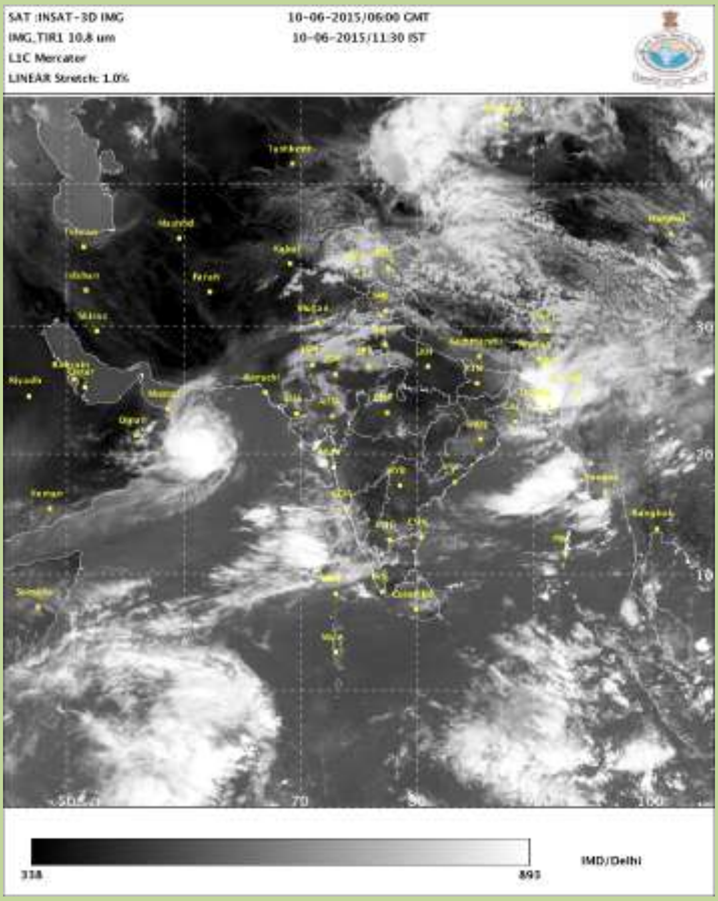
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
EARTH SYSTEM SCIENCE ORGANISATION
INDIA METEOROLOGICAL DEPARTMENT

Cyclonic Storm, ASHOBAA over the Arabian Sea (07-12 June 2015): A Report



Satellite imagery CS ASHOBAA

Cyclone Warning Division

India Meteorological Department

New Delhi

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Cyclonic Storm (CS) ASHOBAA over the Arabian Sea (07-12 June 2015)

1. Introduction

The Cyclonic Storm 'ASHOBAA' (07-12 June 2015) developed over eastcentral Arabian Sea from monsoon onset votex in the morning of 5th June 2015. It gradually moved northwards and concentrated into a low pressure area over southeast and adjoining eastcentral Arabian Sea in the morning of 6th June. It concentrated into a Depression (D) in the morning of the 7th June over eastcentral Arabian Sea. Moving nearly north-northwestwards and it intensified into a Deep Depression (DD) in the early hours of 8th June over eastcentral Arabian Sea. It further intensified into the Cyclonic Storm (CS) 'ASHOBAA' in the morning of of 8th June. It gradually intensified till the night of 10th June. Thereafter, while moving west-southwestwards from forenoon of 10th June to morning of 11th June, it encountered high vertical wind shear and low ocean thermal energy and started weakening. It slowly moved westwards over a colder oceanic region and weakened into a deep depression in the night of 11th June. Due to adverse environmental conditions, interaction with land surface and dry air intrusion from western side, it further weakened into a depression in the morning of 12th June and into a well marked low pressure area over northwest Arabian Sea and adjoining Oman coast in the evening of 12th June.

The salient features of this system are as follows.

i. CS 'ASHOBAA' developed over eastcentral Arabian Sea during the onset phase of monsoon.
ii. It had a unique track, as it moved initially northwards, then north-northwestwards and finally west-southwestwards towards Oman coast.
iii. It dissipated over northwest Arabian Sea off Oman coast before landfall.
iv. The numerical weather prediction (NWP) and dynamical statistical models provided reasonable guidance with respect to its genesis, track and intensity, though there was large divergence in model guidance with respect to track, intensity and landfall.

Brief life history, characteristic features and associated weather along with performance of numerical weather prediction models and operational forecast of IMD are presented and discussed in following sections.

2. Monitoring of CS ASHOBAA

The CS 'ASHOBAA' was monitored & predicted continuously since its inception by the IMD. The forecast of its genesis on 7th June, its track, intensity, point & time of landfall were predicted with sufficient lead time.

At the genesis stage, the system was monitored mainly with satellite observations, supported by meteorological buoys and coastal and island observations. Various national and international NWP models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

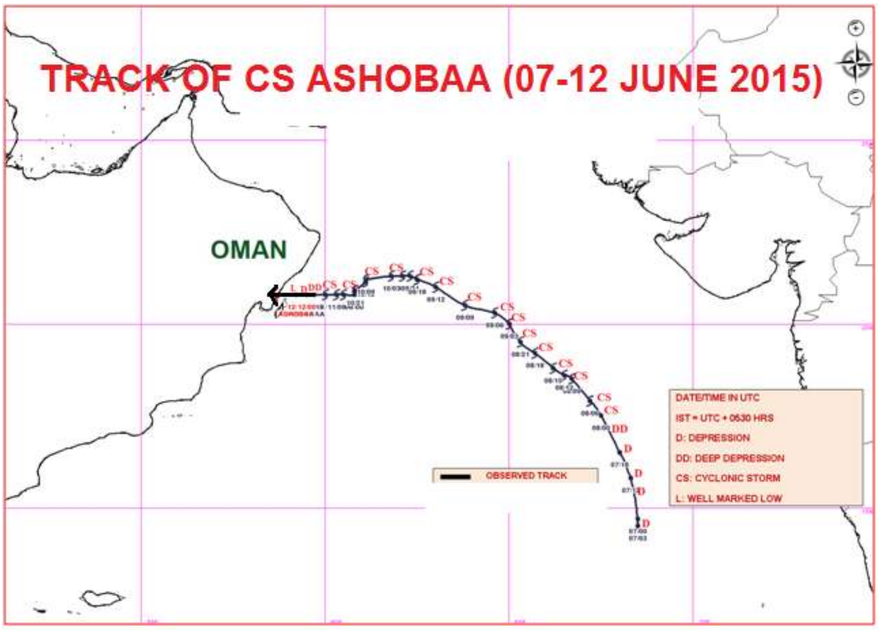

Fig.1 Observed track of CS ASHOBAA during 7th-12th June 2015

3. Brief life history

3.1. Genesis

The CS 'ASHOBAA' (07-12 June 2015) developed over eastcentral Arabian Sea from monsoon onset vortex. In association with the southwest monsoon onset over Kerala, a cyclonic circulation in lower levels developed over southeast Arabian Sea on 5th June. It gradually moved northwards and concentrated into a low pressure area over southeast and adjoining eastcentral Arabian Sea on 6th morning. As per satellite imagery, broken low and medium clouds with embedded intense to very intense convection lay over Arabian Sea between latitude 9.0˚N & 19.0˚N and longitude 61.0˚E & 74.0˚E in association with the system. The convective clouds remained fragmented in the embedded broad scale cyclonic circulation. The lowest cloud top tempereature was -70˚C. The buoy and Ascat observations suggested the associated maximum sustained surface winds of about 10-20 kts. Estimated central pressure was about 1005 hPa. The sea surface temperature was 29-30˚C, ocean thermal energy was about 80-100 KJ/cm^2, low level convergence was (10-15)x10^{-5} s^{-1}, upper level divergence was about (10-20)x10^{-5} s^{-1}, the low level relative vorticity was about (5-10)x10^{-5} s^{-1}, vertcal wind shear was low to moderate(10-20 knots). Upper tropospheric ridge lay along 20˚N and middle tropospheric ridge was near about 16˚N. There was trough in westerlies in middle troposphere to the west of the system. Under these conditions, the low pressure area moved slowly northwards/north-northwestwards and concentrated into a depression over eastcentral Arabian Sea and lay centred at 0300 UTC of 7th June near 14.5^{0}N/68.5^{0}E about 700 km southwest of Mumbai. The intensity of the system as per the Dvorak's technique was T1.5. Intense to very intense convection lay over the area between 6.0^{0}N & 19.5^{0}N and longitude 63.0^{0}E & 74.0^{0}E. Lowest CTT was -70^{0}C.

3.2. Intensification and Movement

On 7th June, as the depression lay over eastcentral Arabian Sea, it experienced the ocean thermal energy of about 100-120 KJ/cm^2 with SST of 30-32^{0}C. Compared to previous day, the low level convergence, upper level divergence and low level relative vorticity increased and were about 15-20x $10^{-5}s^{-1}$, 20-30 x $10^{-5}s^{-1}$ and 10-20 x $10^{-5}s^{-1}$ respectively. The vertical wind shear was moderate (10-20 kts). The Madden Julian lay over Phase-2 with amplitude>1. All these environmental and large scale features were favourable for the intensification of the system. The upper tropospheric ridge at 200 hPa level ran along 20^{0}N. However, there was a trough in westerlies in the middle troposphere to the west of the system. As a result, though the system was far south of upper tropospheric ridge (5.5^0), its westward component was restricted and the system moved nearly north-northwestwards and intensified into a deep depression at 0000 UTC of 8th June over eastcentral Arabian Sea near 17.5^{0}N/67.5^{0}E about 600 km west-southwest of Mumbai. It further intensified into the cyclonic storm (CS) 'ASHOBAA' at 0300 UTC of 8th June near 17.9^{0}N/67.2^{0}E. As per Dvorak's technique, the intensity was T2.5 and maximum sustained wind (MSW) was 35 Kts. It continued to move north-northwestwards till 0900 UTC of 8th June and then moved northwestwards till 0600 UTC of 9th June. Thereafter, it moved west-northwestwards till 0600 UTC of 10th June and then west-southwestwards till 0000 UTC of 11th June. Finally, it moved westwards on 11th and 12th June. The maximum intensity of T3.0 (45Kts) was maintained till 2100 UTC of 10th June. From the night of 10th June, the lower level convergence, divergence and relative vorticity decreased slightly. The vertical wind shear was moderate near the system centre and was high to the south. As the system moved west-southwestwards from 0600 UTC of 10th June to 0000 UTC of 11th June, it encountered the high vertical wind shear. Further, the ocean thermal energy was less than 50 KJ/cm^2 near the system centre. As a result the intensity of CS'ASHOBAA' decreased from T3.0 (45Kts) at 2100 UTC of 10th June to T2.5 (35Kts) at 0600 UTC of 11th June. On 11th June, as the system moved very slowly westwards over a colder oceanic region, alongwith the adverse environmental conditions like moderate to high vertical wind shear, interaction with land surface and dry air intrusion from western side, it further weakened into a deep depression at 1800 UTC of 11th June near 20.8^{0}N/59.7^{0}E. It further weakened into a depression at 0000UTC of 12th June near 20.8^{0}N/59.5^{0}E and into a well marked low pressure area over northwest Arabian Sea and adjoining Oman coast at 1200 UTC of 12th June. The system moved west-northwestwards on 9th June as the trough in the middle latitude westerlies moved away eastwards. During 10th to 12th June, the upper tropospheric ridge at 200 hPa level ran along 22-24^0 N with an anticyclone located to the northeast of the system centre and another to the northwest. While the anticyclonic circulation in the northeast influenced the system to move northwestwards, the anticyclonic circulation in the northwest tried to restrict movement towards north and rather pushed the system towards southwest. As a result, the system moved slowly westwards during 10-12th June. The observed track of the system is shown in Fig.1. The best track parameters of the systems are presented in Table 1.

Table 1: Best track positions and other parameters of the Cyclonic Storm, 'ASHOBAA' over the Arabian Sea during 07-12 June, 2015

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
07/06/2015	0300	14.5/68.5	1.5	1004	25	3	D
	0600	15.0/68.2	1.5	1004	25	3	D
	1200	16.0/68.0	1.5	1003	25	4	D
	1800	16.5/68.0	1.5	1003	25	4	D
08/06/2015	0000	17.5/67.5	2.0	996	30	5	DD
	0300	17.9/67.2	2.5	994	35	7	CS
	0600	17.9/67.2	2.5	994	35	7	CS
	0900	18.5/66.7	2.5	994	35	7	CS
	1200	18.6/66.5	2.5	994	35	7	CS
	1500	18.8/66.2	2.5	994	35	7	CS
	1800	19.2/65.7	2.5	994	35	7	CS
	2100	19.5/65.3	2.5	994	35	7	CS
09/06/2015	0000	20.0/65.0	2.5	992	35	8	CS
	0300	20.0/65.0	2.5	992	35	8	CS
	0600	20.3/64.6	2.5	990	35	10	CS
	0900	20.5/63.8	3.0	990	40	10	CS
	1200	21.0/63.0	3.0	990	40	10	CS
	1500	21.2/62.5	3.0	990	40	10	CS
	1800	21.2/62.5	3.0	990	45	10	CS
	2100	21.3/62.3	3.0	990	45	10	CS
10/06/2015	0000	21.3/62.1	3.0	990	45	10	CS
	0300	21.3/61.8	3.0	990	45	10	CS
	0600	21.3/61.5	3.0	990	45	10	CS
	0900	21.2/61.1	3.0	990	45	10	CS
	1200	21.2/61.1	3.0	990	45	10	CS
	1500	20.9/60.8	3.0	990	45	10	CS
	1800	20.9/60.8	3.0	992	45	10	CS
	2100	20.9/60.8	3.0	992	45	10	CS
11/06/2015	0000	20.8/60.8	2.5	994	40	10	CS
	0300	20.8/60.8	2.5	994	40	10	CS
	0600	20.8/60.5	2.5	994	35	10	CS
	0900	20.8/60.3	2.5	994	35	10	CS
	1200	20.8/60.0	2.5	994	35	10	CS
	1500	20.8/59.7	2.5	994	35	10	CS
	1800	20.8/59.7	2.0	996	30	6	DD
12/06/2015	0000	20.8/59.5	1.5	996	25	4	D
	0300	20.8/59.5	1.5	996	25	4	D
	0600	20.8/59.5	1.5	996	25	4	D
	1200	Well marked low pressure area over northwest Arabian Sea and adjoining Oman coast					

4. Features observed through satellite

Satellite monitoring of the cyclone was mainly done by using half hourly Kalpana-1, INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries of CS ASHOBAA representing to the life cycle of the cyclone are shown in Fig. 2.

Intensity estimation using Dvorak's technique suggested that the system attained an intensity of T 1.5 on 07th June 2015 / 0300 UTC. Associated broken low and medium clouds embedded with intense to very intense convection was seen over the area between 6.0^0 N & 19.5^0 N latitudes and 63.0^0 E & 74.0^0 E longitudes and Lakshadweep. The lowest CTT was about -70^0C. At 1200 UTC of 7th, the system intensity was T1.5 and associated broken low and medium clouds embedded with intense to very intense convection was seen over the area between latitude 6.0^0 N & 21.5^0 N, longitude 60.0^0 E & 74.0^0 E, coastal Karnataka, extreme north Kerala and Lakshadweep. The lowest CTT was about -90^0 C. At 0000 UTC of 8th, the system attained intensity of T2.0 corresponding to deep depression and at 0300 UTC of 08th, the intensity was T 2.5 corresponding to cyclonic storm. Intense to very intense convection was seen over $13\text{-}21^0$N and $61\text{-}69^0$E. The lowest CTT was about -93^0 C. On 9th / 0900 UTC, the system intensified to T 3.0. It showed curved band pattern and covered 0.6 of 10 degree log spiral. Intense to very intense convection was seen over $17.0\text{-}22.0^0$ N and to the west of 66.0^0 E. The system continued to show curved band pattern until 10th /0000 UTC and the lowest CTT was about -92^0 C. At 1200 UTC of 10th, the system maintained the intensity of T 3.0 and convection showed central dense overcast pattern. However, a slight decrease in the compactness of the system was observed.At 1800 UTC of 10th, convection showed signs of disorganisation and the lowest CTT was -73^0 C. On 11th / 0000 UTC, the intensity of the system decreased to T 2.5. Convection was disorganised and the major convective clouds were observed in the southern sector. Areas of intense convection were over $18.5\text{-}22^0$ N and to the west of 62.5^0 E. At 0600 UTC of 11th, the major convective clouds observed in the southern sector was elongated from northeast to southwest direction. At 1800 UTC of 11th, the intensity of the system further decreased to T 2.0. Areas of intense to very intense convection were between $18\text{-}24^0$ N and to the west of 62.5^0 E and Oman. The lowest CTT was -64^0 C. On 12th / 0000 UTC, the intensity of the system became T 1.5. Convection was disorganised with convective clouds sheared to the southwest of the system centre. Moderate to intense convection was seen over $18\text{-}23.5^0$ N and the west of 61.5^0 E and Oman. Enhanced IR imageries depicting the growth of the system to T 1.5, T 2.0, T 2.5, T 3.0 and its weakening to T 2.5, T 2.0 and T 1.5 are presented in Fig.3. The system further weakened with intensity becoming T1.0 at 1200 UTC of 12th June 2015 corresponding to a well marked low pressure area. It moved over Oman on 13th June as a low level cyclonic circulation.

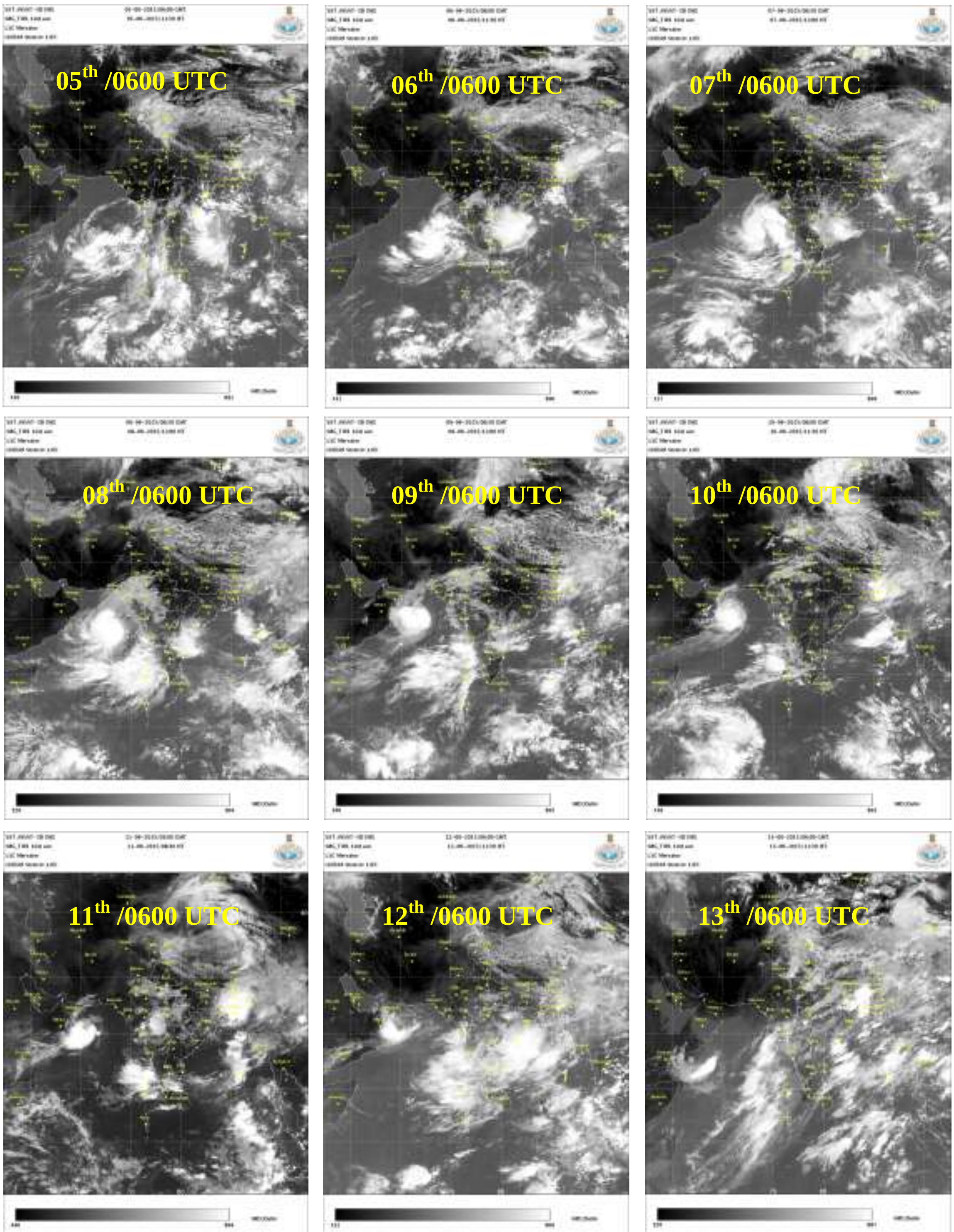

Fig.2. INSAT-3D IR imageries based on 0600 UTC of 05-13 June 2015

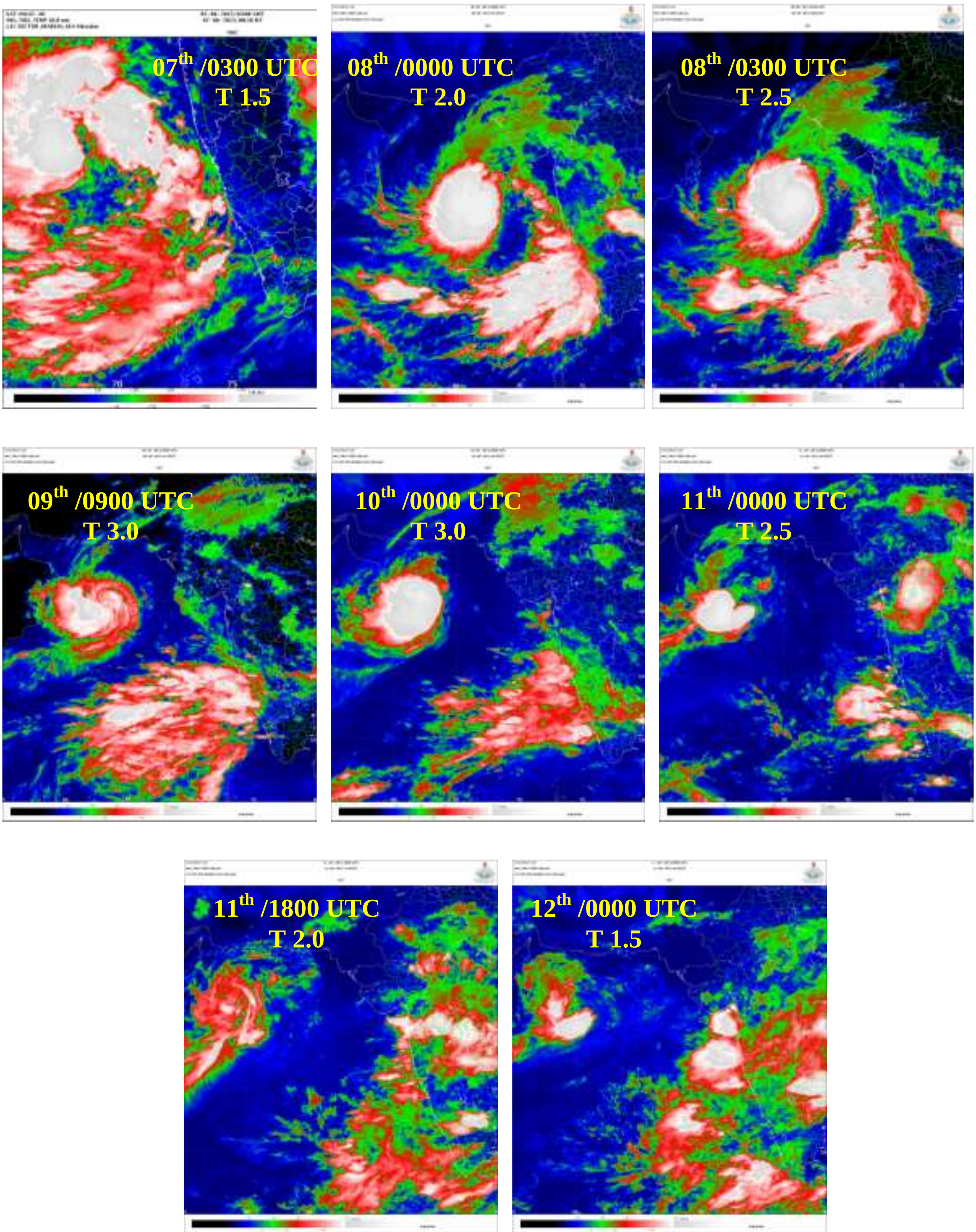

Fig.3 INSAT-3D IR imageries based on 07/0300, 08/0000, 08/0300, 09/0900, 10/0000, 11/0000, 11/1800 and 12/0000 UTC of June 2015

5. Bulletins issued by IMD

5.1 Bulletins issued by Cyclone Warning Division, New Delhi

IMD continuously monitored, predicted and issued bulletins containing track & intensity forecast at +06, +12, +18, +24, +36, +48, +60, +72, +84, +96, +108 and +120 hrs or till the system weakened into a low pressure area. The above structured track and intensity forecasts were issued from the stage of deep depression onwards. The cone of uncertainty in the track forecast was also given for all cyclones. The radius of maximum wind and radius of≥28 knots, ≥34 knots, ≥50 knots and ≥64 knots wind in four quadrants of cyclone was also issued for every six hours. The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The storm surge forecast was given based on IIT, Delhi model. The prognostics and diagnostics of the systems were described in the RSMC bulletins and tropical cyclone advisory bulletins. The TCAC bulletin was also sent to Asian Disaster Risk Reduction (ADRR) centre of WMO at Honkong like previous years. Tropical cyclone vitals were prepared every six hourly from deep depression stage onwards to various NWP modeling groups in India for bogusing purpose. Bulletins issued by Cyclone Warning services of IMD in association with CS ASHOBAA are given in Table 2

Table-2: Bulletins issued by Cyclone Warning Division, New Delhi

Bulletins issued by Cyclone Warning Division, New Delhi in association with Cyclonic Storm "ASHOBAA" during the period 07-12 June 2015			
SN	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	21	1. IMD's website 2. FAX to Control Room NDM, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Dir. Indian Railways, Indian Navy, IAF 3. Email's to a. Modelling Groups- IIT-DLH & BBN, NCMRWF, INCOIS.
2	RSMC Bulletin	38	1. IMD's website 2. All WMO/ESCAP member countries through GTS and E-mail. 3. Indian Navy, IAF, by E-mail
3	Press Release	02	1. Put up on IMD's website 2. Emails to : a. Senior Officers of NDMA, NDM, NDRF, MoHA, b. Senior Officers of MoES, IMD c. Modelling Groups- IIT-DLH & BBN, NCMRWF, INCOIS.
4	DGM's Bulletin for	04	FAX and E-mail to

	High Government Officials		Cabinet Secretary, Principal Secretary to PM, P.S. to Hon'ble Minister for S &T and MoES, Secretary- Ministry of Home Affairs, Ministry of Defence, Ministry of Agriculture, Ministry of I & B, MoES, DST, Ministry of Shipping & Surface Transport, Director General, Shipping, Central Relief Commissioner, Ministry of Home Affairs Control Room, NDM, Ministry of Home Affairs, Director Of Punctuality, Indian Railways, Director Central Water Commission, Director General, Doordarshan, AIR,
5	No. of Press Conferences		Nil
6	Personal Briefings At National level		MHA, NDMA for Disaster Management, Press, Electronic Media & Public.
7	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	15	1. IMD's website 2. Meteorological Watch Office for International Civil Aviation
8	ADRR Bulletin to Hong Kong website	15	(Through ftp) to ADRR HongKong
9	TC vitals For creation of synthetic vortex in NWP Models	22	(Through ftp) To: modelling group-NCMRWF, IIT, INCOIS, IMD NWP (Through E-mail).To: NCMRWF, IIT, INCOIS, IMD NWP
10	Quadrant Wind – radii forecast	15	E-mail to modelling group- NCMRWF, IIT, INCOIS, IMD NWP.
11	SMS to Senior Govt. Officials	192	1. IMD Group. A officers 2. Disaster Management Officers, at National level.

6. Performance of operational NWP models

6.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for cyclone ASHOBAA

a. Grid point analysis and forecast of GPP

Grid point analysis and forecast of GPP is used to identify potential zone of cyclogenesis. Figure 4(a-f) below shows the predicted zone of formation of cyclogenesis. It could predict the genesis well in advance (144 hours ahead of its formation).

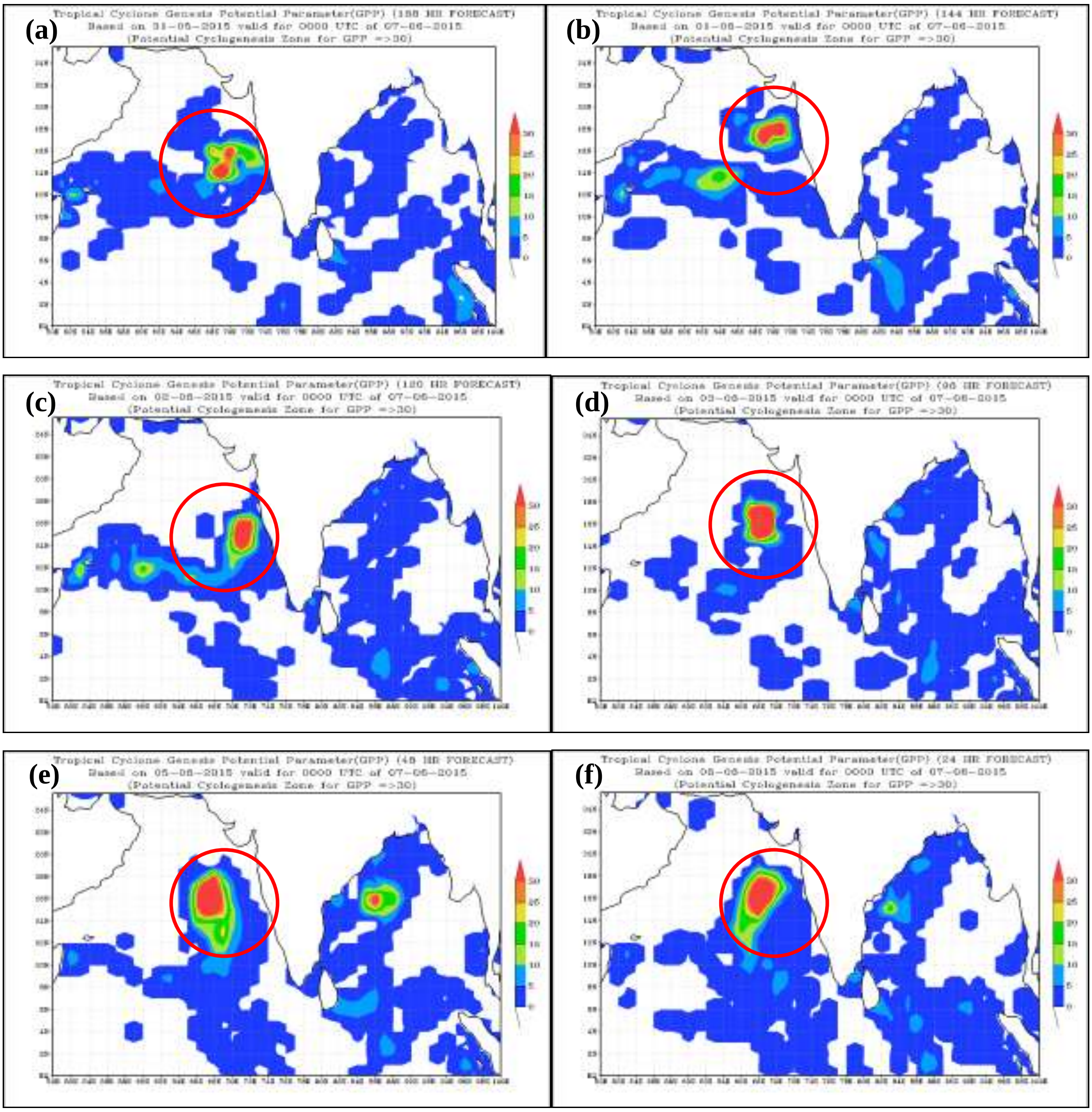

Fig.4(a-f) Predicted zone of cyclogenesis valid for 07th June 2015 /0000 UTC based on (a) 31st May / 0000 UTC, (b) 01st Jun / 0000 UTC, (c) 02nd / 0000 UTC, (d) 03rd / 0000 UTC (d) 04th / 0000 UTC (e) 05th / 0000 UTC and (f) 06th / 0000 UTC initial conditions

b. Area average analysis of GPP

Analysis and forecasts of GPP (Fig.5(a-c)) shows that GPP ≥ 8.0 (threshold value for intensification into cyclone, T3.0) indicated its potentential to intensify into a cyclone at early stages of development (T.No. 1.0 to 1.5).

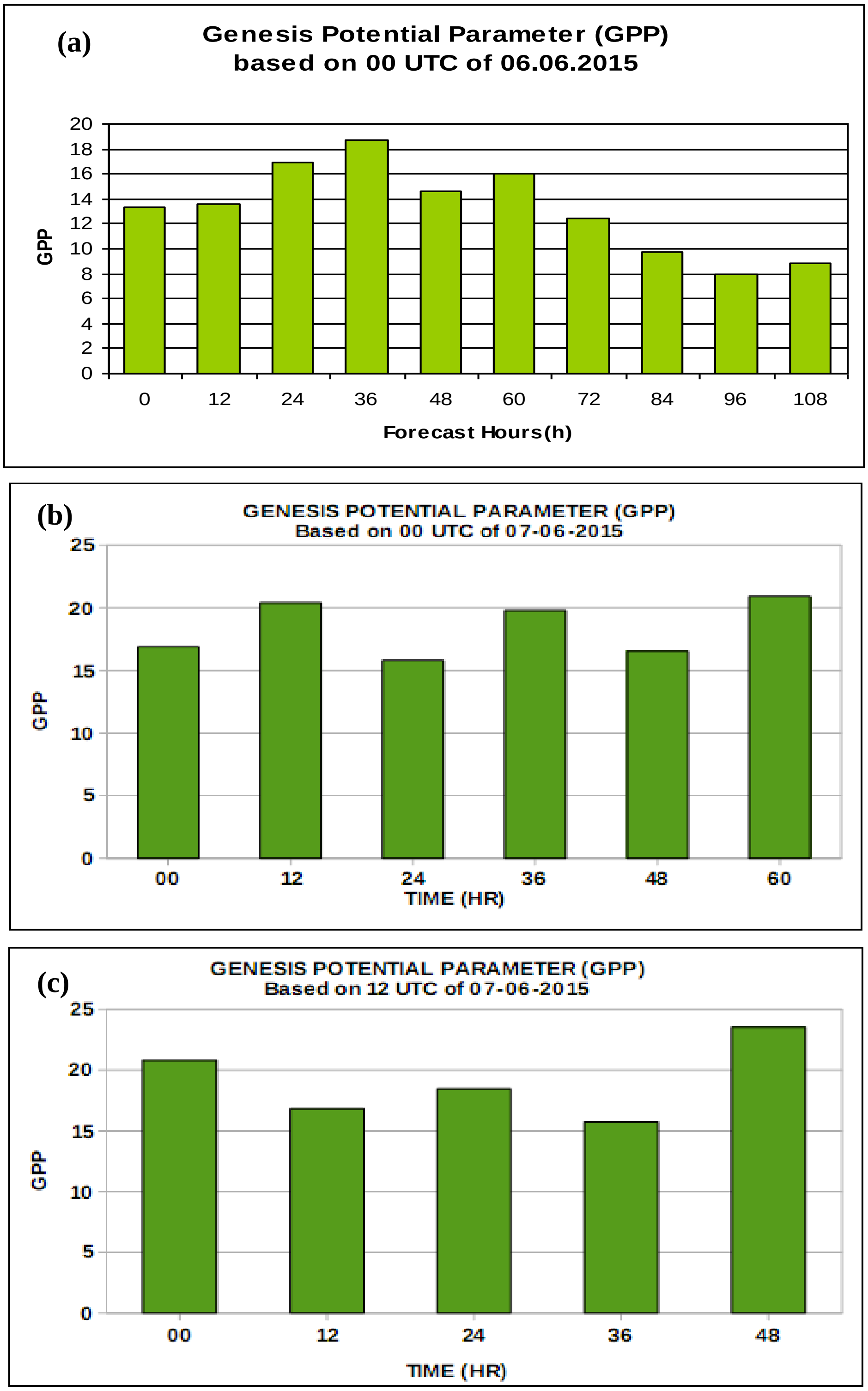

Fig. 5(a-c) Area average analysis of GPP based on (a) 06th/0000 UTC, (b) 06th/1200 UTC and (c) 07th/0000 UTC

6.2 Track prediction by NWP models

NWP guidance for track forecast was provided by IMD-HWRF, IMD-WRF, JMA, NCEP-GFS, UKMO, ECMWF and IMD'S Multi model ensemble (MME) technique and GFS, GEFS and Unified model products of NCMRWF. The IMD-MME guidance is presented in Fig.6(a-j).

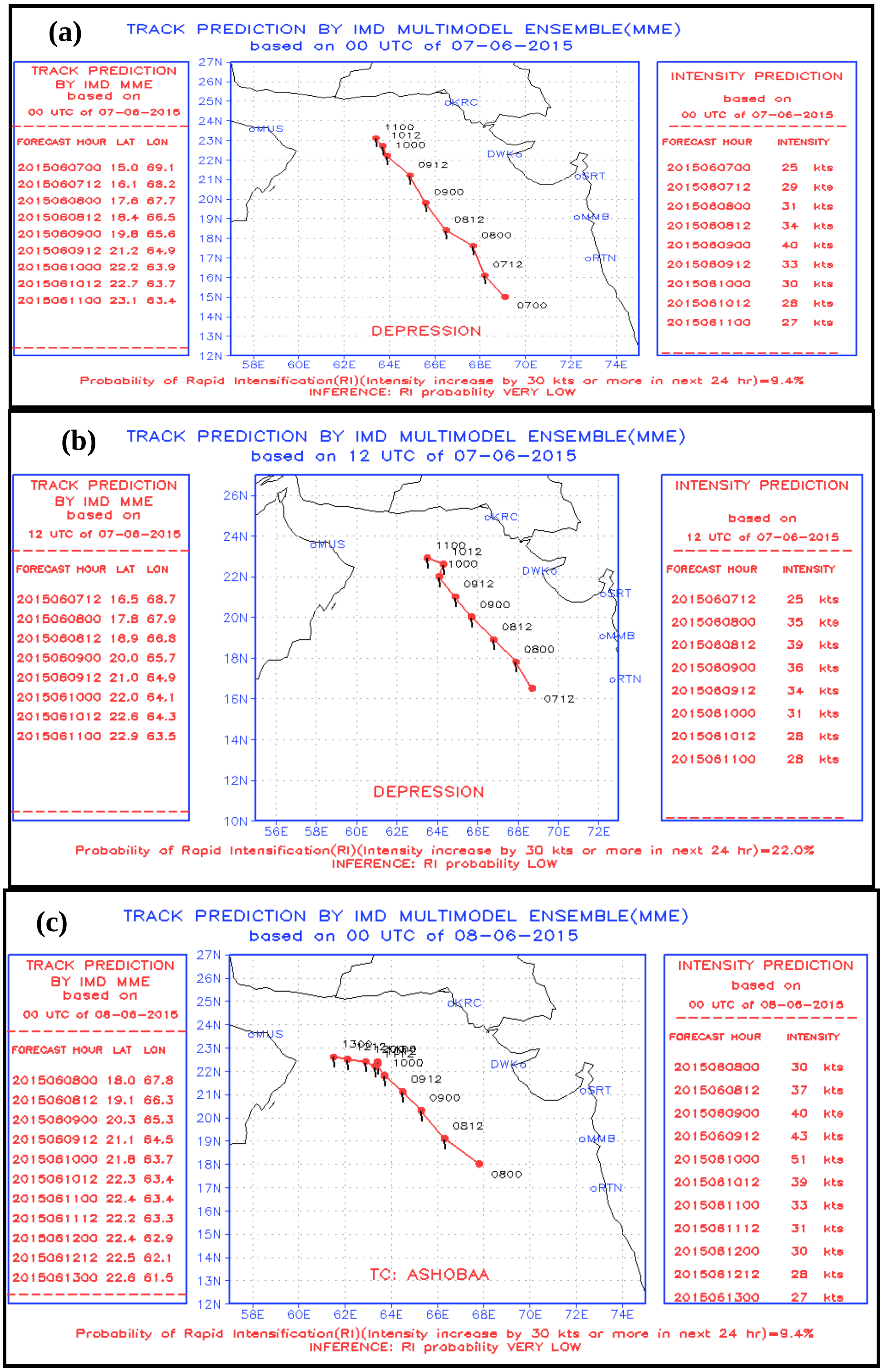

Fig. 6(a-c): Track prediction by MME and Intensity forecast by SCIP model based on (a) 07/0000 UTC, (b) 07/1200 UTC and (c) 08/0000 UTC

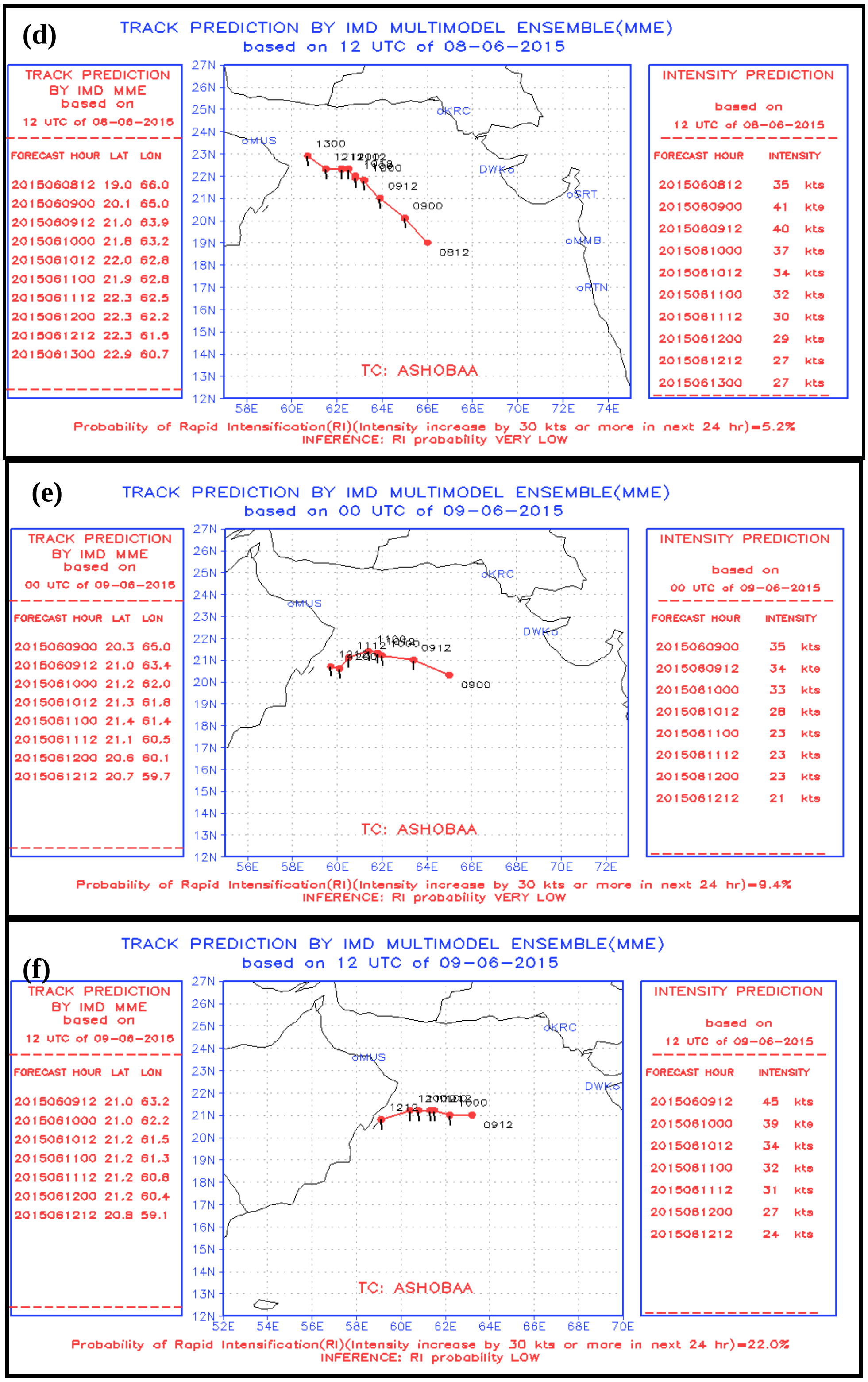

Fig. 6(d-f): Track prediction by MME and Intensity forecast by SCIP model based on (d) 08/1200 UTC, (e) 09/0000 UTC and (f) 09/1200 UTC

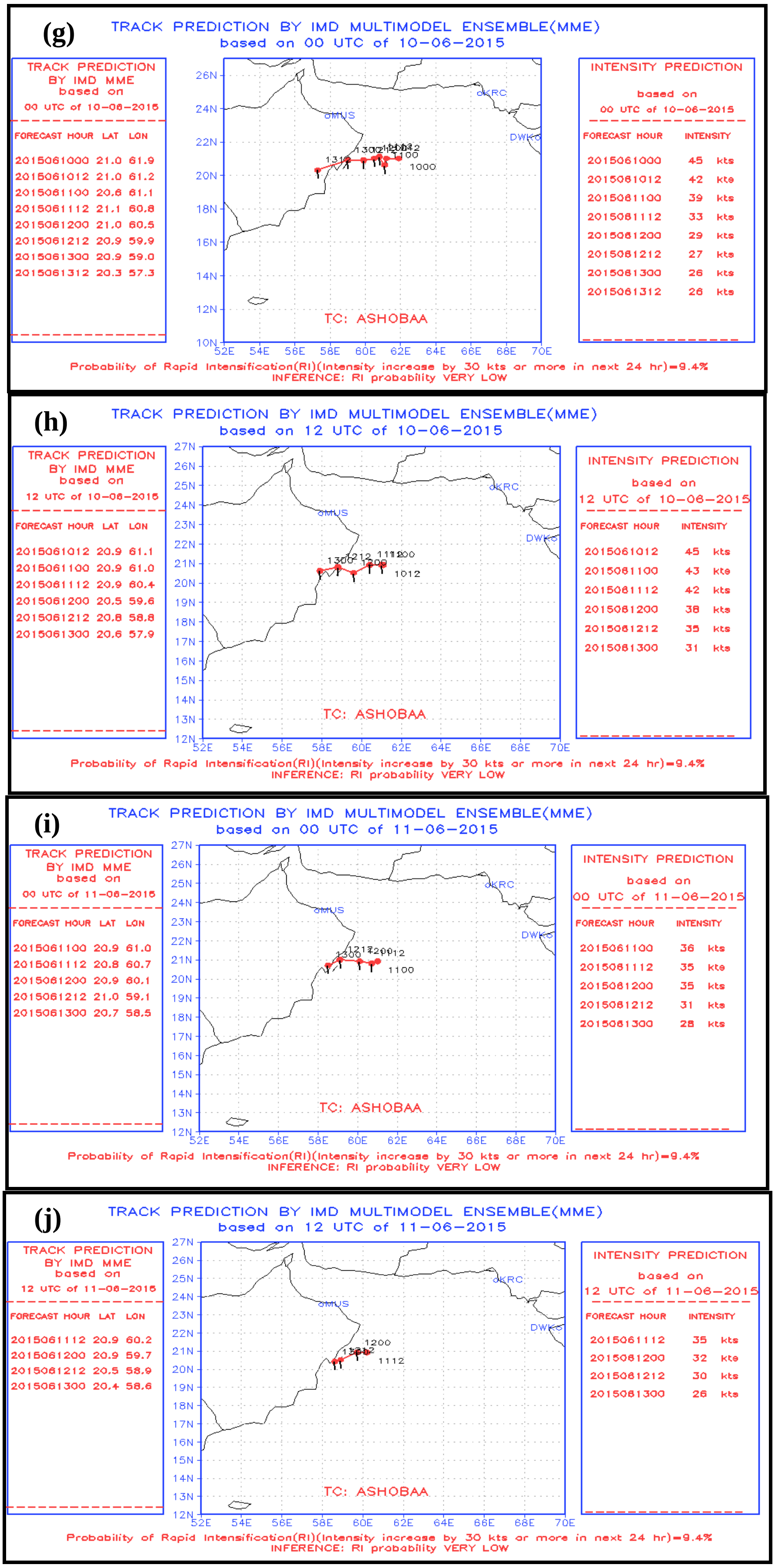

Fig. 6(g-j): Track prediction by MME and Intensity forecast by SCIP model based on (g) 10/0000 UTC, (h) 10/1200 UTC, (i) 11/0000 UTC and (j) 11/1200 UTC, Jun 2015

Track prediction by HWRF model based on 07th June 2015/0000 UTC, 07/1200 UTC, 09/0000 UTC, 09/1200 UTC, 10/0000 UTC, 10/1200 UTC and 11/0000 UTC are presented in Fig.7(a-g).

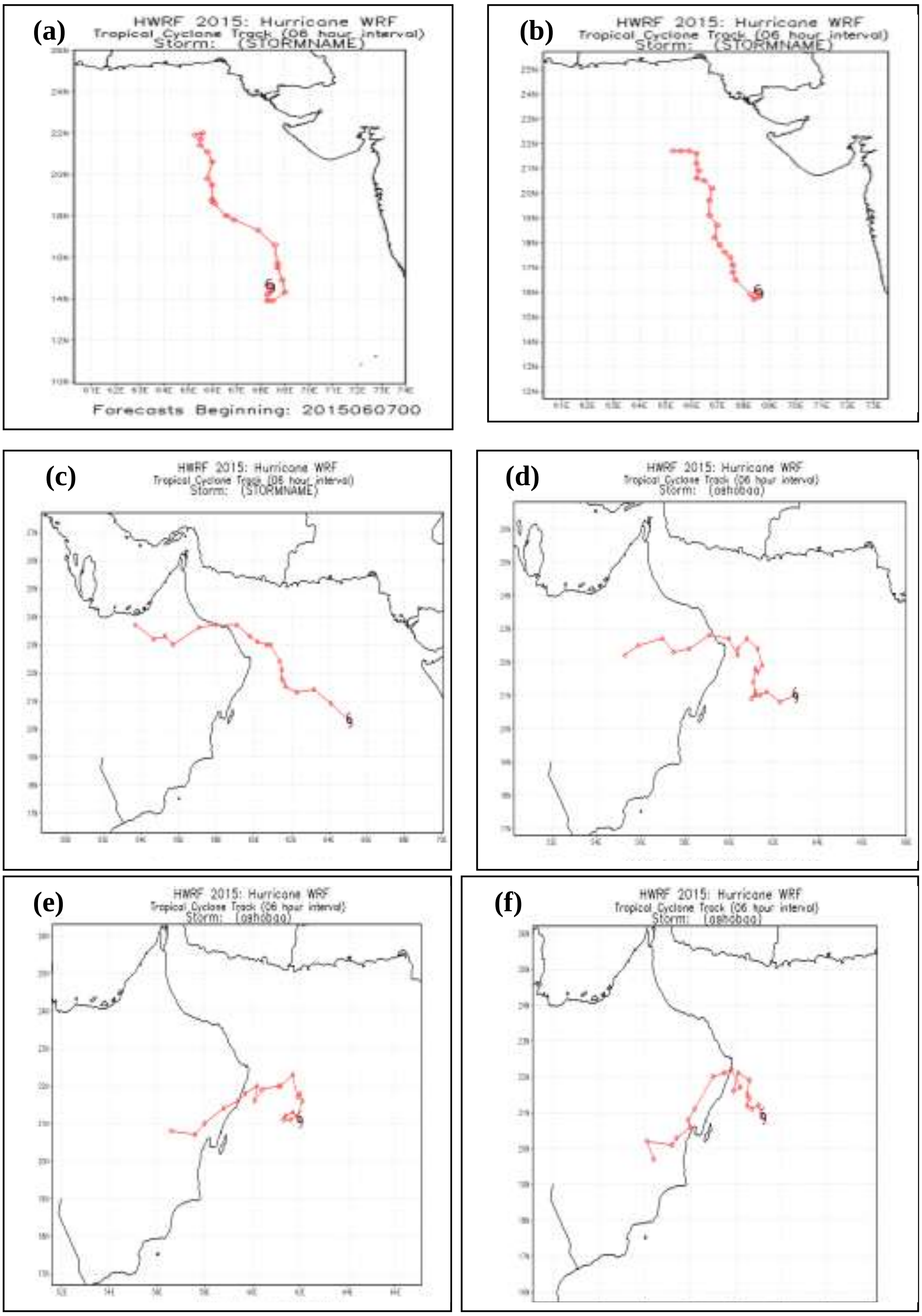

Fig.7(a-f) Track prediction by HWRF model based on 07/0000, 07/1200, 09/0000 and 09/1200 UTC, 10/0000 UTC and 10/1200 UTC of June 2015

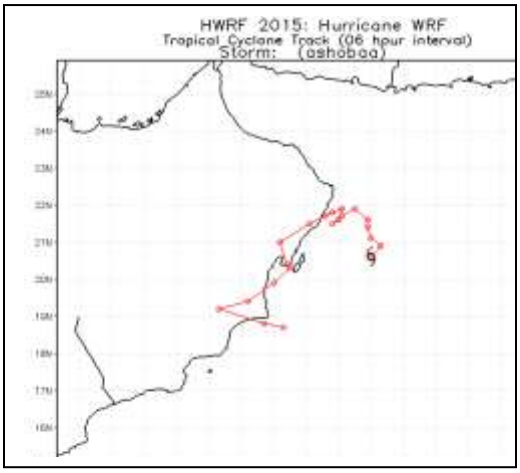

Fig.7g Track prediction by HWRF model based on 11/0000 UTC of June 2015

NCMRWF's observed and forecast tracks based on 10th June 2015/0000 UTC are presented in Fig.8

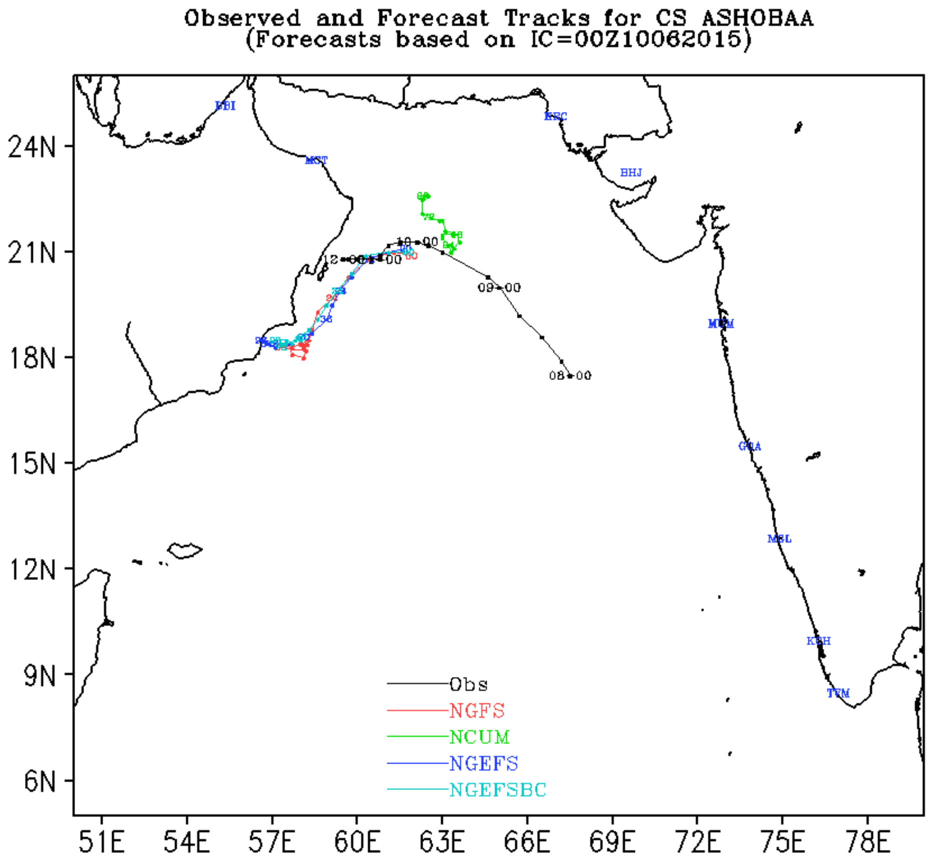

Fig.8 NCMRWF's NGFS, NCUM and NGEFS track forecasts based on 10th/0000 UTC of June 2015.

6.3 Accuracy of track forecasts by NWP models

Table 3 presents the average errors in track forecast of various models.

Table-3: Average track forecast errors (Direct Position Error) in km

Lead time	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr
IMD-WRF	125(10)	207(9)	268(8)	291(7)	290(6)	305(5)	-	-
JMA	55(10)	67(9)	92(8)	116(7)	132(6)	155(5)	171(4)	-
NCEP-GFS	40(10)	63(9)	72(8)	89(7)	150(6)	226(5)	231(4)	316(2)
UKMO	45(10)	61(9)	76(8)	127(7)	208(6)	308(5)	412(4)	408(2)
ECMWF	60(10)	80(9)	138(8)	215(7)	306(6)	393(5)	464(4)	530(2)
IMD-HWRF	100(7)	135(7)	217(6)	339(5)	408(4)	462(3)	569(2)	598(2)
IMD-MME	39(10)	52(9)	80(8)	132(7)	182(6)	254(5)	345(4)	382(2)
NCMRWF-NGFS		101(4)		251(3)		234(2)		316 (1)
NCMRWF-NCUM		241(4)		447(3)		679(2)		919(1)
NCMRWF-NGEFS		96(4)		269(3)		365(2)		349(1)

(Number of forecasts verified)

As seen, all models had large track forecast errors for lead times beyond 72 hours. For 72-hr lead time, all model forecasts had errors greater than 200 km except JMA which had an error of 155 km. IMD-MME forecasts had least errors in 12- and 24-hr lead times and NCEP-GFS performed better in 36- and 48-hr forecasts.

6.4 Intensity (kt) prediction by SCIP and HWRF Model

NWP guidance for intensity prediction was providecd by IMD's statistical-dynamical model (SCIP) and HWRF. The average absolute and root mean square errors in maximum surface wind speed predicted by the models are presented in Table 4 and Table 5 respectively.

Table-4: Average absolute errors of SCIP and HWRF model

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr
IMD-SCIP	5.2(10)	6.6(9)	5.9(8)	7.6(7)	8.2(6)	8.2(6)	8.0(4)	6.5(2)
IMD-HWRF	14.0(7)	11.9(7)	12.7(6)	12.4(5)	15.3(4)	15.0(3)	11.0(2)	1.5(2)

(Number of forecasts verified is given in the parentheses)

Table-5: Root Mean Square (RMSE) errors of SCIP and HWRF model

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr
IMD-SCIP	6.0(10)	7.4(9)	8.2(8)	8.3(7)	9.4(6)	10.5(6)	9.6(4)	6.6(2)
IMD-HWRF	15.0(7)	13.1(7)	14.2(6)	14.4(5)	17.8(4)	23.2(3)	13.6(2)	1.6(2)

(Number of forecasts verified is given in the parentheses)

7. Operational Forecast Performance

Following are the salient features of the bulletins issued by IMD.

(i) **6th June:** Forecast for intensification of low pressure area into well marked low by 8th June and probability of cyclogenesis LOW during next 48-72 hours over southeast and adjoining east-central Arabian Sea.

(ii) **7th June:** Depression formed in the morning of 7th June over east-central Arabian Sea and regular special bulletin commenced. Forecast was issued for further intensification into a deep depression within next 24 hours.

(iii) **8th June** (morning): Deep Depression formed in the morning of 8th June and forecast was issued for its intensification into CS during next 24 hours

(iv) **8th June** (forenoon): Cyclonic Storm, Ashobaa formed in the forenoon of 8th June over east-central Arabian Sea. Forecast was issued for its intensification into severe cyclonic storm during next 36 hours. The system intensified slightly from T2.5 to T3.0 in the evening of 9th June

(v) **9th June morning :** Forecast was issued at 0300 UTC that Ashobaa would cross OMAN coast as a cyclonic storm between Sur And Mina Sultan Qaboos (Muscat) around night of 11 June 2015.

(vi) **10th June evening:** Forecast was issued at 1200 UTC that Ashobaa would weaken over the sea and cross Oman coast as a depression on 11th evening.

(vii) **11th June forenoon:** The system weakened to intensity T2.5. Forecast was issued at 0000UTC of 11th that system would move west-southwestward and cross OMAN coast as a depression near lat. 20.5^0N around 0900 UTC of 12 June 2015.

(viii) **11th June night:** The system weakened into a deep depression and forecast was issued that the system would move nearly westwards and cross Oman coast as a depression near latitude 20.8^0N around 0900 UTC of 12 June 2015.

(ix) **12th June morning:** The system weakened into a depression and the forecast was issued that the system would cross Oman coast as a well marked low pressure area.

(x) **12th June evening:** The system weakened into a well marked low pressure area over northwest Arabian and adjoining Oman coast at 1200 UTC of 12th June.

7.1. Operational track forecast error and skill

The operational average track forecast errors and skills (compared to CLIPER forecasts) are shown in Table 6 and Table 7 respectively.The errors were higher than the long period average (LPA) for all forecast time scales except the 12 hr forecast. They were significantly higher than the LPA for 48 hr forecast and beyond. The track forecast skill has also been less than the long period average for all forecast time scales except the 12 hr forecast.

Table-6: Operational Track Forecast Error (km) of CS, ASHOBAA

Lead Period (hrs)	**Track forecast error (km)**	
	Official	**Long period average based on 2010-14**
12	61.6 (16)	61.8
24	120.8 (14)	106.8
36	127.6 (12)	132.4
48	225.1 (10)	164.6
60	246.8 (8)	188.9
72	296.1 (6)	230.1
84	347.8 (4)	185.6
96	375.9 (2)	219.0
108	-	259.1
120	-	276.4

( ) : Number of six hourly forecasts verified.
- : Forecast could not be verified as the life period of the cyclone from deep depression stage was limited to 96 hrs only.

Table-7: Operational Track Forecast Skill (%)

Lead Period (hrs)	Skill (%) with reference to climatology and persistence forecast	Long period Average skill (%) based on 2010-14
12	40.5	39.2
24	31.3	46.1
36	57.7	56.6
48	46.3	62.3
60	63.2	67.1
72	62.9	68.1
84	60.4	77.0
96	58.5	76.8
108	-	74.0
120	-	76.4

7.2. Operational Intensity forecast error and skill

The operational intensity forecast error in terms of absolute error (AE) and root mean square error (RMSE) are presented in Table 8 and the forecast skills compared to persistence forecasts are presented in Table 9.

Table-8: Operational Intensity forecast errors

Lead period (hrs)	Absolute Error (knots)	Root mean square (RMS) Error (knots	Long period Average (2010-2014):Absolute Error (knots)	Long period Average (2010-2014): RMS Error (knots)
12	3.5	5.1	7.2	10.1
24	6.0	7.6	11.1	14.6
36	6.8	7.8	14.3	18.5
48	8.0	8.7	15.8	20.3
60	7.4	9.6	16.2	19.5
72	7.6	9.6	17.7	21.9
84	10.4	11.0	18.2	22.8
96	5.4	7.2	18.3	21.3
108	-	-	16.5	17.6
120	-	-	13.9	15.0

Table-9: Operational Intensity Forecast skill (%)

Lead period (hrs)	Skill (%) with reference to persistence forecast		Long period average Skill (%) based on 2010-14	
	Absolute Error	Root mean square (RMS) error	Absolute Error	RMS Error
12	18.6	13.6	26.7	34.6
24	43.9	35.6	40.2	45.2
36	58.3	58.5	49.3	53.1
48	60.0	66.7	55.4	60.4
60	68.0	70.7	63.5	69.1
72	66.7	67.1	67.7	72.8
84	74.0	76.3	72.9	76.3
96	92.0	89.9	75.3	77.8
108	-	-	78.7	81.5
120	-	-	81.7	84.7

- : Forecast could not be verified as the life period of the cyclone from deep depression stage was limited to 96 hrs only.

The AE varied from about 4 knots to 10 knots in different time scales. The error was significantly less than the long period average error based on 2010-2014. However, comparing the skill, the skill in intensity forecast compared to persistence forecast varied from 19% to 92% for different lead periods and has been higher as compared to long period average skill (Table 6). Considering the RMSE, it varied from 05 knots to 11 knots for different forecast time scales and was significantly less than long period average RMS errors. The skill varied from 14% to 90% and is higher than the long period average skills except for the 12-, 72- and 84-hr forecasts.

8.3. Storm surge forecast verification

As the system weakened over the Sea, no storm surge was realized along Oman coast, though there was prediction of storm surge of height of 0.5 to 1 meter above the astronomical tide at the time of landfall (Table 10).

Table-10: Verification of Storm Surge Forecast issued by IMD

Forecast Storm surge above astronomical tide and area to be affected	Actual Storm Surge
10.06.15/1730 IST Storm surge of about one meter height above the astronomical tide would inundate low lying areas near the landfall point around the time of landfall. **10.06.15/2330 IST** Storm surge of about 0.5 to one meter height above the astronomical tide would inundate low lying areas near the landfall point around the time of landfall.	NIL, as the system weakened over the Sea.