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Comparison of best track parameters of RSMC, New Delhi with satellite estimates over north Indian Ocean

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सार – भारत मौसम विज्ञान विभाग (आई. एम. डी.) एक प्रादेशिक विशिष्ट प्रकार के मौसम केन्द्र होने के कारण चक्रवातीय विक्षोभों (सी.डी.$_{एस}$) का मॉनीटरन एवं पूर्वानुमान देने के लिए जिम्मेवार है इसके अंर्तगत चक्रवातीय विक्षोभें से संबंधित सभी प्रकार के आँकड़े जिसमें अवदाब एवं उष्णकटिबंधीय चक्रवात (टी. सी.) शामिल है, का संग्रह, संसाधन एवं भंडारण किया जाता है और उत्तरी हिन्द महासागर (एन. आई. ओ.) में बनने वाले चक्रवातों के मार्ग को सही–सही निर्धारित करने में इनका उपयोग किया जाता है। ऋतु के पश्चात् चक्रवातीय विक्षोभों के विश्लेषण के द्वारा किसी चक्रवातीय विक्षोभ की स्थिति एवं उसकी तीव्रता का निर्धारण चक्रवात की अवधि के दौरान की अन्य विशेषताओं के साथ–साथ किया जाता है जिसे हम बेस्ट ट्रैकिंग के नाम से जानते हैं। बेस्ट ट्रैकिंग प्रक्रिया उत्तरी हिन्द महासागर सहित विश्व में अलग–अलग प्रकार की है और यह मॉनीटरन एवं विश्लेषण के साधन तथा प्रक्रिया में भिन्नता के कारण होती है। यद्यपि चक्रवातीय विक्षोभों के स्थान एवं तीव्रता का मॉनीटरन करने के लिए भू–स्थैतिक उपग्रह ही मुख्य उपकरण माना जा रहा है। उत्तरी हिन्द महासागर में चक्रवातीय विक्षोभों के बेस्ट ट्रैक के स्थान एवं तीव्रता के निर्धारण के लिए उपग्रह की भूमिका और उसकी सीमा का आकलन करने के लिए कुछ प्रयास किए गए है। अतः प्रादेशिक विशिष्ट प्रकार के मौसम केन्द्र (आर. एस. एम. सी.) नई दिल्ली के बेस्ट ट्रैक प्राचलों के आधार पर चक्रवातीय विक्षोभों के स्थान एवं तीव्रता की तुलना इनसैट और कल्पना उपग्रहों के आधार पर आई. एम. डी. के उपग्रह प्रभाग द्वारा आकलित परिणामों से करने के लिए एक अध्ययन किया गया है।

उत्तरी हिन्द महासागर, बंगाल की खाड़ी तथा अरब सागर में आए चक्रवातीय विक्षोभों के स्थानों के निर्धारण में औसत अंतर क्रमशः 39 कि. मी., 40 कि. मी. एवं 37 कि. मी. पाए गए है। कुल घटनाओं में से लगभग 65 प्रतिशत के स्थन निर्धारण में 50 कि. मी. या कम का अंतर पाया गया और उत्तरी हिन्द महासागर में संपूर्ण घटनाओं में से 6 प्रतिशत में 100 कि. मी. का अथवा इससे अधिक का अंतर पाया गया। बंगाल की खाड़ी में यह अंतर 62 प्रतिशत तथा 6 प्रतिशत का था ओर अरब सागर में लगभग 70 प्रतिशत एवं 5 प्रतिशत का पाया गया। स्थान निर्धारण में अंतर टी नंबर में वृद्धि के साथ धीरे–धीरे कम होता जाता है। जब बंगाल की खाड़ी, अरब सागर और उत्तरी हिन्द महासागर में सिस्टम की तीव्रता टी.–4.0 या अधिक (अतिप्रचंड चक्रवातीय तूफान और उच्च तीव्रता) हो तो यह अंतर लगभग 30 कि.मी. का होता है। चक्रवातीय विक्षोंभों के स्थान में अंतर के स्थानिक वितरण को देखते हुए यह कहा जा सकता है कि यह अंतर समुद्र तट के निकट अधिक रहता है ओर जैसे– जैसे हम तट से दूर जाते है यह कम होता जाता है। लगभग 85.5 प्रतिशत घटनाओं में बेस्ट ट्रैक की तीव्रता उपग्रह के द्वारा आकलन से मेल खाती है। जबकि उपग्रह आधारित तीव्रता 9.5 प्रतिशत घटनाओं में कम आकलित हुई है (उपग्रह प्रभाग द्वारा आकलित टी. नंबर बेस्ट ट्रैक टी. नंबर से कम है), उत्तरी हिन्द महासाग में लगभग 5 प्रतिशत घटनाओं में यह अधिक (उपग्रह प्रभाग द्वारा आकलित टी. नंबर बेस्ट ट्रैक टी. नंबर से अधिक) आकलित हुई है। स्थानिक वितरण की दृष्टि से हम देखते है तो पाते है कि यह अंतर अक्सर तब होता है जब चक्रवातीय विक्षोभ समुद्र तट के निकट होता है अथवा उत्तरी हिन्द महासागर के द्वीपों के स्थान में इसी प्रकार का अंतर होता है।

ABSTRACT. India Meteorological Department (IMD), as a Regional Specialized Meteorological Centre (RSMC) has the responsibility of monitoring and prediction of cyclonic disturbances (CDs) including depressions and tropical cyclone (TC); collection, processing and archival of all data pertaining to CDs and preparation of best track data over the north Indian Ocean (NIO). The process of post-season analysis of CDs to determine the best estimate of a CD's position and intensity along with other characteristics during its lifetime is described as "best tracking". The best tracking procedure has undergone several changes world-over including NIO due to change in monitoring and analysis tools & procedure. However, the geostationary satellite remains the main tool for monitoring of location and intensity of CDs. There have been a few attempts to document the role and extent of satellite estimates in determining the best track location and intensity of CDs over the NIO. Hence, a study has been undertaken to compare the location and intensity of CDs based on best track parameters prepared by RSMC, New Delhi with those estimated by satellite division of IMD based on INSAT and Kalpana satellites.

The average difference in location of CDs over the NIO, BOB and AS is about 39, 40 and 37 km respectively. The difference in location is 50 km or less in about 65% of the total cases and about 6% of the cases have a difference of 100 km or more over the NIO as a whole. It is about 62% and 6% over the BOB and about 70% and 5% over the AS respectively. Difference in location gradually decreases with increase in T number. It is about 30 km when the intensity of the system is T4.0 or more (very severe cyclonic storms and above intensity) over the BOB, AS and NIO. Considering the spatial distribution of difference in location of CDs, it is higher near the coast and decreases as we move away from the coast. The intensity in the best track agrees with the satellite estimates in about 85.5% of the cases. While the satellite based intensity is underestimated (Satellite division estimated T number is less than best track T number) in 9.5% cases, it is overestimated (Satellite division estimated T number is greater than best track derived T number) in about 5% cases over the NIO. Considering the spatial distribution, the difference occurs mostly when the CD lies near the coast or the islands in the NIO like the difference in location.

Key words – Tropical cyclone, North Indian Ocean, Best track, Intensity, Satellite

1. Introduction

Various agencies involved in monitoring and prediction of tropical cyclones (TCs) over different Ocean basins perform a post-season analysis of TCs to determine the best estimate of a TC's position and intensity during its lifetime. This process is described as "best tracking". However, the best tracking process is temporally inhomogeneous by construction because available data and techniques and general knowledge have changed over time. Furthermore, procedures and data availability differ at each agency. Thus, the resulting best track and intensities from the Regional Specialised Meteorological Centres (RSMCs) and Tropical Cyclone Warning Centres (TCWCs) have temporal (due to technological advances) and spatial (due to varying practices between agencies) heterogeneities. In light of these differences, it is important to understand and document the factors leading to temporal and spatial variations of best track information of TCs like location and intensities, particularly if temporal or spatial trends are to be discerned in the data for the study of climate change and related issues.

Operational procedures to produce TC best track data depend on the way the data are constructed and reported. These procedures vary by forecast centers. Currently, the location of the centre of the system over the north Indian Ocean (NIO) is determined based on (a) Synoptic position, (b) Satellite position and (c) radar position. The satellite is the main source of locating centre of cyclonic disturbances (CDs) over the mid-oceanic region as the observational data from ships and buoys are very meagre. It is the case when the CD is far away from the coast and not within the radar range. Of course the satellite based location of CD is modified sometimes with availability of ship and buoy observations. When the system comes closer to the coast, radar position gets maximum preference followed by the satellite position. When the system is very close to coast or over the land surface, the coastal observations get the highest preference followed by radar and satellite observations. Synoptically, the location of the centre is determined from the location of the lowest pressure at the mean sea level and the centre of the available 10 metre wind circulation over the CD region at the surface level (IMD, 2003).

Intensity of a CD is generally reported as the maximum sustained surface wind (MSW) over a specified time period. Operationally, the value of MSW is almost never measured. The procedure followed in IMD for estimating the intensity of a CD over the north Indian Ocean is discussed in the cyclone manual (IMD, 2003). It necessarily deals with estimation of associated MSW, estimated central pressure and pressure drop at the centre with the available observations in the CD region. Currently, the intensity estimation takes into consideration (a) satellite (INSAT/METSAT, NOAA, TRMM, SSMIS, scatterometer wind etc), (b) Radar (conventional S-band cyclone detection radar and S-band Doppler weather radar) and (c) synoptic analyses. Like the location of the system, when the system is far away from the coast and not within the radar range, satellite estimated intensity based on Dvorak's technique (Dvorak, 1984) gets maximum weight. When the system comes closer to the coast, radar estimated intensity is considered along with satellite estimated intensity. When the system is very close to coast or over the land surface, the coastal observations get the highest preference followed by radar and satellite observations for estimating the intensity.

As a result, the best track estimations by the RSMCs differ from the satellite estimations during the life time of a CD which includes depression and TCs. This difference is expected to be minimum in the mid-oceanic region and maximum near the coast. Given the need to understand the location and intensity of TCs and associated in uncertainties in the best track parameters, it is necessary to determine the differences between the satellite estimates and the best tracks. The quality of best tracks and the role of satellite inputs in the best tracks parameters over the NIO have been reviewed by various authors for different Ocean basins Knapp *et al.* (2010). Similar review has been made by Mohapatra *et al*. (2012) for the north Indian Ocean. However, studies are limited in quantifying the contribution of satellite estimates in the best track estimates of CDs. Hence a study has been taken up in this

TABLE 1

Classification of CDs over the NIO

Low pressure system	T Number	Maximum sustained surface winds in knots (mps)
Low pressure area	1.0	< 17 (09)
Depression	1.5	17 – 27 (09-14)
Deep Depression	2.0	28 – 33 (15-17)
Cyclonic storm	2.5-3.0	34 – 47 (18-24)
Severe Cyclonic storm	3.5	48 – 63 (25-32)
Very Severe Cyclonic storm	4.0-6.0	64 – 119 (33-61)
Super Cyclonic storm	6.5 and above	120 (62) & above

TABLE 2

Resolution of satellites used for TC monitoring

Satellites	Met Payload	Channels	Spectral Range (μm)	Resolution	
				Spatial (km)	Temporal (hrs)
KALPANA-1(Sep'02)	VHRR	VIS	0.55-0.75	2	1
		WV	5.7-7.1	8	1
		IR	10.5-12.5	8	1
INSAT-3A (Apr'03)	VHRR	VIS	0.55-0.75	2	3
		WV	5.7-7.1	8	3
		IR	10.5-12.5	8	3
	CCD	VIS	0.62-0.68	1	3
		NIR	0.77-0.86	1	3
		SWIR	1.55-1.69	1	3

TABLE 3

Number of cases during 2006-2010 considered in the study with respect to T Numbers mentioned in best track parameters of RSMC, New Delhi

T No.	Arabian Sea	Bay of Bengal	North Indian Ocean
1.5	45	94	139
2	78	92	170
2.5	23	54	77
3	25	39	64
3.5	15	32	47
4	13	29	42
4.5	15	4	19
5	2	18	20
5.5	3	10	13
6	5	5	10
6.5	2	0	2
Total	226	377	603

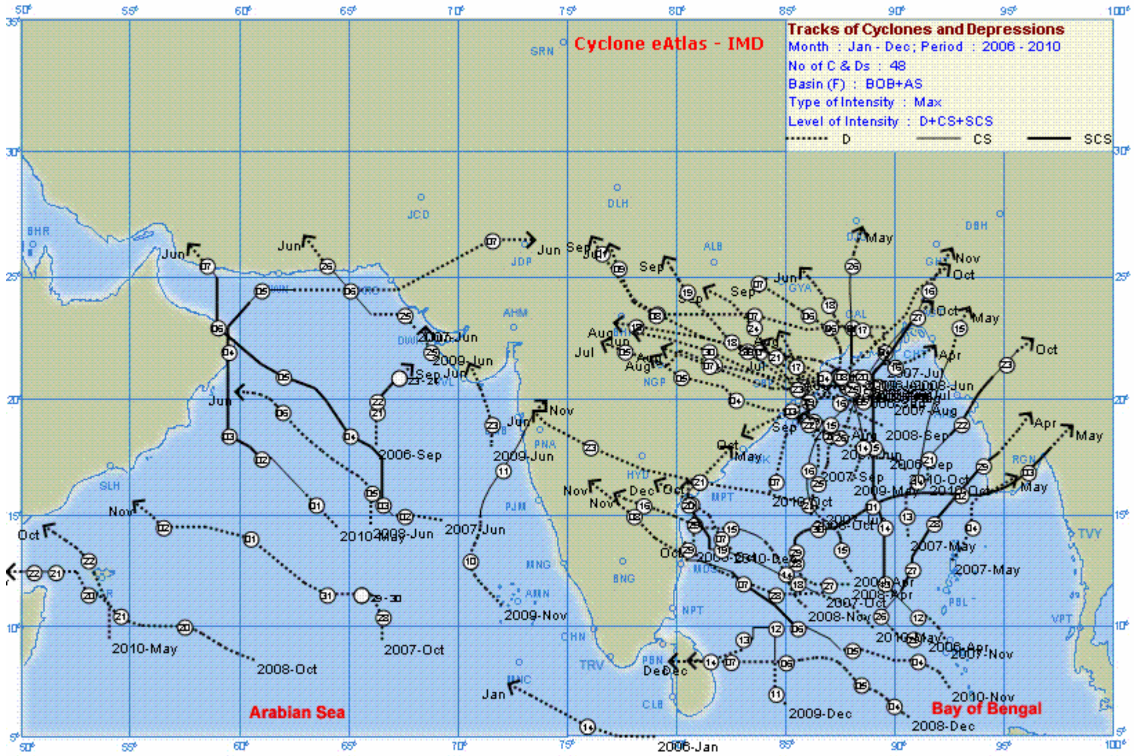


Fig. 1. Tracks of CDs during 2006-2010 considered in the study

regard based on data of five years (2006-10). The outcome of this study will be helpful to forecasters and decision makers in arriving at a decision to determine the location and intensity of the TC over the north Indian Ocean basin.

2. Data and Methodology

The best track parameters of the CDs over the NIO during 2006-2010 have been collected from the RSMC, New Delhi for every 03/06 hrs during the life periods of the CDs. The classification of CDs as adopted by RSMC, New Delhi has been used in this study. The detailed classification of CDs into depression, deep depression, cyclonic storm, severe cyclonic storm, very severe cyclonic storm and super cyclonic storm and associated Dvorak's T number and MSW are given in Table 1. Accordingly the INSAT 3A/ Kalpana-1 satellite based estimates of track and intensity of the CDs have been collected from the Satellite Meteorology Division of IMD, New Delhi. The characteristics of these satellites in terms of its spatial and temporal resolution and the products available for estimating location and intensity of the CDs are shown in Table 2. The tracks of the CDs over the NIO considered in the study are shown in Fig.1. There are 48 CDs considered in the study. The number of track locations considered in the study is 226, 377 and 603 respectively over the Bay of Bengal (BOB), Arabian Sea (AS) and the NIO as a whole (Table 3). It consists of 139 such cases in the stage of depression (T1.5), 170 cases in the stage of deep depression (T2.0), 141 cases in the stage of cyclonic storm (T2.5-3.0), 47 cases in the stage of severe cyclonic storm (T3.5) and 106 cases in the stage of very severe cyclonic storm and above intensity (T4.0 and above). Table 3 shows that the statistics presented in this study is dominated by the number of low intensity cases. There has been no case with T 6.5 over the BOB for the period of study.

The difference in location estimated in best track and the satellite estimates are calculated and analysed for all the CDs throughout their life periods. The difference in location is the measure of the great circle distance between the location of CD according to best track and satellite estimates. Further the difference in location has been calculated for different intensities of the system according to Dvorak's T-intensity scale (Dvorak, 1984) to find out the variation in difference in location with respect to intensity of CDs. The standard deviation (SD) in difference in location has also been calculated for different intensities of CDs as mentioned above. All these average difference in location of CDs based on best track and satellite estimates have been calculated for the CDs over the Bay of Bengal (BOB), Arabian Sea (AS) and north Indian Ocean (NIO) as a whole.

TABLE 4

Frequency (percentage frequency) distribution of difference in location of CDs according to best track and satellite estimation of IMD

Location difference (km)	Arabian Sea	Bay of Bengal	North Indian Ocean
0	50(22.1)	67(17.8)	117(19.4)
1-25	61(27)	92(24.4)	153(25.4)
26-50	48(21.2)	75(19.8)	123(20.4)
51-75	34(15)	89(23.6)	123(20.4)
76-100	22(9.7)	30(8)	52(8.6)
>100	11(4.9)	24(6.4)	35(5.8)
Total	226(100)	377(100)	603(100)

To find out the spatial variation in the average difference in locations based on best track and satellite estimates, the average difference has also been calculated for all the 2.5° × 2.5° blocks over the NIO. The results of this analysis will be helpful to find out the impact of the coastal observations, buoys/ships and radar on the best track locations and its variation from the satellite estimates.

To analyse the difference in intensity, the intensity based on Dvorak's T classification as mentioned in the best track and in the satellite estimates of IMD are considered. Difference between these two intensities has been calculated and analysed for CDs in the BOB, AS and NIO as a whole. Further the difference in intensities has been calculated and analysed with respect to the location and category of CDs. For this purpose the intensity based on best track has been taken as the reference.

The salient features of the results obtained are discussed in section 3, major implications of the study in section 4 and the broad conclusions are presented in section 5.

3. Results and discussion

The difference in location of CDs based on best track and satellite estimates are presented and discussed in section 3.1. The difference in intensities of CDs based on best track and satellite estimates are presented and discussed in section 3.2.

3.1. *Difference in location of CDs*

The frequency (percentage frequency) distribution of difference in location of CDs according to best track and satellite estimation of IMD are presented in Table 4. The average difference in location of CDs over the NIO, BOB and AS is about 39, 40 and 37 km respectively. However, the standard deviation (SD) in difference is about 34, 33 and 37 km respectively over the NIO, BOB and AS. The high magnitude of SD (almost equal to mean) indicates higher variability in difference and low reliability of the mean value. According to Elsberry (2003), the errors in determining the TC centre over the northwest Pacific Ocean can be upto 50 km by satellite fixes, 20-50 km by radar observations and by about 20 km by aircraft reconnaissance with reference to best track estimates. The induction of DWR has reduces the error in fixing the centre of the TCs in radar range.

It is observed that the difference in location is 50 km or less in about 65% of the total cases and about 6% of the cases have a difference of 100 km or more over the NIO as a whole (Table 4). It is about 62% and 6% respectively over the BOB and about 70% and 5% respectively over the AS. The lower difference over the AS may be due to fact that (*i*) AS is relatively more data sparse with larger open sea, (*ii*) less coastal observations available from the Arabia-Africa coast and (*iii*) most of the CDs either move to Arabia Africa coast or dissipate over the Sea (Tyagi *et al*., 2010). The fact of more dependence of best track data on satellite over the AS has also been brought out by Mohapatra *et al*. (2012). At the same time the coastal observations are more over the BOB region along with the observations from Andaman and Nicobar Islands and number of CDs dissipating over the sea is less. When the CDs come closer to the coast, the coastal observations help in determining the location of the CDs in addition to the radar observations. It results in substantial difference in the location estimated by best track and by the satellite method. To verify the above fact, the grid-wise difference in location has been calculated and analysed the same is presented in section 3.1.1.

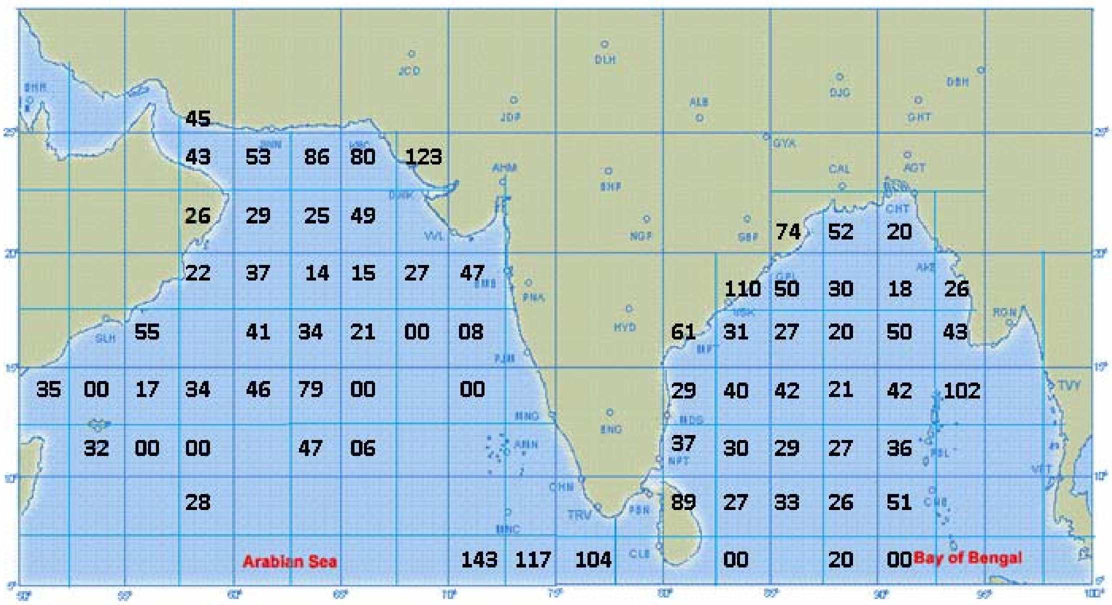


Fig. 2. Mean difference in location of CDs according to best track and satellite estimates of IMD over different 2.5° × 2.5° latitude/longitude grids of north Indian Ocean

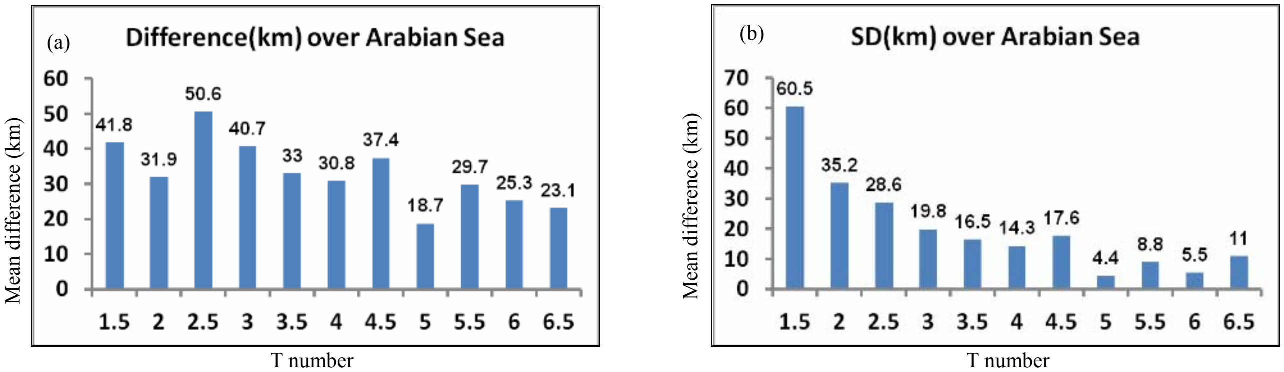
3.1.1. *Spatial variation of difference in location of CDs*

The spatial distribution of difference in location of CDs is presented in Fig.2. It is observed that in general the difference in location is higher near the coast and decreases as we move away from the coast. The difference is more significant near India, Pakistan and Sri Lanka coasts, as it is well distributed with dense observational network. It is minimum in the mid-sea region of both BOB and AS. Further, the difference in location is relatively less over other coasts, *viz*., Myanmar, Bangladesh, Oman and Yemen coasts. It may be due to sparse observational network along these coasts and the best track is more dependent on the satellite estimates.

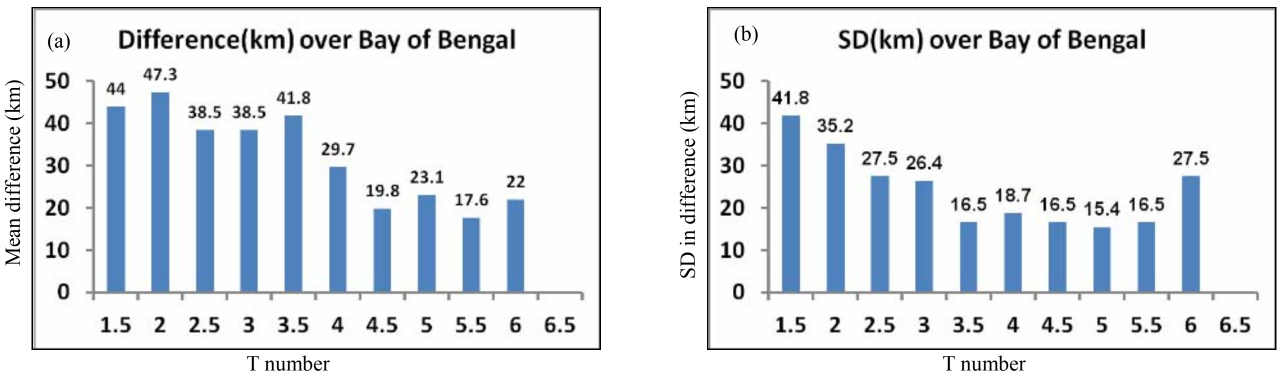
Considering the coasts of India separately, the average difference in location is about 51 km for east coast. However, the error is significantly higher (about 110 km) over south Odisha, and adjoining north Andhra Pradesh coast (17.5° N – 20.0° N and 80.0° E to 82.5° E). To find out the reason, the data was examined. It was found that the average over this grid is based on 2 observation of error of 165 and 55 km. In both the cases; the intensity of the system was 1.5. Hence it is observed that due to low intensity of the system the centre could not be properly determined by satellite method, while the centre remain same near 16.0° N / 84.5° E at 0300 and 0600 UTC of 7th October 2010 in association with the depression. The depression moved from 16.5° N / 84.5° E at 0300 UTC to 17.5° N / 84.5° E at 0600 UTC as per best track leading to large difference at 0600 UTC (165 km) between best track estimates and satellite estimates. Past studies indicate that Dvorak's technique (Dvorak, 1984) has the limitation in determining the location and intensity of monsoon depressions and low intensity systems. It has also the limitations in fast moving systems. The average difference for west coast has not been calculated due to insufficient data along the west coast. The difference is higher over the northern latitude covering north Andhra Pradesh, Odisha and West Bengal coasts.

3.1.2. *Difference in location with respect to intensity of CDs*

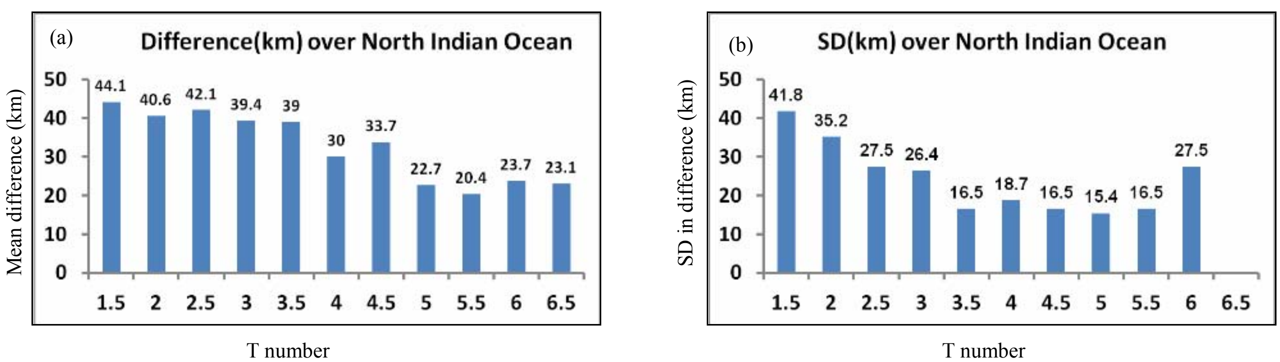
The difference in location with respect to intensity of CDs has been analysed for BOB, AS and NIO as a whole. The average differences over the BOB, AS and NIO for different intensities are presented in Figs. 3-5 respectively. In general, the difference in location gradually decreases with increase in T number. It is about 30 km when the intensity of the system is T4.0 or more (very severe cyclonic storms and above intensity) over the BOB, AS and NIO. It may be due to the fact that the very severe cyclonic storms are mostly associated with the eye and the centre of the system is better defined with the appearance of eye. The little difference (<30 km) between the location estimated by best track and the satellite estimates may be due to the fact that the location of the CDs are rounded



Figs. 3(a&b). (a) Mean and (b) standard deviation (SD) in difference of location of CDs over the Arabian Sea (AS) based on best tracks and satellite estimates of IMD



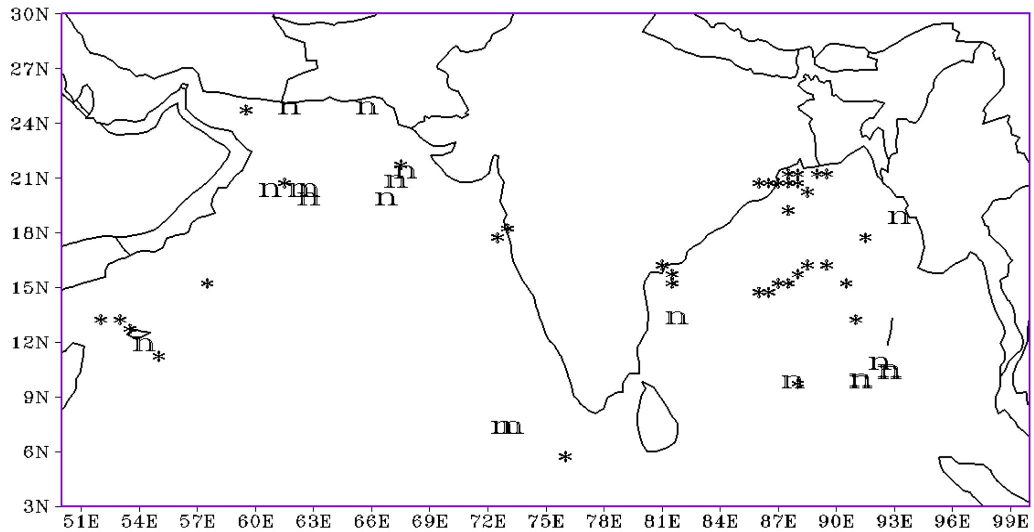
Figs. 4(a&b). (a) Mean and (b) standard deviation (SD) in difference of location of CDs over the Bay of Bengal (BOB) based on best tracks and satellite estimates of IMD



Figs.5. (a&b). (a) Mean and (b) standard deviation (km) in difference of location of CDs over the north Indian Ocean (NIO) based on best tracks and satellite estimates of IMD

upto 0.5° in the best tracks unlike the satellite estimates, where the location is given in nearest 0.5° latitude/longitude in depression stage (T 1.5) and nearest 0.1° latitude/longitude in cyclonic storm and higher stages of intensity (T 2.5 and above). The latitude and longitude of the location of centre in the best track estimates are rounded off to nearest 0.5° in the mid-sea region where the satellites are the only alternative for detecting the location. It is done so considering the inherent error in estimating by the satellite (Elsberry, 2003).

Considering the SDs (Figs. 3-5), it also decreases gradually with increase in T number. The SD is higher than the mean difference in low intensity system like



* T number based on best track of IMD – T number based on satellite estimation of IMD = Positive
n T number based on best track of IMD – T number based on satellite estimation of IMD = Negative

Fig. 6. Difference in intensity (T Number) of CDs over the north Indian Ocean based on best track and satellite estimation of IMD

depressions and deep depressions (T 2.0 and less) over the Arabian Sea and almost equal to the difference in location in case of the depressions/ deep depressions over the BOB and NIO. It indicates that the difference is highly variable and the mean value has low reliability in case of depressions and deep depressions.

3.2. *Difference in intensity of CDs according to best track and satellite estimates*

The difference in intensities of CDs according to best track and satellite estimates for the CDs over the NIO are shown in Fig.6. The frequency distribution of difference of intensity is shown in Table 5. From Fig.6 and Table 5, it is observed that the intensity in the best track agrees with the satellite estimates in about 85% of the cases. While the satellite based intensity is underestimated (Satellite division estimated T number is less than best track T number) in 10% cases, it is overestimated (Satellite division estimated T number is greater than best track T number) in about 5% cases over the NIO compared to intensity based on best track. Similar is the situation over the BOB, where it intensity is underestimated in satellite method in 11% cases and overestimated in 2% cases. However the AS shows opposite behavior with overestimation in 10% cases and underestimation in 7% cases by the satellite method compared to the intensity estimated in best tracks of IMD.

Considering the spatial distribution of the difference in intensity (T number), the difference occur mostly when the CD lies near the coast or the islands (Fig.6). However, there are also a few cases in the central BOB with the difference of T as 0.5 or more. It may be due to the adjustment in T number in the best track estimates over the central BOB with the support of buoy and ship observations. Based on seven TCs, Mishra and Hem Raj (1975) have shown large difference between wind speed inferred from synoptic data and those derived from satellite technique. According to them, the MSW could be under-estimated by 8-17 knots (5-9 mps) in depression/ deep depression stage, 26-28 knots (13-14 mps) in cyclonic storm stage and 37 knots (19 mps) in severe cyclonic storm or higher stage.

4. Major implications

Considering the results presented in section 3, there is a need for (*i*) validation of Dvorak technique over the NIO, (*ii*) validation of pressure – wind relationship in TCs over the NIO (Koba *et al*., 1991, Knaff and Zehr, 2007), (*iii*) development/validation of wind conversion factor for converting 3-minute average wind to 1-minute average wind (used in Dvorak's technique) and 10 minute average wind (as required for preparation of standardized international best tracks archives) and (*iv*) reanalysis of best tracks with modified pressure-wind relationship, wind adjustment and modified Dvorak classification of

TABLE 5

Frequency (percentage frequency) distribution of difference in intensity of CDs (Best track – satellite estimate)

Intensity difference (T Number)	Arabian Sea	Bay of Bengal	North Indian Ocean
0	188(83)	328(87)	516(86)
-0.5	22(10)	08(02)	30(05)
0.5	13(06)	41(11)	54(09)
1.0	03(1.3)	00(00)	03(0.5)
Total	226(100)	377(100)	603(100)

intensity, as it is carried out in north Atlantic Ocean (Landsea *et al*., 2007). Also there is need for augmentation of buoy network over the NIO and aircraft reconnaissance for *in-situ* observations for more accurate determination of location and intensity of the CDs (Martin *et al*., 1993). There is also need for the augmentation of Doppler weather radar and automatic weather station (AWS) network along the coast bordering the NIO. Mohapatra *et al.* (2011) has shown that the landfall location estimates in the best track has reduced from about 55 km to 30 km in recent years due to augmented AWS network along east and west coasts of India. With respect to satellite tools, the microwave imagery products needs to be more explored and used by the satellite division of IMD for estimating location and intensity of the systems, as the visible and IR imageries have their own limitations as discussed in section 3.3.

5. Conclusions

The average difference in location of CDs over the NIO, BOB and AS is about 39, 40 and 37 km respectively. The difference in location is 50 km or less in about 65% of the total cases and about 6% of the cases have a difference of 100 km or more over the NIO as a whole. It is about 62% and 6% over the BOB and about 70% and 5% over the AS respectively.

Difference in location gradually decreases with increase in T number. It is about 30 km when the intensity of the system is T4.0 or more (very severe cyclonic storms and above intensity) over the BOB, AS and NIO.

Considering the spatial distribution of difference in location of CDs, it is higher near the coast and decreases as we move away from the coast. The difference is more significant near Pakistan, Sri Lanka and north Andhra Pradesh, Odisha & West Bengal coasts in India, as it is well distributed with dense observational network. Further, the difference in location is relatively less over Myanmar, Bangladesh, Oman and Yemen coasts, which are data sparse. The average difference in location is about 51 km for east coast of India. The average difference for west coast has not been calculated due to insufficient data along this coast.

The intensity in the best track agrees with the satellite estimates in about 85.5% of the cases. While the satellite based intensity is underestimated (Satellite division estimated T number is less than best track T number) in 9.5% cases, it is overestimated (Satellite division estimated T number is greater than best track T number) in about 5% cases over the NIO. Similar is the situation over the BOB, where intensity is underestimated (overestimated) in 11% (2%) cases. Intensity is underestimated (overestimated) in 7% (10%) cases over the AS. Considering the spatial distribution, the difference occurs mostly when the CD lies near the coast or the islands in the NIO like the difference in location.

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