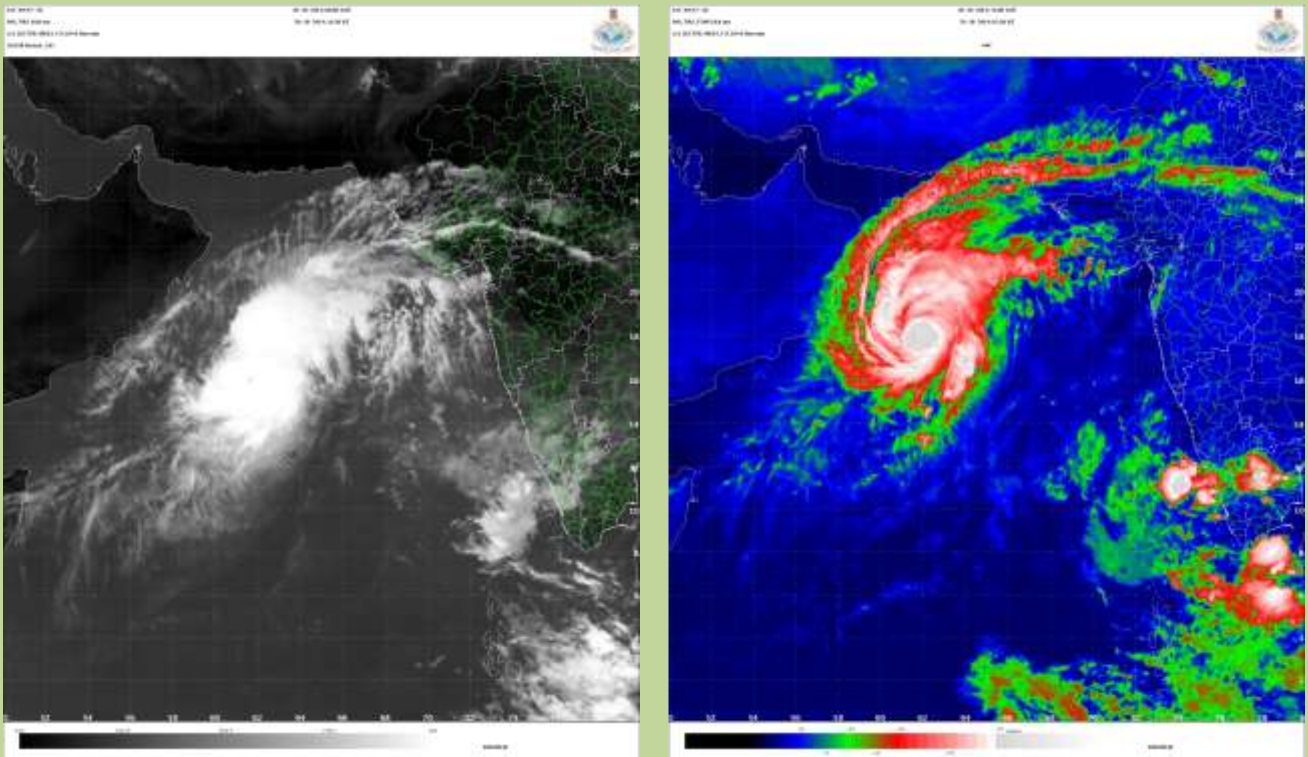
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
EARTH SYSTEM SCIENCE ORGANISATION
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm, NILOFAR over the Arabian Sea (25-31 October 2014): A Report



Satellite imageries of VSCS NILOFAR

Cyclone Warning Division

India Meteorological Department

New Delhi

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Very Severe Cyclonic Storm (VSCS) NILOFAR over the Arabian Sea (25-31 October 2014)

1. Introduction

The very severe cyclonic storm, Nilofar developed from a low pressure area which lay over southeast Arabian Sea in the morning of 21st October. It moved northwestwards and concentrated into a Depression in the early morning of 25th over westcentral and adjoining southwest Arabian Sea. It intensified into a Cyclonic Storm over the same region in the morning of 26th. It then moved nearly northwards and further intensified into a Severe Cyclonic Storm (SCS) over westcentral Arabian Sea in the early morning of 27th and into a Very Severe Cyclonic Storm (VSCS) around noon of the same day. It continued to move nearly northwards and reached its maximum intensity around midnight of 28th with wind speed of 205 kmph. It then moved north-northeastwards and started to weaken rapidly under the influence of high vertical wind shear, entrainment of dry and cold air from the north and relatively lower ocean thermal energy. It weakened into a Severe Cyclonic Storm during early hours of 30th October and into a Cyclonic Storm in the afternoon of 30th October. It weakened into a Deep Depression in the early hours and into a Depression in the early morning of 31st October. It weakened into a well marked low pressure area over northeast Arabian Sea off north Gujarat coast in the forenoon of 31st Oct.

The salient features of this system are as follows.

i. The track of the system was unique, as it initially moved northwestward on the day of formation and then re-curved northeastwards. It further moved nearly northwards very slowly upto 29th evening and then east-northeastwards.

ii. The estimated maximum sustained surface wind speed in association with the cyclone was about 110 kt (205 kmph).

iii. The estimated central pressure was 950 hPa with a pressure drop of 56 hPa at the centre compared to surroundings.

iv. It exhibited Rapid Intensification as well as Rapid Weakening. The maximum sustained wind increased from about 100 kmph in the early morning of 27th to about 205 kmph in the early evening of 28th (in 36 hours). It weakened rapidly from VSCS (wind speed of about 200 kmph) in the morning of 29th into SCS (wind speed of about 110 kmph) in the morning of 30th and further into a low pressure area (wind speed < 30 kmph) on 31st morning.

v. Though the re-curvature of the track could be predicted by NWP models 3 to 4 days in advance, there was large variation in the position and time of the landfall as well as re-curvature.

vi. The genesis, track and intensification/weakening were predicted by IMD with reasonable accuracy five days in advance.

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 and prediction of VSCS NILOFAR

The VSCS Nilofar was monitored & predicted continuously since its inception by the IMD. IMD could predict well in advance the genesis, intensification, weakening as well as the re-curvature of the track towards Gujarat coast. The VSCS Nilofar was monitored mainly with satellite observations, supported by meteorological buoys and ship observations. OMNI buoys deployed in the Arabian Sea captured the signals of the NILOFAR cyclone passage and the time series observations clearly exhibit the importance of the proximity of the location of the buoys to the cyclone track.

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.

3. Brief life history

3.1. Genesis

Under the influence of the active northeast monsoon, a cyclonic circulation extending upto mid – tropospheric level lay over Lakshadweep area and adjoining Kerala in the morning of 19th October. It lay over southeast Arabian Sea and adjoining Lakshadweep on 20th October. Under its influence, a low pressure area formed over southeast Arabian Sea in the morning of 21st October. It persisted over the same region and became well marked in the early morning of 23rd October. It concentrated into a Depression in the early morning of 25th October and lay centered at 0530 hrs IST of 25th over westcentral and southwest Arabian Sea near Lat. 12.5°N/ Long. 61.5°E. According to the satellite imagery intensity was T 1.5. The convection increased from 24th to 25th with increase in organization and depth of cloud. The associated cloud showed shear pattern with major convection being shifted to west of the low level circulation centre. The associated maximum sustained wind speed was 25 kts. However, the winds were higher in the northern sector due to prevailing northeast monsoon circulation. A ship located near Lat. 12.5°N/ Long. 60.3°E reported MSLP of 1001 hPa and surface wind speed of 330°/20 kts indicating the fact that areal extent of the strong winds in the northwestern sector was less compared to the northeast and southwest sector.

Considering the environmental condition, the SST was 28-30°C around the system centre prior to the genesis of Depression. Ocean thermal energy was 60-80 kJ/cm^2 and vertical wind shear was moderate 10-20 kts around the system centre. The low level convergence was about $15*10^{-5}s^{-1}$ and vorticity was about $200 *10^{-5}s^{-1}$. The upper level divergence was about $30*10^{-5}s^{-1}$. The low level relative vorticity and convergence as well as the upper level divergence increased from 24th to 25th. There was poleward favourable outflow in association with an anti-cyclone to the east-northeast of the system. The upper tropospheric ridge at 200 hPa level ran along 15°N. The MJO was located in Phase 1 with amplitude greater than 1.

The observed track of the system is shown in fig.1.

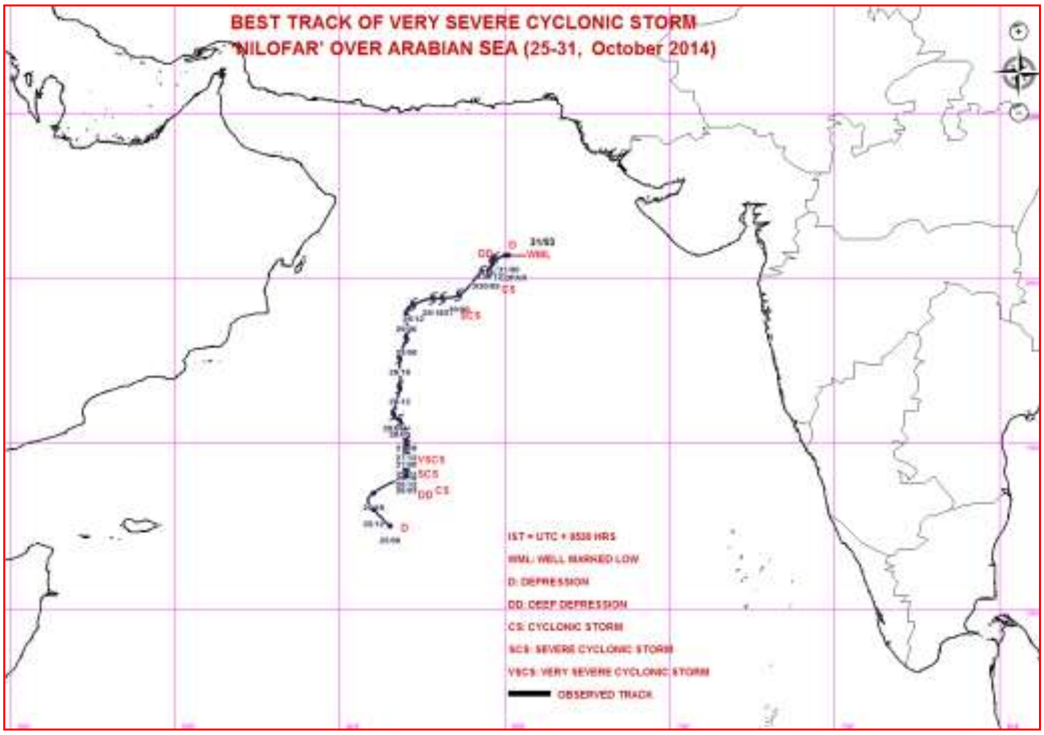


Fig. 1: Observed track of the Very Severe Cyclonic Storm 'NILOFAR' over Arabian Sea during 25-31 October, 2014

3.2. Intensification and movement

In association with the favourable environmental and meteorological conditions as mentioned in previous section, the Depression moved north-northwestwards and intensified into a Deep Depression at 0830 hrs IST of 26th over westcentral and adjoining southwest Arabian Sea near Lat. 14.0°N/ Long. 62.0°E. It intensified into a cyclonic storm over the same region at 1130 hrs IST of 26th. As the system was lying close to the ridge, it moved slowly northwards and intensified into an SCS over west central and adjoining southwest Arabian Sea at 0230 hrs IST of 27th and into a VSCS at 1130 hrs IST of the same day and lay centered over westcentral Arabian Sea near Lat. 14.9°N/ Long. 62.0°E. It continued to intensify further and reached the peak intensity with T 5.5 at 2330 hrs IST of 29th and lay centered over westcentral Arabian Sea near Lat. 17.6°N/ Long. 61.8°E.

The system exhibited Rapid Intensification as well as Rapid Weakening. The maximum sustained wind increased from about 100 kmph in the early morning of 27th to about 205 kmph in the evening of 28th (in 36 hours) because of low vertical wind shear and increase in vorticity. It weakened rapidly from VSCS (wind speed of about 200 kmph) in the morning of 29th into SCS (wind speed of about 110 kmph) in the morning of 30th and further into a low pressure area (wind speed < 30 kmph) on 31st morning under the influence of high vertical wind shear, entrainment of dry and cold air and relatively lower ocean thermal energy. Also the convection was highly sheared from the low level circulation centre. The best track parameters of VSCS 'NILOFAR' are shown in Table 1.

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'NILOFAR' over the Bay of Bengal during 25-31 October, 2014

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
25-10-2014	0000	12.5/61.5	1.5	1004	25	3	D
	0300	12.5/61.5	1.5	1004	25	3	D
	0600	12.5/61.5	1.5	1004	25	3	D
	1200	13.0/61.0	1.5	1003	25	3	D
	1800	13.5/61.0	1.5	1003	25	3	D
26-10-2014	0000	14.0/62.0	1.5	1002	25	4	D
	0300	14.0/62.0	2.0	999	30	5	DD
	0600	14.1/62.0	2.5	998	35	6	CS
	0900	14.1/62.0	2.5	996	35	7	CS
	1200	14.2/62.0	2.5	994	40	8	CS
	1500	14.3/62.0	3.0	994	40	8	CS
	1800	14.4/62.0	3.0	994	45	10	CS
	2100	14.5/62.0	3.0	994	50	12	SCS
27-10-2014	0000	14.8/62.0	3.5	990	55	16	SCS
	0300	14.9/62.0	3.5	990	60	18	SCS
	0600	14.9/62.0	4.0	986	65	20	VSCS
	0900	14.9/62.0	4.0	984	65	22	VSCS
	1200	15.0/62.0	4.0	982	70	24	VSCS
	1500	15.1/62.0	4.0	981	70	25	VSCS
	1800	15.3/62.0	4.0	980	70	26	VSCS
	2100	15.6/61.8	4.0	979	75	27	VSCS
28-10-2014	0000	15.7/61.8	4.0	978	75	28	VSCS
	0300	15.8/61.7	4.0	977	75	29	VSCS
	0600	15.9/61.6	4.5	974	80	32	VSCS
	0900	16.3/61.6	5.0	966	90	40	VSCS
	1200	16.7/61.8	5.5	954	100	52	VSCS
	1500	17.2/61.8	5.5	952	105	54	VSCS
	1800	17.6/61.8	5.5	950	110	56	VSCS
	2100	18.0/61.8	5.5	950	110	56	VSCS
29-10-2014	0000	18.2/62.0	5.5	954	105	52	VSCS
	0300	18.7/62.0	5.0	958	100	48	VSCS
	0600	18.9/62.0	5.0	962	95	44	VSCS
	0900	19.0/62.0	5.0	968	90	40	VSCS
	1200	19.2/62.2	4.5	974	80	32	VSCS
	1500	19.4/62.5	4.0	980	70	26	VSCS
	1800	19.4/62.8	4.0	986	70	24	VSCS
	2100	19.4/63.1	3.5	988	60	20	SCS
30-10-2014	0000	19.5/63.6	3.5	990	60	18	SCS
	0300	19.8/64.1	3.0	994	50	14	SCS
	0600	20.2/64.3	3.0	998	45	10	SCS
	0900	20.2/64.5	2.5	1000	40	9	CS
	1200	20.5/64.6	2.5	1001	40	8	CS
	1800	20.6/64.7	2.5	1002	35	7	CS
	2100	20.7/65.0	2.0	1003	30	5	DD
31-10-2014	0000	20.7/65.1	1.5	1004	25	4	D
	0300	Weakened into a well marked low pressure area over northeast Arabian Sea off north Gujarat coast					

4. Maximum Sustained Surface Wind speed (MSW) and estimated central pressure at the time of landfall:

The MSW in association with a cyclone affecting Indian coasts is defined as the average surface wind speed over a period of 3 minutes measured at a height of 10 meters. The MSW is either estimated by the remotely sensed observations or recorded by the surface based instruments. Based on satellite imagery, an empirical technique known as the Dvorak technique is utilized worldwide to estimate the intensity of cyclone and hence the associated MSW. Based on the observation of the pressure drop at the centre, MSW can also be estimated using the empirical pressure-wind relationship (MSW= 14.2* √ pressure drop at the centre).

The lowest Estimated Central Pressure (ECP) of the system was 950 hPa at 2330 hrs IST of 28th Oct. with a pressure drop of 56 hPa. The estimated MSW was 110 kts. The variations in ECP and MSW are shown in Fig. 2.

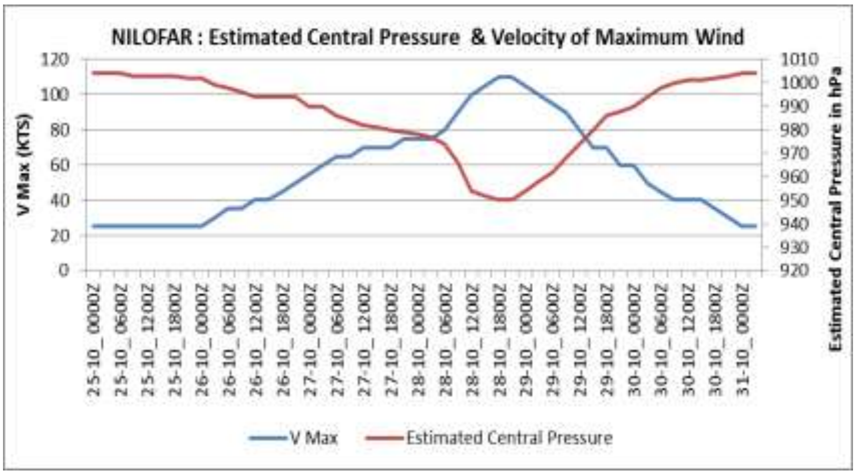


Fig. 2. Variations in ECP and MSW during VSCS Nilofar for the period 25 -31 Oct. 2014.

The buoys AD06, AD02 and AD07 were closer to the track. The buoys AD08, AD09 and AD10 were away from the cyclone track, with very less response in the met and ocean parameters. Table 2 shows the distance between NILOFAR cyclone track and OMNI buoy locations. Figures 3 - 5 shows the atmospheric air pressure, wind speed and significant wave height during the period 22 Oct. – 2 Nov. 2014.

Table -2: Distance between NILOFAR cyclone track and OMNI buoy locations

Sl.No	Buoy ID	Distance between cyclone track and Buoy position
1	AD02	421 nm
2	AD04	876 nm
3	AD06	158 nm
4	AD07	417 nm
5	AD08	578 nm
6	AD09	897 nm
7	AD10	758nm

The Atmospheric Pressure showed a maximum drop observed at AD07 with recorded minimum pressure of 1004.46 hPa on October 26, 2014.

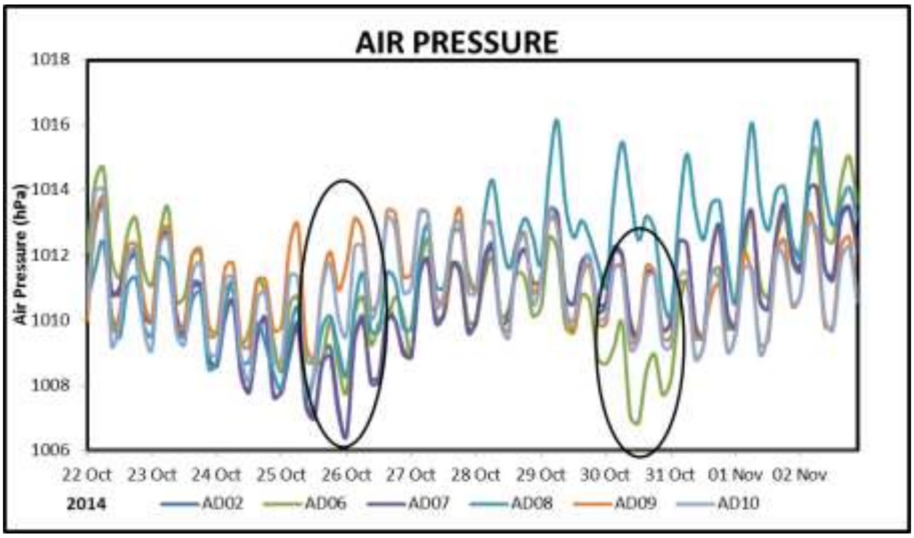


Fig. 3. Atmospheric Pressure recorded by the buoys during 22 Oct. – 2 Nov. 2014

The buoy AD06 which was near the track of the cyclone recorded a maximum wind speed of 11.4 m/s on October 24, 2014 and 11.2 m/s on October 30, 2014.

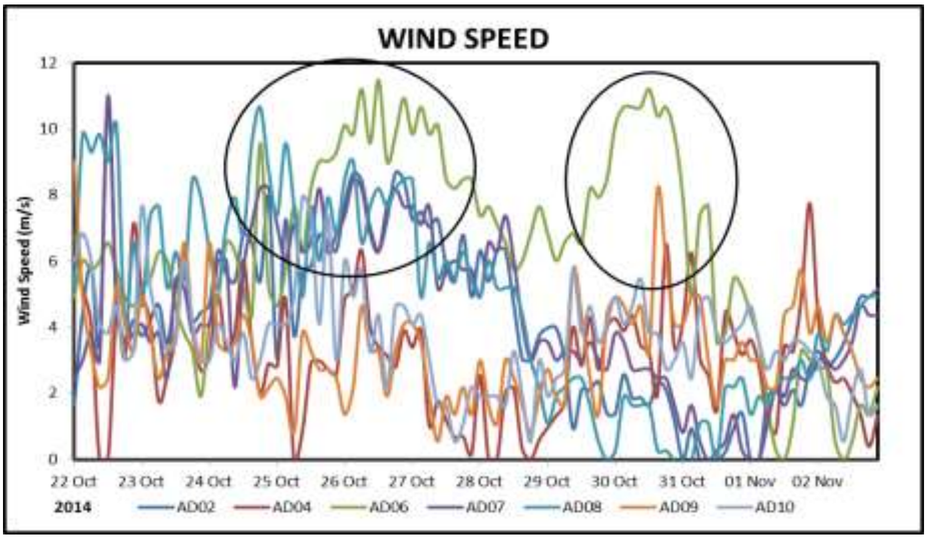


Fig. 4. Wind speed recorded by the buoys during 22 Oct. – 2 Nov. 2014

The increase in significant wave height was recorded maximum at AD07 and AD06 location with a significant wave height of 3.22 m and 3.16 m on 26th and 30th October, 2014 respectively.

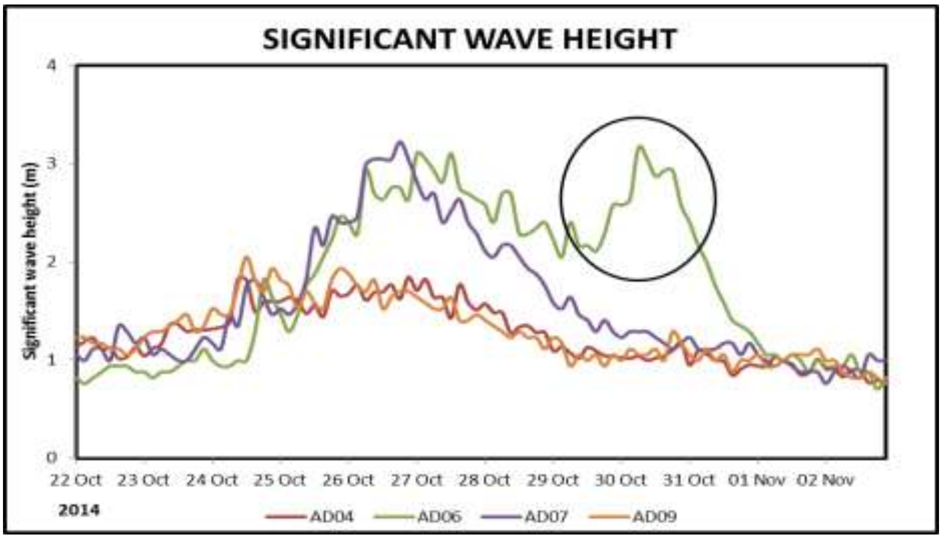


Fig. 5. Significant wave height recorded by the buoys during 22 Oct. – 2 Nov. 2014

5. Characteristic features observed through Satellite and RADAR

5.1 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 VSCS NILOFAR representing the life cycle of the cyclone are shown in Fig. 6 - 8.

According to INSAT-3D imageries and products, a low level circulation centre (LLCC) attained intensity of T.1.5 over westcentral Arabian Sea and adjoining east-central and south Arabian Sea on 25th/0000 UTC. Associated broken low and medium clouds with embedded intense to very intense convection extended over 8-10° laittude/longitude box around the vortex centre over the Arabian Sea and adjoining Indian Ocean. Convection increased gradually and started organising. The system attained intensity of T.2.0 at 0300 UTC of 26th. It further intensified to T.2.5 at 0600 UTC of 26th and convection organised into a curved band pattern with the lowest cloud top temperature of -93.0°C. It intensified to T.3.0 and T.3.5 at 26th/1500 UTC and 27th/0000 UTC respectively. The convection showed eye pattern from 0000 UTC of 27th. It attained intensity of T.4.0. and T.4.5 around 0600 UTC of 27th and 28th respectively and further attained its peak intensity of T.5.5 within next 6 hours (28th/1200 UTC). On 29th/0300 UTC the system started showing signs of weakening with ragged eye pattern and intensity T.5.0. By 29th/1500 UTC, its intensity decreased further to T.4.0. By 30th/0300 UTC, its T. No. became T.3.0. At 2100 UTC of 30th, its intensity was T.2.0 and on 31st/0000 UTC, it was T.1.5. During weakening phase the cloud pattern changed from eye pattern to curved band pattern and finally to shear pattern on 30th and 31st Oct. 2014.

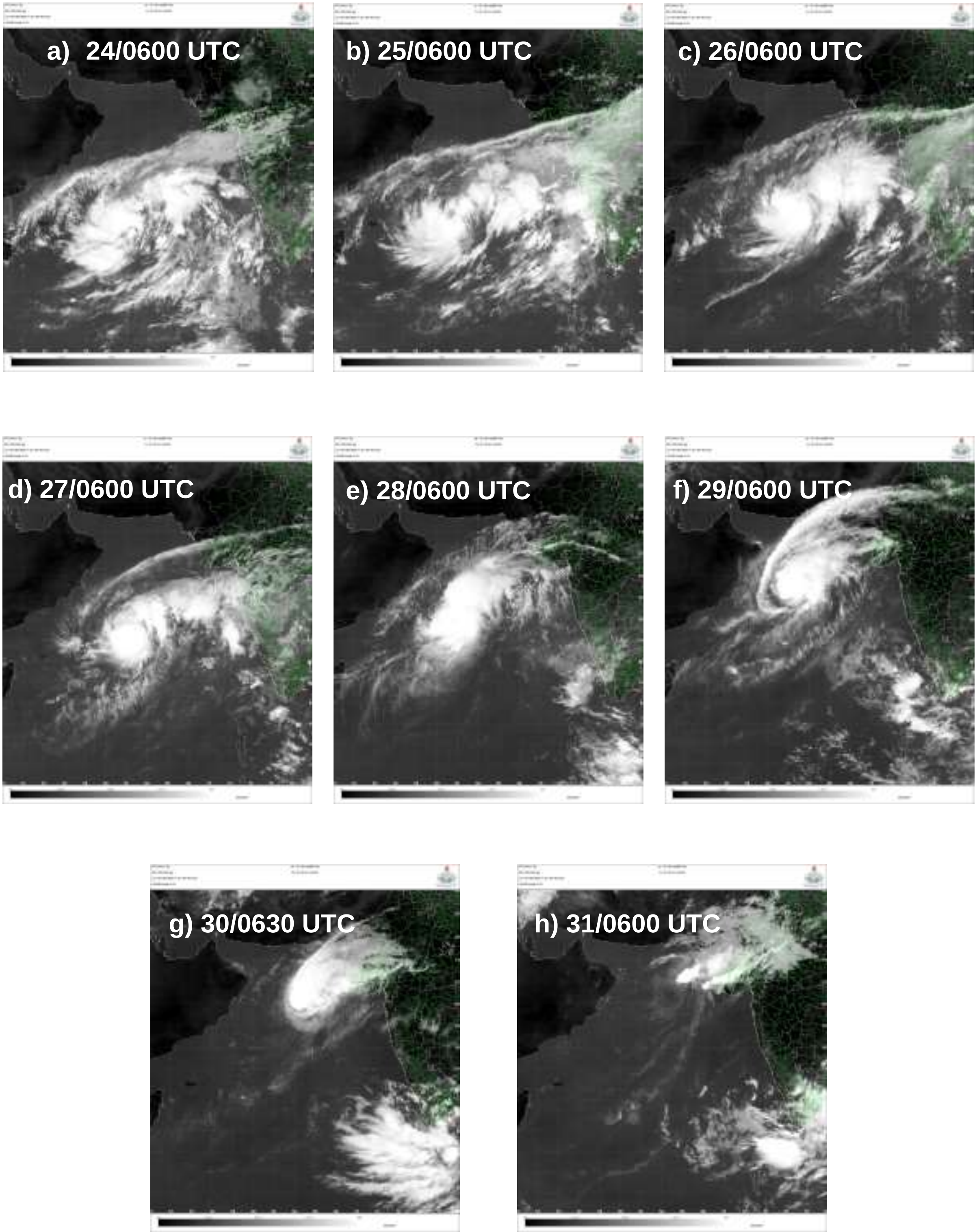


Fig. 6: Typical INSAT-3D IR imageries based on 0600 UTC in association with VSCS NILOFAR during 24-31 October 2014

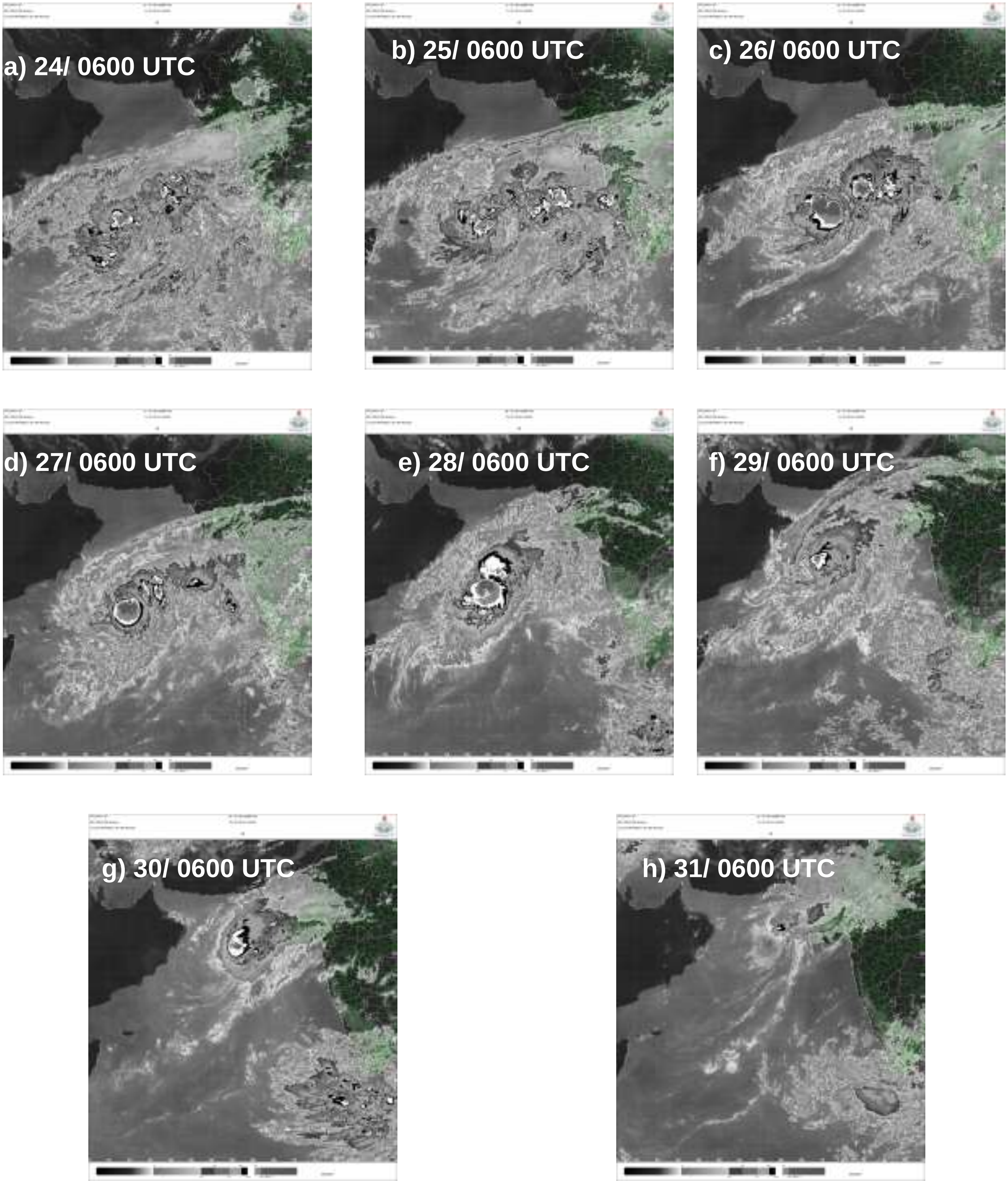


Fig. 7: INSAT-3D enhanced IR imageries in association with VSCS NILOFAR during 24-31 October 2014

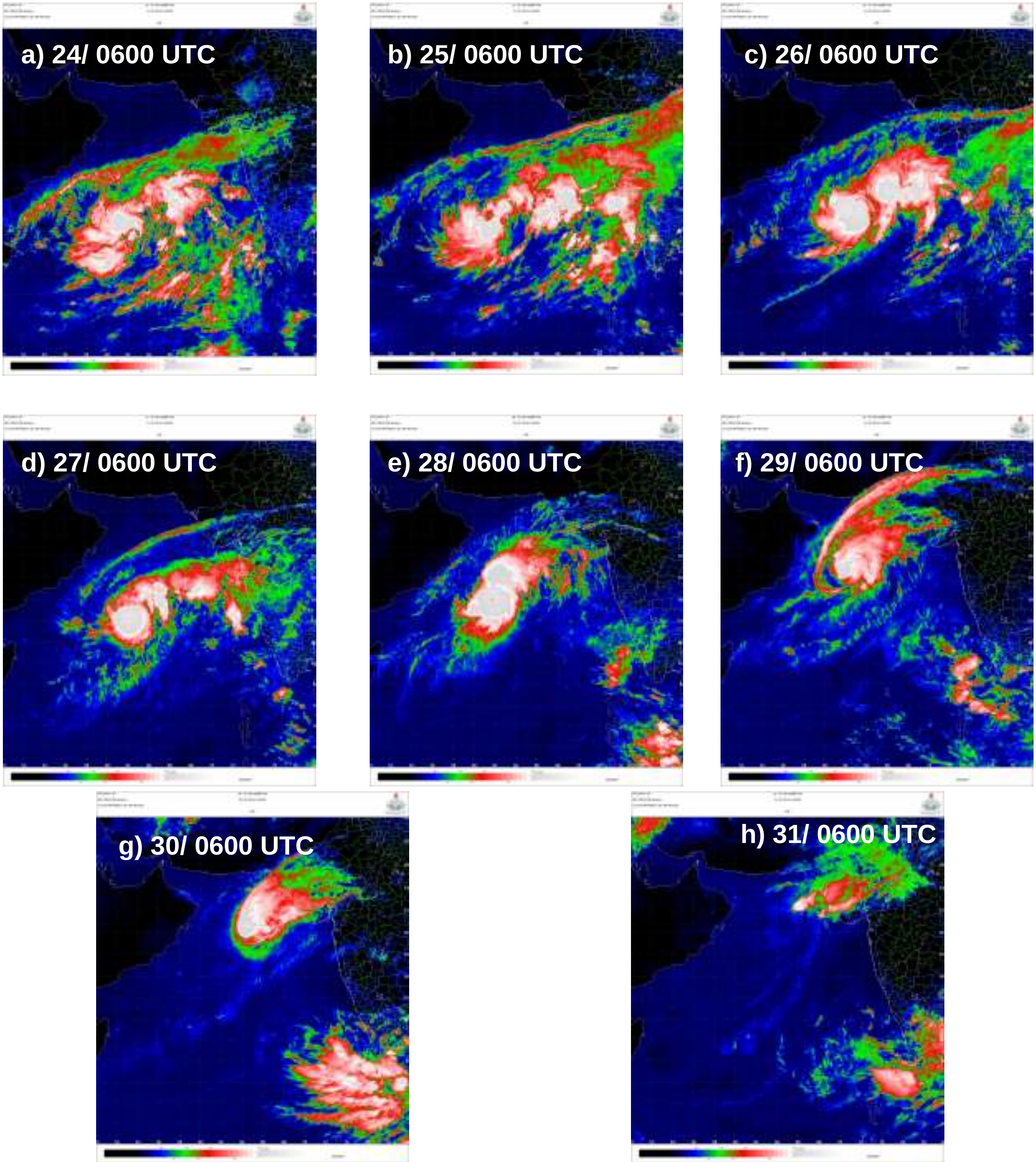


Fig. 8: INSAT-3D colored enhanced IR imageries based on 0600 UTC in association with VSCS NILOFAR during 24-31 October 2014

5.2 Features observed through RADAR

Cyclone Detection Radar (CDR) Bhuj could monitor the system on 31st Oct. as the system came in its range. Due to weakening of the system the characteristic features like location and intensity could not be detected with RADAR. However, the convection in association with the system lying to the right of the system centre was well captured in the RADAR imagery as shown in Fig. 9.

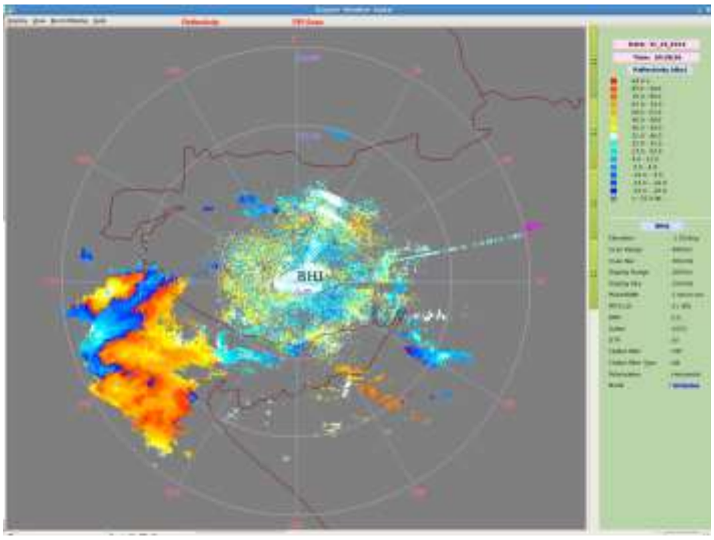


Fig. 9: RADAR Imagery from CDR Bhuj based on 0000 UTC of 31st Oct. 2014

6. Dynamical features

To analyse the dynamical features, the Mean Sea Level Pressure (MSLP), surface winds at 10 m height and winds at 850, 500 and 200 hPa levels during the period 25 – 31 October 2014 are presented in Fig. 10 based on IMD-GFS analysis.

The maximum wind at lower level was oriented north-south and active northeast monsoon flow prevailed to the north during genesis stage i.e., 25th Oct. The wind speed was little bit higher in the northern sector. Hence the wind distribution was asymmetric. While the size of the gale wind gradually increased with intensification of the system and continued to be asymmetric, the core wind became symmetric when system intensified into VSCS on 27th Oct. However, with the weakening of the system from 29th Oct., the size of the gale wind decreased in the northeast and southeast sector.

During 26-28th, the VSCS Nilofar was sandwiched between two anti-cyclonic circulation, one lying to the southeast and another to the west-northwest of the system centre. As a result, during 26-28th the system nearly moved northwards with very slow speed. At the same time it provided a very low vertical wind shear (5-10 kts) which resulted in rapid intensification.

A trough in the upper tropospheric westerly approached from west which led to increase in the westerlies in the storm region from 29th Oct. 2014. Subsequently, as the system moved to the north of the ridge line it was steered northeastwards from 29th onwards towards Gujarat and adjoining Pakistan coast. However, as it moved northeastwards, it encountered high vertical wind shear, entrainment of dry and cold air towards to the core due to mid-latitude westerlies. Hence, it started weakening rapidly over the sea itself before reaching the Gujarat coast.

The analysis could very well capture the genesis and track of the system. However, the rapid intensification and rapid weakening before reaching coast could not be detected reasonably.

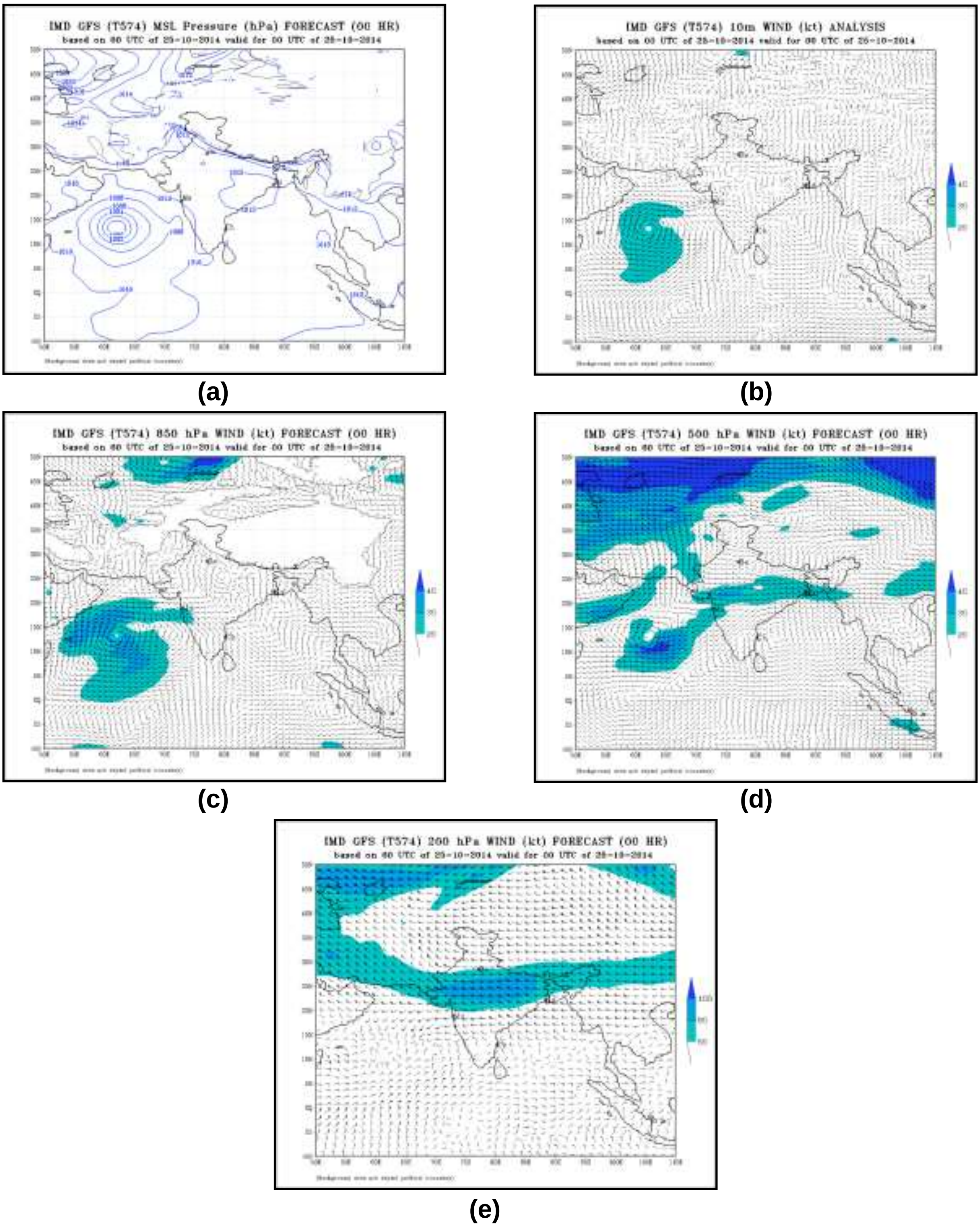
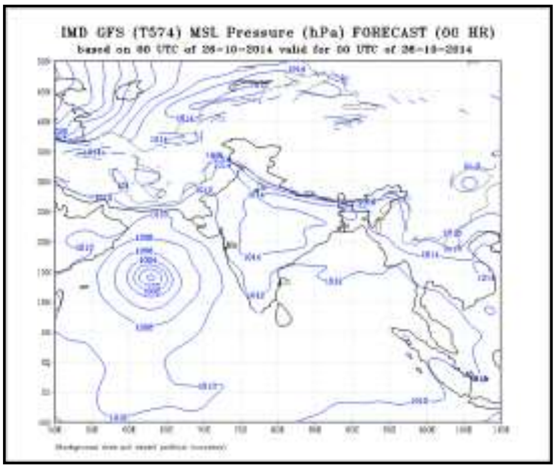


Fig. 10: IMD-GFS Analysed charts on 25th October 2014

(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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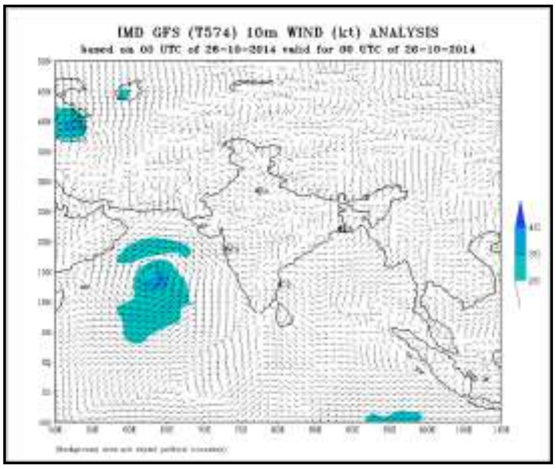

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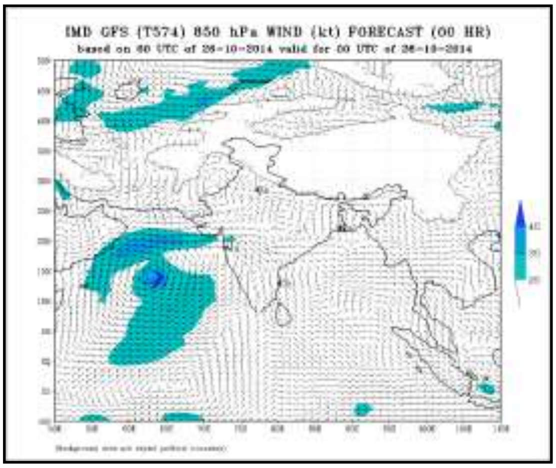

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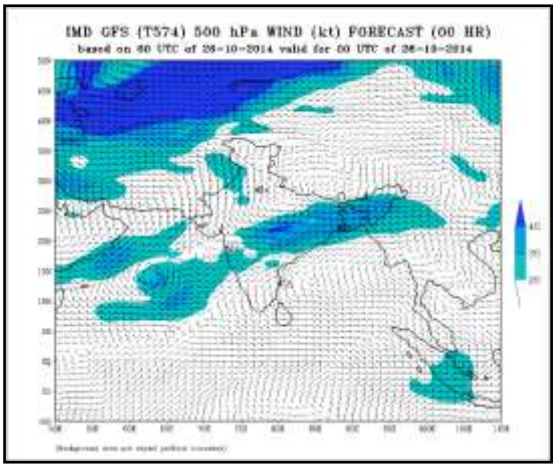

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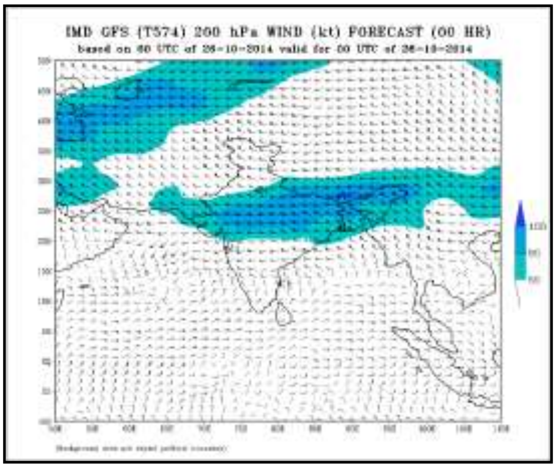
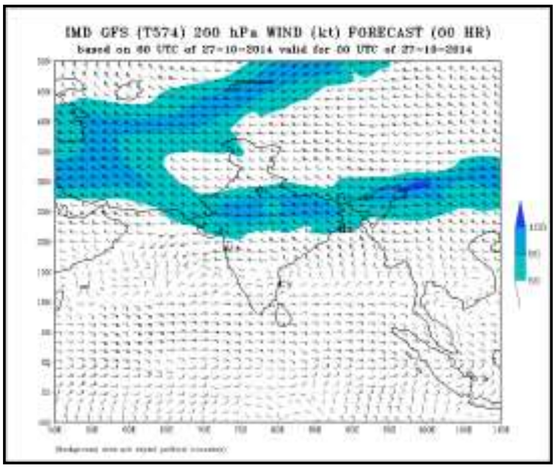


(e)

Fig. 10 (contd): IMD-GFS Analysed charts on 26th October 2014

(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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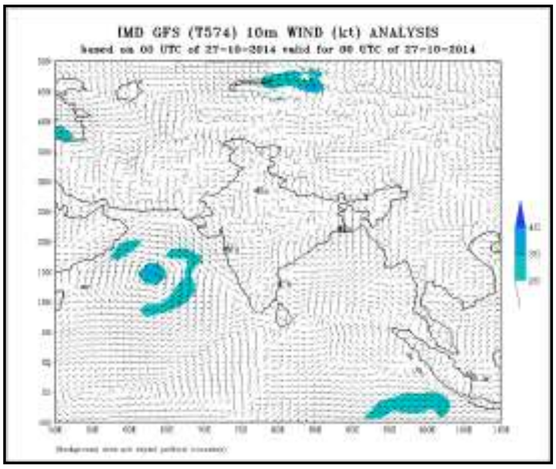

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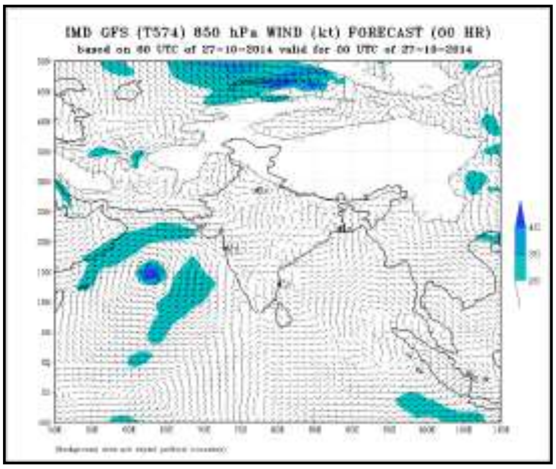

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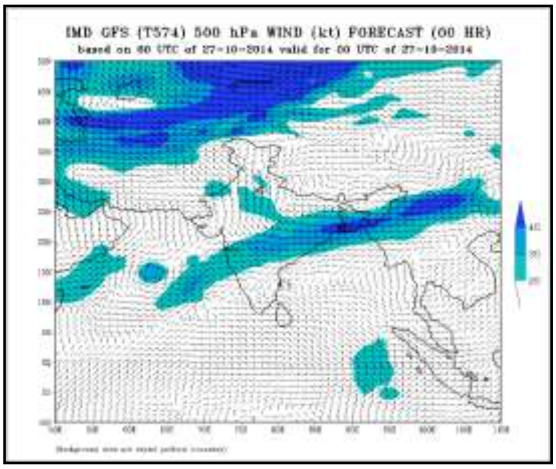

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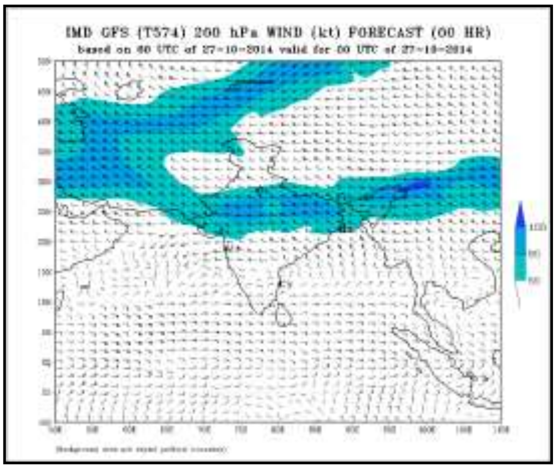

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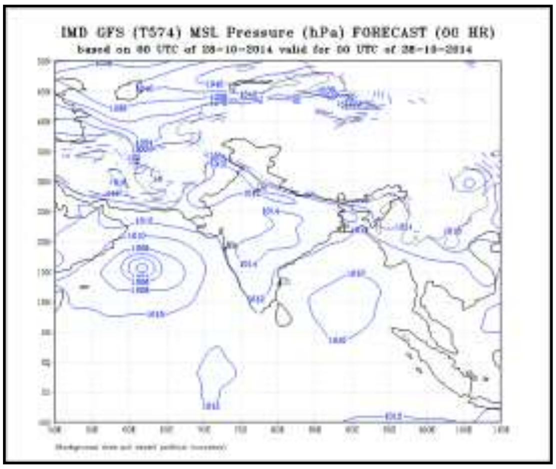
Fig. 10 (contd): IMD-GFS Analysed charts on 27th October 2014
(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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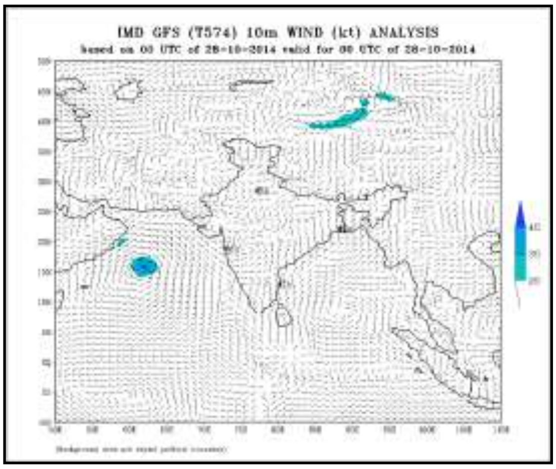

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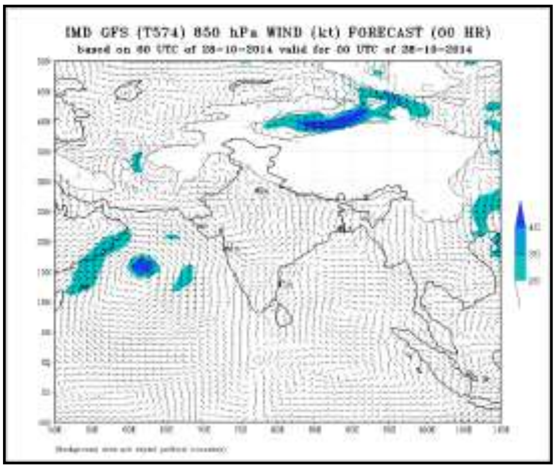

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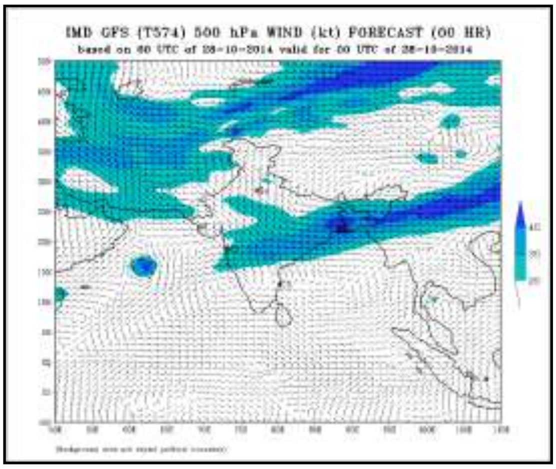

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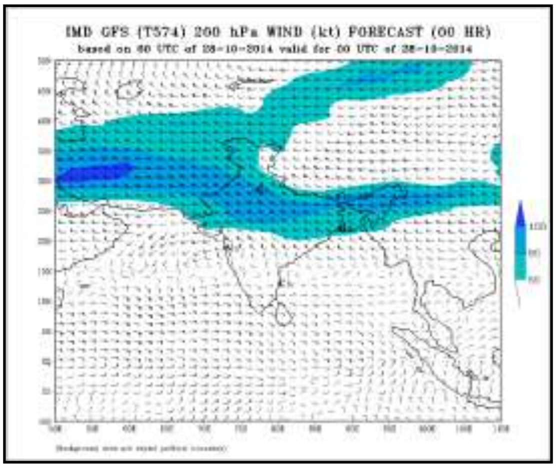
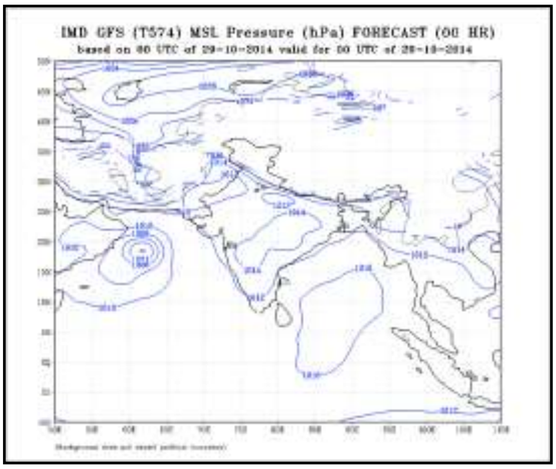
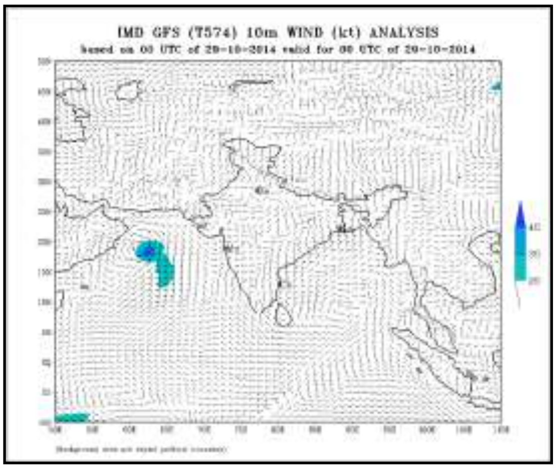


(e)

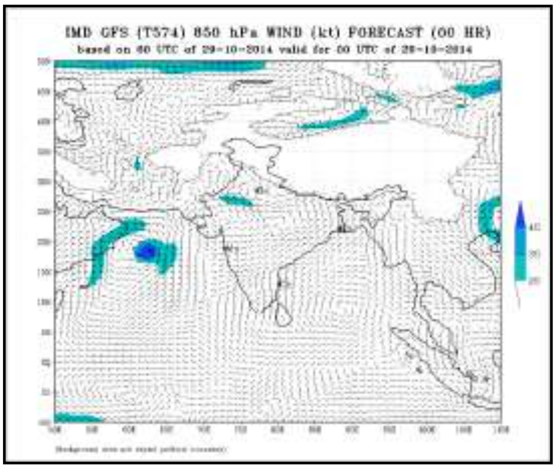
Fig. 10 (contd): IMD-GFS Analysed charts on 28th October 2014
(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



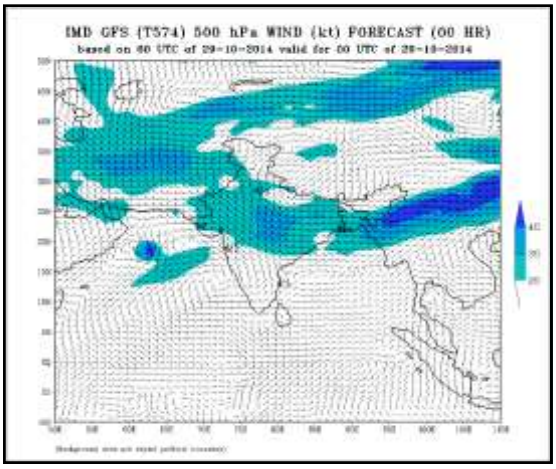
(a)



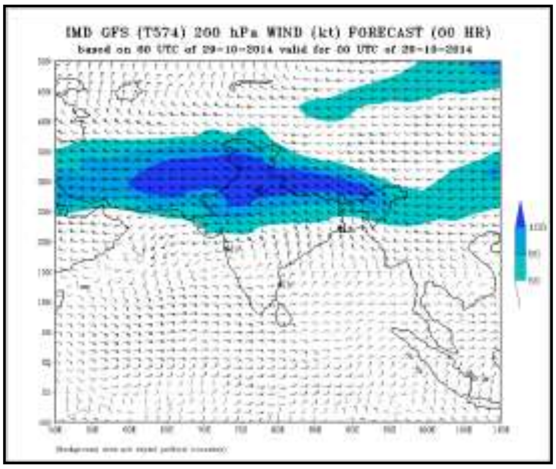
(b)



(c)

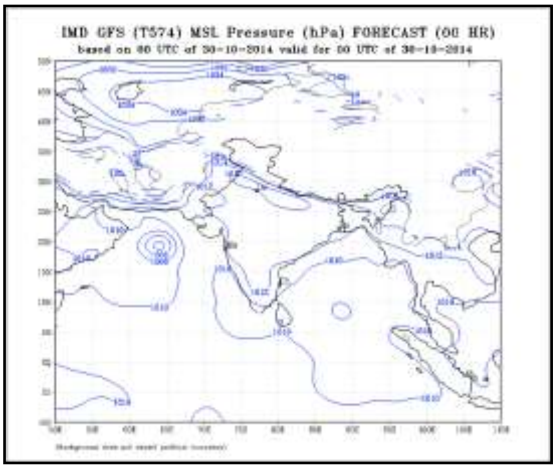


(d)

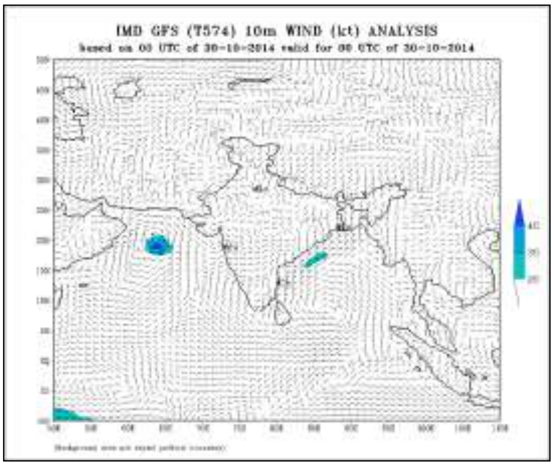


(e)

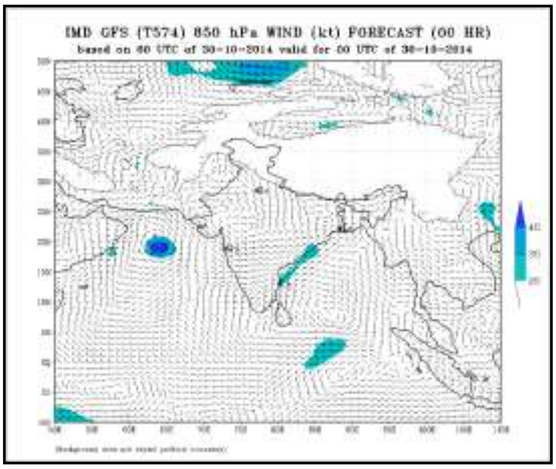
Fig. 10 (contd): IMD-GFS Analysed charts on 29th October 2014
(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



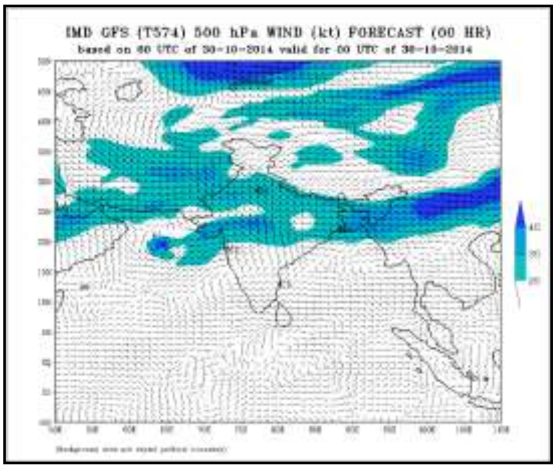
(a)



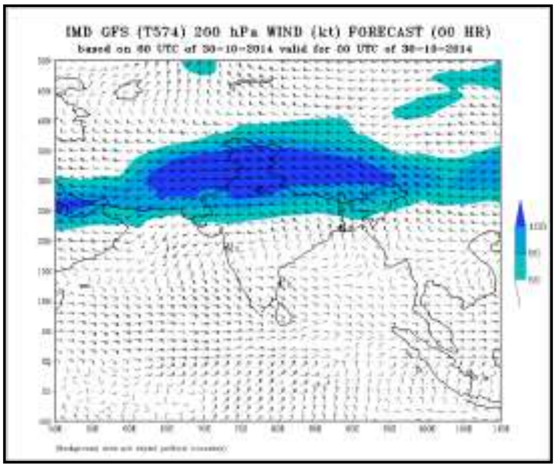
(b)



(c)

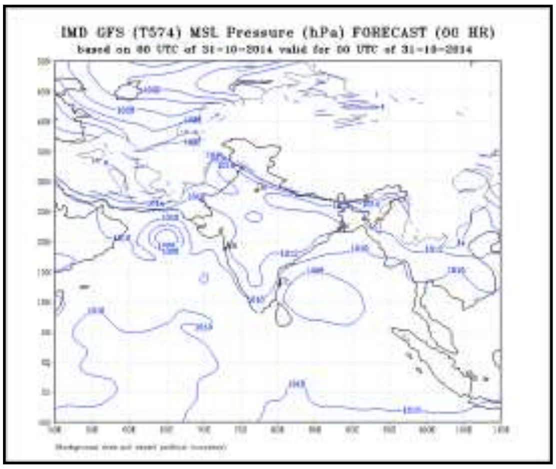


(d)

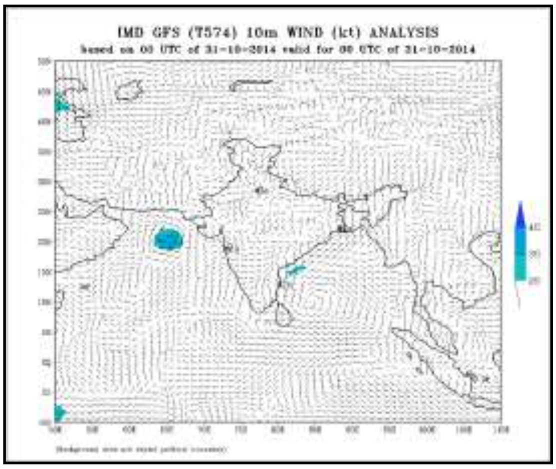


(e)

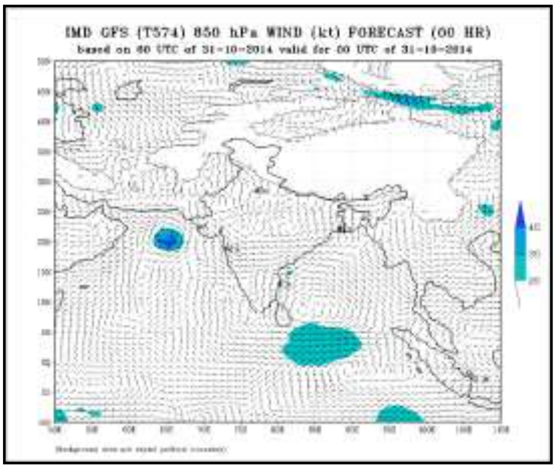
Fig. 10 (contd): IMD-GFS Analysed charts on 30th October 2014
(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



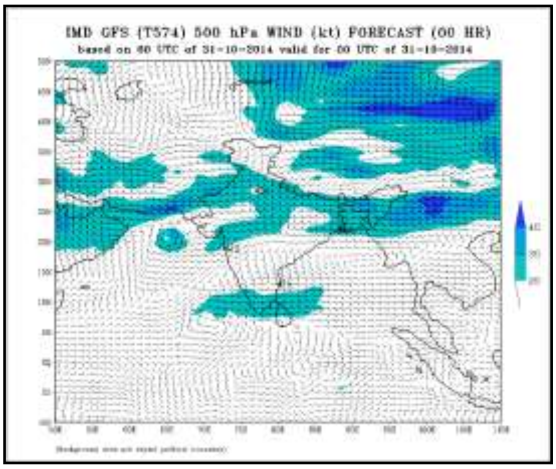
(a)



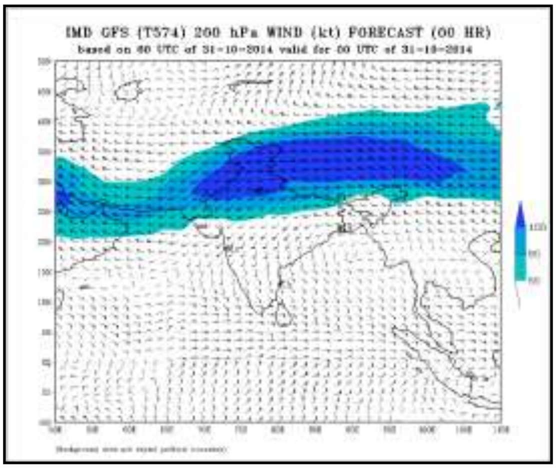
(b)



(c)



(d)



(e)

Fig. 10 (contd): IMD-GFS Analysed charts on 31th October 2014
(a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds

7. Realized Weather:

7.1 Heavy rainfall due to NILOFAR:

Under the influence of **TC NILOFAR**, Konkan and Goa region experienced widespread rain with heavy rainfall at isolated places on 25th, widespread rain with heavy to very heavy rainfalls at a few places on 26th. However, as the system started to weaken rapidly over the sea itself on 30th/31st, without crossing the coast significant rainfall was not realised over the Gujarat. Rainfall realised in association with the TC NILOFAR during the period 25-31 October 2014 is furnished below:

Rainfall amounts (≥ 7cm) realised in association with passage of TC NILOFAR' during 25-31 October 2014

25 October 2014

KONKAN & GOA:

Margaon-12

26 October 2014

KONKAN & GOA:

Margao-29, Marmugao-14, Mapusa-14, Panjim-14, Ponda-12, Dabolim N.A.S.- Navy-11, Quepem-11, Sanguem-10, Pernem-8, Vengurla-7.

MADHYA MAHARASHTRA:

Chandgad-7

Rainfall associated with the TC NILOFAR when it was out in the sea is determined from satellite-gauge merged rainfall dataset generated by IMD-NCMRWF for the North Indian Ocean region from 2013 onwards based on TRMM data. 24-hour accumulated rainfall associated with the TC NILOFAR during the period 25 -31 October 2014 as well as the 7-day average rainfall during the same period are furnished in Fig. 11a.

As can be seen, during the period 26-27 October, when the system was in its intensification phase, rainfall was observed over a wide area covering about 8-10° latitude / longitude belt in the vicinity of the TC centre and mainly in the northeast sector of the TC centre. Rainfall of the order of 2 - 8 cm are observed in the outer storm area covering regions of Konkan and Goa and adjoining areas of Madhya Maharashtra and Marathwada. However, after the recurvature on 29th, associated with the weakening of the system, area of rainfall activity during 29 October – 1st Nov is decreased to about 5° latitude/ longitude belt. No rainfall is observed over Gujarat region as the system weakened rapidly over the sea itself on 31st Oct. and 1st Nov. 2014.

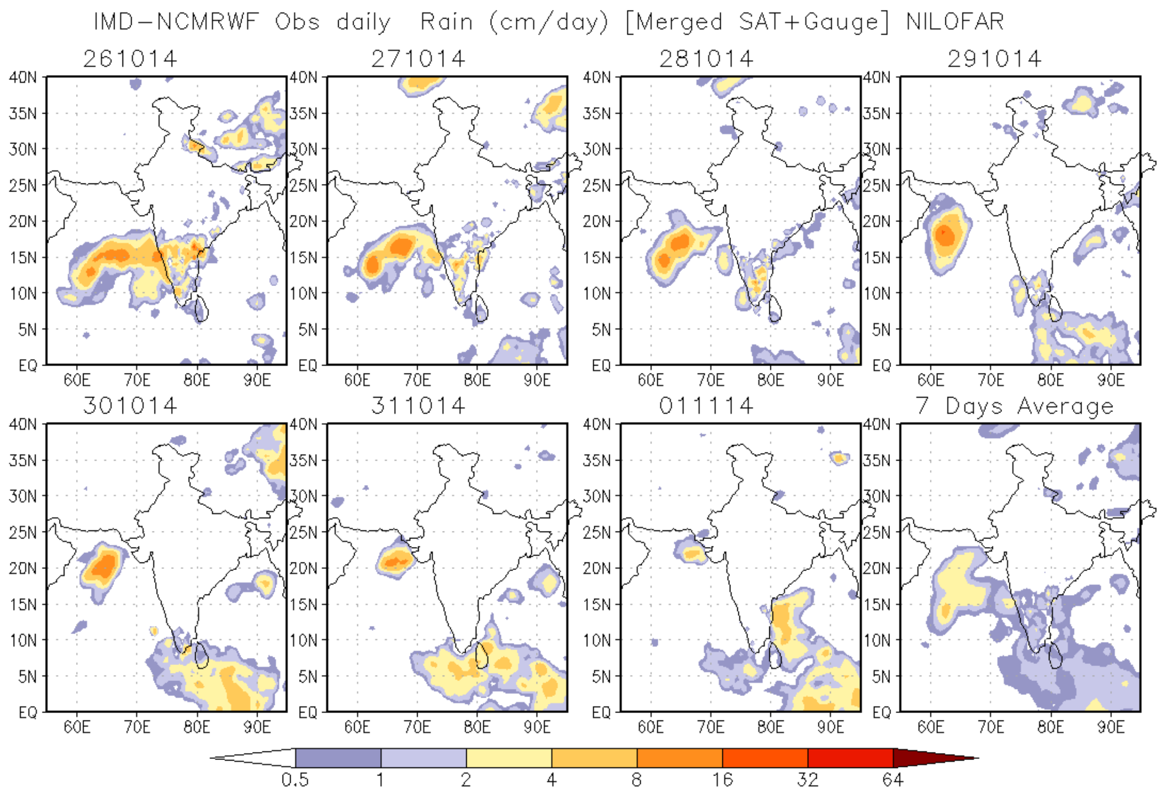


Fig. 11a IMD-NCMRWF satellite-gauge merged daily rainfall (in cm) during the period 25 October – 1 November 2014 and the 7-day average rainfall during the same period.

7.2 Gale Wind

As the system weakened over the sea, no gale wind was reported. However, strong winds with speed of 30 kmph at 1435 IST and 25 kmph at 1828 IST was recorded by High Wind Speed Recorders (HWSRs) at Dwarka and Okha respectively on 31st Oct. (Fig. 11b).

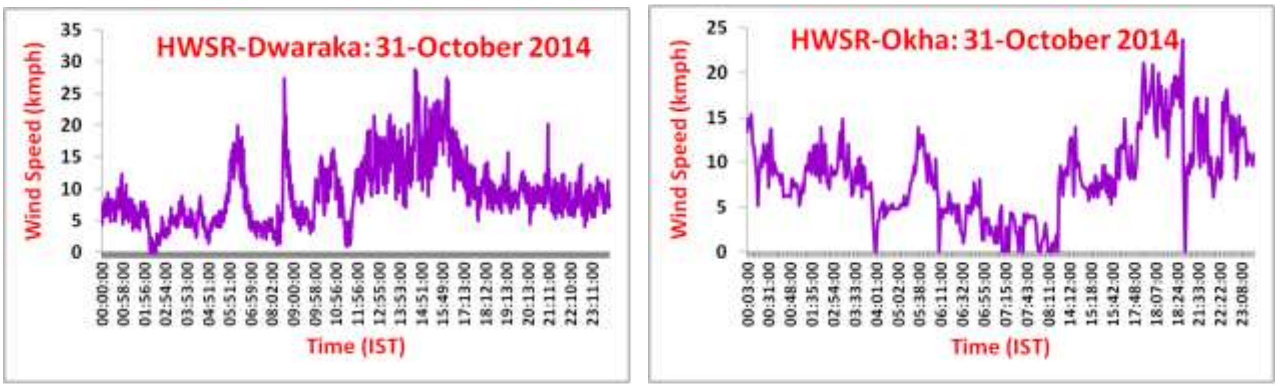


Fig. 11b: Time series of wind speed recorded by HWSR at Dwarka and Okha on 31st October 2014.

7.3. Storm Surge

No storm surge has been reported due to weakening of the system over the sea.

7.4. Damage due to Cyclone 'NILOFAR'

No damage has been reported due to this system.

8. NWP model forecast performance

India Meteorological Department (IMD) operationally runs a regional model, WRF for short-range prediction and one Global model T574L64 for medium range prediction (7 days). The WRF-Var model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^o S to 45^o N and long 40^o E to 120^o E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 23 km. The boundary conditions are updated at every six hours interval. IMD also makes use of NWP products prepared by some other operational NWP Centres like, ECMWF (European Centre for Medium Range Weather Forecasting), GFS (NCEP), JMA (Japan Meteorological Agency). Hurricane WRF (HWRF) model and Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones.

In addition to the above NWP models, IMD also run operationally "NWP based Objective Cyclone Prediction System (CPS)". The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, GFS (NCEP), ECMWF and JMA. The Statistical Cyclone Intensity Prediction (SCIP) model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). In this report performance of the individual models, MME etc., is presented.

Global models are also run at National Centre for Medium Range Weather Forecasting (NCMRWF), Noida, India. These include GFS and unified model adapted from UK Meteorological Office. Apart from the observations that are used in the earlier system, the new observations assimilated at NCMRWF include (i) Precipitation rates from SSM/I and TRMM (ii) GPSRO occultation (iii) AIRS and AMSRE radiances (iv) MODIS winds. Additionally ASCAT ocean surface winds and INSAT-3D AMVs are also assimilated.

NCUM (N512/L70) model features a horizontal resolution of 25km and 70 vertical levels. It uses 4D-Var assimilation and features no cyclone initialization/relocation. At NCMRWF the Global Ensemble Forecast System (NGEFS) provides analysis and forecast run out to 10 days based on 20 perturbed forecasts. Additionally verification and intercomparison is also provided for the forecast tracks from the Met Office UK (UKMO) and the Australian Bureau of Meteorology model ACCESS-TC. The model forecast integration are carried out at respective centers and the only forecast output is analyzed for verification and intercomparison. The results of these models guidance are presented and discussed.

8.1. Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for cyclone NILOFAR

a. Grid point analysis and forecast of GPP

Figure 12 (a-f) below shows the predicted zone of formation of cyclogenesis.

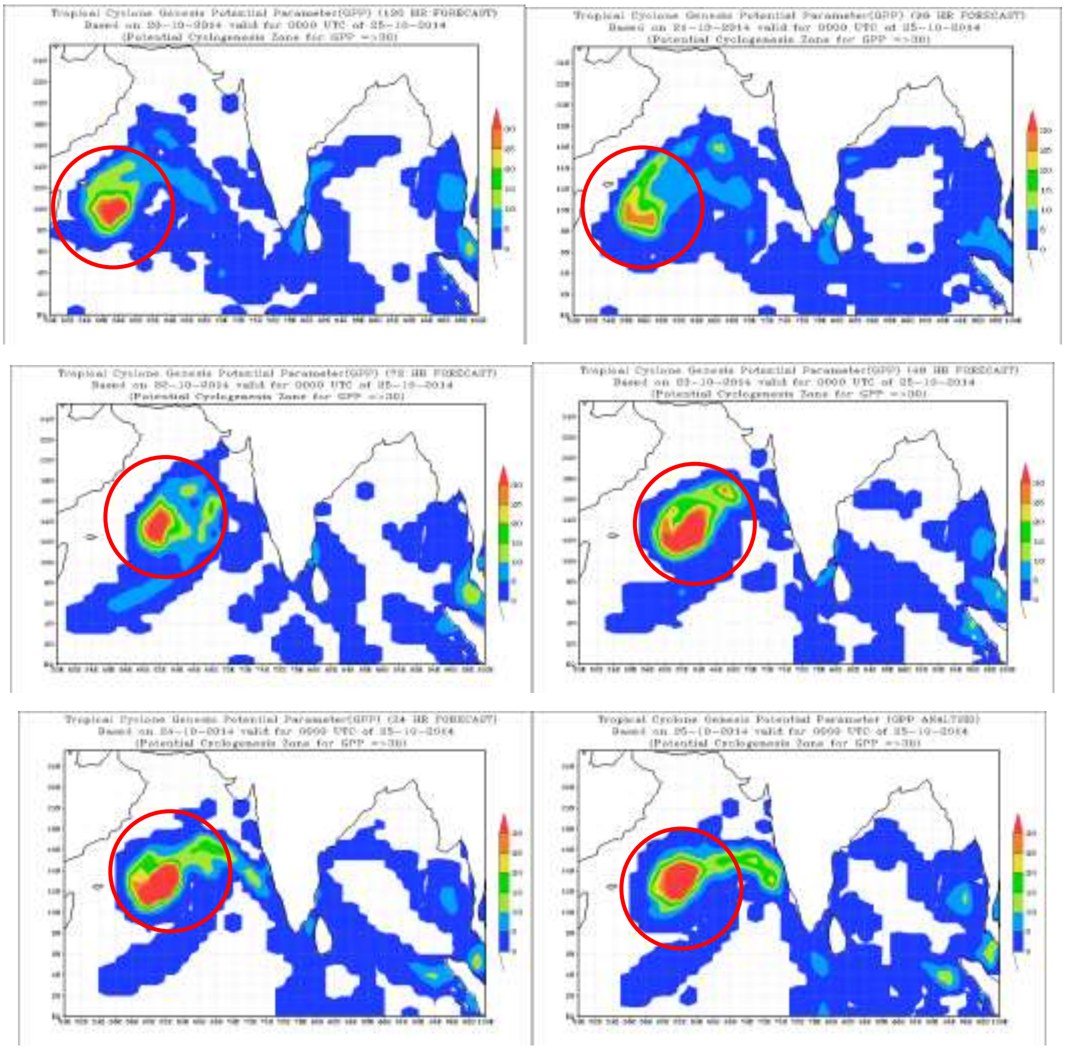


Fig. 12(a-f): Predicted zone of cyclogenesis.

Grid point analysis and forecasts of GPP (Fig. 12 (a-f)) shows that it could predict the formation and location of the system before 120 hours of its formation.
(Product available at http://www.imd.gov.in/section/nhac/dynamic/Analysis1.htm)

b. Area average analysis of GPP

Since all low pressure systems do not intensify into cyclones, it is important to identify the potential of intensification (into cyclone) of a low pressure system at the early stages of development. Analysis and forecasts of GPP based on 0000 UTC of 24 October 2014 showed that GPP ≥ 8.0 (Threshold) at very early stage of development (T.No.-1.0) and thus indicated its potentential to intensify into a cyclone. Analysis and forecasts of GPP based on 0000 and 1200 UTC of 25th and 26th October 2014 also indicated its potentential to intensify into a cyclone (Fig.13(a-e). However, the value of GPP based on 0000 UTC of 26th October was showing decreasing trend, though the system rapidly intensified upto VSCS (110 kmph) on 28th October.

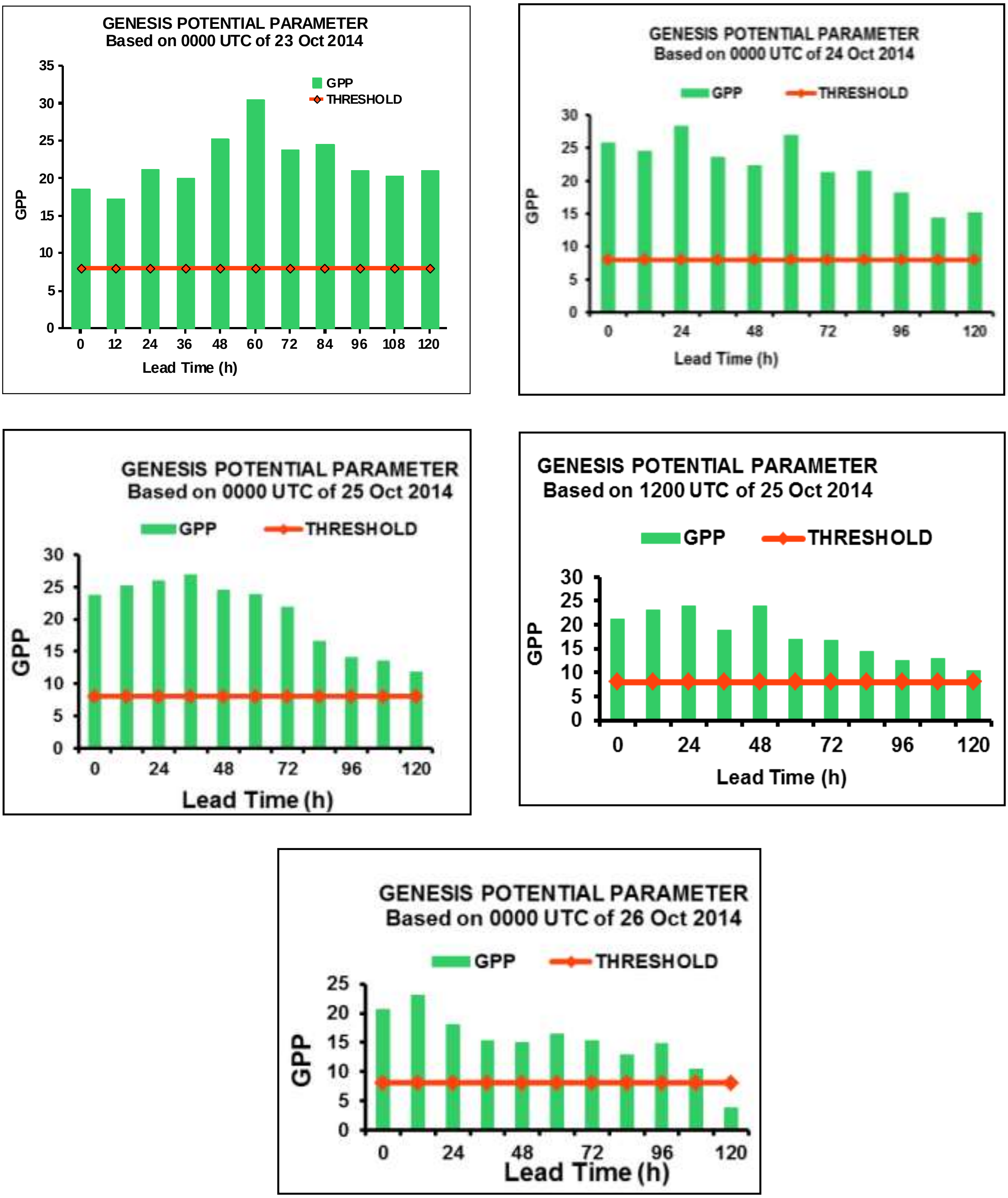


Fig. 13 (a-e) Area average analysis of GPP

(Product available at http://www.imd.gov.in/section/nhac/dynamic/gpp.pdf)

8.2 Track and intensity prediction by NWP models

The track forecast of MME models are shown in Fig.14. It indicates that the MME could predict the re-curvature of the system. The track forecast by HWRF model is shown in Fig. 15. The ensemble prediction tracks are shown in Fig. 16. The average track forecast errors (Direct Position Error) in km of NWP Models at different lead time (hour) is given in Table 3. The Average absolute errors and Root Mean Square (RMSE) errors of intensity forecast by SCIP and HWRF model are given in Tables 4 and 5 respectively. The VSCS track forecasts were also available from NGFS, NCUM and NGEFS run at NCMRWF (Fig. 17-20 and Table 6). Additionally the forecast tracks from NGEFS_BC (bias corrected) are also evaluated.

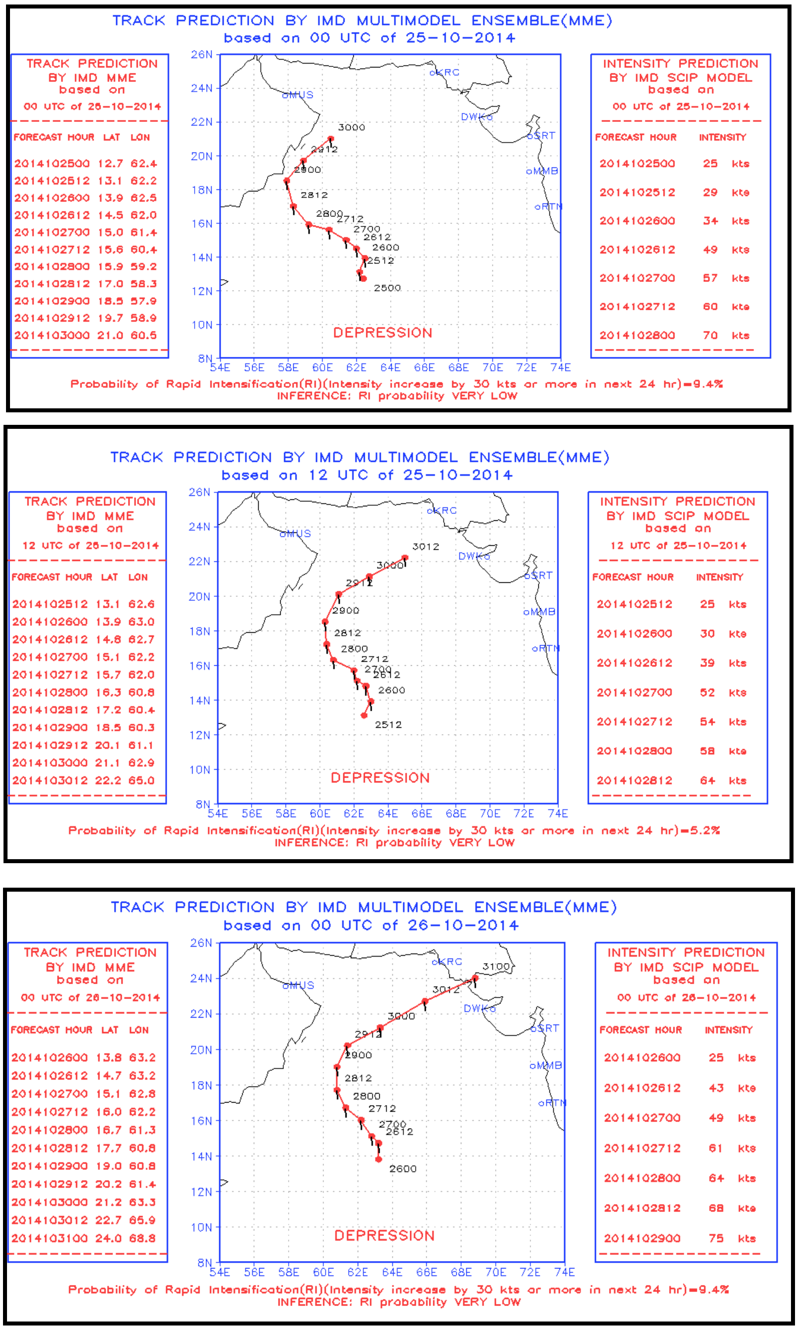
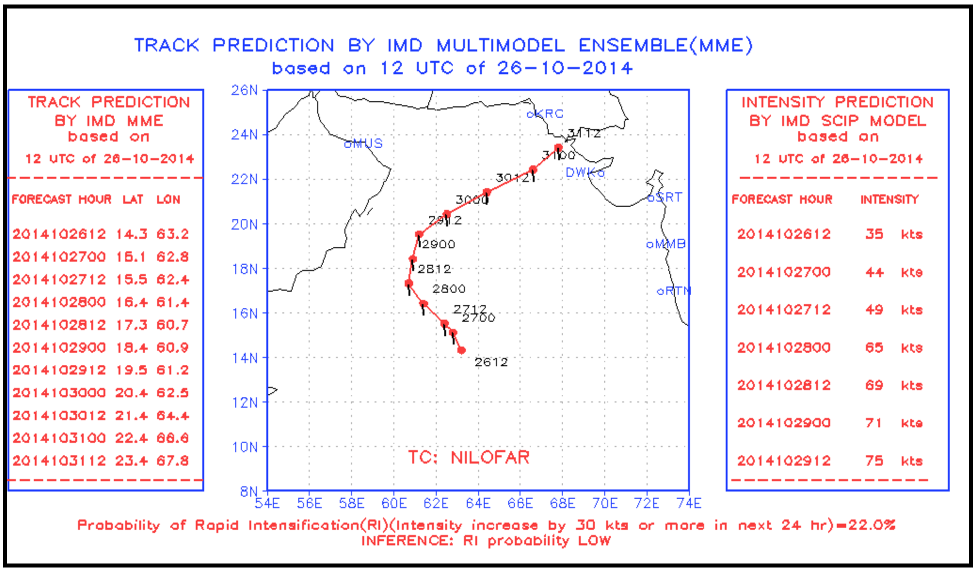
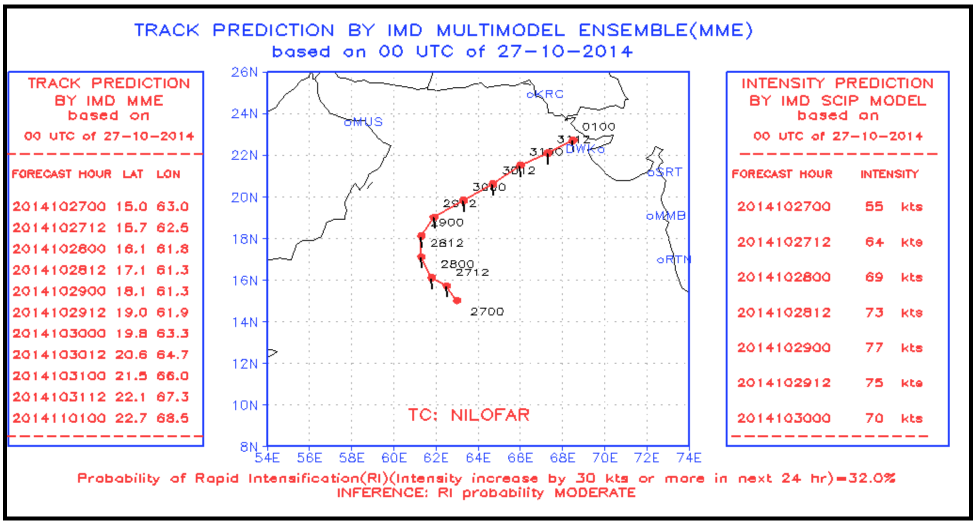


Fig. 14. MME track forecast based on 0000 & 1200 UTC of 25th – 30th October 2014 and 0000 UTC of 31st October 2014





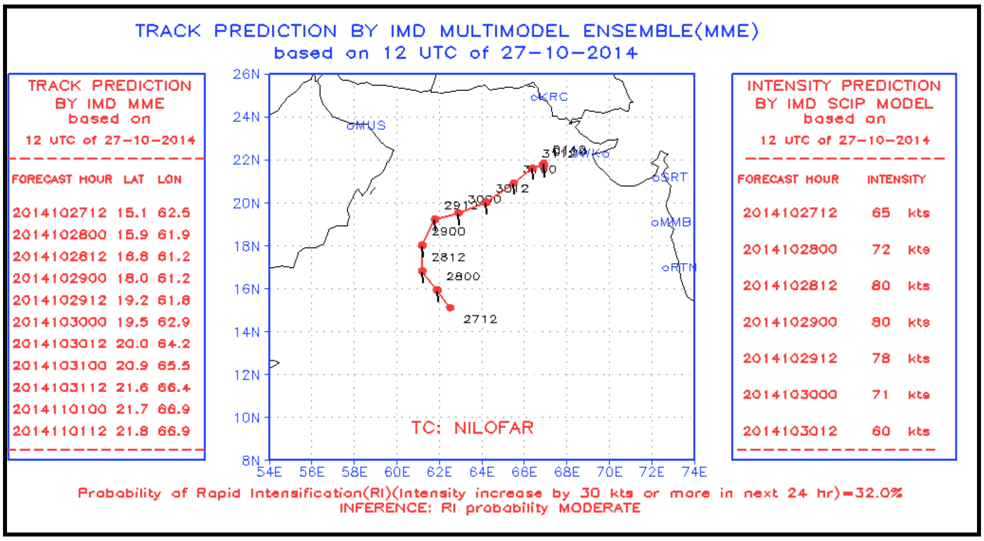


Fig. 14 (contd.). MME track forecast based on 0000 & 1200 UTC of 25th – 30th October 2014 and 0000 UTC of 31st October 2014

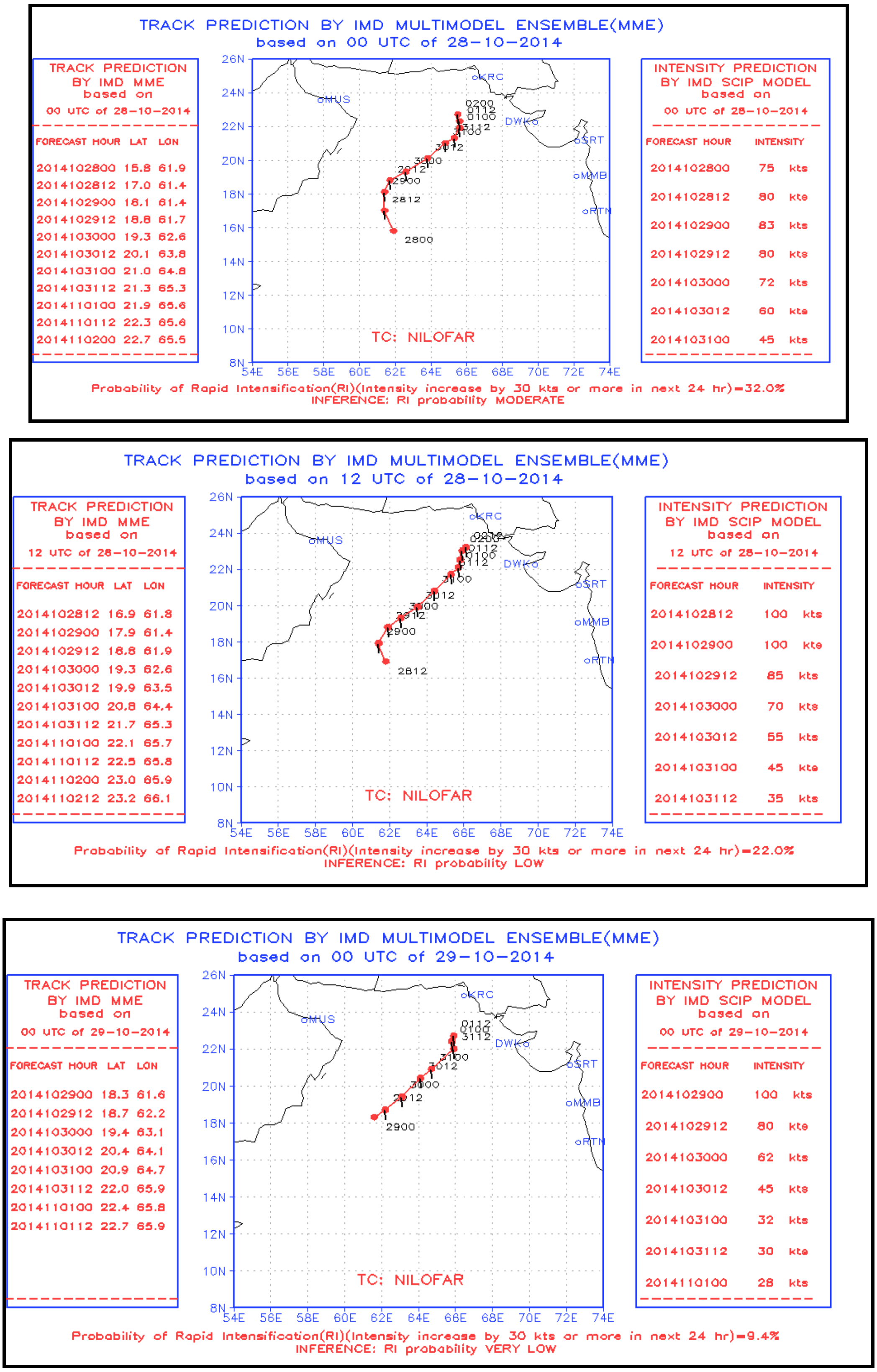


Fig. 14 (contd.) MME track forecast based on 0000 & 1200 UTC of 25th – 30th October 2014 and 0000 UTC of 31st October 2014

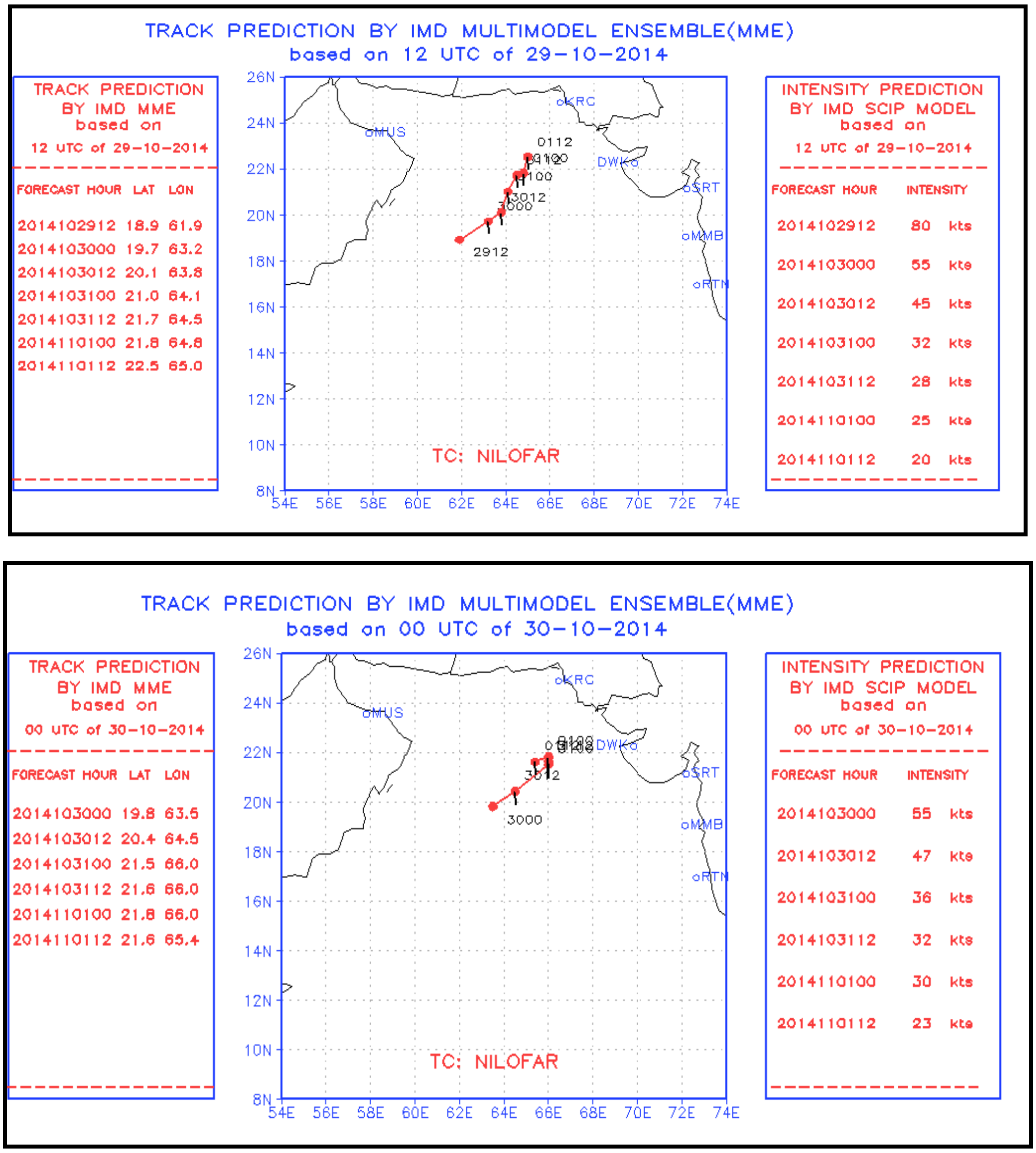


Fig. 14 (contd.) MME track forecast based on 0000 & 1200 UTC of 25th – 30th October 2014 and 0000 UTC of 31st October 2014

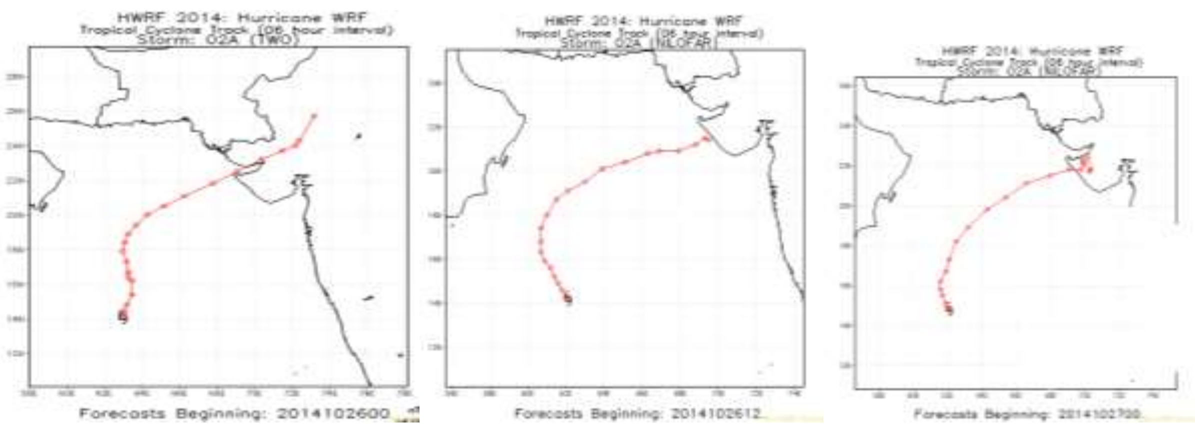


Fig. 15: HWRF track forecast based on 0000 & 1200 UTC of 26th – 30th October 2014

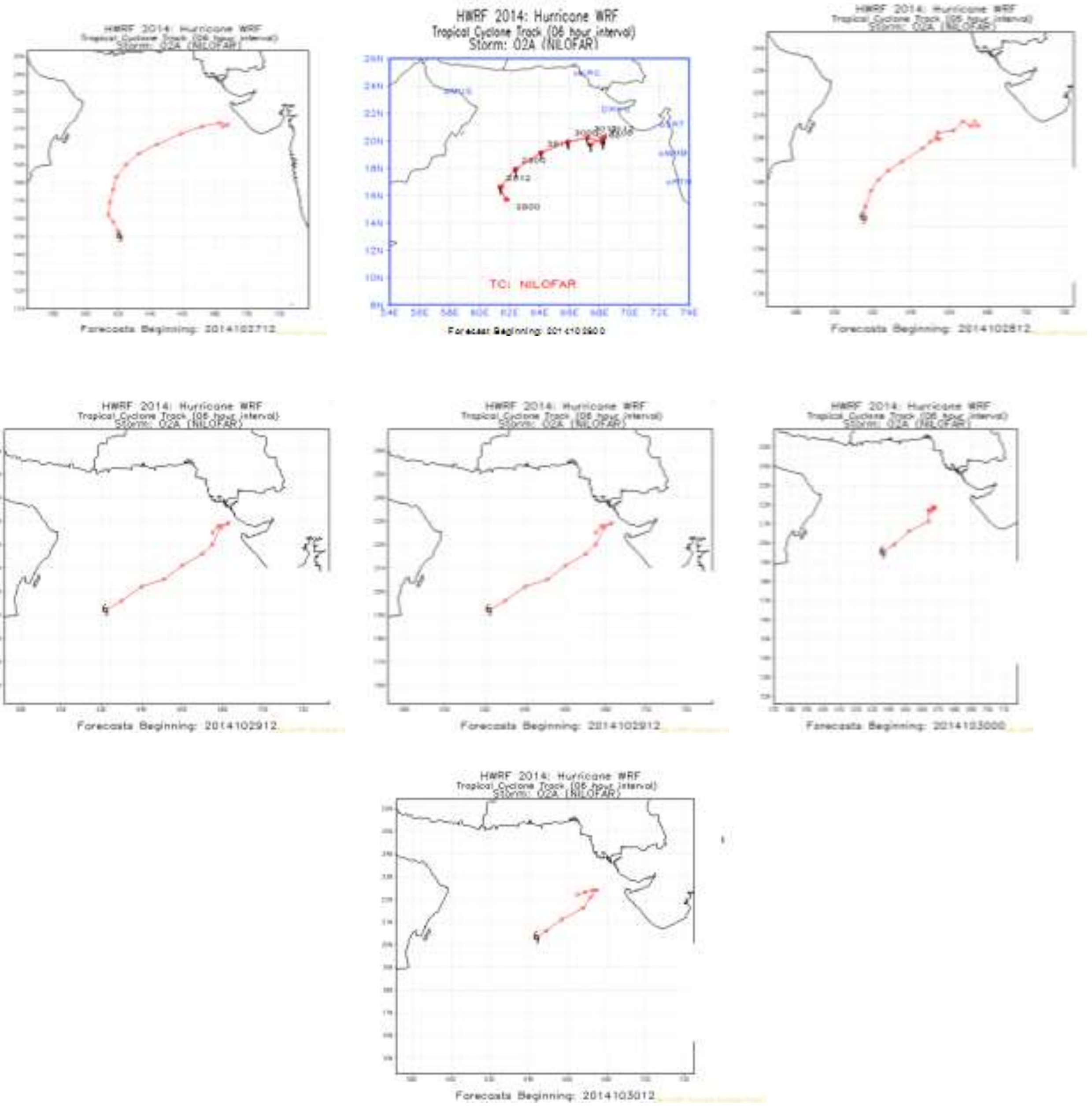


Fig. 15 (contd.): HWRF track forecast based on 0000 & 1200 UTC of 26th – 30th October 2014

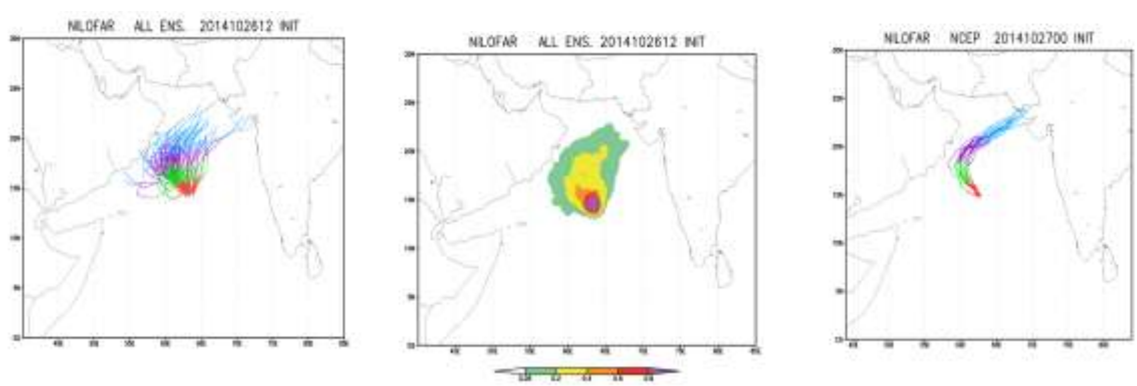


Fig. 16: EPS track forecast based on 1200 UTC of 26th and 0000 UTC of 27th October 2014.

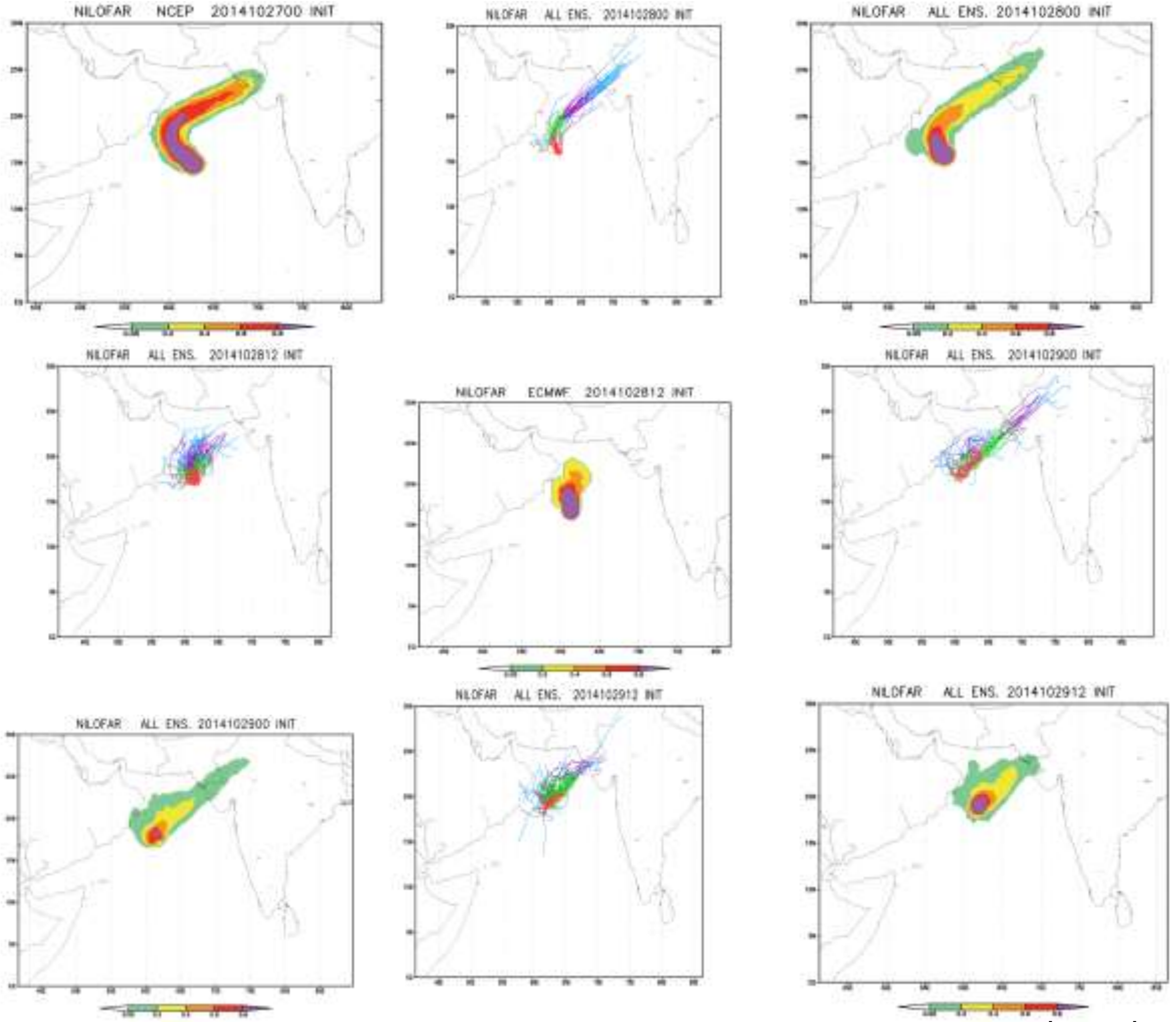


Fig. 16 (contd.) : EPS track forecast based on 0000 & 1200 UTC of 27th - 29th October 2014.

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	108 hr	120 hr
IMD-GFS	85(11)	111(11)	134(10)	171(9)	214(8)	261(7)	254(6)	259(5)	257(4)	392(3)
IMD-WRF	86(11)	107(11)	189(10)	320(9)	477(8)	645(7)	-	-	-	-
JMA	150(11)	151(11)	167(10)	156(9)	130(8)	82(7)	99(6)	-	-	-
NCEP-GFS	87(11)	80(11)	156(10)	184(9)	242(8)	255(7)	331(6)	313(5)	282(4)	342(3)
UKMO	113(10)	140(10)	166(10)	189(9)	185(8)	205(7)	275(6)	385(5)	560(4)	754(3)
ECMWF	80(11)	97(11)	131(10)	192(9)	243(8)	293(7)	304(6)	361(5)	376(4)	440(3)
IMD-HWRF	66(10)	106(9)	136(8)	165(7)	207(6)	284(5)	349(4)	455(3)	543(2)	849(1)
IMD-MME	76(11)	75(11)	77(10)	90(9)	108(8)	123(7)	152(6)	202(5)	266(4)	362(3)

( ) : number of forecasts verified

Table - 4 Average absolute errors of SCIP and HWRF model
(Number of forecasts verified is given in the parentheses)

Lead time	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	6.3(11)	9.8(11)	10.5(10)	13.8(9)	18.6(8)	18.0(7)	-	-	-	-
IMD-HWRF	17.4(10)	11.7(9)	14.0(8)	14.6(7)	19.0(6)	24.8(5)	28.3(4)	30.3(3)	22.5(2)	5.0(1)

Table - 5 Root Mean Square (RMSE) errors of SCIP and HWRF model
(Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	8.1(11)	12.3(11)	13.4(10)	16.8(9)	21.0(8)	21.2(7)	-	-	-	-
IMD-HWRF	21.5(10)	14.0(9)	16.4(8)	15.2(7)	22.3(6)	29.5(5)	30.2(4)	34.7(3)	27.3(2)	5.0(1)

Table 6. Track Forecast Errors in km for the model products of NCMRWF

	00hr	24hr	48hr	72hr	96hr	120hr
NGFS	**26**	**120**	**126**	**199**	**249**	**79**
NGEFS	**3**	**125**	**181**	**263**	**356**	**443**
NGEFS_BC	**2**	**124**	**116**	**127**	**240**	**350**
NCUM	**85**	**169**	**238**	**304**	**212**	**232**
No. of forecasts verified	*5*	*5*	*4*	*3*	*2*	*1*

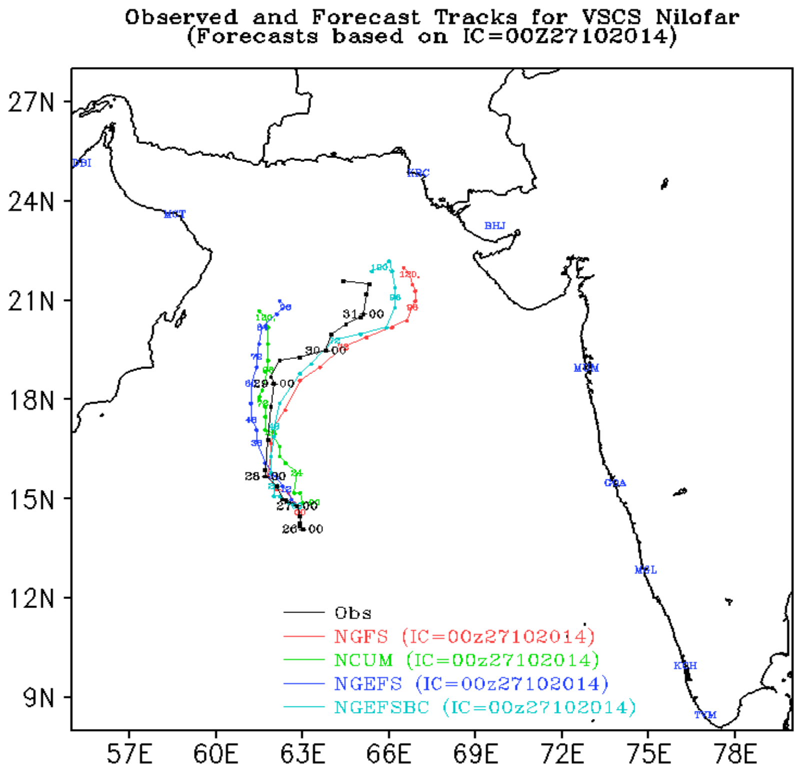


Fig. 17. Track forecasts of the models run at NCMRWF

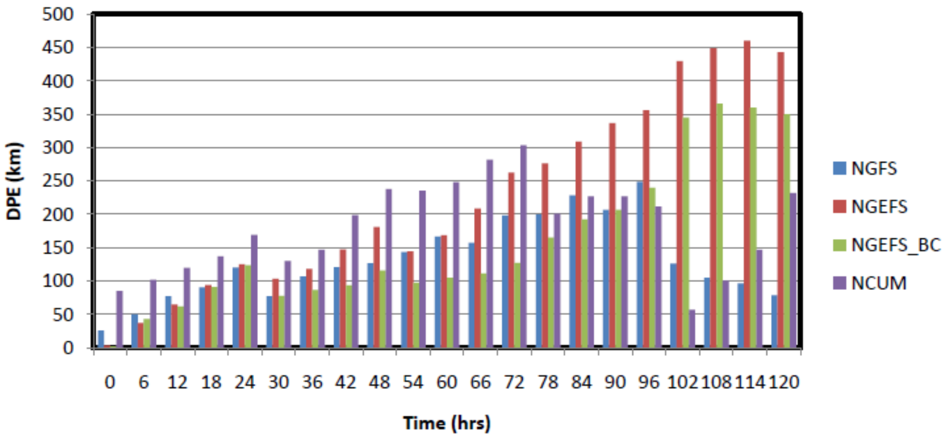


Fig. 18 . Track forecast errors (Direct Position Errors) of different models run at NCMRWF during 26-31 Oct. 2014

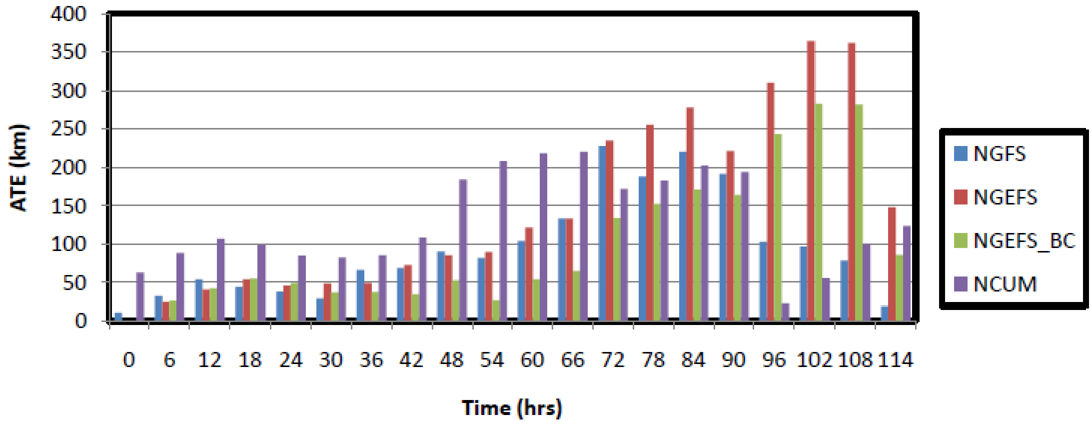


Fig. 19. Along Track Error (ATE) of models during 26 - 31Oct2014

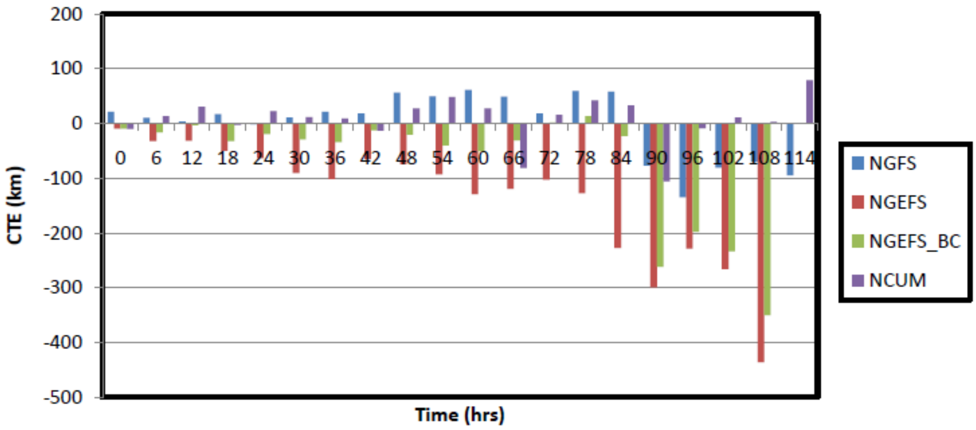


Fig. 20. Cross Track Error (CTE) of models during 26-31Oct2014

From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors was minimum for MME track. It was less than 100 km upto 48 hour forecast and about 100-200 km upto 96 hours. Comparing the individual deterministic models, the performance of NCEP-GFS was best for 24 hour forecast followed by ECMWF. The performance was better for NGFS and NGEFS for 48 hour forecast and it was better for JMA followed by NGFS for 72 hour forecast.

Some conclusions based on the performance of models run in NCMRWF for predicting the tracks of Nilofar are:

- Lowest initial position error is seen in NGEFS and NGEFS_BC (which is close to zero). The highest initial position error is seen in NCUM (85km).
- NGFS shows lowest error in the 24 hr forecast and NGEFS_BC has lowest error in 48, 72 and 96 hr. NCUM has highest error in 24, 48 and 72 hr forecasts and NGEFS shows highest error at 96 and 120 hr.
- Bias corrected NGEFS shows the lowest ATE, CTE and DPE for shorter lead times (84 hour forecast).
- For higher lead times (90 to 114 hour) forecast NGEFS raw shows the highest ATE, CTE and DPE.
- The ATE values are always positive at all lead times indicating that the forecast tracks from all the models are moving forwards at a faster rate as compared to the observed track.
- The CTE values from the ensemble system are negative at all lead times implying that the forecast tracks are always left of the observed track.
- The CTE from NGFS and NCUM for the first 90 hours are positive indicating that forecast tracks are to the right of the observations.

Intensity predicted by SCIP model and HWRF model shows that both the models could predict the intensification phase as well as decay phase of the very severe cyclonic storm NILOFAR. However, there was over prediction by HWRF for 60-108 hr forecasts.

8.3. Heavy rainfall prediction by NWP models

The heavy rainfall guidance from various models was also used for heavy rainfall warning. An example of HWRF model is shown in Fig.21. Comparison with actual rainfall (Fig. 11a) shows that the rainfall was over predicted by HWRF model.

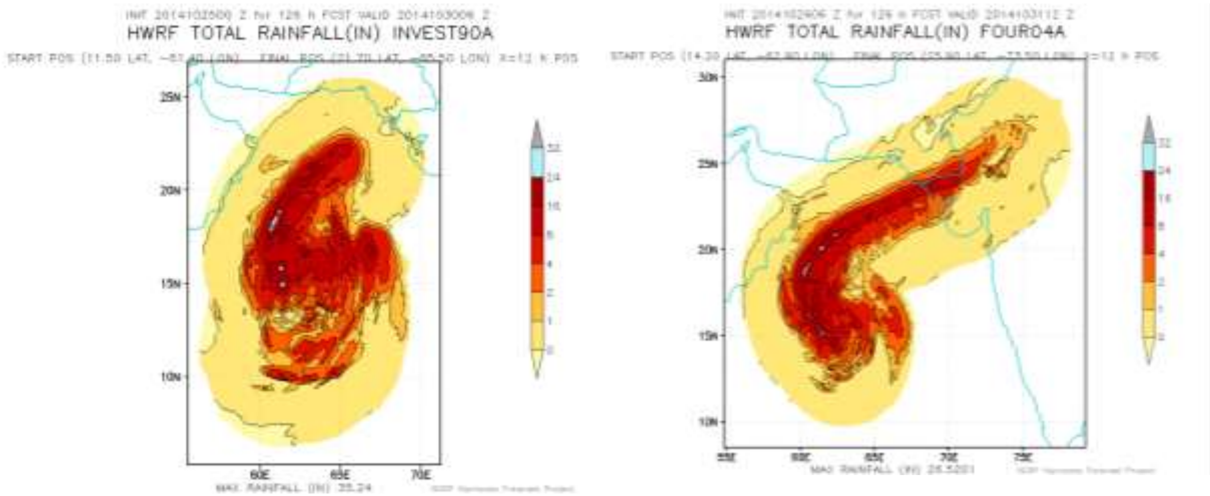


Fig. 21: IMD-HWRF rainfall guidance based on 25/00, 26/06, 27/00, 28/12, 29/00 and 30/00 UTC of October 2014

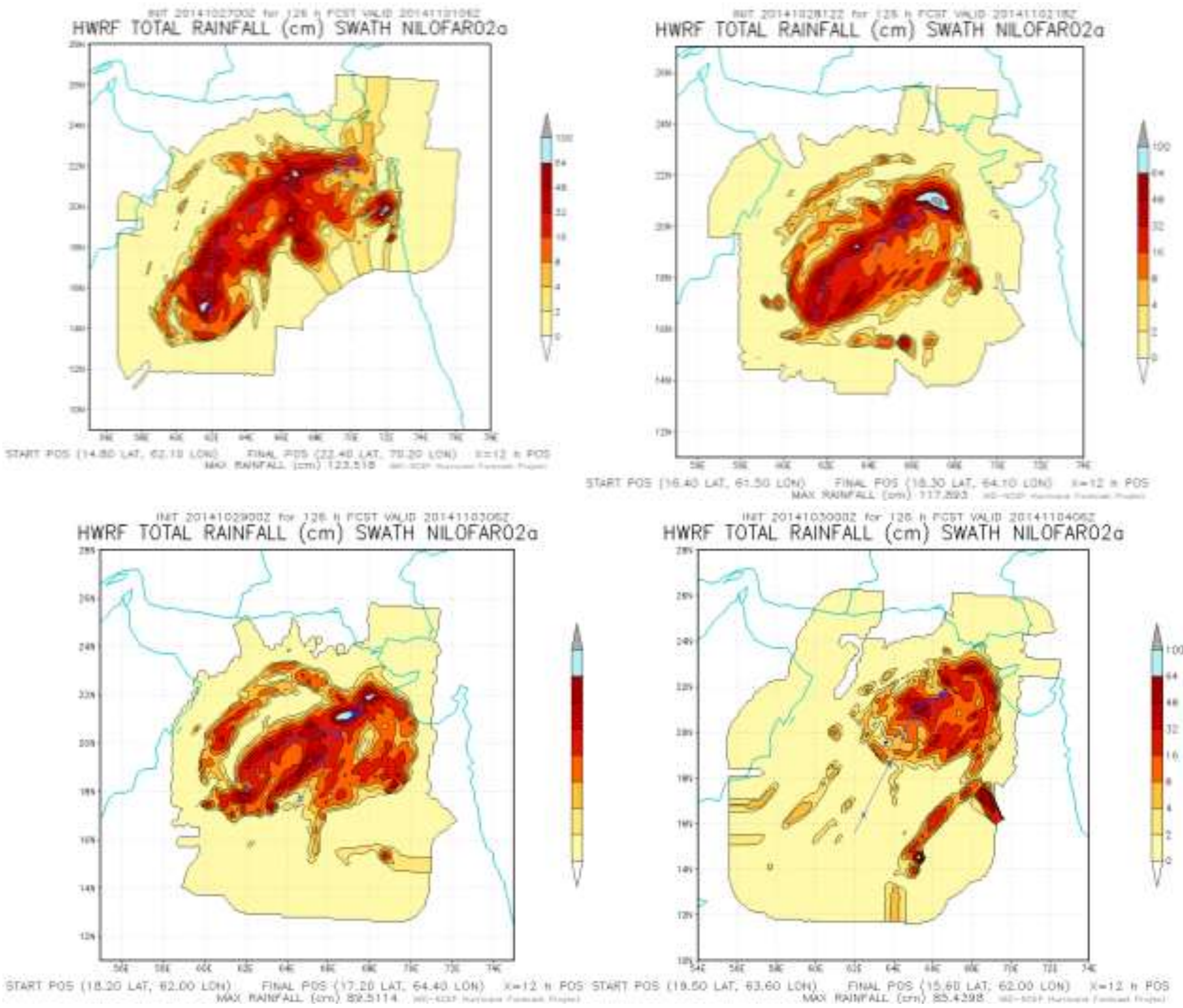


Fig.21 (contd.): IMD-HWRF rainfall guidance based on 25/00, 26/06, 27/00, 28/12, 29/00 and 30/00 UTC of October 2014

9. Bulletins issued by IMD

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. 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 prognostics and diagnostics of the systems were described in the RSMC bulletins. The Tropical Cyclone Advisory Centre (TCAC) bulletin was also sent to Asian Disaster Risk Reduction (ADRR) centre of WMO at Honkong. Tropical cyclone vitals were sent every six hour from deep depression stage onwards to various NWP modeling groups in India for bogusing purpose. Bulletins issued by IMD in association with VSCS NILOFAR are given in Tables 7-9.

Table 7: Bulletins issued by Cyclone Warning Division, New Delhi

Bulletins issued by Cyclone Warning Division, New Delhi in association with Very Severe Cyclonic Storm "NILOFAR" During the period 26-31 October 2014			
SN	Bulletin	No.	Issued to
1	National Bulletin	48	IMD's website 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, Chief Secretary-Govt of Maharashtra, Goa, Karnataka, Gujarat , Kerala, Daman & Diu, Command Meteorological Office, Mumbai. Email to a. Modelling Groups- IIT-DLH & BBN, NCMRWF, INCOIS. b. Command Meteorological Office, Mumbai, c. Chief Secretary- Govt of Maharashtra, Goa, Karnataka, Gujarat ,Kerala, Daman & Diu
2	RSMC Bulletin	47	IMD's website Through GTS and e-mail to All WMO/ESCAP member countries. Through e-mail to Indian Navy and IAF
3	Press Release	1	IMD's website Emails to : Senior Officers of NDMA, NDM, NDRF, MoHA, Modelling Groups- IIT-DLH & BBN, NCMRWF, INCOIS.
4	DGM's Bulletin for High Government Officials	04 (once per day)	FAX and E-mail to 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, Chief Secretary- Govt of Maharashtra, Goa, Gujarat, Adminstrator Dadra Nagar & Haveli and Daman & Diu
5	Personal Briefings At National level		IMD Participated and briefed Crisis Management Committee chaired by

			Cabinet Secretary, Chief Secretary, Special Relief Commissioner MHA
6	Personal Briefings At State level		Crisis Management Committee, Briefings to Chief Secretary, State Relief Commissioner, Disaster Management Authorities District Collectors by CWC Ahmedabad
7	TCAC Bulletin (Text & Graphics)	21	IMD's website (Through GTS) to International Civil Aviation (Through ftp) to International Civil Aviation
8	ADRR Bulletin to Hong Kong website	20	(Through ftp) to HongKong website
9	TC vitals For creation of synthetic vortex in NWP Models	19	(Through ftp) To: modelling group-NCMRWF, IIT, INCOIS, IMD NWP (Through E-mail).To: NCMRWF, IIT, INCOIS, IMD NWP
10	Quadrant Wind	19	E-mail to modelling group- NCMRWF, IIT, INCOIS, IMD NWP.
11	SMS to Senior Govt. Officials	06	Disaster Management Officers at National and State level

Table 8: Bulletins issued by Cyclone Warning Centre Ahmedabad

	Type of Bulletin	**Number**
1.	Port Warnings	11
2.	Fisherman Warning	6
3.	Coastal Weather Bulletin	11
4.	Cyclone informatory messages	8
5.	Cyclone Alert Bulletin	20
6.	All India Radio Bulletins	10
7.	Press Bulletin	4
8.	Heavy Rainfall Warning	1

Table 9: Bulletins issued by Area Cyclone Warning Centre Mumbai

	Type of Bulletin	**Number**
1.	Port Warnings	5
2.	Fisherman Warning	12
3.	Coastal Weather Bulletin	30
4.	Meetings with Chief Minister of State / Senior Government Officers	Regular briefing over Phone

10. Operational Forecast Performance

Following are the salient features of the bulletins issued by IMD (Table -10).

Table 10: Salient features of the bulletins issued by IMD

Date and Time	Current Status	Forecast issued
20.10.2014 (Morning)	Cyclonic circulation over southeast Arabian Sea	A low pressure area may form over South Arabian Sea during next 48 hours and may subsequently concentrate into a depression
21.10.2014 (Morning)	Low pressure area over southeast Arabian Sea	Likely to become well-marked low during next 48 hours.
23.10.2014 (Morning)	Well-marked low pressure area over southeast and adjoining eastcentral Arabian Sea.	It would concentrate into a depression during next 24 hours. It would move initially northwestwards and may intensify into a cyclonic storm.
25.10.2014 (0530 IST)	Depression over westcentral and adjoining southwest Arabian Sea	It would intensify into a deep depression within next 24 hrs and may intensify further into a cyclonic storm during subsequent 24 hrs. It would move initially west-northwestwards.
26.10.2014 (0830)	Deep Depression over westcentral and adjoining southwest Arabian Sea.	It would intensify into a Cyclonic Storm during next 12 hrs and into a severe cyclonic storm during subsequent 24 hrs and subsequently into a very severe cyclonic storm. It would move initially north-northwestwards during next 48 hrs and then recurve northeastwards towards North Gujarat and adjoining Pakistan coast. While moving towards north Gujarat coast, it would weaken into a severe cyclonic storm with wind speed of 90-100 kmph.
27.10.2014 (0530 IST)	Severe Cyclonic Storm over westcentral and adjoining southWest Arabian Sea	It would intensify further into a Very Severe Cyclonic Storm (130-140 kmph gusting to 155 kmph) during next 24 hrs. It would move initially northwards during next 24 hrs and then recurve northeastwards and cross North Gujarat and adjoining Pakistan coast around Naliya by 31st October as a severe cyclonic storm with wind speed of 100-110 kmph.
28.10.2014 (1130 IST)	Very Severe Cyclonic Storm over westcentral Arabian Sea.	Maximum wind speed would be 160-170 kmph gusting to 185 kmph. It would cross North Gujarat and adjoining Pakistan coast around Naliya by 01st November Forenoon. As the system would come closer to Gujarat coast, it would weaken and cross the coast as a Cyclonic Storm (80-90 kmph).
28.10.2014 (1730 IST)	Very Severe Cyclonic Storm over westcentral Arabian Sea.	Maximum wind speed: 200-210 kmph gusting to 230 kmph.
29.10.2014 (0830 IST)	Very Severe Cyclonic Storm over westcentral Arabian Sea.	As the system would come closer to Gujarat coast, it would weaken and cross the coast as a marginal Cyclonic Storm with wind speed of 60-70 kmph gusting to 80 kmph.
29.10.2014 (1730 IST)	Very Severe Cyclonic Storm over westcentral Arabian Sea.	As the system comes closer to Gujarat coast, it would weaken into a depression near North Gujarat coast by 31st October evening

8.1. Operational landfall forecast error

The system dissipated over the sea. However, a figure depicting the forecast track alongwith cone of uncertainty is shown below:

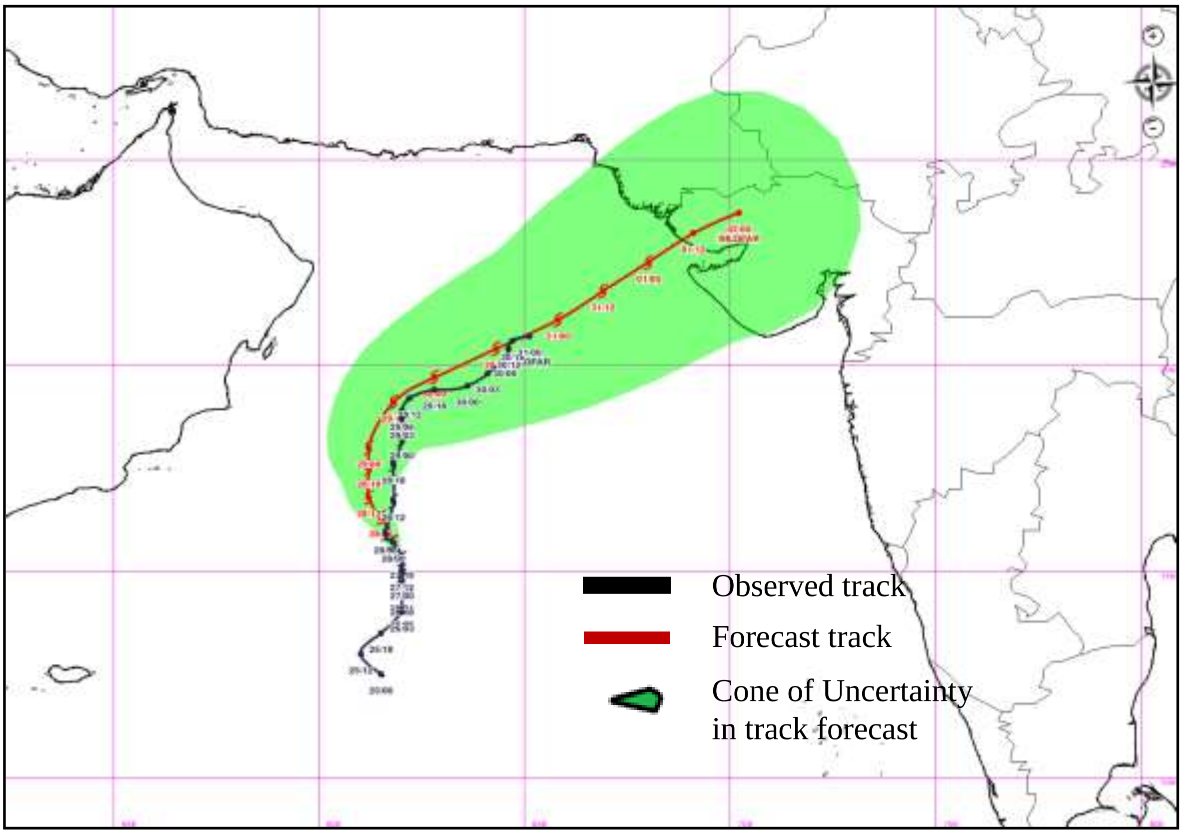


Fig. 22. An example of forecast track along with cone of uncertainty based on 0000 UTC of 28th October 2014.

10.2. Operational track and intensity forecast error and skill

The operational average track forecast errors and skill are shown in Table 11. It was less than 100 km for the forecast time scales upto 60 hrs. The track forecast skill varied from 59% to 89 % for various time scales and was significantly higher than long period average.

The operational intensity forecast error in terms of absolute error (AE) and root mean square error (RMSE) are presented in Table 12. The AE varied from about 10 knots to 24 knots in different time scales. However, comparing the skill, the skill in intensity forecast compared to persistence forecast varied from 17% to 84% for different lead periods and has been significantly higher as compared to long period average skill (Table 13). Considering the RMSE, it varied from 13 knots to 27 knots for different forecast time scales. The skill varies from 25% to 83% and is significantly higher than the long period average skills.

Table 11. Operational average track forecast errors and skill

Lead Period (hrs)	Track forecast error(km)	Track forecast skill (%) with reference to climatology and persistence forecast	Long period Average based on 2009-13	
			Track forecast error (km)	Track forecast skill (%)
12	64.7(17)	59	68.5	31.2
24	90.5 (15)	72	124.1	35.9
36	80.4 (13)	84	163.8	43.9
48	94.1 (11)	86	202.1	52.6
60	93.8 (9)	89	233.8	58.1
72	166.1 (7)	83	268.2	61.8
84	223.5 (5)	81	-	-
96	221.7 (3)	83	-	-
108	275 (1)	74	-	-

-:120 hr forecast has been introduced in 2013. Hence, no long period average is available for 84-120 hrs. ( ) : Number of six hourly forecasts verified. 120 hr forecast could not be verified as the cyclone dissipated over the sea.

Table -12. Operational Intensity forecast errors (knots)

Lead period (hrs)	Absolute Error	Root mean square (RMS) Error	Long period Average (2009-2013):	
			Absolute Error	RMS Error
12	10.0	12.8	10.4	14.0
24	17.1	19.6	15.7	20.5
36	23.7	27.4	20.5	25.2
48	23.9	27.4	22.5	27.6
60	21.6	25.4	23.5	26.4
72	17.4	19.3	26.7	30.8
84	15.3	17.5	-	-
96	22.2	22.5	-	-
108	21.8	21.8	-	-

Table - 13. Operational Intensity Forecast skill (%)

Lead period (hrs)	Skill (%) with reference to persistence forecast		Long period average Skill (%) based on 2009-2013	
	Absolute Error	RMS error	Absolute Error	RMS Error
12	16.9	24.8	10.4	14.0
24	31.7	47.5	15.7	20.5
36	34.4	54.1	20.5	25.2
48	57.9	67.1	22.5	27.6
60	58.7	59.1	23.5	26.4
72	75.4	77.0	26.7	30.8
84	84.1	83.5	-	-
96	11.9	76.4	-	-
108	75.8	75.8	-	-

10.3 Adverse weather forecast verification

The adverse weather warning verification is presented in Table 14-16.

Table 14. Gale wind forecast verification for VSCS NILOFAR (25-31 October 2014)

Date/ Time(IST)	Gale wind Forecast	Recorded wind
26.10.2014 / 1430	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Gujarat coast from 30th October morning.	**Gujarat:** **31st** October 2014 Dwarka recorded 30 kmph at 1435 IST and Okha recorded 25 kmph at 1828 IST Deesa recorded wind speed of 20 kmph.
27.10.2014 / 0530	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Gujarat coast from 30th October morning and would become 100-110 kmph gusting to 125 kmph at the time of landfall	
28.10.2014 / 0530	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Gujarat coast from 31st October night and would become 80-90 kmph gusting to 100 kmph at the time of landfall.	
29.10.2014 / 0830	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Gujarat coast from 31st October and would become 60-70 kmph gusting to 80 kmph at the time of landfall.	
29.10.2014 /1730	Squally wind speed reaching 40-50 kmph gusting to 60 kmph would prevail along and off Gujarat coast on 31st October.	
31.10.2014 /0230	Squally wind speed reaching 35-45 kmph gusting to 55 kmph would prevail along and off Gujarat coast today the 31st October.	

Table 15 Heavy rainfall forecast verification for VSCS NILOFAR (25-31 October 2014)

Date/ Time(IST)	Forecast Rainfall	Observed Rainfall
26.10.2014 / 1430	Rainfall at many places with isolated heavy to very heavy falls along coastal districts of Saurashtra and Kutch from 30th morning.	**Gujarat**: No rainfall due to weakening of the system over the sea itself
27.10.2014 / 0530	Rainfall at most places with isolated heavy to very heavy falls along coastal districts of Saurashtra and Kutch from 30th morning. Intensity would increase gradually with heavy to very heavy falls at a few places and isolated extremely heavy falls from the night of 30th.	
28.10.2014 / 0530	Rainfall at most places with isolated heavy to very heavy falls along coastal districts of Saurashtra and Kutch from 31st night.	
29.10.2014	Moderate rainfall at most places with heavy to very	

/ 1730	heavy falls at isolated places over all districts of Saurashtra and Kutch and North Gujarat on 30th and 31st October.	
30.10.2014 / 0830	Moderate rainfall at most places with isolated heavy to very heavy falls over Kutch and coastal districts of Saurashtra during next 48 hrs. Light to moderate rainfall at many places with isolated heavy falls over remaining districts of Saurashtra, North Gujarat and Southwest Rajasthan during the same period.	
31.10.2014 / 0230	Moderate rainfall at most places with isolated heavy to very heavy falls over Kutch and coastal districts of Saurashtra during next 24 hrs. Light to moderate rainfall at many places with isolated heavy falls over remaining districts of Saurashtra, North Gujarat and Southwest Rajasthan during the same period.	
31.10.2014 / 0830	Moderate rainfall at many places over Kutch and Saurashtra during next 24 hrs	

Description of spatial rainfall distribution: Isolated (one or two places): <25% of area gets rainfall; Scattered (A few places): 26-50% of area gets rainfall; Fairly Widespread (A many places): 51-75% of area gets rainfall; Widespread (Most places): 76-100% of area gets rainfall.
Description of rainfall intensity: Light: 2.5-7.5 mm; Moderate: 7.6-35.5 mm; Rather heavy: 35.6-64.4 mm; Heavy: 64.5-124.4 mm; Very Heavy: 124.5-244.4 mm

Table 16: Verification of storm surge prediction for TC NILOFAR

(25-31 October, 2014)

Forecast Storm surge above astronomical tide and area to be affected	Actual Storm Surge
No storm surge was forecast	No storm surge reported

11. Conclusions:

The very severe cyclonic storm, Nilofar had a unique track characteristic, alongwith rapid intensification and rapid weakening. Though this track could be predicted well with reasonable accuracy, the intensity was over predicted especially during its rapid weakening phase. Of course, the weakening of the cyclone was indicated in the bulletin even when the cyclone was in intensification phase. Due to over prediction of intensity during rapid weakening phase, there was over warning of wind and rainfall over Saurashtra & Kutch coast. These aspects of rapid weakening near the coast before landfall need further improvement.