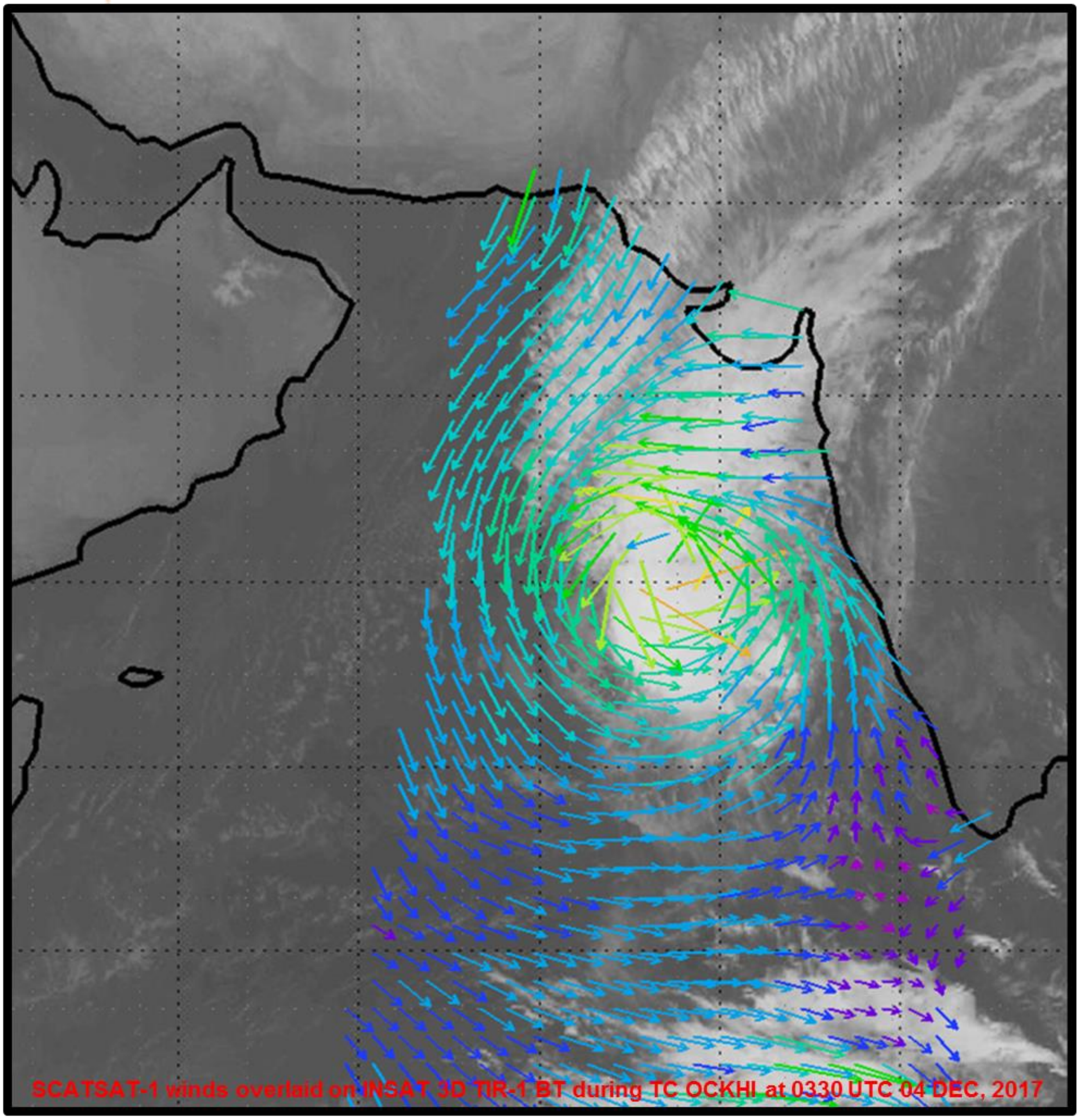
Real-time monitoring and prediction of tropical cyclone OCKHI

SAC/EPSA/AOSG/ASD/SR-05/2018



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Abstract	The accurate and timely advance prediction of tropical cyclones is very important to disseminate the warnings and preparedness. Prediction of development of any cyclone system in the North Indian Ocean is being done at Space Applications Centre (ISRO) Ahmedabad, using the in-house developed algorithms. Once the low pressure system is formed, it is continuously monitored by satellite observations. Possibility of its cyclogenesis, and after its development into tropical cyclone its track is predicted and updated. These forecasts are disseminated through web-portal SCORPIO linked to MOSDAC. The real-time prediction of cyclone OCKHI has been presented in this report. The real-time monitoring of cyclones and its structural analysis using satellite observations are also discussed.
Key words	Tropical cyclone, cyclogenesis prediction, track prediction, center determination, satellite observations
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Table of contents

1. INTRODUCTION.. 7

1.1 OVERVIEW OF TROPICAL CYCLONE OCKHI (29 NOVEMBER-06 DECEMBER, 2017) 7

2. DATA AND METHODOLOGY 11

2.1 PREDICTION OF TROPICAL CYCLOGENESIS... 11

2.1.1 Short range TCG prediction based on wind pattern matching technique 11

2.2. CYCLONE TRACK PREDICTION... 12

2.2.1 SAC-Lagrangian Advection Model.. 12

2.2.2 SAC-WRF Model.. 13

3. RESULTS: PREDICTION OF TC OCKHI.. 14

3.1 REAL-TIME PREDICTION OF TROPICAL CYCLOGENESIS OF TC OCKHI USING SCATSAT WINDS... 14

3.1 REAL-TIME PREDICTION OF TROPICAL CYCLOGENESIS OF TC OCKHI USING WRF MODEL 15

3.2 REAL-TIME TRACK PREDICTION OF TC OCKHI 15

3.3 INTENSITY PREDICTION OF TC OCKHI 21

4. SATELLITE OBSERVATIONS OVER TC OCKHI 23

REFERENCES.. 28

1. Introduction

Indian sub-continent is one of the most adversely affected cyclone active basins that experience on an average 4-5 cyclones every year. In comparison to other cyclone basins this region is the most vulnerable due to relatively dense coastal population, shallow bottom topography and coastal configuration. Though the cyclones formed in this region are considered to be weaker in intensity and smaller in size as compared to other regions, yet the number of deaths in the region is highest in the globe (3,00,000 human deaths were estimated from tropical cyclone (TC) associated storm surge in Bangladesh in 1970). To overcome such loss, advance prediction of cyclones in terms of their genesis, track and intensity is highly important. The timely prediction of impending cyclonic activity can save life of people and help in decision making for taking preventive measures like evacuation during the cyclone landfall. The predictions of TC are generated based on the models using satellite observations and ground based radar networks when cyclone reaches close to the land. Due to the advancements in numerical prediction models and satellite observations with high temporal and spatial resolutions, during the last decades, the track prediction accuracy has improved drastically. However, the prediction of cyclogenesis and cyclone intensity is still challenging.

Prediction of development of any cyclone system in the North Indian Ocean (NIO) including the Bay of Bengal (BoB) and Arabian Sea is being done as a regular exercise at Space Applications Centre (ISRO) Ahmedabad, using the in-house developed algorithms. Once the system is developed in the NIO basin its track and intensity are predicted in real-time and disseminated through web-portal Satellite based cyclone real-time prediction in Indian Ocean (SCORPIO) linked to MOSDAC (www.mosdac.gov.in). The similar exercise was performed during the formation of cyclone “OCKHI” in NIO during 29 November-06 December, 2017, which has been discussed in the present report.

1.1 Overview of Tropical cyclone OCKHI (29 November-06 December, 2017)

The cyclone name “OCKHI” which meant “eye” in Bengali, was provided by Bangladesh, in the comprehensive nomenclature list for cyclones in the Arabian Sea and Bay of Bengal. Tropical cyclone “OCKHI” was the most intense cyclone in the Arabian Sea

Since cyclone Megh in the year 2015. Ockhi was the third cyclonic storm of the annual cyclone season after cyclone MORA and MAARUTHA that formed in BoB.

It was originated from an area of low pressure that formed on the Gulf of Thailand on November 21. While traversing the southern part of the Bay of Bengal, favorable conditions enabled it to consolidate into a deep depression. As a deep depression, it caused damage to property and life in Sri Lanka on November 29. Due to moisture and warmer temperatures between Sri Lanka and Kanyakumari (Cape Comorin) in mainland India, it intensified into a Cyclonic Storm on November 30. Near Kanyakumari in mainland India, Cyclone Ockhi changed its path and headed towards Lakshadweep in the Arabian Sea, while intensifying. Although it headed away from the coast of mainland India, it caused severe damages to structures and property and also claiming the lives of people in the Southern parts of Tamilnadu and Kerala in India. The storm tracked westwards and intensified further into a Severe Cyclone Storm, early on December 1. Soon afterwards, Ockhi intensified further into a Very Severe Cyclonic Storm. Ockhi caused landfalls in Lakshadweep on December 2. The cyclone uprooted coconut trees and caused extensive damages to houses, power lines and other infrastructure in the islands.

As Ockhi moved further into the Arabian Sea, it travel through an area of sea surface temperatures greater that 28^0 C and decreasing wind shear; eye became visible on satellite imagery, on December 2. On December 4, analysis showed that Ockhi was maintaining a source aloft, but there was restricted outflow on the western edge, due to a deepening trough advancing rapidly from the west. Increasing vertical wind shear along with a deep layered subtropical ridge to the east steered it to north-northeast, and dry air intrusion from the west gradually weakened the system. On the following day, the storm quickly became disorganized as it encountered increasingly unfavorable conditions, including high wind shear. Dry and cold air from the subcontinent rapidly weakened the storm, and TC Ockhi dissipated near the south coast of Gujarat in India on December 6, even before entering the coast

The IMD classification of cyclone categories has been given in the Table 1. IMD best track of cyclone with its intensity category have been shown in the Figure 1.

Table 1: IMD classification of categories of cyclonic system

System	Associated wind speed (knots)
Low pressure area	<17
Depression	17-27
Deep Depression	28-33
Cyclonic Storm	34-47
Severe Cyclonic Storm (SCS)	48-63
Very SCS	64-85
Extremely SCS	86-119
Super Cyclonic Storm	>119

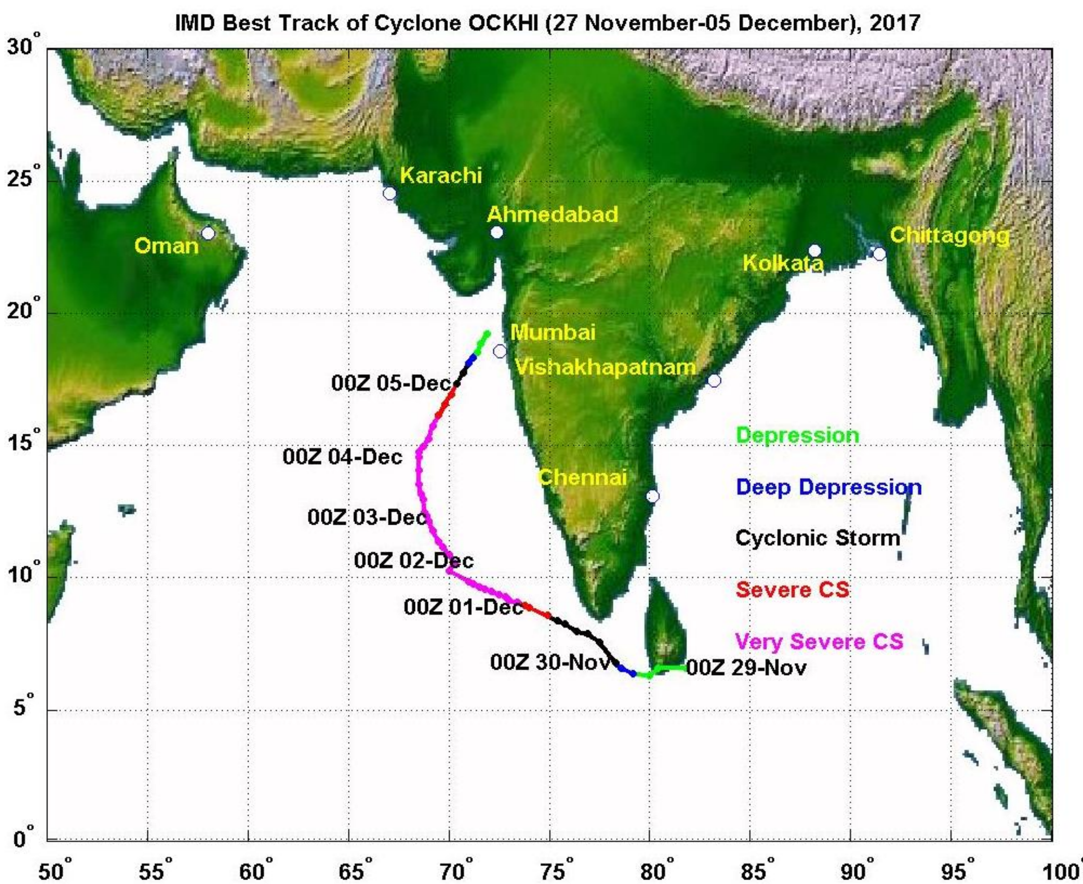

Figure 1: IMD best track of cyclone OCKHI with its intensity categories.

Developments of the cyclone OCKHI were continuously monitored by the visible and infrared observations from geo-stationary satellites viz., INSAT-3D and high resolution microwave satellite viz., SAPHIR onboard Megha-Tropiques. SCATSAT provided very good observations over these cyclonic systems, which were found to be very helpful for its prediction and structural analysis. Using the observations and models the real-time predictions of cyclogenesis, track, intensity, rainfall and wind structure were performed. The real-time prediction of the cyclone using in-house developed algorithms and the satellite observations over the system that helped in monitoring and prediction has been discussed in this report. The in-house developed techniques used for the cyclone prediction are briefly discussed in the section 2. The separate sections are made for the detail discussion of predictions and analysis.

2. Data and Methodology

A system has been formed in the SAC to predict the cyclones from its birth till death. This starts with predicting the earliest signatures of development of a low pressure system i.e. tropical cyclogenesis. After the declaration of system as tropical cyclone or cyclonic storm by JTWC or IMD, its track is predicted and updated during the life period of the cyclone till its landfall occurs. The track prediction also includes its landfall time and position prediction. Predictions of cyclone intensity and rainfall are also generated. All these predictions are disseminated in the real-time through a web server "Satellite based cyclone observations and real-time prediction in Indian Ocean" i.e. SCORPIO linked with MOSDAC (www.mosdac.gov.in).

2.1 Prediction of tropical cyclogenesis

The prediction of tropical cyclogenesis (TCG) of the cyclonic systems that develop in the NIO is being done at SAC using two in-house developed techniques viz., (i) TCG prediction based on multi-model ensemble (MME) technique and (ii) TCG prediction by wind pattern matching technique. MME technique utilizes the global model output for 1-15 days and provides the extended range TCG prediction i.e. 5-15 days advance genesis prediction (Jaiswal et al., 2016). Wind pattern matching technique utilizes the scatterometer derived surface wind observations and provides 1-4 days advance TCG prediction (Jaiswal and Kishtawal, 2011; 2013).

During the cyclone active months of the NIO i.e. April-June and October-December, the cyclogenesis prediction techniques are regularly run to detect the earliest signatures of any possibility of cyclonic activity in the Bay of Bengal (BoB) and Arabian Sea. These cyclogenesis prediction techniques are summarized in the following sections.

2.1.1 <u>Short range TCG prediction based on wind pattern matching technique</u>

The short range TCG prediction using wind pattern matching technique is based on the premise that there is some similarity between the low level wind pattern of the developing systems which can be detected and used to identify the developing and non developing low pressure systems. In this technique the real-time observed winds are matched to the wind patterns archived within the database of all developed systems in the past and the most similar wind pattern was selected. This similarity was quantified using a matching index as given in the following expression.

$$cc = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(A_i - \overline{A}\right)*\left(B_i - \overline{B}\right)}{\sqrt{\frac{1}{N}\sum_{i}^{N}\left(\left|A_i - \overline{A}\right|\right)^2} \times \sqrt{\frac{1}{N}\sum_{i}^{N}\left(\left|B_i - \overline{B}\right|\right)^2}} \qquad (1)$$

where $\overline{A}$ and $\overline{B}$ represents the mean value of the complex vectors *A* and *B* respectively. *N* is the dimension of vector *A* (or *B*) and *A* and *B* are the complex numbers formed using the wind vectors [*for example A = (u+iv)*].

If the matching index value is found to be greater or equal to some pre-defined threshold values (0.6 for NIO), the cyclogenesis is predicted. The scatterometer data of QuikSCAT and OSCAT were used in the development and testing of the algorithm (Jaiswal and Kishtawal, 2011; 2013). During the years 2010-13, OSCAT data was used for the real-time cyclogenesis prediction using the above discussed approach. In the year 2014 the OSCAT stopped working and thereafter the surface wind observations from other foreign satellites (viz., WINDSAT and RAPIDSCAT) were being used in the real-time prediction of TCG in NIO at SAC. SCATSAT1 (Scatterometer Satellite1) satellite was launched on 26th September, 2016 to provide weather forecasting, cyclone prediction, and tracking services to India. It is being developed by ISRO Satellite Centre, Bangalore whereas its payload is being developed by Space Applications Centre, Ahmedabad. The satellite will has taken place of Oceansat2 which has become dysfunctional after its life span of four and a half years.

2.2. Cyclone Track Prediction

After the formation of tropical cyclone in the Indian Ocean, track predictions are carried out using in-house developed Lagrangian advection cyclone track prediction model (SAC-LAGAM). A brief summary of the model has been given in the following subsections.

2.2.1 SAC-Lagrangian Advection Model

SAC-Lagrangian Advection model is dynamical framework based computationally efficient model (Singh et al, 2011; 2012). It requires the high resolution 0.5^0x0.5^0 atmospheric winds and temperature forecasts from Global forecast System (GFS), which is global numerical weather prediction model run by NOAA, and the initial position of cyclone which is obtained from JTWC. The cyclone track prediction is provided using SAC- Lagrangian Advection model upto 96 hour with 6 hour interval. As a first step, the steering flow has been computed for every 6-hour forecast interval up to 96 hours, using the analysis as well as forecast wind fields data at 21 pressure levels (100-1000 mb) by the weighted average scheme. The weight for each level was assigned by estimating the potential vorticity (PV) which is adapted from the study by Hoover et al., 2006. Then a cyclonic vortex is removed using a synthetic cyclone which is constructed by using the vorticity equation (Chan and Williams, 1987):

$$\frac{\partial \zeta}{\partial t} + V.\nabla(\zeta + f) = 0$$

Where ζ is the vorticity and $f = \beta y + f_0$. Here y denotes latitudinal displacement, f_0 is the value of coriolis parameter at y = 0 and β is the rate of change of coriolis parameter with latitude. In case of axisymmetric vortex, the velocity is calculated using the equation (Chan and Williams, 1987):

$$V(r) = V_m\left(\frac{r}{r_m}\right)\exp\left[\frac{1}{b}\left(1-\left(\frac{r}{r_m}\right)^b\right)\right]$$

Where V_m and r_m denote the maximum value of tangential velocity and the radius at which V_m occurs, respectively. This synthetic cyclone was used to remove the existing cyclonic wind fields present in the steering flow to achieve the residual steering current. To avoid the discontinuity of wind fields due to removal of cyclonic circulation, tapered weights *W (k)* are used for generation of residual flow fields. Now, resulting steering flow that is obtained after removing the cyclonic vortex from steering flow is used in model to forecast the cyclone track. The computation for the trajectory of the cyclone (or the cyclone track) is initiated by interpolating the steering wind from model grid points to the initial location of the cyclone (Brand, 1981).

2.2.2 SAC-WRF Model

WRF model is run at SAC routinely for real-time weather prediction at 5 km x 5 km resolution. The model outputs are also used for prediction of TC OCKHI.

The above discussed techniques and models are used in the real-time for the prediction of cyclone OCKHI.

3. Results: Prediction of TC OCKHI

Real-time cyclogenesis and track prediction of TC OCKHI was carried out at SAC using the above discussed algorithms. The results of real-time prediction and the validation of the forecasts have been discussed in this section.

3.1 Real-time prediction of tropical cyclogenesis of TC OCKHI

The development of any cyclonic activity is regularly monitored by the satellite observations and in-house developed algorithms.

3.1.1 Tropical cyclogenesis prediction using SCATSAT winds

The wind pattern matching based technique indicated a strong signal of cyclogenesis using the SCATSAT data, on 03:00 Z 27 Nov, 2017. The wind matching index value was found as 0.75 which was higher than the threshold value 0.6. The surface winds obtained by SCATSAT are shown in the Fig. 3, where the cyclogenesis region has been marked with the box. Cyclone OCKHI was declared as tropical cyclone on 30 Nov, 2017. Thus, the wind pattern matching based technique predicted the cyclogenesis of TC approximately 3 days (~69 hours) before the official declaration of the system as a cyclonic storm by IMD. The passes over the system during its genesis stage i.e. 27-30 November, 2017 have been shown in the Fig. 3.

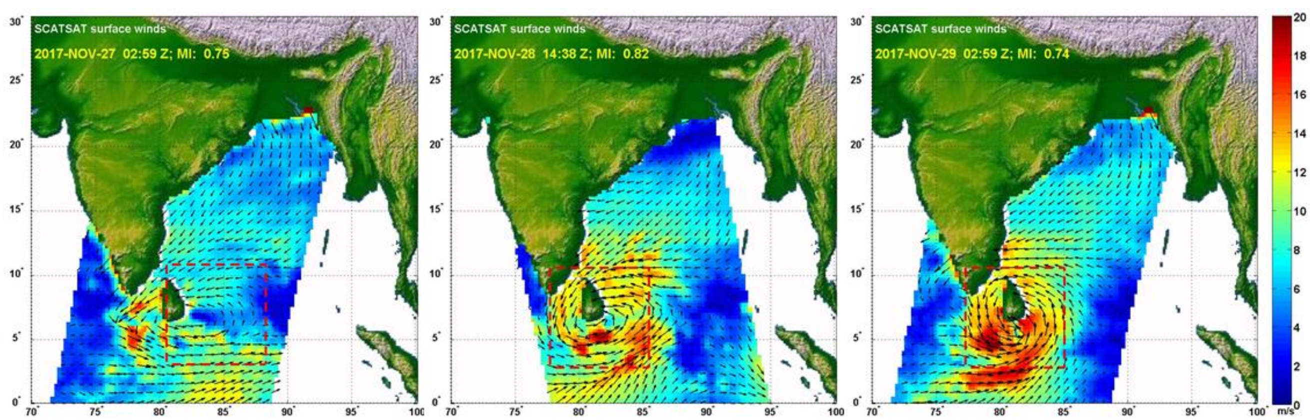

Figure 3: SCATSAT winds during the cyclogenesis of TC OCKHI. The earliest cyclogenesis signature was detected on 0300 UTC 27th Nov 2017.

3.1.2 Tropical cyclogenesis prediction using SAC-WRF model

The NWP model WRF at 5 km resolution is routinely run at Space Applications Centre for Indian region. The earliest prediction of TC OCKHI was shown since the forecast generated at 00 UTC 27 November 2017. WRF Model predicted all stages of development of TC OCKHI. The forecast generated on 00 UTC 27 November, 2017 by WRF model showing the development of TC in the next 48 hours are shown in the Figure 4. This was disseminated in the real-time through the SAC web-server

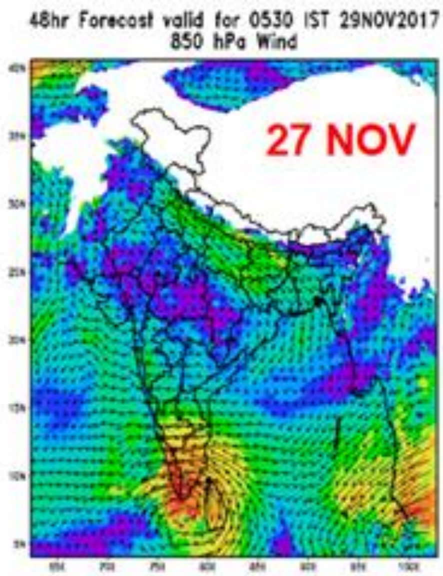

Figure 4: WRF model forecast generated at 00 UTC 27 November, 2017 shows the formation of tropical cyclone in the next 48 hours.

3.2 Real-time track prediction of TC OCKHI

After the formation of TC OCKHI (designated as tropical storm by JTWC or IMD) its track was predicted using the SAC-Lagrangian Advection model and SAC-WRF model.

3.2.1 Track prediction using SAC-Lagrangian model

The cyclone track forecasts using SAC-Lagrangian model were generated on 00Z of 29 November-04 December, 2017. All the real-time predicted tracks along with the observed best track of IMD have been shown in the Fig. 5. Each point in the figure is representing the six hours' movement of the cyclone. The forecasts generated on different initial conditions have been shown in different colors.

Each point in the figure is representing the six hours movement of the cyclone.

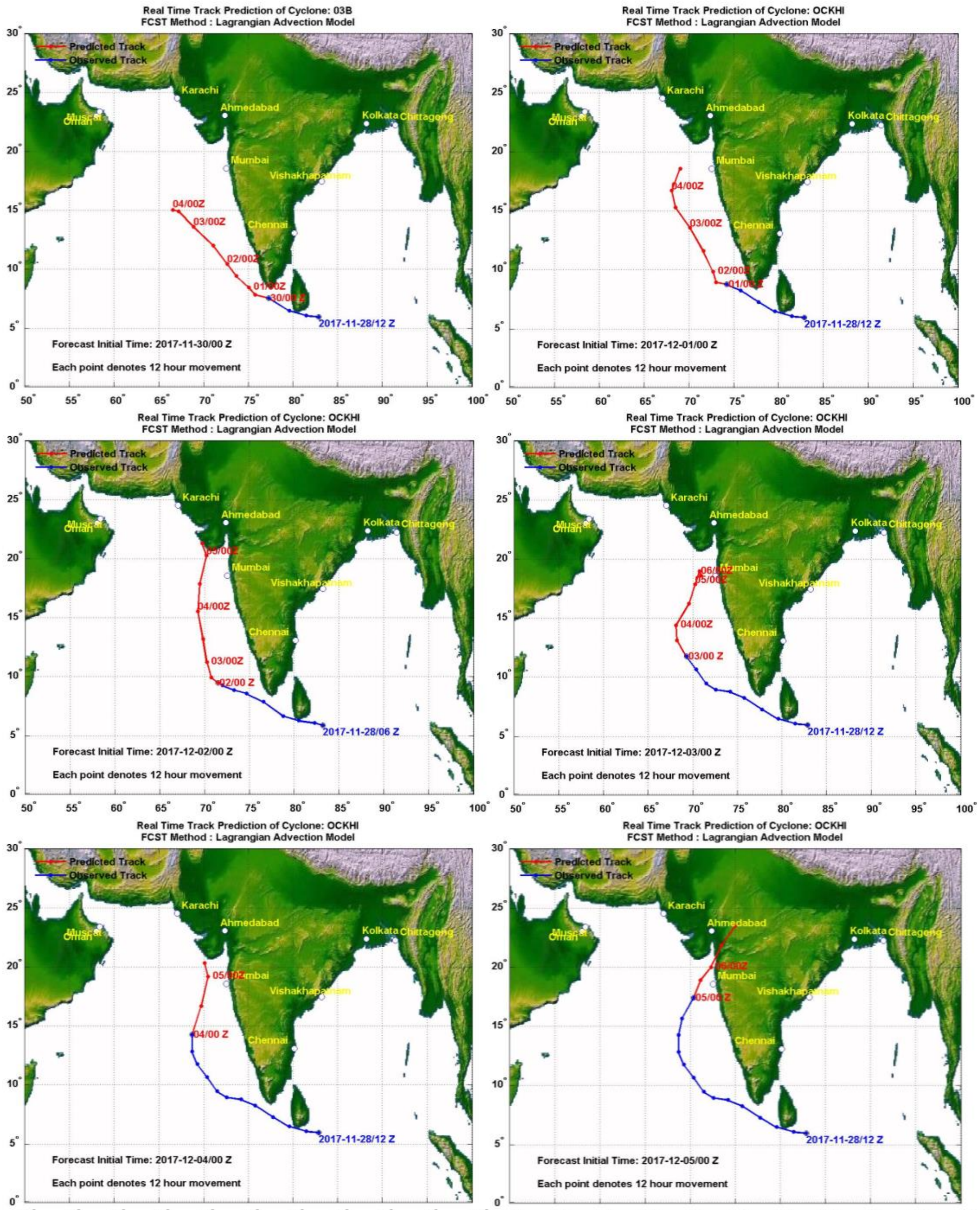

Figure 5a: Real-time predicted track of TC OCKHI at 00Z on 30 November -05 December, 2017.

It can be seen from the figure that all the tracks generated on different initial conditions are showing the system making landfall over the west coast of India near south Gujarat region. All these forecasted tracks have been plotted together with IMD best track and the error of track forecast has been estimated.

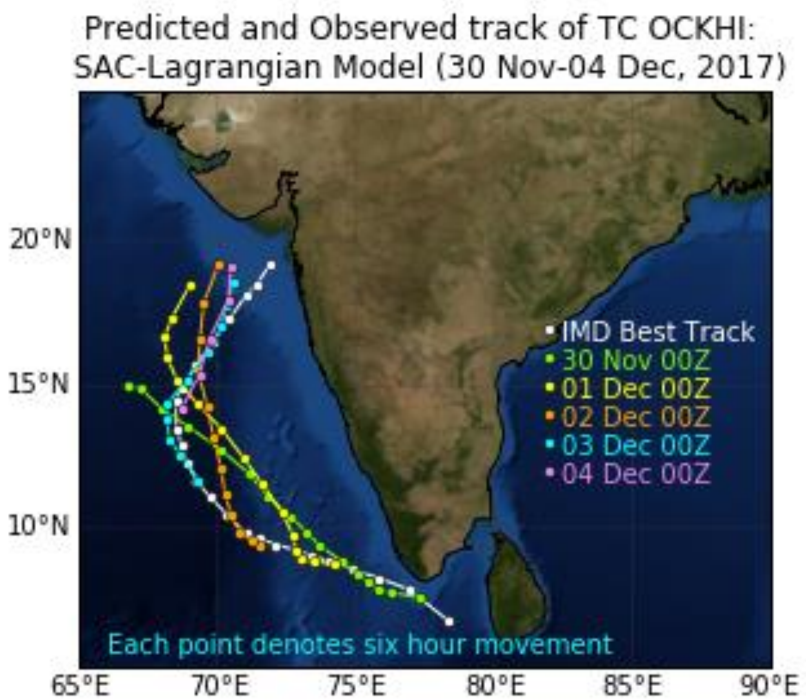

Figure 5b: Comparison of real-time predicted track of TC OCKHI at 00Z on 30 November -04 December, 2017 and the IMD best track.

The direct position error (DPE), cross track (CT) and along track (AT) component of track forecast error were calculated with respect to IMD best track position values for all the forecasts generated on different initial conditions and have been given in the Table 2, 3, and 4, respectively. The schematic showing the computation of the track errors is shown in the Fig. 6.

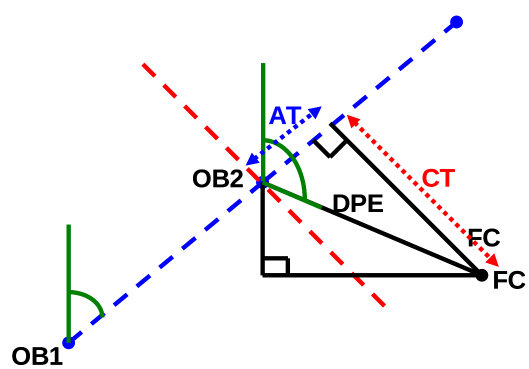

Figure 6: Schematic showing the positional forecast errors (Heming, 1994).

Average track forecast error (DPE) for TC Ockhi was found as 120 km at 24 hrs, 142 km at 48 hrs and 266 km at 72 hrs. Average along track forecast error (AT) for was found as 89 km at 24 hrs, 53 km at 48 hrs and 169 km at 72 hrs. Average cross track forecast error

(CT) was found as 71 km at 24 hrs, 124 km at 48 hrs and 169 km at 72 hrs. It can be seen that in 24 average cross track error was less than the average along track error but in 48 hours forecast along track error was much less than the cross track error value.

Table 2: Direct position track error (km) of SAC-Lagrangian advection track prediction model for TC OCKHI

FCST Initial time → Lead time↓	30 NOV 00Z	01DEC 00Z	01DEC 06Z	02DEC 00Z	03 DEC 00Z	04 DEC 00Z	04 DEC 06Z	Average track error (km)
6	73.82	25.81	61.65	40.98	43.92	85.40	12.29	49.13
12	46.96	43.68	127.42	88.55	51.34	120.46	33.69	73.16
18	72.97	83.23	125.43	114.13	51.22	175.91	32.35	93.61
24	126.31	133.03	158.66	129.33	42.70	206.15	46.16	120.33
30	118.28	165.90	150.16	132.84	37.64	228.19	75.12	129.73
36	98.30	184.94	146.01	128.03	70.01	241.26	133.59	143.16
42	131.30	204.13	160.95	151.40	71.69	231.32		158.46
48	153.21	224.91	132.96	140.26	58.85			142.04
54	170.87	236.48	154.16	207.24	67.93			167.34
60	183.01	260.18	180.72	241.32	82.35			189.51
66	220.62	276.00	140.41	296.94	118.07			210.41
72	289.12	246.81	197.97	328.76				265.67
78	310.09	277.49	239.66	339.19				291.61
84	340.24	315.61	248.00	356.37				315.06
90	310.97	369.31	237.16	337.60				313.76
96	306.14	383.83	172.26					287.41

Table 3: Along track error (km) of SAC-Lagrangian advection track prediction model for TC OCKHI

FCST Initial time → Lead time↓	30 NOV 00Z	01DEC 00Z	01DEC 06Z	02DEC 00Z	03 DEC 00Z	04 DEC 00Z	04 DEC 06Z	Average track error (km)
6	69.53	11.26	61.58	35.57	42.91	76.96	9.79	43.94
12	4.24	35.40	123.10	87.66	32.70	120.23	30.14	61.92
18	72.93	83.22	99.71	113.75	45.81	169.54	27.16	87.45
24	116.13	119.05	85.30	118.09	0.00	170.74	13.34	88.95
30	106.72	104.97	14.02	74.47	37.48	119.35	35.97	70.43
36	69.51	21.79	35.23	12.71	69.34	40.16	125.32	53.44
42	50.83	14.82	77.44	47.67	71.48	68.35		55.10
48	26.25	88.78	107.96	0.00	39.56			52.51
54	24.43	192.53	149.93	206.14	14.16			117.44
60	63.72	252.70	174.93	219.90	12.92			144.83
66	133.05	270.90	0.00	250.83	99.82			150.92
72	227.22	0.00	194.15	252.65				168.51
78	268.12	228.33	228.55	204.15				232.29
84	329.82	256.48	233.08	86.80				226.54
90	255.44	322.75	186.34	38.53				200.76
96	248.80	289.56	70.37					202.91

Table 4: Cross track error (km) of SAC-Lagrangian advection track prediction model for TC OCKHI

FCST Initial time → Lead time↓	30 NOV 00Z	01DEC 00Z	01DEC 06Z	02DEC 00Z	03 DEC 00Z	04 DEC 00Z	04 DEC 06Z	Average track error(km)
6	24.79	23.23	3.13	20.35	9.37	37.02	7.43	17.90
12	46.77	25.59	32.89	12.52	39.58	7.48	15.07	25.70
18	2.35	0.91	76.09	9.35	22.91	46.92	17.58	25.16
24	49.66	59.35	133.78	52.73	42.70	115.53	44.19	71.14
30	51.00	128.46	149.51	110.00	3.45	194.49	65.94	100.41
36	69.51	183.65	141.69	127.40	9.64	237.90	46.26	116.58
42	121.07	203.59	141.09	143.70	5.50	220.99		139.32
48	150.95	206.64	77.61	140.26	43.57			123.81
54	169.11	137.31	35.90	21.31	66.44			86.01
60	171.56	61.94	45.40	99.40	81.33			91.93
66	175.99	52.77	140.41	158.91	63.05			118.23
72	178.77	246.81	38.73	210.36				168.67
78	155.79	157.69	72.14	270.87				164.12
84	83.56	183.92	84.72	345.64				174.46
90	177.35	179.50	146.71	335.40				209.74
96	178.39	251.95	157.23					195.85

Comparison of mean track forecasts by SAC-Lagrangian advection model and IMD operational model w.r.t. IMD best track data.

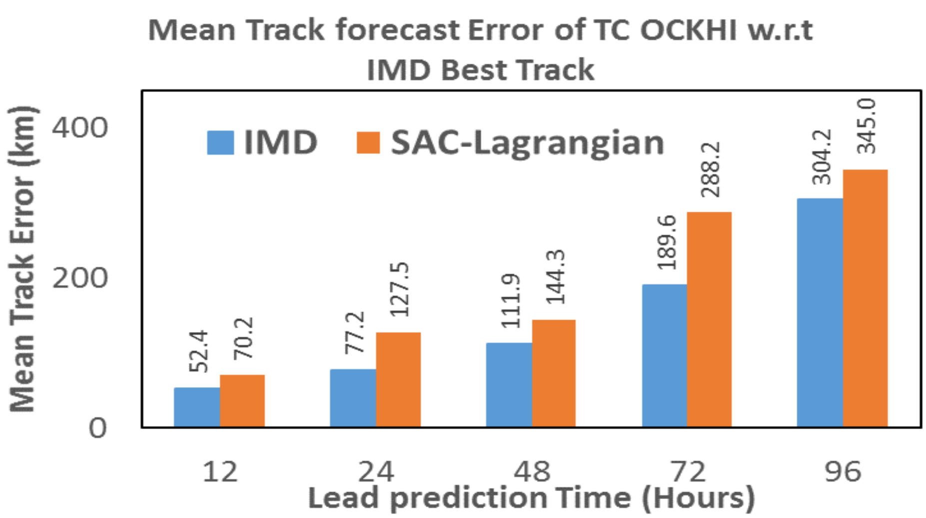

Figure 7: Comparison of mean track forecast error of SAC-Lagrangian model and IMD operational forecasts w.r.t. IMD best track positions.

The above results show that the forecasts of IMD operational model was more accurate than the SAC-Lagrangian track prediction model for all the forecast lead time. The forecasts from SAC model can be further improved by including the high resolution (17km x 17 km) first guess conditions provided by NCMUM model from National Centre of Medium Range Weather Forecast (NCMRWF) in place of currently being used 50 km x 50 km gfs initial conditions.

3.2.2 <u>Track prediction using SAC-Lagrangian model</u>

The real-time predicted track of SAC-WRF model has for all the initial conditions and IMD best track has been shown in the Figure

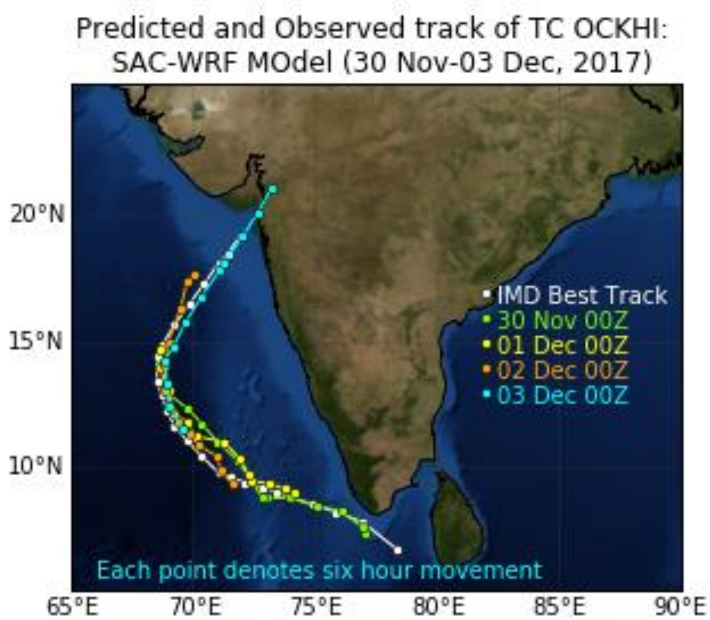

Figure 8: Comparison of real-time predicted track of TC OCKHI at 00Z on 30 November -04 December, 2017 by SAC-WRF model and the IMD best track.

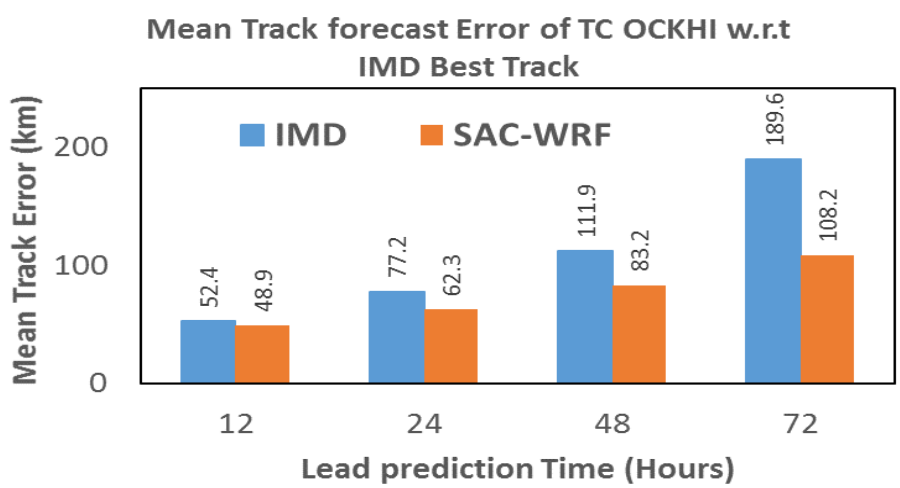

Figure 9: Comparison of mean track forecast error of SAC-WRF model and IMD operational forecasts w.r.t. IMD best track positions.

3.3 Intensity Prediction of TC OCKHI

Intensity of TC OCKHI was predicted using output of HWRF model which is operationally run at NCEP. Real-time generated intensity products are shown in the figures.

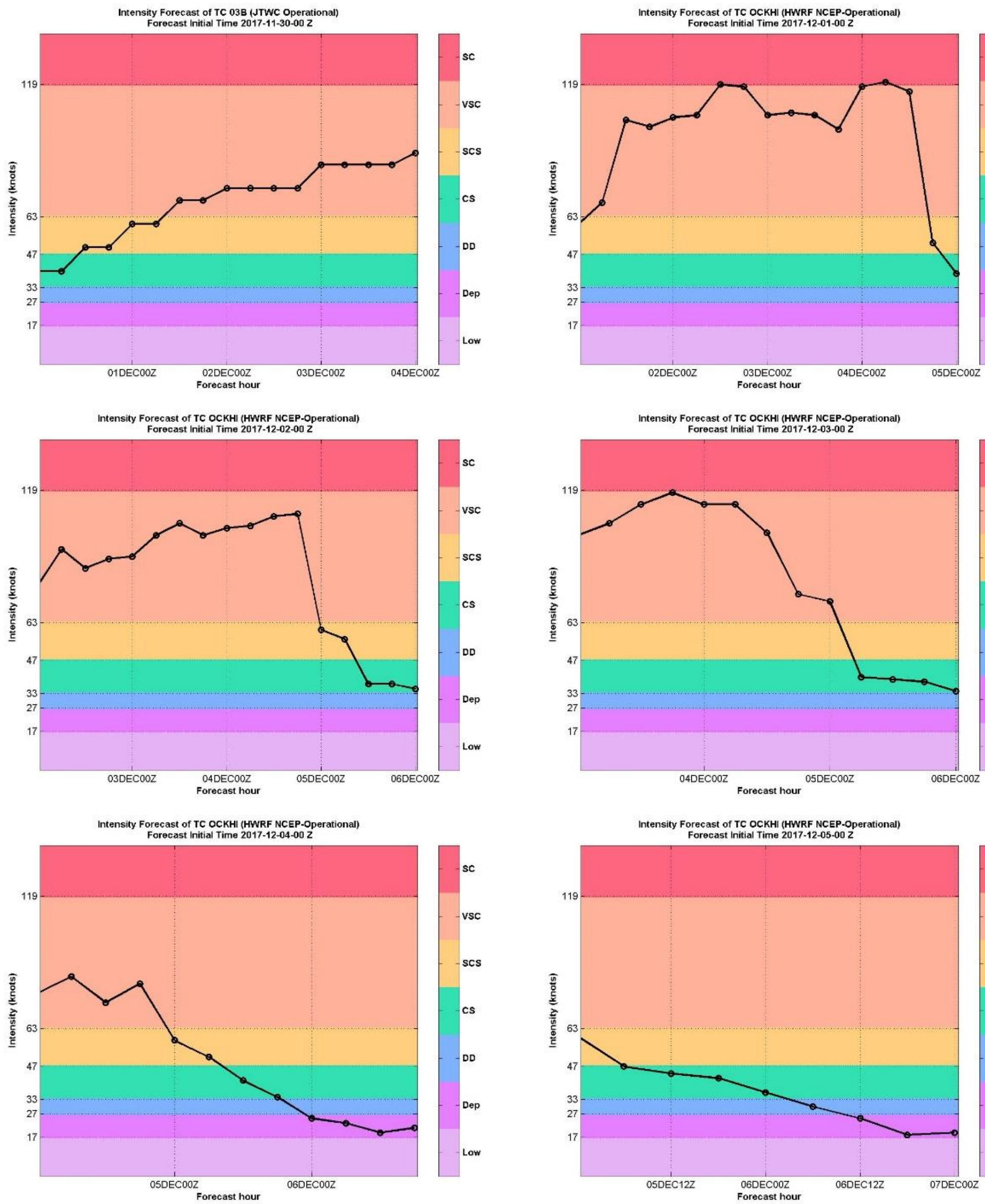

Figure 10: Real-time generated intensity prediction of TC OCKHI during 00 UTC of 30 November-05 December, 2017

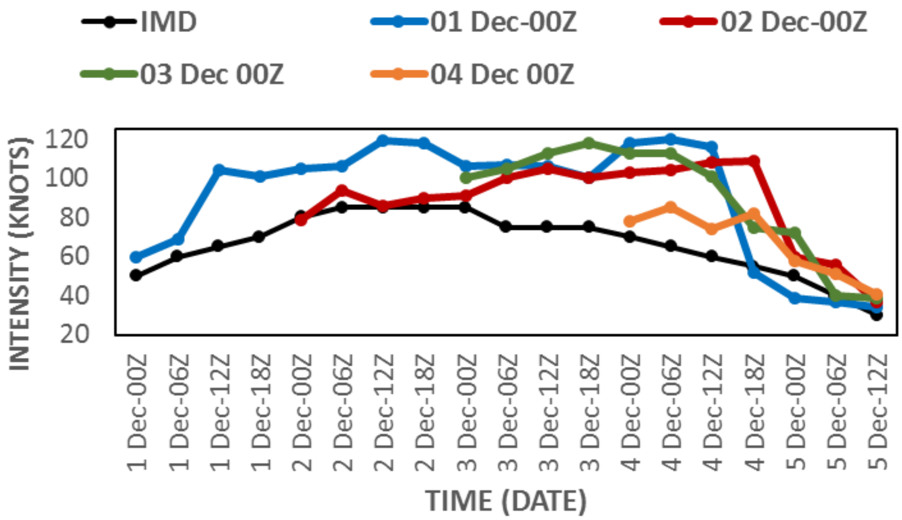

Figure 11: Comparison of Intensity predicted by HWRF model and IMD best track estimates for TC OCKHI for different initial conditions during 00 UTC 01-04 Dec, 2017

The figure shows that The HWRF model predicted intensity values were over-estimated for all the initial conditions. IMD best track shows that the TC had maximum intensity of 85 knots during 06 UTC 2 Dec- 00 UTC 03 Dec, 2017. This was over estimated by HWRF model forecast generated on 01 Dec as 118 knots. This shows that model need to further investigated for the Indian Ocean cyclone intensification processes.

4. Satellite Observations over TC OCKHI

Different sensors onboard the geostationary and polar orbiting satellites provide observations at different times and different phases of intensification of TCs which are very useful to estimate the correct geo-location of the system and retrieve its structural parameters. Different satellite observations over TC OCKHI have been discussed in this section.

4.1 INSAT 3D

Cyclone Geo-location

TC OCKHI was continuously observed by the half hourly acquisition of INSAT-3D satellite. In half hourly TIR imageries of INSAT 3D satellite the center location of cyclone was estimated by center determination algorithm developed at SAC. The results were disseminated through SCORPIO web-server. One of the sample products generated in the real-time has been shown in the Fig. 6.

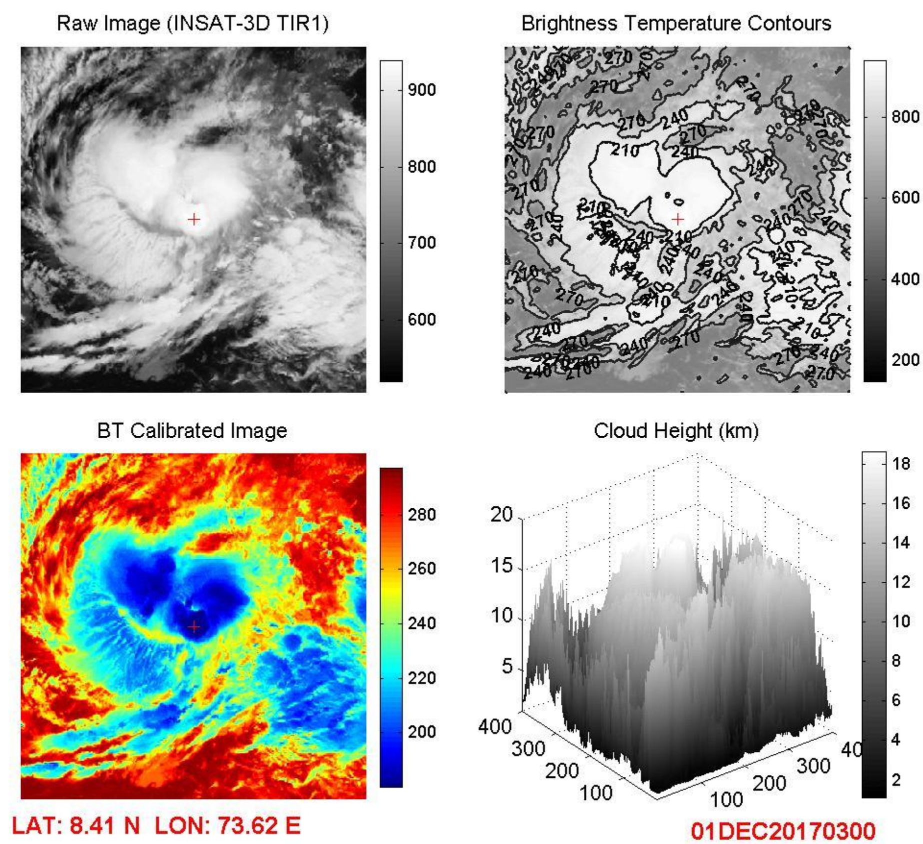

Figure 12: Center of TC estimated using INSAT 3D TIR image (0300Z 01 Dec, 2017).

Cyclone centric products of INSAT3D satellite

A procedure has been developed to produce cyclone centric products from each half hourly image of INSAT3D satellite. These images are very useful to study the structural changes in the core of tropical cyclone. A sample product generated on 0330 Z 02 DEC, 2017 have been presented in the figure 7.

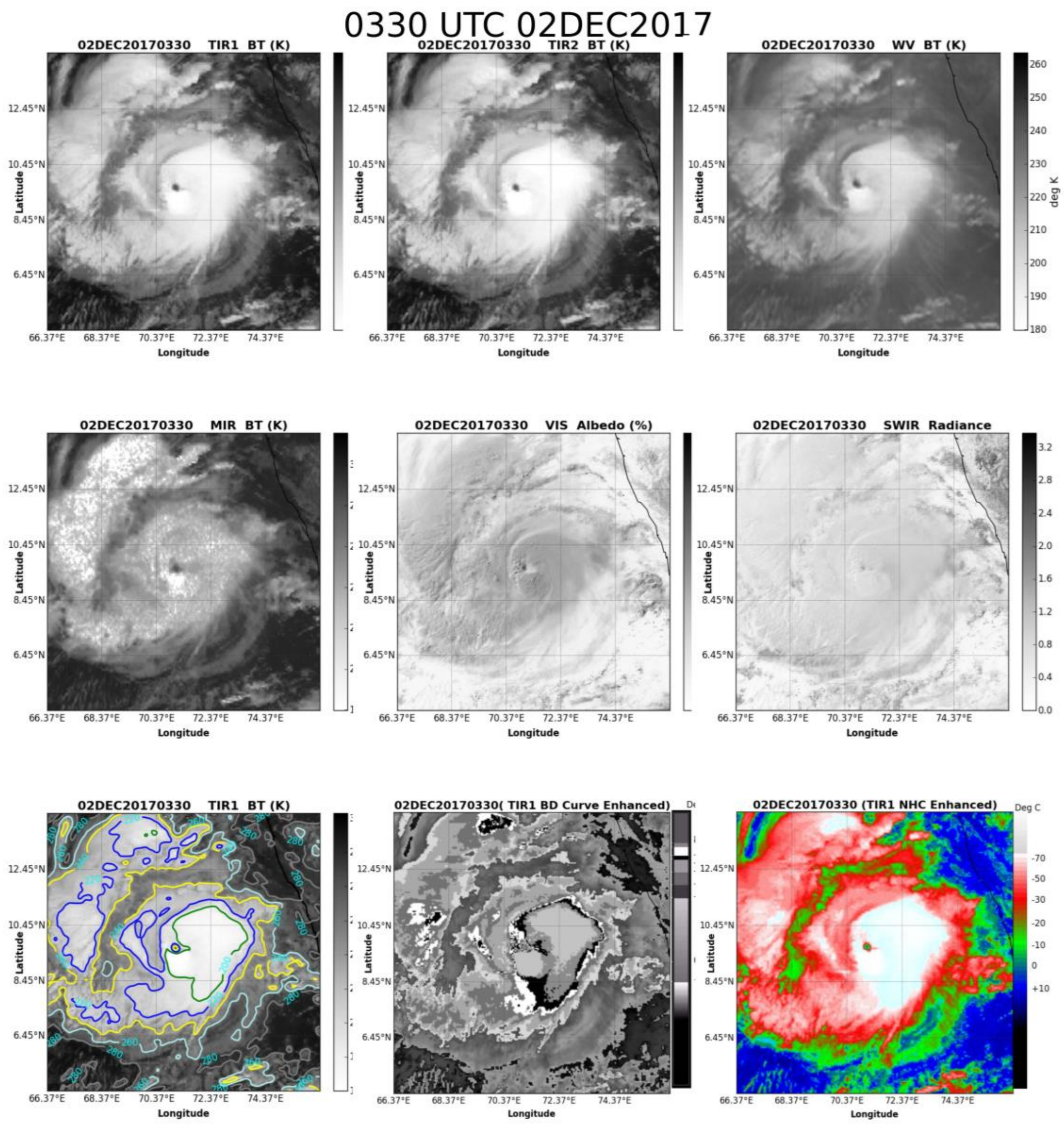

Figure 13: Cyclone centric products of INSAT3D imager channels

4.2 SAPHIR

SAPHIR onboard Megha-Tropiques satellite is a sounding instrument with six channels near the absorption band of water vapor at 183.31 GHz. The channels provide continuous observations of 10 km resolution (at nadir) at 6 different atmospheric layers at least 2-3 times in a day. These high resolution data was found very useful to observe the internal changes in the cyclone structure during the intensification process of TCs. SAPHIR onboard Megha-Tropiques satellite is a sounding instrument with six channels near the absorption band of water vapor at 183.31 GHz. The channels provide continuous observations of 10 km resolution (at nadir) at 6 different atmospheric layers at least 2-3 times in a day. These high resolution data was found very useful to observe the internal changes in the cyclone structure during the intensification process of TCs.

The BT values observed from SAPHIR 01-04 Dec, 2017 have been shown in the Fig. 8. Such images are very useful to determine the lower level structure of cyclone and its geo-location.

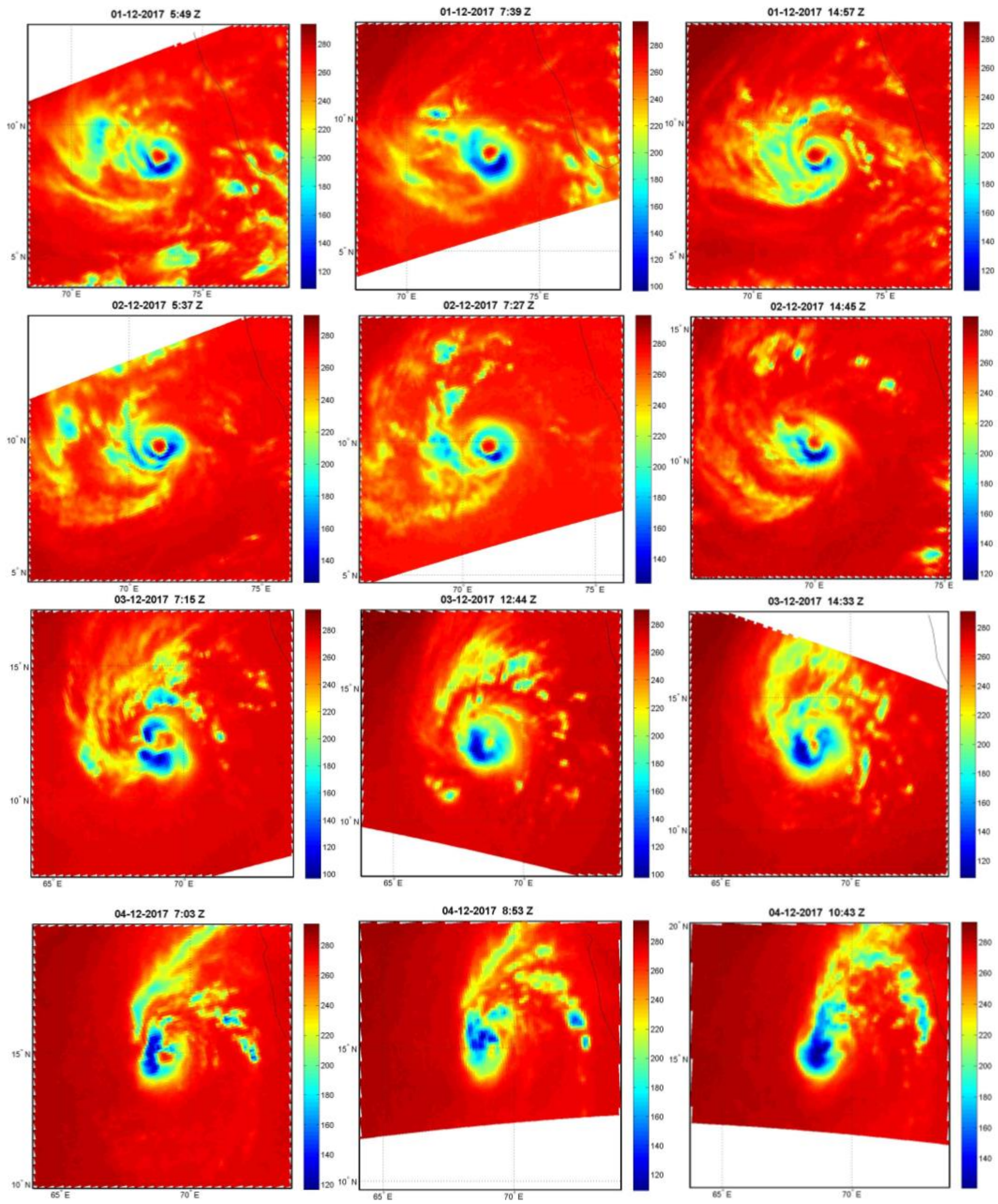

Figure 14: BT values observed by SAPHIR channel-6 over the tropical cyclone OCKHI

4.3 SCATSAT-1

The observations of surface wind vectors over TC OCKHI by SCATSAT-1 have been analyzed. The TC OCKHI was observed during 30 November-04 December, 2017 by at least one pass in a day. On 30th November and 01 December, the passes were partially covering the cyclone, however, on 2nd Dec -4th Dec cyclone was fully covered by

SCATSAT-1 winds as shown in the Figure 13. During this period cyclone was categorized as very severe cyclone category by the IMD best track measurements. The maximum winds estimated by SCATSAT-1 over the above fully covered cyclone passes were found as 32.79 m/s, 32.71 m/s and 30.72, respectively, however the IMD best track estimated wind speed during this time was 80 kt (41.16 m/s), 75 kt (38.58 m/s) and 65 kt (33.44 m/s). Thus the maximum sustained wind speed measurements were underestimated by SCATSAT-1 during cyclone intense categories.

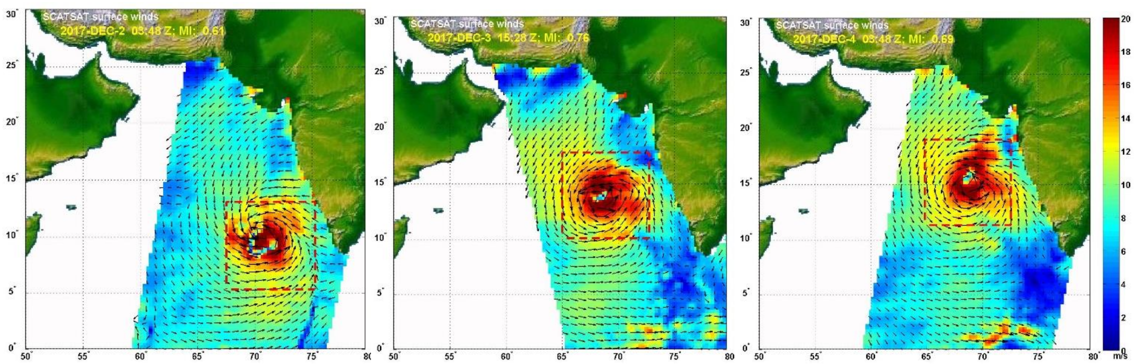

Figure 15: SCATSAT-1 wind vector products over the TC OCKHI (2nd - 4th Dec, 2017)

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