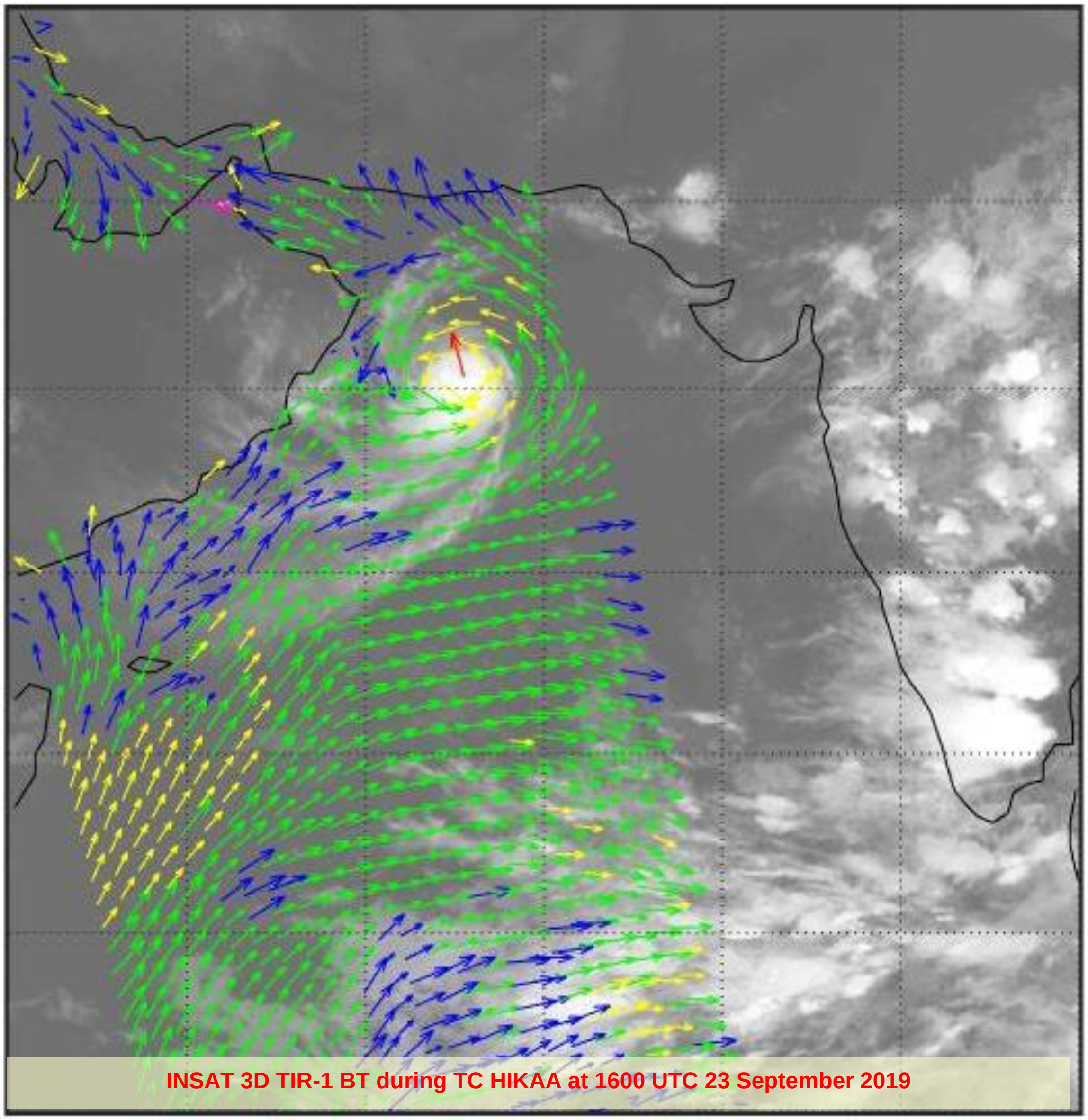
Real-time Monitoring and Prediction of Tropical Cyclone HIKAA

SAC/EPSA/AOSG/ASD/SR-27/2019



INSAT 3D TIR-1 BT during TC HIKAA at 1600 UTC 23 September 2019

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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. The tropical cyclone track is predicted and updated. These forecasts and satellite based cyclone inputs are disseminated through web-portal SCORPIO linked to MOSDAC. The real-time prediction of cyclone HIKAA and its structural analysis using satellite observations are presented in this report. The surface wind observations over TC HIKAA by different satellites e.g. SCATSAT-1, CYGNSS and SMAP are also presented.
Key words	Tropical cyclone, track prediction, cyclogenesis, center determination, satellite observations
Security classification	Unrestricted

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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. However, the cyclones formed in this region are considered weaker in intensity and smaller as compared to other regions, yet the number of deaths in the region is highest in the globe. 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, computational resources 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 “HIKAA” in NIO during 23 -25 September 2019 and discussed in the present report.

1.1. Overview of Tropical cyclone HIKAA (23-25 September, 2019)

The tropical cyclone “HIKAA” was classified by IMD as very severe cyclonic storm. It was originated from a tropical depression formed in the Arabian Sea region of North Indian Ocean. The system gradually intensified into severe cyclonic storm and then reached its peak intensity as a severe cyclonic storm. The TC HIKAA weakened due to dry air intrusion and made landfall in the Oman region as a severe cyclonic storm on 25

September early morning hours. It quickly weakened after its landfall and dissipated on the next day. The Observed track of TC HIKAA with its intensity categories provided by JTWC has been shown in the Figure 1. The IMD classification of cyclone intensity category is given in Table 1.

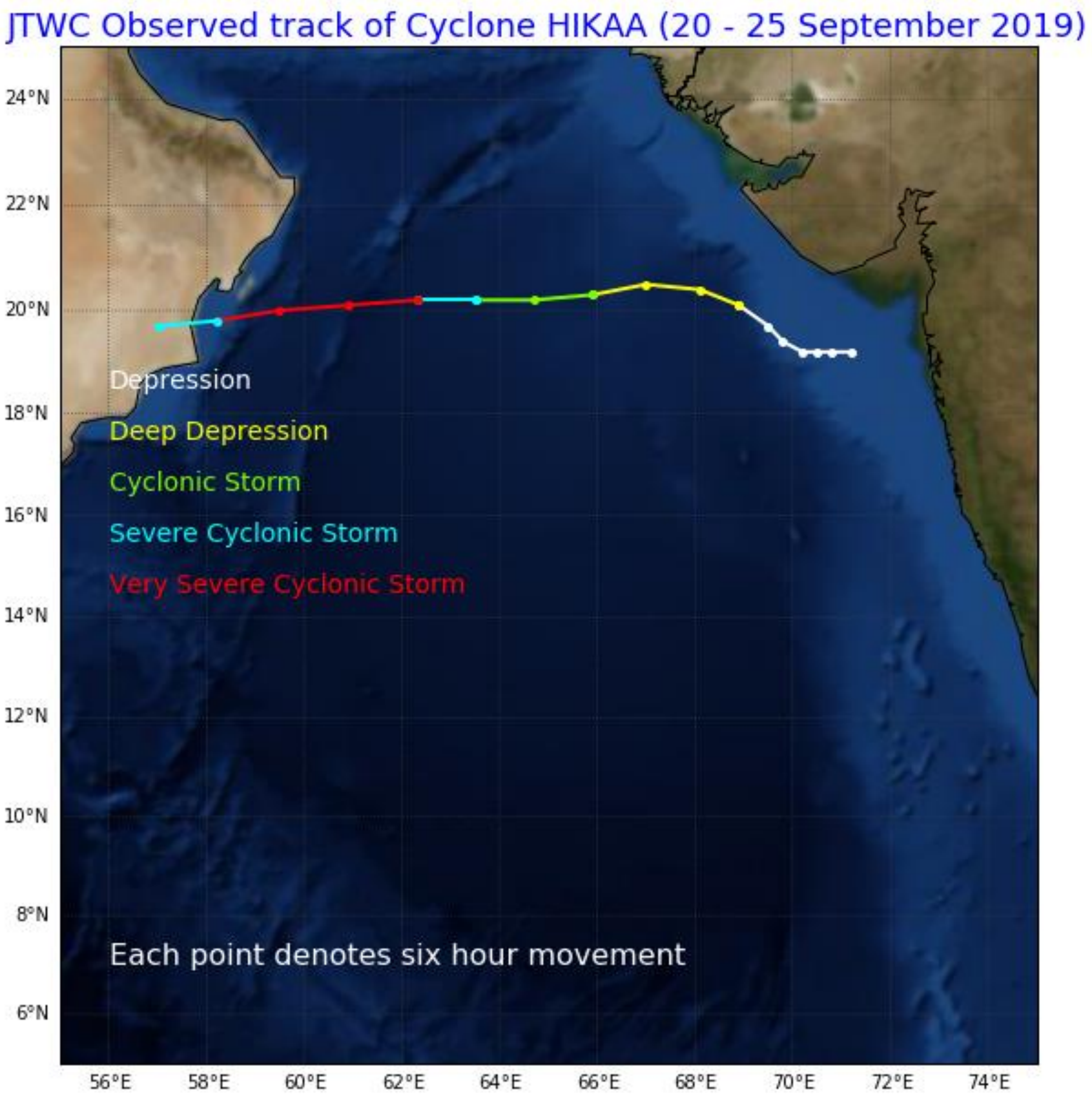


Figure 1: Real-time observed track (JTWC) of cyclone HIKAA with intensity categories.

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 (VSCS)	64-85
Extremely SCS (ESCS)	86-119
Super Cyclonic Storm(SuC)	>119

The cyclone name “HIKAA”, was given by Maldives. As per global convention, the eight countries that make up the Indian Ocean Region—Bangladesh, India, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, Thailand —have drawn up a list of names for tropical cyclones, which are assigned serially with the alphabetic order of the nation’s name.

Development stages of the cyclone HIKAA were continuously monitored by the visible and infrared observations from geo-stationary satellites viz., INSAT-3D. SCATSAT provided very good observations over these cyclonic systems, which were found to be very helpful for its prediction and structural analysis. The surface wind observations provided by advanced satellites like CYGNSS, SMAP and WINDSAT were also been discussed in this report. Using the observations and models, the real-time predictions of cyclone track, intensity, and rainfall and wind structure were performed at SAC-ISRO. 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 satellite estimated surface wind analysis and its comparison w.r.t IMD and JTWC estimates.

2. Data and Methodology

A system has been formed in the SAC to predict the cyclones from its birth until 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 until its landfall occurs. The track prediction also includes its landfall time and position prediction. Predictions of cyclone intensity is also generated using NWP models. 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 Tropical Cyclogenesis Prediction

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.

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

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 Oceansat-2, which 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 North 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 0.5^0 x 0.5^0 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 up to 96 hour with 6 hours 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).

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

3. Results: Prediction of TC HIKKA

Real-time cyclogenesis and track prediction of TC HIKAA 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 Cyclogenesis prediction of TC HIKAA

The wind pattern matching based technique indicated a strong signal of cyclogenesis using the SCATSAT data, on 0330 UTC 21 September 2019. The wind matching index value was found as 0.6, which was satisfying the threshold criterion. The surface winds obtained by SCATSAT-1 are shown in the Fig. 2, where the cyclogenesis region has been marked with the box. Cyclone HIKAA was declared as tropical cyclone on the morning hours of 23 September 2019. Thus, the wind pattern matching based technique predicted the cyclogenesis of TC approximately 2 days before the official declaration of the system as a cyclonic storm by IMD. The passes over the system during its genesis stage i.e. 20-22 September have been shown in the Fig. 2.

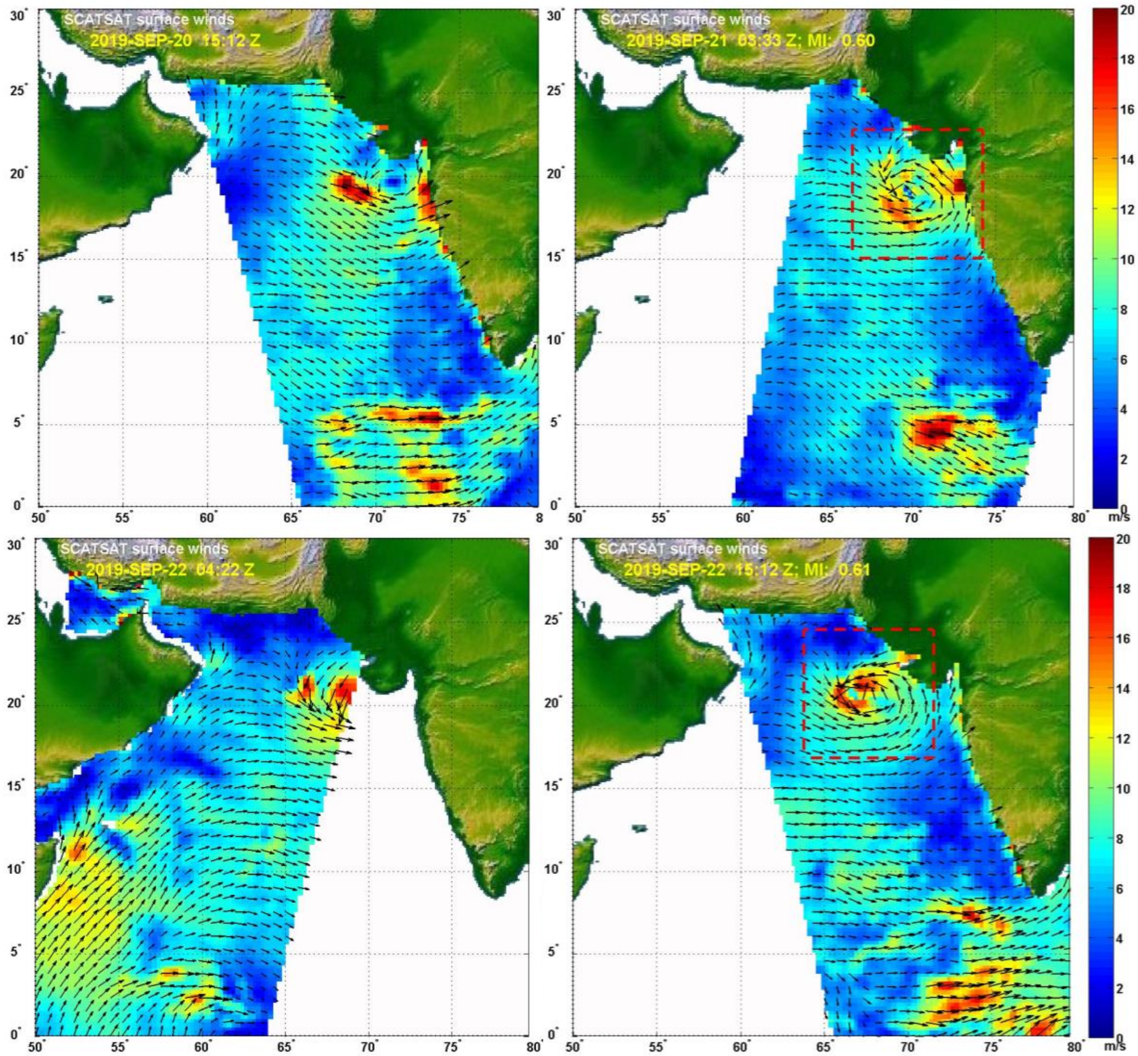


Figure 2: SCATSAT winds during the cyclogenesis of TC HIKAA. The earliest cyclogenesis signature was detected on 03 UTC 21st September 2019.

3.2 Real-time track prediction of TC HIKAA

After formation of TC HIKAA, its track was predicted using the SAC-Lagrangian Advection model and WRF model. The cyclone track forecast using SAC-Lagrangian model was generated on 00 UTC of 23-24 September 2019 and have been shown in the Fig. 3. The initial position of cyclone in the forecasts was taken from the real-time provided cyclone bulletins of JTWC. Each point in the figure is representing the six hours' movement of the cyclone. JTWC real-time observed track has also been presented in the figure.

In the real-time only 00 UTC track were disseminated over the website, which have been provided in Fig. 4. Based on the past track error statistics of the model, the cone of uncertainty has been computed and shown as a shaded region along the predicted track.

The position error of track forecast by SAC-model is also estimated w.r.t. IMD best track positions. The values have been summarized in the Table 5.

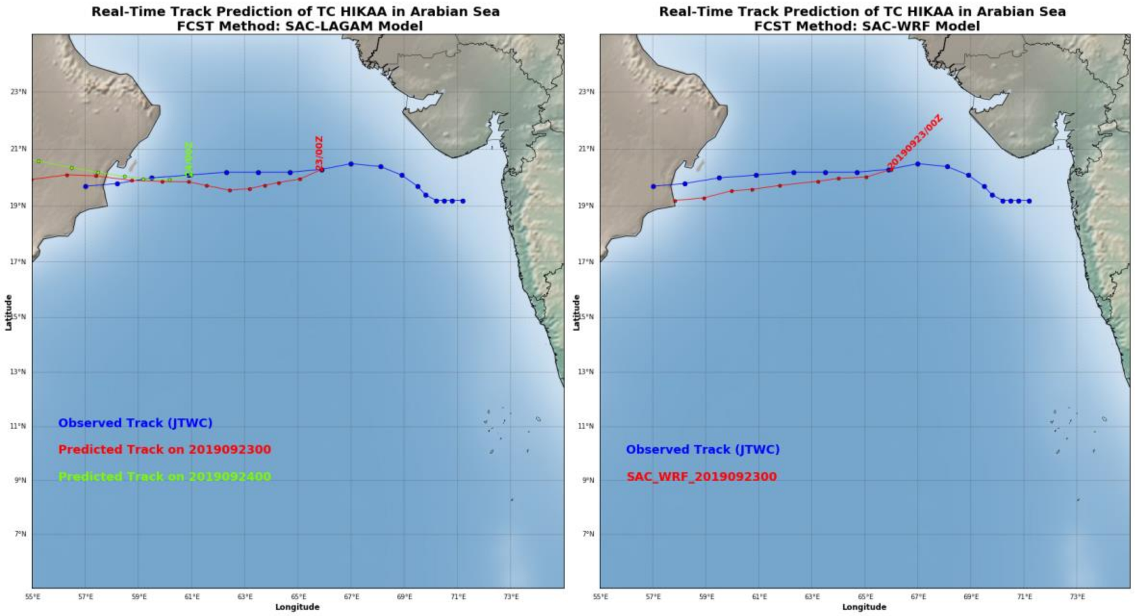


Figure 3: Real-time predicted track of TC HIKAA with initial conditions of 00 UTC 23 September 2019, by SAC-Lagrangian track prediction model and WRF model.

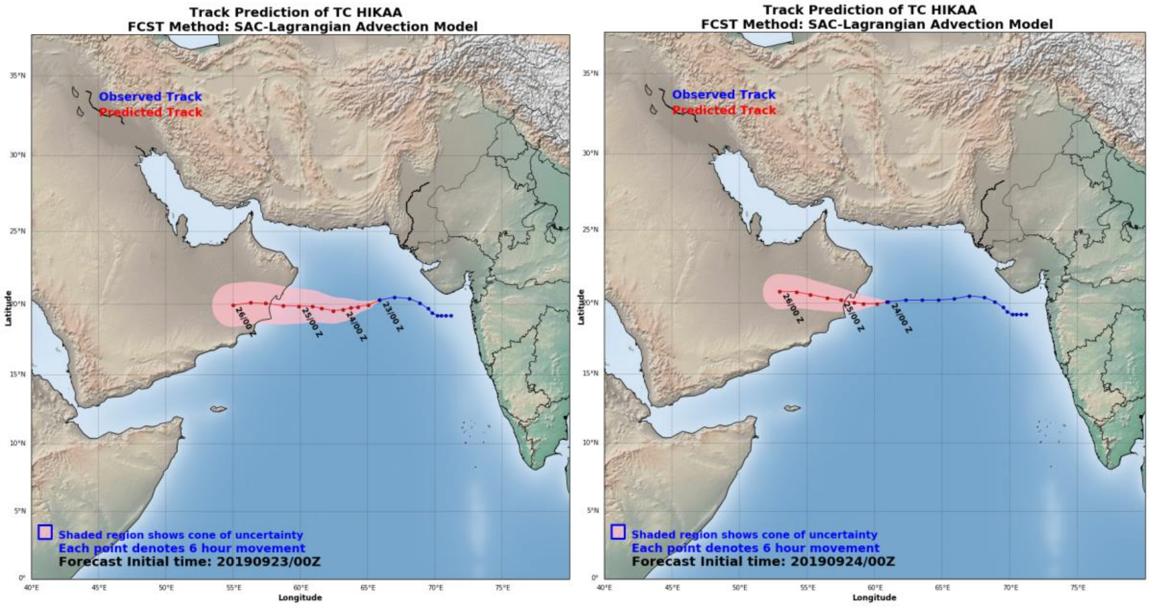


Figure 4: Real-time predicted track of TC HIKAA at 00 UTC 23-24 September 2019 with its cone of uncertainty by SAC-Lagrangian track prediction Model.

Table 2: Direct position error of SAC-Lagrangian track prediction model for TC HIKAA w.r.t JTWC real-time observed track

FCST Initial time	**Track Error (km) in different Forecast Lead time**						
	6	**12**	**18**	**24**	**30**	**36**	**42**
2300	46.96	90.36	160.93	245.36	311.49	351.68	407.41
2400	10.44	69.3	103.17	158.57			
Mean Error	28.7	79.83	132.05	201.97	311.49	351.68	407.41

Table 3: Cross track error of SAC-Lagrangian track prediction model for TC HIKAA w.r.t JTWC real-time observed track

FCST Initial time	**Track Error (km) in different Forecast Lead time**						
	6	**12**	**18**	**24**	**30**	**36**	**42**
2300	28.74	39.14	48.36	67.32	67.93	60.70	17.12
2400	0.74	11.17	2.15	23.79			
Mean Error	14.74	25.16	25.26	45.56	67.93	60.70	17.12

Table 4: Along track error of SAC-Lagrangian advection track prediction model for TC HIKAA w.r.t JTWC real-time observed track

FCST Initial time	**Track Error (km) in different Forecast Lead time**						
	6	**12**	**18**	**24**	**30**	**36**	**42**
2300	37.14	81.44	153.49	235.95	303.99	346.41	407.05
2400	10.42	68.39	103.15	156.77			
Mean Error	23.78	74.92	128.32	196.36	303.99	346.41	407.05

Table 5: **Direct position error of SAC-Lagrangian advection track prediction model for TC HIKAA w.r.t IMD Best Track**

FCST Initial time	**Track Error (km) in different Forecast Lead time**									
	6	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**60**
2300	39.66	38.18	74.75	168.38	246.62	327.00	358.68	417.27	441.00	416.84
2400	72.90	97.51	155.54	186.94	201.14					
Mean Error	56.28	67.85	115.15	177.66	223.88	327.00	358.68	417.27	441.00	416.84

Table 5: **Direct position error of SAC-WRF model for TC HIKAA w.r.t IMD Best Track**

FCST Initial time	**Track Error (km) in different Forecast Lead time**							
	6	**12**	**18**	**24**	**30**	**36**	**42**	**48**
2300	59.13	15.86	69.05	69.05	86.62	139.92	172.90	157.67

IMD reported that cyclone crossed Oman coast near Latitude 19.7 N and longitude 57.7 E between 1400 UTC and 1500 UTC of 24 September 2019. The landfall point and time error of all the real-time generate track forecasts by SAC-model has been computed with respect to IMD estimated landfall position and have been summarized in the Table 6.

Table 6: Landfall point error (km) of SAC-Lagrangian track prediction model for TC HIKAA

Forecast initial time	**Landfall point**		**Landfall time (after FCST initial time)**	**Landfall Error**	
	Longitude	**Latitude**	**Lead Hours**	**Position Error (km)**	**Time Error (hours)**
00 UTC 23 SEP 2019	57.84	20.02	58 hours (25 SEP 10 Z)	38.42	+20
00 UTC 24 SEP 2019	57.91	20.14	21 hours (24 Sep 21 Z)	53.63	+6

It can be seen that landfall error, of track predicted before 24 hours (00 UTC 24 September 2019), in position was 53.6 km and time was six hours delay.

The forecasts from SAC model can be further improved by including the high resolution (17 km 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.

Table 6: Landfall point error (km) of SAC-WRF model for TC HIKAA

Forecast initial time	**Landfall point**		**Landfall time (after FCST initial time)**	**Landfall Error**	
	Longitude	**Latitude**	**Lead Hours**	**Position Error (km)**	**Time Error (hours)**
2300	57.87	19.21	57 (25 SEP 09 Z)	57.05	+19

3.3 Intensity Prediction of TC HIKAA

Intensity of TC HIKAA was predicted using output of WRF model, which was run at SAC. Real-time generated intensity product is shown in the figure.

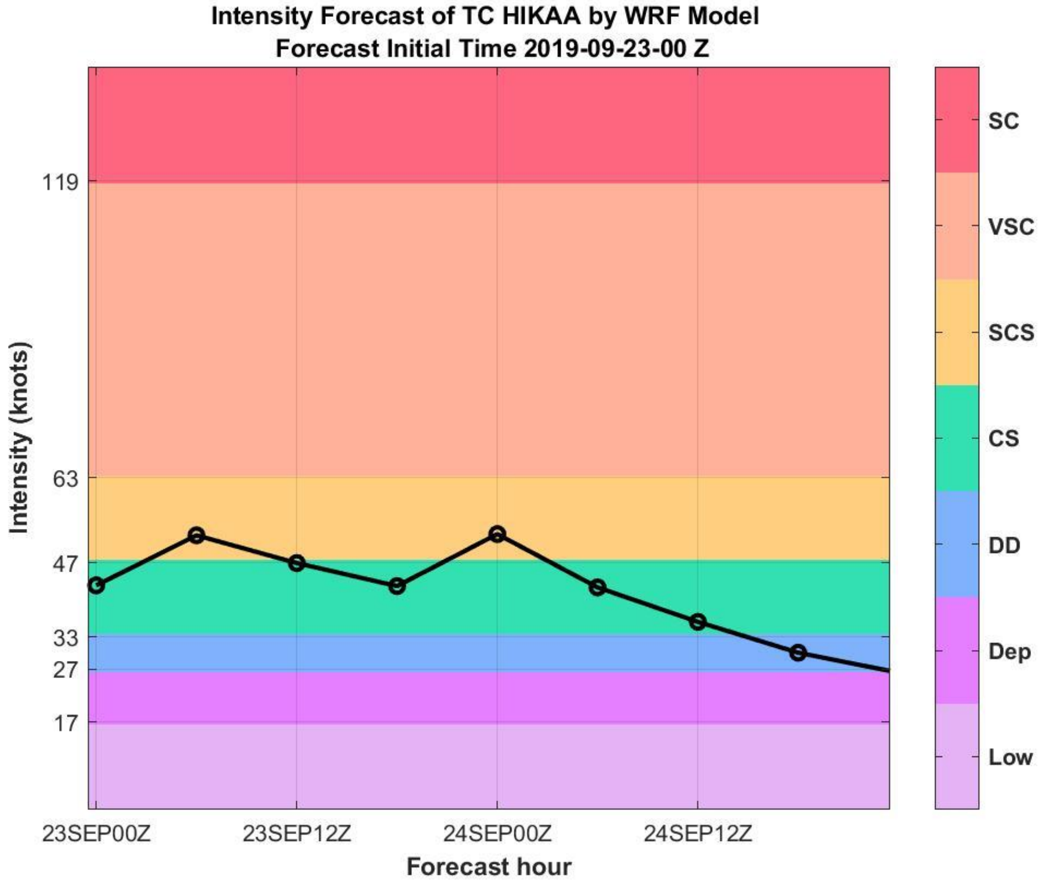
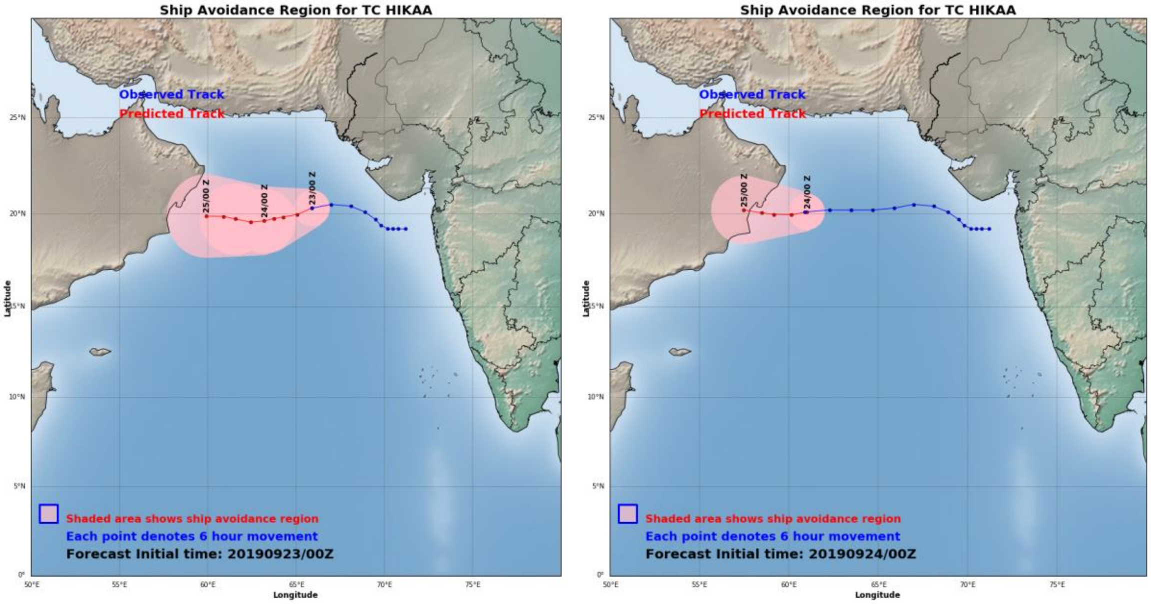


Figure 6: Real-time generated intensity prediction of TC HIKAA during 00 UTC of 23 September 2019.

3.4 Ship Avoidance Region Prediction for TC HIKAA

For vessels at sea, avoiding the 34-knot wind field of a tropical cyclone is paramount. Any ship near a tropical cyclone should make every effort to remain clear of the maximum radius of analyzed or forecast 34-knot winds associated with the tropical cyclone. Knowing that the area of 34 knot around tropical cyclones is rarely symmetric but instead varies within semi-circles or quadrants is important. Understanding that each tropical storm or hurricane has its own unique 34-knot wind field are necessary factors to account for when attempting to remain clear of this dangerous area around a tropical cyclone. Based on operational HWRF 34 knot wind radial distances the graphical inputs of ship avoidance region was also generated for TC HIKAA and disseminated through SCORPIO server.



Ship Avoidance Region for TC HIKAA

Ship Avoidance Region for TC HIKAA

Figure 7: Real-time predicted ship avoidance region for TC HIKAA during 00 UTC of 23 - 24 September 2019.

4. Satellite Observations over TC HIKAA

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 HIKAA have been discussed in this section.

4.1 INSAT 3D

Cyclone Geo-location

TC HIKAA 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. 8.

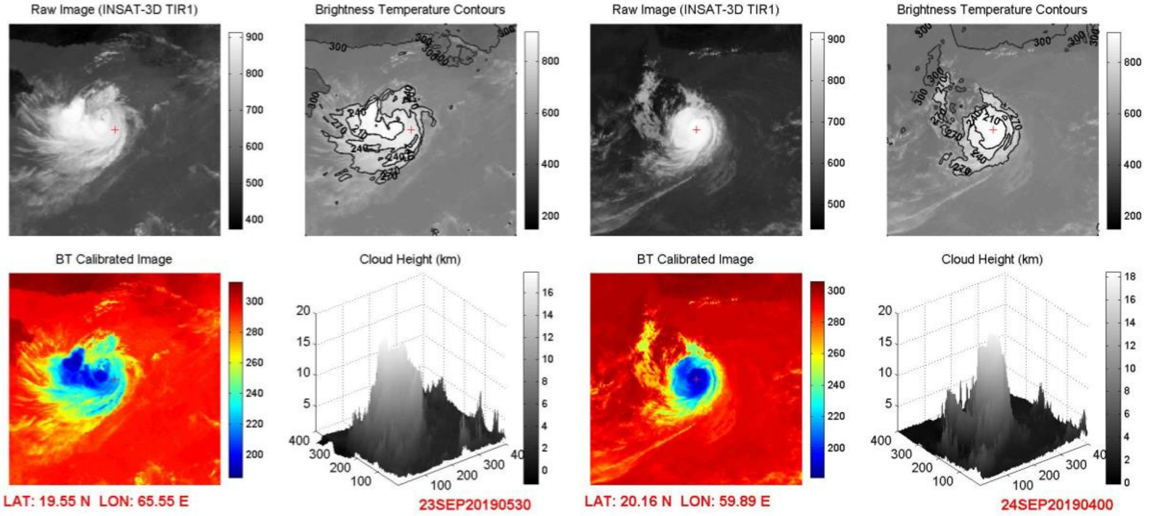


Figure 8: Center of TC estimated using INSAT 3D TIR image.

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 0400 UTC 24 September 2019 have been presented in the Figure 9.

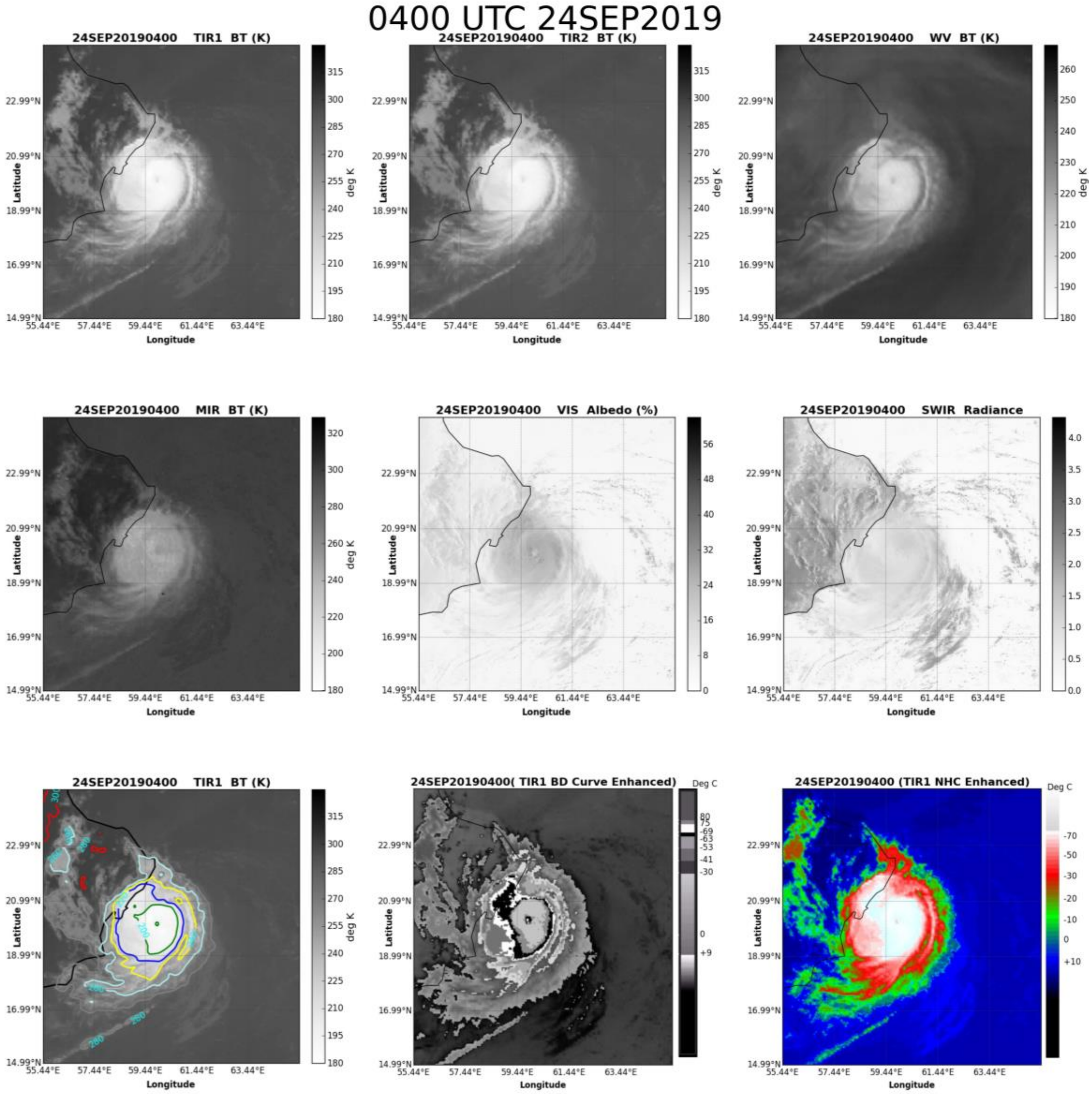


Figure 9: Cyclone centric products of INSAT3D imager channels

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. The BT values observed from SAPHIR over TC HIKAA have been shown in the Fig. 10. The lower level structure of cyclone during 20th September shows the cloud organization during cyclogenesis stage. No other pass of SAPHIR was obtained over TC HIKAA.

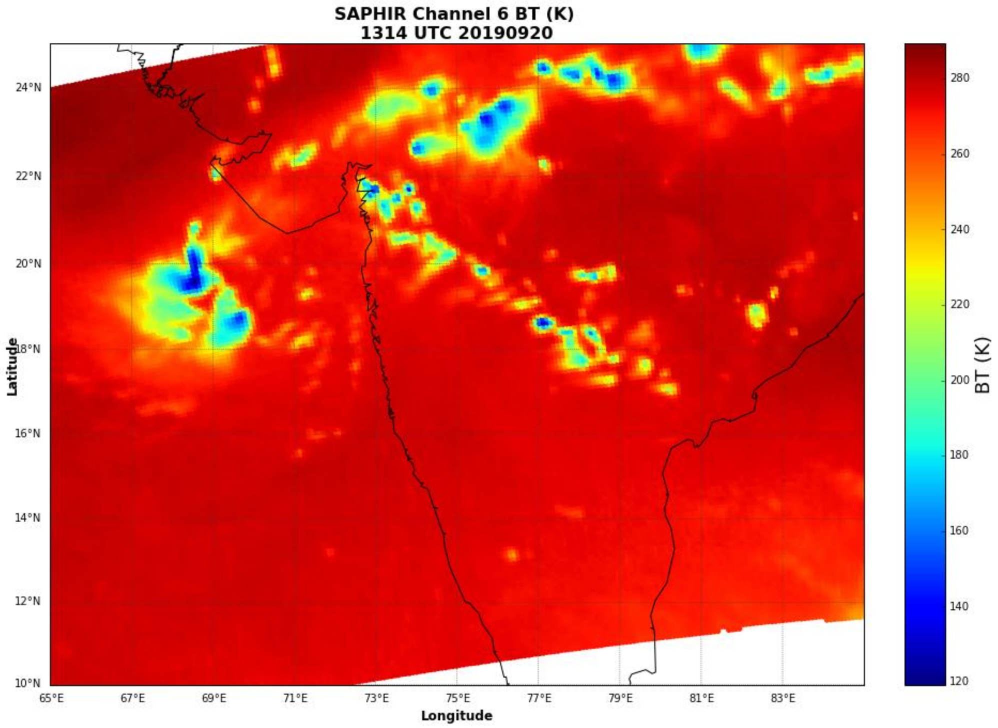


Figure 10: BT values observed by SAPHIR channel-6 over the tropical cyclone HIKAA

4.3 Satellite based surface wind observations over TC HIKAA

The wind observations over TC HIKAA observed by different sensors onboard different Indian and foreign satellites e.g. SCTASAT-1, CYGNSS, SMAP and WINDSAT have been discussed in this section.

4.3.1 SCATSAT-1

The SCATSAT-1 satellite had three coverage over mature stage of cyclone HIKAA during its life over ocean. The wind vectors (L2B: 25 km x 25 km) from all the pass covering the cyclonic have been shown in the Figure 11.

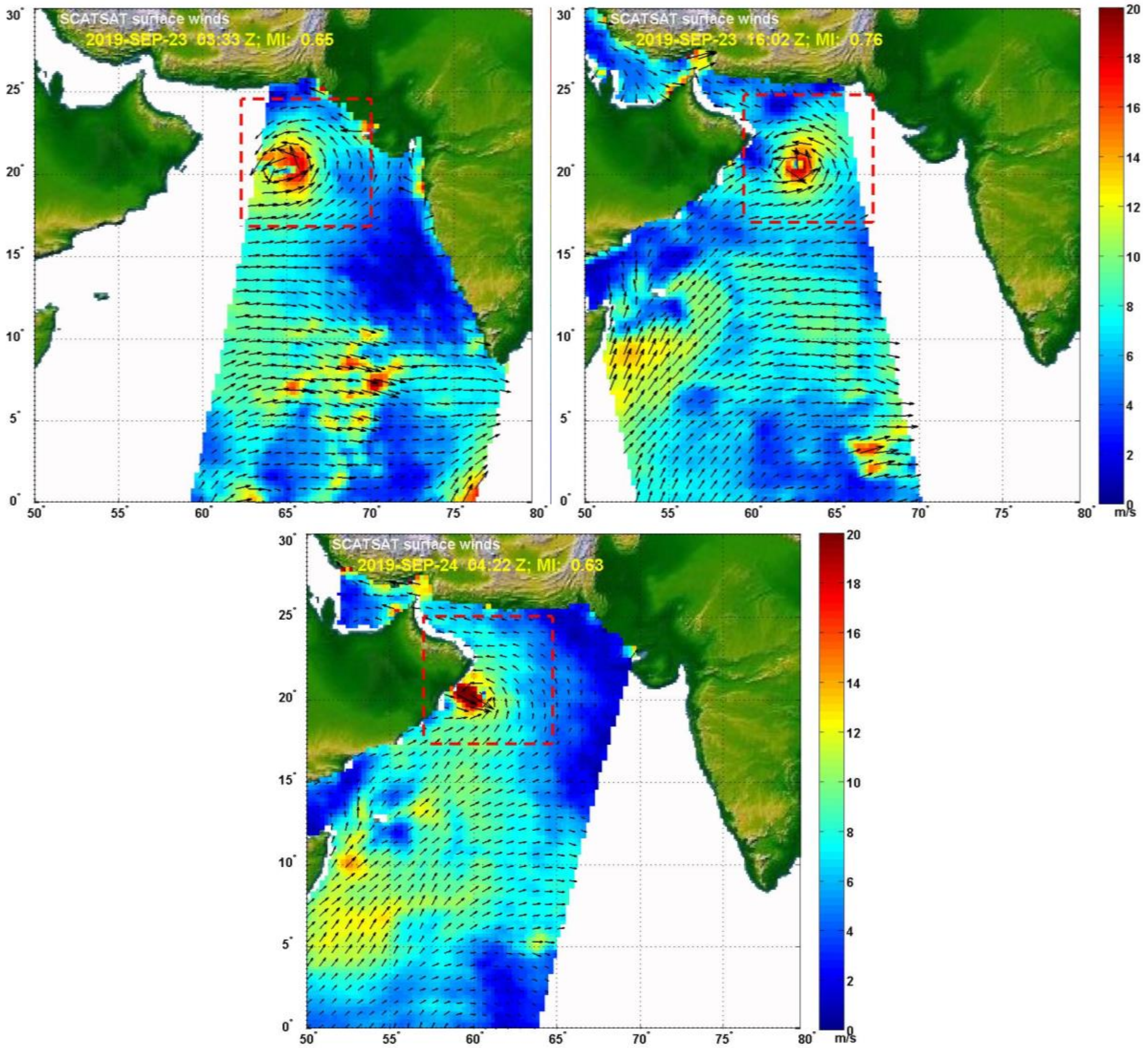


Figure 11: SCATSAT-1 wind vector products over the TC HIKAA (23-24 September 2019)

4.3.2 CYGNSS

CYGNSS (Cyclone Global Navigation Satellite System) is part of the NASA ESSP (Earth System Science Pathfinder) program referred to as an EVM (Earth Venture Mission). CYGNSS will use a constellation of eight small satellites in LEO (Low Earth Orbit) carried to orbit on a single launch vehicle. In orbit, CYGNSS's eight microsatellite observatories will receive both direct and reflected signals from GPS (Global Positioning System) satellites. The direct signals pinpoint CYGNSS observatory positions, while the reflected signals respond to ocean surface roughness, from which wind speed is retrieved.

The overall objective of CYGNSS is to improve extreme weather predictions. The mission is focused on tropical cyclone (TC) inner core process studies. CYGNSS attempts to resolve the principle deficiencies with current TC intensity forecasts, which lie in inadequate observations and modeling of the inner core. The inadequacy in observations results from two causes viz. (i) much of the inner core ocean surface is obscured from conventional remote sensing instruments by intense precipitation in the eye wall and inner rain bands and (ii) the rapidly evolving (genesis and intensification) stages of the TC life cycle are poorly sampled in time by conventional polar-orbiting, wide-swath surface wind imagers. CYGNSS is specifically designed to address these two limitations by combining the all-weather performance of GNSS bistatic ocean surface scatterometry with the sampling properties of a constellation of eight satellites. The use of a dense constellation of microsatellites results in spatial and temporal sampling properties that are markedly different from conventional imagers.

The observations by the constellations of CYGNSS system over TC HIKAA have been shown in the Figure 12. All the passes within a day have been plotted together. The maximum wind speed observed by the satellite system has been summarized in the Fig. 16.

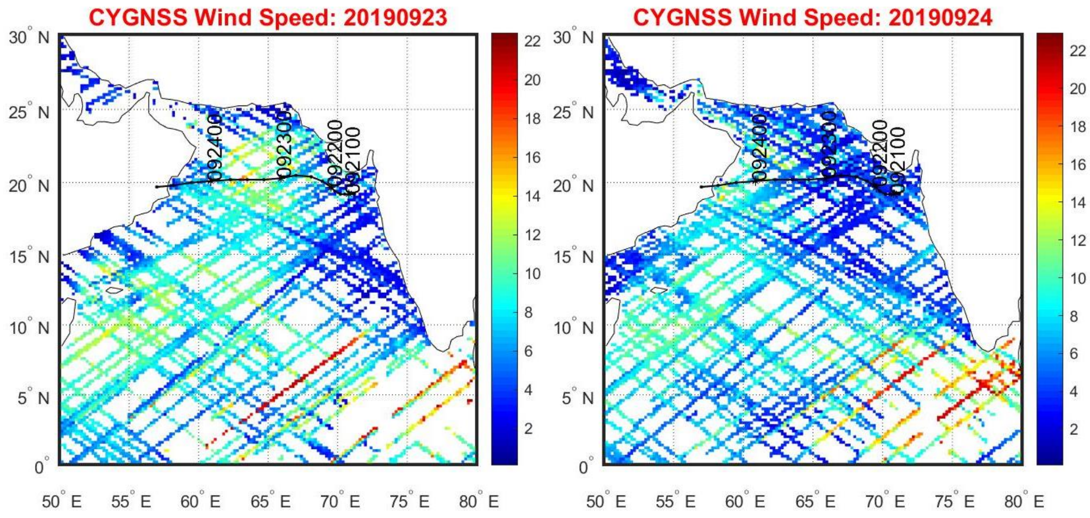


Figure 12: GYGNSS wind speed products over the TC HIKAA (23-24 September 2019)

4.3.3 SMAP

Soil Moisture Active Passive (SMAP) is a United States environmental research satellite launched on 31 January 2015. The SMAP observatory includes a dedicated spacecraft and instrument suite in a near-polar, Sun-synchronous orbit. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. The combined active and passive measurement approach takes advantage of the spatial resolution of the radar and the sensing accuracy of the radiometer.

SMAP provides two wind speed products e.g. (i) Near-Real Time (NRT) wind speed and (ii) Final wind speed product. The NRT wind processing uses ancillary fields of shorter latency but lower quality. A Final Wind Speed version, reprocessed with a 1-month delay, which uses higher quality ancillary data. The wind speed from NRT product of SMAP over TC HIKAA has been shown in the Fig. 13. There were five passes of SMAP over the TC HIKAA during its different intensity stages.

Additionally, SMAP also provide Tropical Cyclones (TC) ASCII files with SMAP 10-min maximum-sustained winds (in kn) and wind radii (in nm) for the 34 kn (17 m/s), 50 kn (25 m/s), and 64 kn (33 m/s) winds for each SMAP pass over a TC in all tropical ocean basins. The wind radii estimated by SMAP satellite for TC HIKAA for four of its full coverage pass has been shown in the Figure 14. The values have been summarized in Table 7.

Table 7: Critical wind radii estimates by SMAP product

Pass Time (MMDD)	Maximum Wind (kt)	R34: 34 knots wind radii (nm)				R50: 50 knots wind radii (nm)				R64: 64 knots wind radii (nm)			
1330	30	38	36	48	54	0	0	30	41	0	0	0	0

Figure 13: SMAP wind speed NRT products over TC HIKAA (23-24 September 2019)

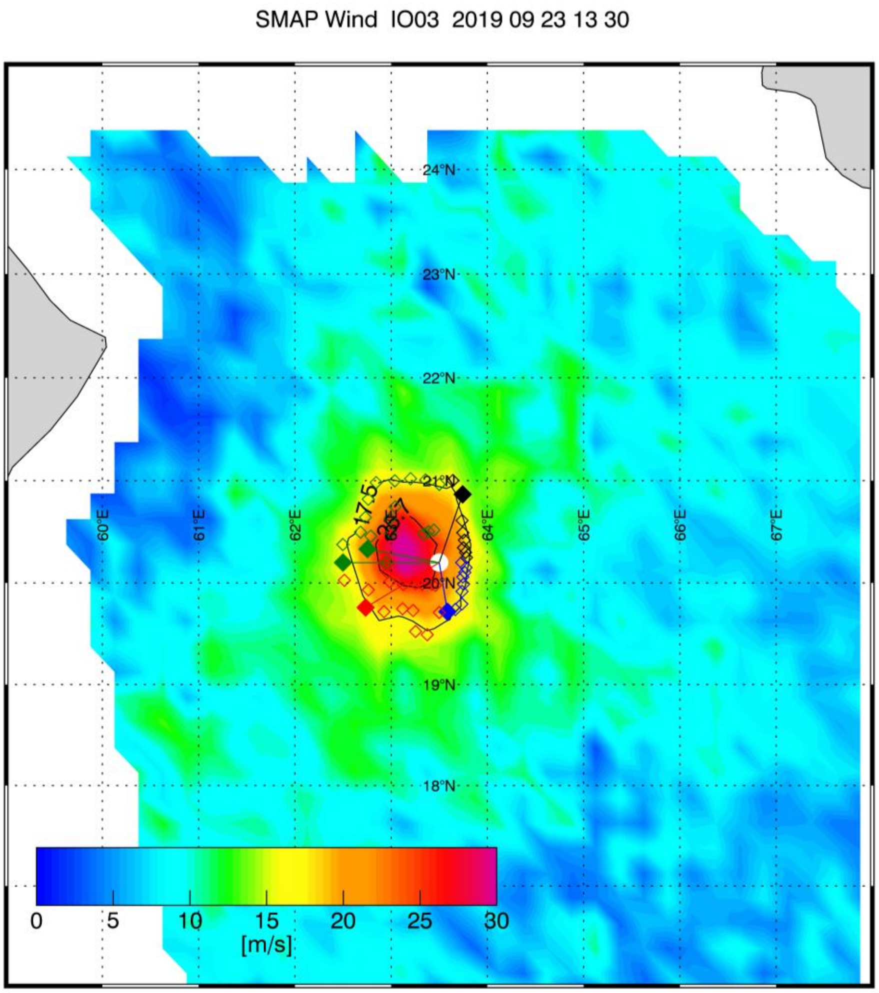


Figure 14: SMAP critical wind radii estimation over TC HIKAA (13:30 UTC 23 September 2019)

5. Conclusions

The real-time monitoring and prediction of TC HIKAA based on in-house developed techniques and the satellite products have been summarized in this report.

The real-time track prediction of track TC based on in-house developed model SAC-LAGAM for different initial conditions at 00 UTC during 23 - 24 September 2019 have been presented in the report. The Forecast by SAC WRF model are also discussed. The track error with respect to JTWC observed track and IMD best track has been computed for all forecast lead hours. The landfall position and time accuracy for 24 hour lead-time (FCST initial time: 23 September 00Z) was 39 km with 20 hours delay and 57 km with 19 hours delay, respectively by SAC LAGAM and WRF model.

Scatsat-1 capture the vortex development during its genesis stage. The wind pattern matching based technique using SCATSAT-1 surface wind observations predicted the cyclogenesis of TC HIKAA approximately 2 days before the official declaration of the system as a cyclonic storm by IMD.

The real-time satellite cyclone centric products on Indian satellite INSAT-3D, SCATSAT-1 and SAPHIR has been discussed in this report. During the lifetime of TC, there were seven passes of SCATSAT with full coverage over the system.

The real-time products of TC intensity forecast and ship avoidance region prediction based on the WRF model run at SAC has been presented in this report.

The wind speed estimated by different satellite products (available in near real-time) have been presented in this report for all passes of satellites (SCATSAT-1, CYGNSS and SMAP).

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