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TROPICAL CYCLONE ASHOBAA TRACKING BY USING BRIGHTNESS TEMPERATURE DATA OF SAPHIR SENSOR

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Abstract

The Megha-Tropiques satellite developed under the joint Indo-French spaceborne climate mission, carries a six-channel millimetre-wave sounder SAPHIR (Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie) primarily meant for profiling the atmospheric humidity of the tropics. It has a high spatial resolution of 10km at Nadir with a swath of more than 1800km. The satellite operating at an altitude of 865km and an inclination of 20 degrees provides a high temporal frequency of 4-6 times in a day. These characteristics have facilitated studies on the genesis, development and tracking of tropical cyclones (TC) in the oceans around the Indian

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subcontinent. The recent Ashobaa cyclone that occurred in the Arabian Sea in 2015 was studied using the brightness temperature (TB) measured by the SAPHIR instrument. Dvorak's technique of interpretation of satellite observation is used for determining TC intensity variation and eye location. A critical analysis on the variations in TB is obtained at its six wavelengths centred at about 183GHz. A comparative evaluation of the capabilities of all six channels of SAPHIR in measuring TC development is made to assess the best channel suitable for detection of TC and its intensity variations. It is found that channel 6 at 183+/−11.0GHz is relatively more sensitive to detect TC. Further, evaluation of capabilities of TB measured by SAPHIR made in our study confirms that orbit position of Megha-Tropiques satellite with more frequent sampling (4-6 times) is useful for supporting forecasting and now-casting of TC genesis to dissipation and its effects on land.

1. Introduction

Tropical cyclone is one of the major natural events which causes variation in monsoon and climatic condition, besides causing physical disasters. Forecasting TC genesis and TC intensity tracking is essential to minimize the possible life and material losses. Similarly, atmospheric humidity is chiefly responsible for variation in energy budget in the atmosphere. Tropical cyclone has strong impact on atmospheric humidity, climate and vegetation. Hence the knowledge about variation of atmospheric humidity due to tropical cyclone is necessary. Observations of: (i) TC genesis and intensities, (ii) atmospheric humidity and (iii) land surface emissivity using microwave and/or infrared images obtained by sounder onboard satellites enable us to obtain almost real time information relating to the said parameters. Among the various satellite missions useful to these activities, the advance microwave sounding unit (AMSU) sensors on NOAA satellite, SAPHIR sensor on Megha-Tropiques satellite and infrared (IR) sounder on INSAT-3D satellite missions have been considered for our studies [6]. The primary data used for our analysis is in the form of brightness temperature measurement of IR and microwave sounders.

In this paper, an attempt has been made to understand: (i) the capability of the sounder channels, (ii) find the possible, optimal bandwidth/frequencies suitable for correct measurement and (iii) to show the best technique to deduce sensor (sounder) information. The forecasts of cyclone indicating its accurate eye location and intensity at 24 hr and/or 48 hr time-steps are useful for all rehabilitation measures. Measurements of TC properties made by all the six channels of SAPHIR have been used for comparative evaluation of their ability in measuring properties of TC occurred in Arabian Sea and Bay of Bengal of the Indian sub-continent [14]. Our discussion will highlight the role of SAPHIR aboard Megha-Tropiques satellite mission having high temporal frequency (4-6 times in a day in the tropics) and good sampling followed by improved and correct (best resolution 10km) measurement in all atmospheric conditions. Further, a brief comparison on the data from the Indian Meteorology Department (IMD) which is cyclone eye method in tracking TC intensity has been made [17].

2. Background

For the past four decades, passive microwave sensor missions such as SEASAT, special sensor microwave imager (SSMI), microwave humidity sounder (MHS), humidity sounder for Brazil (HSB), AMSU-A and B, SAPHIR have been used for oceanographic applications. SAPHIR aboard Indian satellite mission is launched for profiling the atmospheric humidity. SAPHIR onboard Megha-Tropiques (MT) satellite has a good spatial resolution of 10 to 20km and a swath of ~2060km. Megha-Tropiques has been in near-circular inclined orbit of 20 degrees on 12 October 2011 [3, 4] and providing high-quality data related to ocean surface, atmospheric humidity profile [1] and land-related application [2]. Its unique features are: (i) frequent and simultaneous observations (up to 6 times a day) and (ii) good spatial sampling. By using brightness temperature, SAPHIR measures the vertical distribution of atmospheric water-vapor (from surface to 12km height) [5].

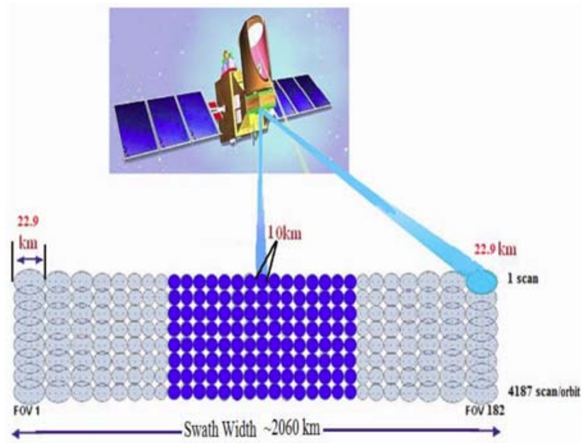
Although SAPHIR is primarily meant for atmospheric humidity profile studies, it has shown interesting results demonstrating the possibilities of detection, tracking movement of the features over the ocean surface. A number of such tropical cyclones occurred ever since Megha-Tropiques launch till 2015 (Keila, Thane, Nilam, Phailin, Hudhud, Nilofar and Ashobaa). This paper brings out a vivid picture of cyclonic features as observed over a period from (from: 0300 UTC 8 June 2015 up to −1200 UTC 12 June 2015). Satellite images of cyclone show a prominent eye encircled by the eye wall and spiral bands of convection. Dvorak [16] developed a method to observe the central and banding features of TC's and cloud-top temperatures near the eye by using visible and IR satellite imagery and the same was popularly adopted as Dvorak Technique. Demuth [8], by using AMSU sounder data, (i) azimuthally averaged radii of 34, 50 and 64 knots winds, (ii) estimated tropical cyclone intensity and (iii) proposed algorithms for wind radii estimation. Timothy and Velden [15] based on rigorous statistical and empirical analysis developed an algorithm to improve pattern recognition which introduced three major changes in automated storm center determination methodology. Nishimura et al. [14] used an improved version of Dvorak technique to analyze center positions of tropical cyclones. Uusing this microwave imagery analysis is also developed.

3. Sensor Details

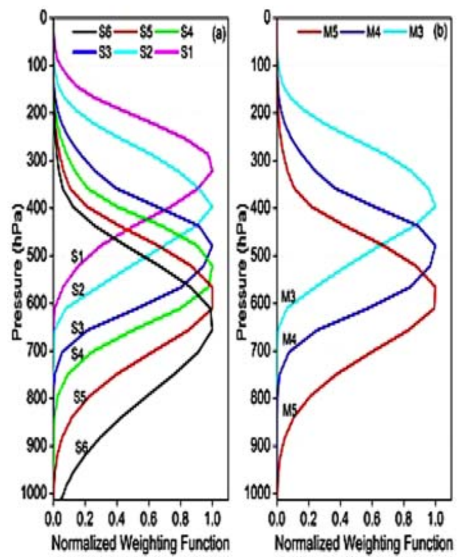
The SAPHIR instrument provides atmospheric humidity profile using six channels ranging from surface 1000hpa to the stratosphere 86hpa (layer 1: 1000-850hpa; layer 2: 850-700hpa; layer 3: 700-550hpa; layer 4: 550-400hpa; layer 5: 400-250hpa; and layer 6: 250-100hpa), as compared to 3 layers of AMSU-B and additionally some more layers supplementing these data with INSAT-3D. Table 1 shows the comparison of technical specifications of SAPHIR [15], AMSU-B [5], INSAT-3D [3] and MHS sounder [2].

SAPHIR sounder performing cross track scanning when satellite is moving ahead offers 10km at nadir resolution and 22.9km at edge spatial resolution, number of pixels per each scan is 182 per scan (130 per scan without overlap) and for one complete orbit 4187 scans as shown in Figure 1(a).

SAPHIR measures vertical distribution of atmospheric water-vapour from six channels providing relatively narrow weighting functions from the surface to about 12km as shown in Figure 1(b) which shows the normalized weighting function of SAPHIR (S3, S4 and S5) that are similar to AMSU-B (M3, M4 and M5) channels [8].



(a) SAPHIR scanning geometry



(b) Weighting function of SAPHIR and AMSU-B

Figure 1

Table 1. Comparison of SAPHIR, AMSU-B, INSAT-3D and MHS specifications

Features	SAPHIR	AMSU-B	INSAT-3D	MHS
Orbital inclination	20°	98°	82°E	55°
No. of sounding channels	6	3	5	2
Swath width	~2060km	~2300km	6000 × 6000km for 160 min	~2134km
Max. incidence angle	50.4°	58.5°	-	49.44°
Pixel size across track	10-22.7km	20-64km	10km × 40km	16km
Pixel size along track	10-14.5km	16-27km	10km	27.10km
No. of pixels/scans line 1	182	90	10km E-W every 0.1 sec	90
Polarization	Horizontal	Horizontal	Linear-vertical	Horizontal
Central frequency/central wavelength (GHz/μm)	183.31 ± 0.2 183.31 ± 1.1 183.31 ± 2.8 183.31 ± 4.2 183.31 ± 6.8 183.31 ± 11.0	183.299 183.299 183.299	12.66μm 12.02μm 7.43μm 7.02μm 6.51μm	183.311 ± 1.0 183.311 ± 3.0
NEΔT (K)	2.35, 1.45, 1.36, 1.38, 1.03, 1.10	1.06, 0.7, 0.6	0.3, 0.15, 0.2, 0.2, 0.2	0.51, 0.4

4. Methodology

A. Data source

Megha-Tropiques SAPHIR metadata products named as "MT1SAPSL1A" contain all the scientific parameters including brightness temperature temporal, humidity profile, etc. of all six channels dataset available from 2011 to 2015 from MOSDAC (ISRO Ahmedabad) and ICARE (France) [20].

Figure 2 shows the selection processes of data product type orbit-wise or segment-wise of respective level is archived in HDF5 format. Level-1 products generate two types of files which are segment-wise (possibly exceeding one revolution, variable in size) and orbit-wise (i.e., one revolution). The L1 products that are available to the users are L1A and L1A2. Level 1A (L1A) is the brightness temperature geo-tagged product and along the scan line, samples of all the six channels are collocated and have exactly the same footprint dimensions projected on ground as well as the same geo-location [10]. Level 1A2 (L1A2) is the re-sampling of L1A (180 pixels) data brightness temperature to produce de-correlated non-overlapping 130 pixels for all channels [11, 18].

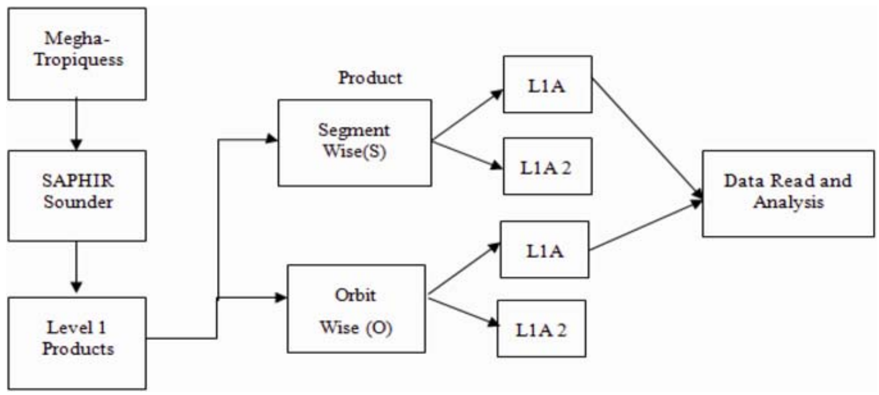


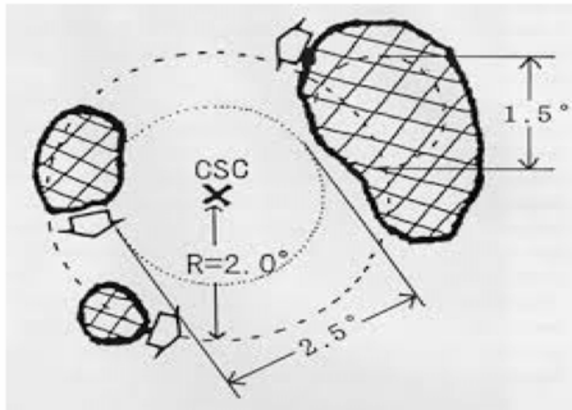
Figure 2. Data flow structure.

B. Tropical cyclone tracking by intensity estimation

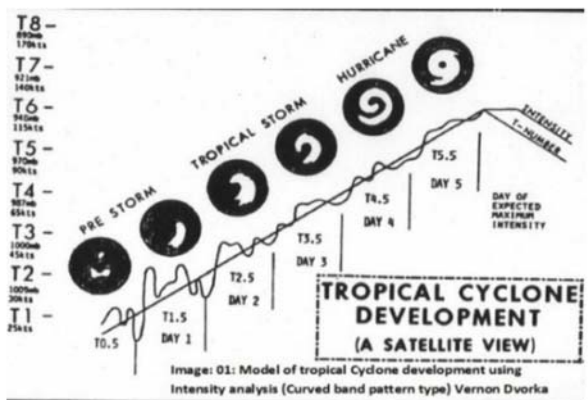
Dvorak technique (TC eye detection and tracking method) is used to detect and track TC Ashobaa from brightness temperature data as derived/ obtained from all the six channels of SAPHIR sounder.

Figure 3(a) illustrates the organized cloud system center (CSC) formation to determine the cyclone intensity: (i) the cloud system has a CSC within the diameter 2.5° latitude or less and CSC lasts for 6 hours or more, (ii) the cloud system has an area of dense, cold that appears less than 2° latitude from center and 1.5° latitude in diameter and (iii) if CSC satisfied above features, then it determines T-number as T1.0, otherwise, consider the T-number of less than T1.0 [17]. Figure 3(b) shows the Dvorak model of tropical cyclone development using curved band type intensity analysis.

TC detection and tracking from Dvorak technique using brightness temperature data obtained from all six channels of SAPHIR sounder images with an intention in establishing the best efficient satellite data can be used to identify the genesis and tracking of TC over Indian sub-continent.



(a) Cyclone intensity number determination



(b) Tropical cyclone development model [12]

Figure 3

5. Observation and Analysis

A number of cyclone observations is used to study the impact of ocean surface features and atmospheric humidity. Apart from several cyclones, a few severe cyclones that occurred in the Indian geographical region have been listed in Table 2. As a preliminary study, qualitative analysis of tropical cyclone features over Arabian Sea and Bay of Bengal surrounding the Indian sub-continent from 2011 to 2015 has been observed during October to December of every year.

Table 2. Cyclones occurred during 2011 to 2015

Year	Cyclone name	Duration	Ocean
2011	Keila	29 Oct. 2011 to 4 Nov. 2011	Arabian Sea
2011	Thane	25 Dec. 2011 to 31 Dec. 2011	Bay of Bengal
2012	Nilam	28 Oct. 2012 to 3 Nov. 2012	Bay of Bengal
2013	Phailin	4 Oct. 2013 to 14 Oct. 2013	Bay of Bengal
2014	Hudhud	7 Oct. 2014 to 14 Oct. 2014	Bay of Bengal
2014	Nilofar	25 Oct. 2014 to 31 Oct. 2014	Arabian Sea
2015	Ashobaa	7 June 2015 to 12 June 2015	Arabian Sea

As an example, the Dvorak technique is applied to Ashobaa cyclone that occurred from 7 June to 12 June 2015 as highlighted in Figure 4 and when the eye region of the cyclone (deep depression area) has been surrounded by cloud band at least halfway around the eye, the cyclone intensity T-number is assigned as T1.0. If the cloud area is more organized than at the earlier analysis, then 0.5 is added to the earlier T-number and CSC increases along with their T-number.

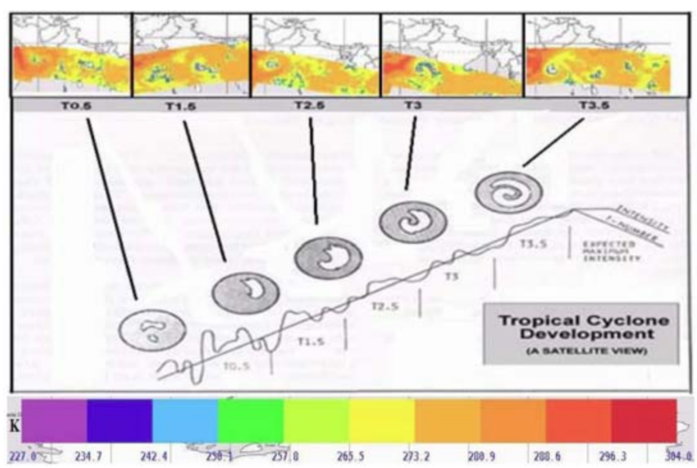


Figure 4. Ashobaa cyclone development.

Figure 5 shows the progressive development of Ashobaa cyclone (7 June to 12 June 2015) eye pattern method of Dvorak technique for the lead time of 24 hours observation based on cyclonic rotation of cloud area. A CSC is noticed with respect to time variation from Day 1 to Day 7 as the curvature and length of cloud bands rotation area increased. The mean error (variation/ difference) between actual observations and estimation of wind speed (MSSLP) reported by IMD is shown in Table 3. Estimated latitude and longitude positional error of Ashobaa cyclone IMD is as seen in Table 4. Further, the graphical representation of variation between observed and estimated wind speed is as shown in Figure 6.

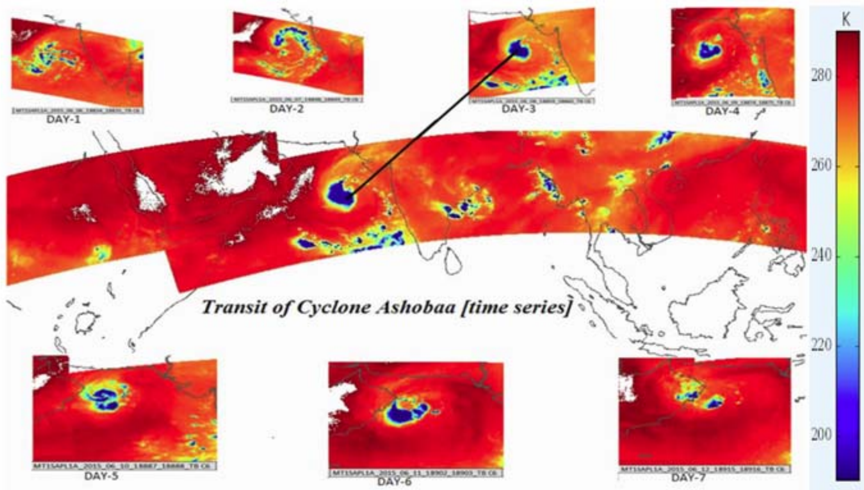


Figure 5. Development and movement of Ashobaa cyclone over Arabian Sea from Day 1 to Day 7 where Day 3 is shown in enlarged image (source ICARE France SAPHIR data).

Figure 6. Error in wind speed (kmph) of Ashobaa cyclone tracking.

Table 3. Comparison of observed and estimated parameters for Ashobaa cyclone tracking

Estimated ref-issued	Date	Time (UTC)	Estimated surface wind speed (kmph)	Category	Observed ref-issued	Observed surface wind speed (kmph)	Category
03:00 UTC 08 06 2015	08 06 2015	06:00	50-60 Gust: 70	DD	0900 UTC 08 06 2015	60-70 Gust: 80	CS
09:00 UTC 08 06 2015	09 06 2015	12:00	90-100 Gust: 120	CS	15 00 UTC 09 06 2015	80-90 Gust: 100	CS
21 00 UTC 09 06 2015	10 06 2015	12.00	95-105 Gust: 120	SCS	15 00 UTC 10 06 2015	80-90 Gust: 100	CS
1500 UTC 10 06 2015	11 06 2015	12.00	65-75 Gust: 85	CS	15 00 UTC 11 06 2015	60-70 Gust: 80	CS
0600 UTC 11 06 2015	12 06 2015	12.00	25-35 Gust: 45	L	0300 UTC 12 06 2016	35-45 Gust: 55	D

D-depression; DD-deep depression; CS-cyclone storm; SCS-severe cyclone storm; L-low pressure

Table 4. Estimated positional error (latitude and longitude) of Ashobaa cyclone

Date	Estimated latitude	Estimated longitude	Observed latitude	Observed longitude	Latitude error	Longitude error
08 06 2015	18.2	67.1	18.6	66.5	–0.4	0.6
09 06 2015	19.7	66	21	63	–1.3	3
09 06 2015	21.1	63.8	21.2	62.5	–0.1	1.3
10 06 2015	21.4	62.2	21.3	62.1	0.1	0.1
10 06 2015	21.4	62.1	21.3	62.1	0.1	0
11 06 2015	20.7	60.5	20.8	60.5	–0.1	0
11 06 2015	22.2	60	20.8	60	1.4	0
11 06 2015	20.8	59.6	20.8	59.7	0	–0.1
12 06 2015	20.8	58.9	20.8	59.5	0	–0.6
12 06 2015	20.8	59.1	20.8	59.5	0	–0.4

On 8 June 2015 at different time intervals, cyclone eye center intensity has been calculated using brightness temperature measurement and same shown in Figures 7(a) to 7(e) of Ashobaa cyclone. Estimated positional tracking of Ashobaa cyclone (latitude and longitude) variation from IMD is compared with SAPHIR observed data shown in Table 4 from 8 June 2015 to 12 June 2015.

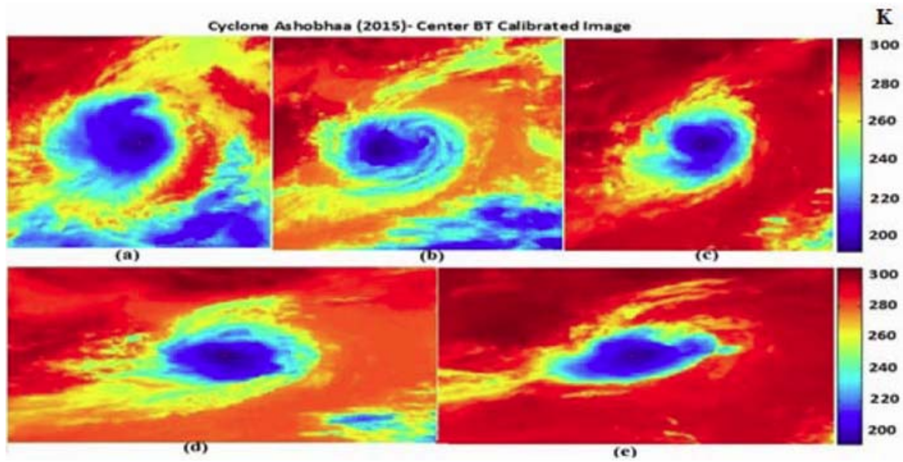


Figure 7. Ashobaa cyclone eye center detected from BT measurement made by SAPHIR sounder, on same day at lead time: (a) 1:40 to 3:33 pm; (b) 3:28 to 5:22 pm; (c) 5:17 to 7:12 pm; (d) 7:17 to 9:02 pm and (e) 11:37 pm to 1:31 am.

A verification of the forecast TC positions, maximum sustained surface wind speed (MSSWS) and gust made by the IMD (using NWP models) with the observed positions reported by the Regional Specialized Meteorological Centre (RSMC) New Delhi has been carried out. Verification of forecast and observed positions of TC Ashobaa is performed by using 121 samples for the lead times 12 hr, 15 hr, 18 hr, 21 hr, 24 hr, 33 hr, 36 hr, 45 hr and 48 hr, which includes verification of increase and decrease between average track forecast and observed positions.

The average mean error detected after verification is summarized as: (i) 0.75°N - 1.16°E average forecast errors in TC positions, (ii) 4.59 knots average forecast error of MSSWS during cyclone period and (iii) average forecast error of 4.81 knots gust during cyclone period. We have made statistical representation of positional error detection of Ashobaa cyclone from 7 to 12 June 2015 as well as mean error in Table 5 of mean track forecast error corresponding to lead times 12 hr, 15 hr, 18 hr, 21 hr, 24 hr, 33 hr, 36 hr, 45 hr and 48 hr, respectively, and the abstract of the same is given as follows.

Table 5. Mean track forecast error corresponding to lead time

Lead time UTC	Verified samples	Lat. (degree-north)			Long. (degree-east)			MSSWS (knots)			GUST (knots)		
		Inc.	Dec.	Avg.	Inc.	Dec.	Avg.	Inc.	Dec.	Avg.	Inc.	Dec.	Avg.
12 hr - 48 hr	121	0.41	0.99	0.75	1.05	1.17	1.16	1.77	7.05	4.59	2.78	8.95	4.81

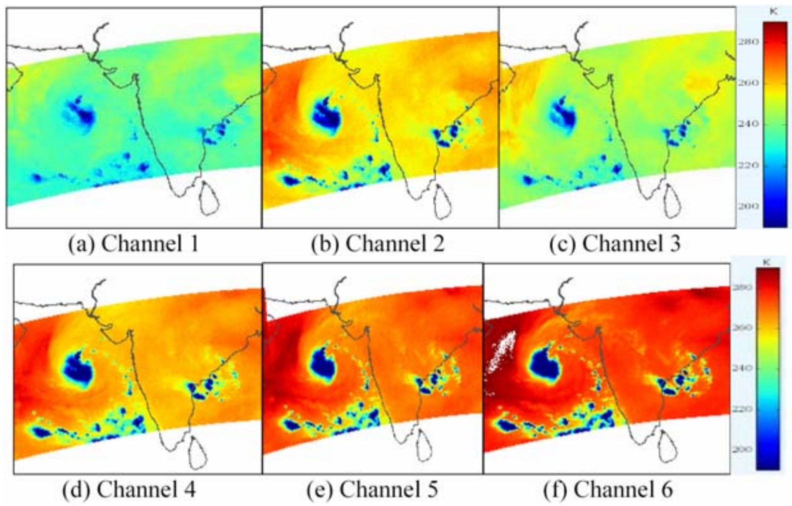


Figure 8. (a) to (f) Show the Ashobaa cyclone eye region observed from SAPHIR all channels on 8 June 2015.

Figures 8(a) to 8(f) show the comparison of Ashobaa cyclone eye occurred on 8 June 2015 of all the six channels of SAPHIR sensor. It is observed that channel 6 of SAPHIR sounder is more clear contrast near real-time image (weighting function is near to surface) in showing the cloud formation area and cloud cyclonic region compared to other channels.

6. Conclusion

This paper shows the results of a study that demonstrate the capabilities of the SAPHIR humidity sounder on board Megha-Tropiques satellite in qualitatively determining the humidity variations at various altitudes. Considering its frequent temporal observations, it can be applied for near real-time applications such as in weather forecasting and cyclone track monitoring.

A comparison of brightness temperature profile of selected images of SAPHIR obtained from all six channels shows: (i) the images of SAPHIR are also capable of providing information relating to TC genesis and development and (ii) since SAPHIR has relatively higher spatial resolution, it is observed that it has more clear contrast near real-time image.

Our study also proves that Dvorak's technique of interpretation of satellite observation is still useful for determining the TC storm intensity. From the comparison of brightness temperature profiles of all six channels of SAPHIR, it is found that channel six is found to be the best one suitable for detection of TC and its intensity variations.

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