADT intensity estimates. In this study aircraft reconnaissance measurements were used for validation and in some cases overestimated result was found. It also supports need of improvement in the accuracy of the ADT during weaker stages of TCs.

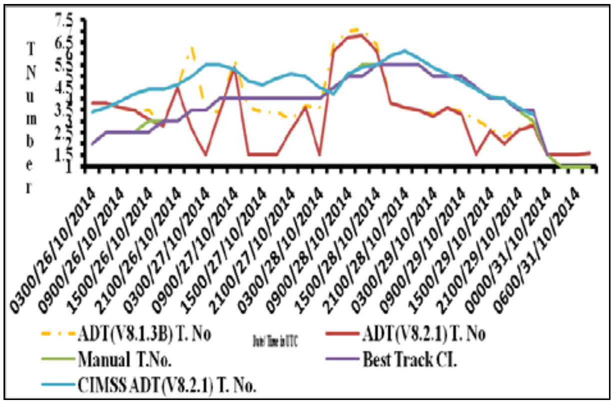


Fig. 6. T number based on (*i*) ADT (V8.1.3B), (*ii*) ADT (V8.2.1), (*iii*) Manual analysis, (*iv*) Best Track CI and (*v*) CIMSS ADT of the TC Nilofar

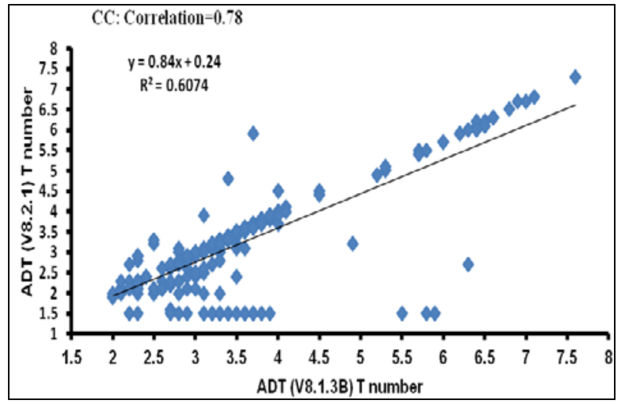


Fig. 9. Scattered plot of T number based on ADT (V8.1.3B) and ADT (V8.2.1) of IMD for TCs over North Indian Ocean during 2014-2015

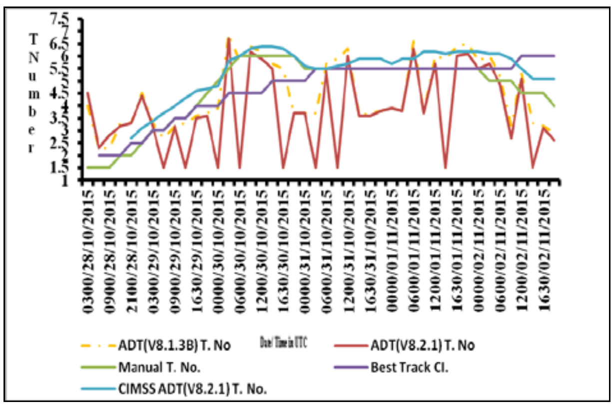


Fig. 7. T number based on (*i*) ADT(V8.1.3B), (*ii*) ADT(V8.2.1), (*iii*) Manual analysis, (*iv*) Best Track CI and (*v*) CIMSS ADT of the TC Chapala from 28th Oct., 2015 to 4th Nov., 2015

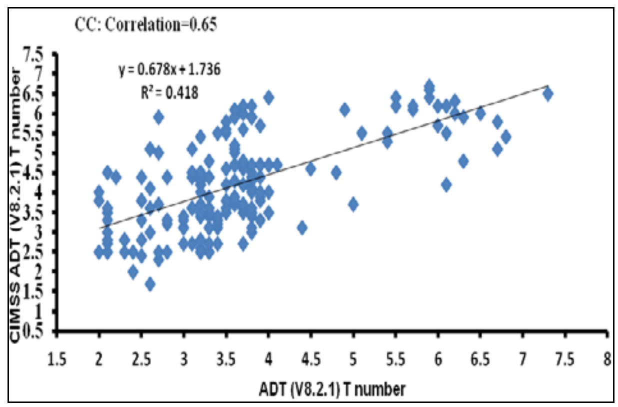


Fig. 10. Scattered plot of T number based on ADT (V8.2.1) and CIMSS_ADT (V8.2.1) for TCs over North Indian Ocean during 2014-2015

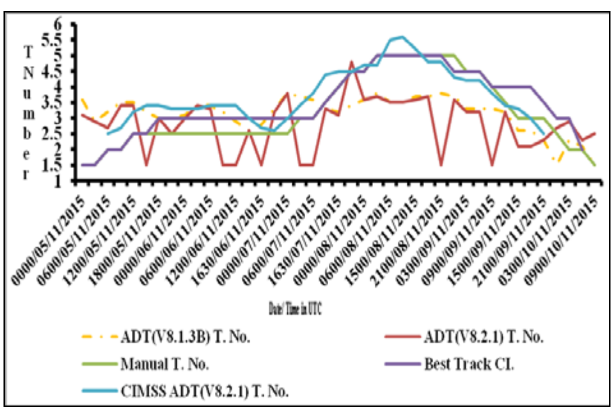


Fig. 8. T number based on (*i*) ADT (V8.1.3B), (*ii*) ADT (V8.2.1), (*iii*) Manual analysis, (*iv*) Best Track CI and (*v*) CIMSS ADT of the TC Megh from 5-10 November, 2015

3.3. *Comparison of ADT (V8.1.3B) & ADT (V8.2.1)*

On comparison of Tables (3 and 4) the results obtained for ADT (V8.2.1) are more consistent. Hence the performance of ADT (V8.2.1) is better than that of ADT (V8.1.3B).The comparison of T number based on ADT (V8.1.3B) and ADT (V8.2.1) is presented in Table 5. It shows that ADT (V8.2.1) overestimates intensity significantly at 95% level of confidence compared to ADT (V8.1.3B) in case of low intensity (up to T2.0). It underestimates for T number 2.1 and above. However the underestimation is statistically significant at 95% level of confidence for T(2.1-4.0) and T(5.1-7.0). The number of cases for T 4.1-5.0 and T7.1-8.0 are very less. Difference in T number is less than or equal to 0.5 for all cases except for T5.1-6.0, where it is about 1.5.

To illustrate the performance, an example of the IR images along with the estimated T number based ADT (V8.2.1) is shown in Figs. 5(a-d). Further the comparison of the intensity estimated by ADT (V8.1.3B), ADT (V8.2.1) and manual T number for the very severe TCs, Nilofar, Chapala and Megh are shown in Figs. 6, 7 and 8 respectively. These figures also demonstrate the overestimation of intensity by ADT (V8.1.3B) as compared to ADT (V8.2.1).

TABLE 6

Root mean square difference, actual mean difference and absolute mean difference of ADT(V8.2.1)_T of IMD from CIMSS_ADT(V8.2.1)_T for all TCs during 2014-15

Total No. of cases	ADT(V8.2.1)_T IMD	Average T. No. of CIMSS_ADT (V8.2.1) (A)	Average T.No. of ADT(V8.2.1) IMD (B)	Actual mean difference (B-A)	Absolute mean difference	RMS difference
22	2.1-3.0	3.66	2.52	**-1.14**	1.15	1.46
91	3.1-4.0	4.34	3.57	**-0.77**	0.96	1.20
6	4.1-5.0	4.45	4.62	0.17	0.8	0.94
12	5.1-6.0	6.05	5.67	**-0.4**	0.47	0.53
13	6.1-7.0	5.69	6.42	**0.73**	0.78	0.99

The difference in T number significant at 95% level of confidence is highlighted

TABLE 7

Comparison of characteristics of Meteosat-7 (data used in CIMSS_ADT) and INSAT-3D (data used in IMD_ADT)

S. No.	Specifications	Meteosat-7	INSAT-3D	
1.	Channel	11.5 μm (IMG_TIR1)	10.8 μm (IMG_TIR1)	
3.	Spatial Resolution	5 km	4 km (ground resolution)	
4.	Wavelength (μm)	11.5	TIR1	TIR2
			10.3-11.3	11.5-12.5
6.	Position	57 º5′ E	82º E	

TABLE 8

Root mean square difference, actual mean difference and absolute mean difference of ADT (V8.2.1)_T of IMD from CIMSS_ADT (V8.2.1)_T for TCs during 2014-15

Cyclone Name	Total No. of cases	Average T.No. of ADT (V8.2.1) IMD (A)	Average T. No. of CIMSS_ADT (V8.2.1) (B)	Actual mean difference (A-B)	Absolute mean difference	RMS difference
Nanauk	33	3.22	3.61	**-0.39**	0.62	0.88
Hudhud	31	4.39	4.82	-0.43	0.77	0.93
Nilofar	35	3.23	4.47	**-1.24**	1.59	1.93
Ashobaa	38	2.93	3.47	**-0.53**	0.71	0.98
Komen	9	2.69	2.6	0.09	0.58	0.62
Chapala	40	3.85	5.44	**-1.59**	1.77	2.14
Megh	35	2.82	3.75	**-0.93**	1.09	1.34

The difference in T number significant at 95% level of confidence is highlighted

Scattered plot of ADT (V8.2.1) and ADT (V8.1.3B) numbers is presented in Fig. 9. It shows a correlation of 0.78. It also demonstrates that the T number by ADT (V8.1.3B) overestimates the intensity compared to that by ADT (V8.2.1) for T≥2.1.

3.4. *Comparison of ADT (V8.2.1) of IMD with the CIMSS ADT (V8.2.1)*

CIMSS ADT overestimates the intensity up to T 4.0 as compared to IMD ADT (V8.2.1) based T number

(Table 6).The overestimation is about one T number. The overestimation is about T 0.5 in the intensity scale of T5.1 and above. Further comparison of ADT estimates for individual TCs under consideration shows that the difference in T number by ADT (IMD) and ADT (CIMSS) method is statistically significant only in case of Arabian Sea TCs (Table 8).While the Advanced Dvorak Technique currently provides forecasters with an objective tool based on IR imagery, the use of supplementary spectral information has the potential to advance satellite-based intensity estimation considerably further than can be achieved with the IR band alone. For example, polar orbiting microwave sensors are being used to denote TC structure and infer intensity (Herndon and Velden, 2004). Employment of these instruments and methods in conjunction with the existing ADT into an integrated algorithm should provide TC analysts with an even more powerful tool for estimating tropical cyclone intensity. This manual intervention by IMD & CIMSS might have also lead to this difference in intensity estimation. The difference may be due to the different sources of data as IMD ADT uses INSAT 3D and CIMSS ADT uses Meteosat 7. Scattered plot of ADT (V8.2.1) and CIMSS_ADT (V8.2.1) numbers is presented in Fig. 10. It shows a correlation of 0.65. In both the cases the algorithm is same. To explain further the characteristics of these two satellites are presented in Table 7. Comparing various parameters as mentioned in Table 7, there is a significant difference in location of the satellite. While Meteosat-7 is located near 57.5° E, INSAT-3D is located near 82° E. The error for the TCs over the Arabian Sea may be due to different adjustments followed for avoiding parallax error. The parallax error can not only lead to error in estimation of location of center of TC, but also its intensity as center determination and intensity estimation are related to each other in Dvorak Technique.

Systematic differences have been reported between various ADTs and between CIMSS and IMD T-Numbers. Similar is the case in other ocean basins. Hence it creates difficulty in deciding intensity in operational scenario. Thus there have been various attempts to decide the final T No. of T based on various manual and automated T. Nos. One of the most important approach has been Satellite Consensus (SATCON) method. This method blends tropical cyclone intensity estimates derived from multiple objective algorithms to produce an ensemble estimate of intensity for current tropical cyclones worldwide. The algorithm uses individual ADT, CIMSS AMSU and CIRA AMSU intensity estimates utilizing a statistically-derived weighting scheme which maximizes/ minimizes the strength/weaknesses of each technique to produce a consensus estimate of the current tropical cyclone intensity Herndon Derrick (2014). This approach can be adopted by IMD based on the present study.

4. Conclusion and future scope

Following broad conclusions are made from the above results and discussion.

There is overestimation of intensity by ADT (V8.1.3B) in the initial stage of development of TC (up to T3.0) as compared to manual T. The estimation in ADT (V8.1.3B) is about one T number higher than manual T. There is underestimation of intensity for $T \geq 4.0$.

Similarly there is overestimation in intensity by ADT (V8.2.1) up to T 2.5 and under estimation in intensity for T 4.0 and above compared to manually estimated T number. It almost agrees with the manual T for T 3.0 to T 3.5. Actual mean difference of ADT (V8.2.1) from Manual T (underestimation) is about 1.5 to 1 T number for T 1.0 to T 2.0 and is about 0.5 for T 2.5. The overestimation is about 1 T number for T 4.0 to T5.5 and about 2 T number for T 6.0.

The performance of ADT (V8.2.1) is better than that of ADT (V8.1.3B). However ADT (V8.2.1) overestimates intensity compared to ADT (V8.1.3B) in case of low intensity (upto T 2.0). It underestimates for T number 2.1 and above. The difference in T number is less than or equal to 0.5 for all cases except for T 5.1-6.0, where it is about 1.5.

Comparing T numbers estimated by IMD with that by CIMSS,CIMSS ADT overestimates the intensity up to T 4.0 as compared to IMD ADT(V8.2.1) based T number. The overestimation is about one T number. The overestimation is about T 0.5 in the intensity scale of T 5.1 and above.

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