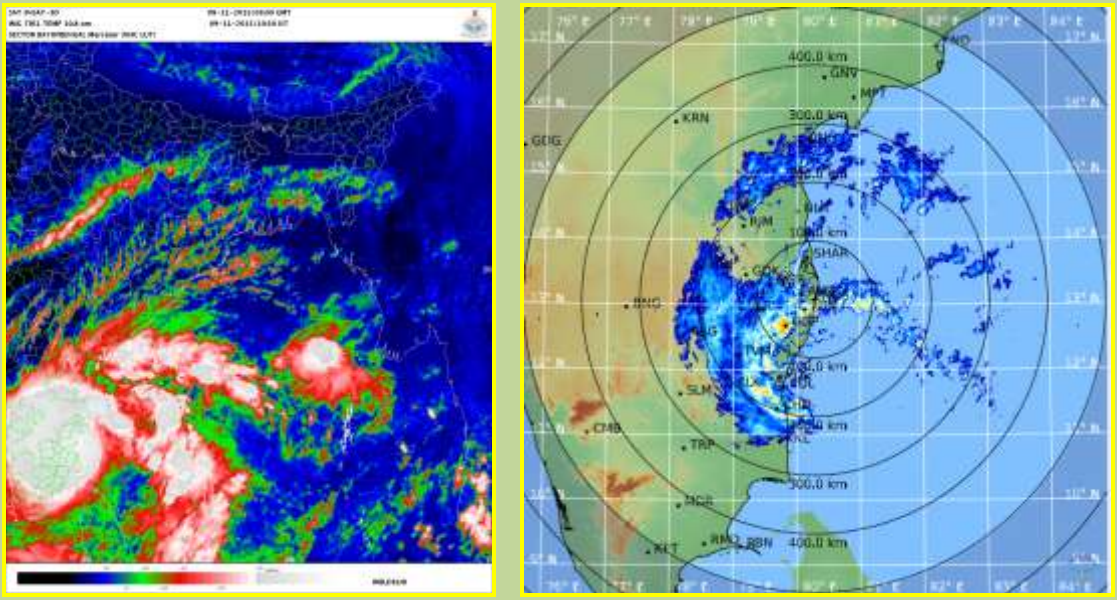
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
EARTH SYSTEM SCIENCE ORGANISATION
INDIA METEOROLOGICAL DEPARTMENT

Deep Depression over the Bay of Bengal (08-10 November 2015): A Report



Satellite imagery at 09/0500 UTC and Doppler Weather Radar, Chennai imagery at 09/0300 UTC of Deep Depression (08-10 November 2015)

Cyclone Warning Division

India Meteorological Department

New Delhi

November 2015

Deep Depression over the Bay of Bengal (08-10 November 2015)

1. Introduction

The Deep Depression (DD) over the Bay of Bengal (BOB) during 08-10 November 2015, formed from a low pressure area (LOPAR) that lay over southwest BOB on 06th. It concentrated into a depression (D; maximum sustained surface wind speed (MSW):17-27 kts) over southwest BOB close to north Tamil Nadu and Sri Lanka coasts at 0300 UTC (0830 IST) of 08th. Moving initially west-northwestward with a speed of 17 kmph, it intensified into a DD (MSW: 28-33 kts) around 08th/midnight. It subsequently moved slowly northwestwards at a speed of about 10 kmph towards north Tamil Nadu and Puducherry coasts on 09th morning. By 09th noon, when the system was close to the coast, it moved very slowly (with a speed of about 5 kmph) nearly northward off north Tamil Nadu and Puducherry coasts and made landfall over north Tamil Nadu coast close to north of Puducherry near latitude 12.2°N and longitude 80.0°E around 1930 hrs IST of 09th. Due to its proximity to the coast throughout the day, it caused exceptionally heavy rainfall over north Tamil Nadu on 9th. The salient features of this system are as follows:

(i) It was a short lived system, forming over southwest BOB close to Tamil Nadu and Sri Lanka coasts, intensifying into a DD and crossing coast within 36 hrs of formation.

(ii) On the day of landfall, the 9th November, maintaining the intensity of DD and moving very slowly northward along the coast, it caused heavy to extremely heavy rainfall over north Tamil Nadu. Even after landfall, the system moved slowly and dissipated over north Tamil Nadu, within about 100 km from the coast, by 1130 hrs IST of 10th November.

(iii) It weakened rapidly after landfall into a well marked low pressure area within 15 hrs of landfall.

(iv) It was the first cyclonic disturbance over the BOB during the post-monsoon season (October-December) of 2015. The activity over BOB in terms of frequency and intensity of cyclonic disturbances has been below normal during this season, mainly due to the fact that 2015 is a strong El Nino year and El Nino has adverse impact on cyclonic activity over BOB.

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 DD(08-10 November,2015)

The DD(08-10 November, 2015) was monitored & predicted by IMD continuously since its formation. Despite the system forming and intensifying close to the coast and making landfall within 36 hrs of formation, forecast of its genesis, movement, intensity, point & time of landfall, as well as associated adverse weather like heavy rain and strong wind were predicted well by IMD with sufficient lead time to enable civil

administrators and disaster managers to take necessary mitigatory actions. The genesis of the system on 08th November was forecast by IMD on 02nd November itself. Its movement towards north Tamil Nadu coast, maximum intensity it would attain (DD / Cyclonic Storm (CS; MSW: 34-47 kts) , landfall near to Puducherry coast and expected adverse weather such as extremely heavy rainfall along north coastal Tamil Nadu on 09th November were predicted by IMD even before its genesis, i.e., from 07th morning itself.

Since the pre-genesis stage itself, the system was monitored continuously by satellite based observations available at every half-an-hour interval. Enhanced INSAT-3D imageries formed the basic satellite input for cyclone monitoring. As the system formed close to the coast, the system was monitored with meteorological buoys, coastal and ship observations from the genesis stage onwards in addition to satellite based observations. Special hourly synoptic observations were taken along Tamil Nadu and Puducherry coasts from 08th morning onwards. As the system moved within the range of coastal radars, continuous radar observations were also taken at Doppler Weather Radar (DWR) facilities at Karaikal and Chennai. Observations from Automatic Weather Stations (AWS) and High Wind Speed Recorders (HWSR) installed along coastal Tamil Nadu also provided crucial data for successful monitoring of the system. Satellite data products and scatterometry products available from other leading meteorological services of the globe were also used for location, intensity and structure estimations.

Various national and international Numerical Weather Prediction (NWP) models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity prediction were utilized to predict the genesis, track and intensity of the system. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various model guidances, decision making process and warning products generation.

3. Brief life history

3.1. Genesis

Under active northeast monsoon conditions, an upper air cyclonic circulation lay over southwest BOB and adjoining equatorial Indian Ocean on 04th November 2015 which was observed over southwest BOB and neighbourhood extending upto mid-tropospheric levels on 05th. Under its influence, a LOPAR formed over southwest BOB off Sri Lanka and Tamil Nadu coasts on 06th morning which became well-marked over the same region on 07th. It concentrated into a Depression and lay centred at 0830 hrs IST of 08th November over southwest BOB off Tamil Nadu coast near latitude 10.7°N and longitude 83.7°E about 440 km east-southeast of Puducherry. According to satellite imagery, intensity at 08th/0300 IST was T 1.5 as convection became more organised during the previous 6 hours. Based on synoptic analysis using buoy, ship and coastal observations and satellite wind analysis products available from leading satellite based analysis centre, MSW was determined to be 25 knots gusting to 35 knots. Winds were higher over the northeast sector due to basic northeast monsoon circulation. The estimated central pressure was about 1004 hPa. State of sea around system centre

was rough to very rough. Minimum cloud top temperature associated with the system was -88°C.

The environmental features associated with the genesis of the system were high sea surface temperature (SST) near the system centre (around 29-30°C), increased upper level divergence and low level relative vorticity & convergence, moderate vertical wind shear (VWS; 10-20 kts) and favourable Madden-Jullian Oscillation (MJO) conditions [MJO index was in phase-3 (east equatorial Indian ocean) with amplitude greater than 1 which is favourable for genesis and intensification of cyclonic disturbances over the BOB].

3.2. Intensification and movement

On 08th/0300 UTC, the upper tropospheric ridge at 200 hPa level was observed along 16°N latitude. In association with an upper air anticyclonic circulation that lay to the northeast of the system centre, the middle and upper tropospheric winds near the system centre were east-southeasterly and the system was initially steered west-northwestward by the steering current. The system moved at a speed of about 20 kmph on this day under the influence of the anticyclonic circulation.

By 08th/1200 UTC, VWS near the system centre decreased considerably and was about 5-10 kts. This, along with other favourable environmental conditions of high SST near the system centre (around 29-30°C), increased poleward outflow above the system centre and favourable MJO conditions (as mentioned in previous section), caused intensification of the system and the system attained the intensity of DD on 08th/2330 IST near latitude 11.5°N and longitude 82.0°E. According to satellite imagery, the intensity was T 2.0.

On 09th 0300 UTC, as the system was located close to the coast, it started interacting with the land which restricted further intensification of the system. By 09th noon, the system started showing signs of slight weakening due to land interaction and slight increase in vertical wind shear. Subsequently, the system started moving northward off Tamil Nadu / Puducherry coasts into regions of higher VWS (20-30 kts) by 09th/1200 UTC. At 1200 UTC of 09th, the system was located near latitude 12.1°N and 80.1°E before crossing coast close to north of Puducherry near latitude 12.2° N and longitude 80.0°E around 1930 hrs IST of 09th with a wind speed of 55-65 kmph. By 09th/1800 UTC, the system was located over north coastal Tamil Nadu near latitude 12.4°N and 79.9°E. As the system was over land, moisture supply decreased considerably and under the influence of higher vertical wind shear, the system weakened gradually into a D on 10th by 0830 IST and subsequently into a well marked LOPAR by 1130 IST of 10th.

The observed track of DD (08-10 November, 2015) and the best track parameters of the system are given in Fig.1 and Table.1 respectively.

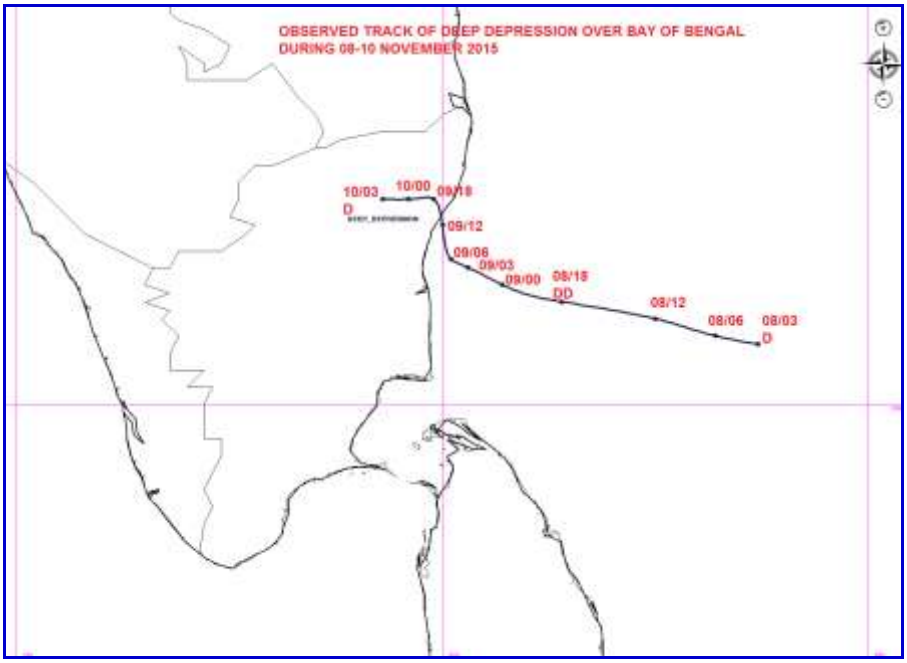


Fig.1 Observed track of Deep Depression over Bay of Bengal during 8-10 November 2015 (D: Depression; DD: Deep Depression)

Table 1: Best track positions and other parameters of Deep Depression over Bay of Bengal during 8-10 November, 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
08-11-2015	0300	10.7/83.7	1.5	1003	25	3	D
	0600	10.8/83.2	1.5	1003	25	3	D
	1200	11.0/82.5	1.5	1002	25	4	D
	1800	11.2/81.4	2.0	1000	30	5	DD
09-11-2015	0000	11.4/80.7	2.0	999	30	6	DD
	0300	11.6/80.3	2.0	998	30	6	DD
	0600	11.7/80.1	2.0	996	30	6	DD
	1200	12.1/80.0	2.0	996	30	6	DD
	Crossed north Tamil Nadu coast close to north of Puducherry near latitude 12.2°N/80.0°E around 1400 UTC						
	1800	12.4/79.9	-	998	30	6	DD
10-11-2015	0000	12.4/79.6	-	1000	30	5	DD
	0300	12.4/79.3		1002	20	4	D
	0600	Well marked low pressure area over north Tamil Nadu and neighbourhood.					

D: Depression; DD: Deep Depression

Speed and direction of movement of the system based on the best track parameters are furnished in Fig. 2. On 08th/0600 UTC, the six hourly average speed of movement of the system was high at about 20 kmph. Subsequently, its speed decreased gradually to about 12 kmph at 1800 UTC. The direction of movement was west-northwestward during this period. However, on 09th/0000 UTC, the direction of movement changed to northward and at 0600 UTC of 09th, speed decreased considerably to about 5-6 kmph when the system centre was located about 50-60 km from the coast.

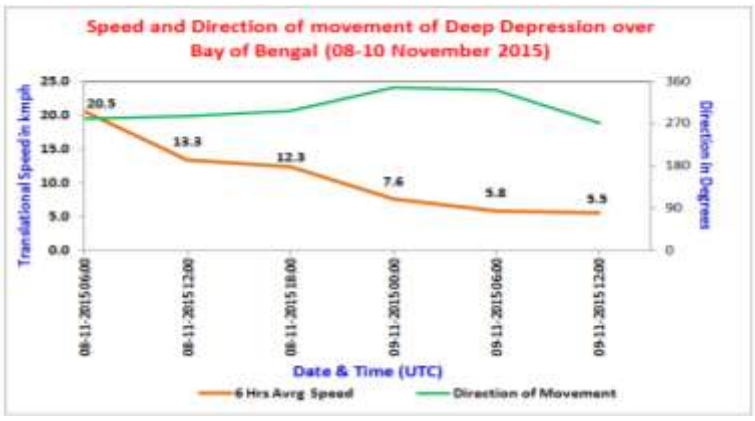


Fig.2 Speed and direction of movement of Deep Depression over Bay of Bengal (08-10 November 2015)

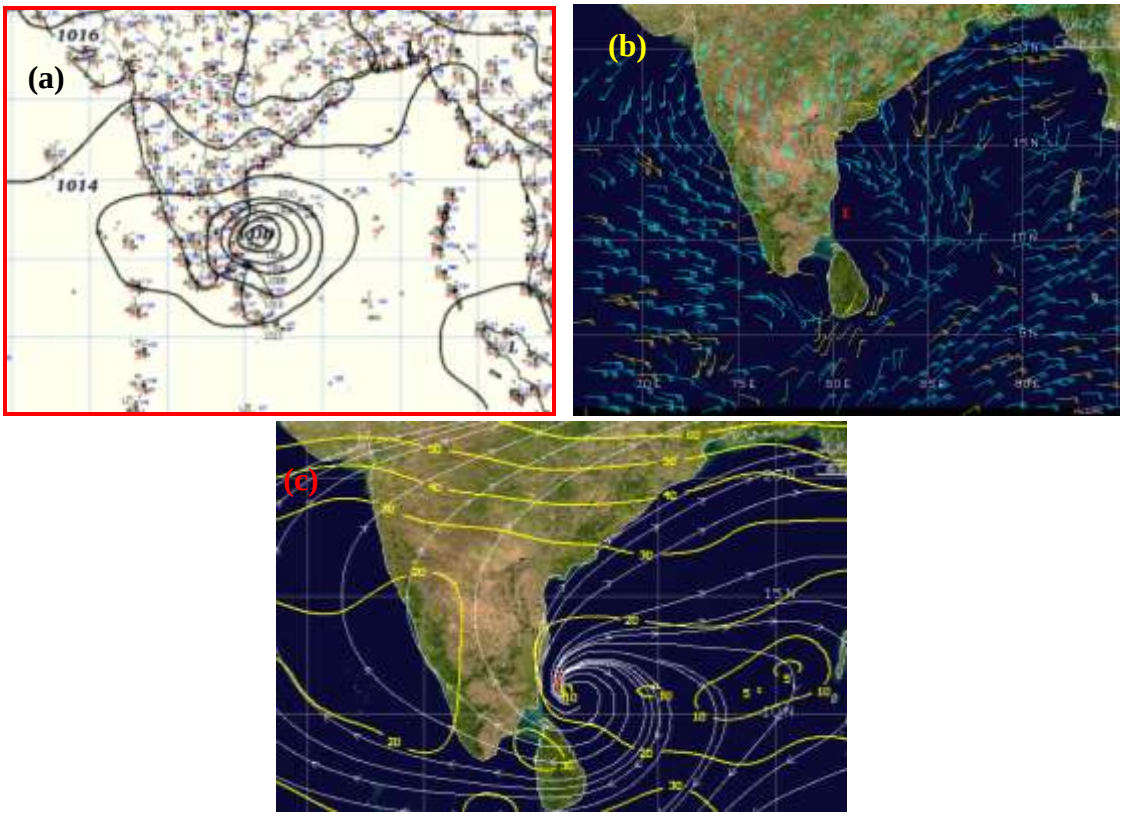


Fig.3 (a) Analysed surface chart (09/0300 UTC), (b) satellite based upper tropospheric winds (09/0000 UTC) and (c) vertical wind shear between upper and lower tropospheric levels (09/0000 UTC)
(Source for b & c: CIMSS Tropical Cyclones)

Synoptic features associated with the location, movement and intensification of the system on 09th when the system was close to the coast are depicted in Fig.3 – (a) surface analysed chart based on 09th/0300 UTC, (b) upper level winds based on 09th/0000 UTC satellite winds (CIMSS - METEOSAT-7 product) and (c) VWS based on 09th/0000 UTC (CIMSS - METEOSAT-7 product). The anti-cyclone located to the northeast of the system centre initially steered it west-northwestwards. However, subsequently, when the system moved to the southwestern periphery of the anti-cyclone, it was steered slowly northwards just prior to landfall.

4. Landfall

The place and time of landfall was determined through monitoring of hourly observations from the coastal stations as shown in Fig. 4. The veering of wind over Chennai and backing of wind over Puducherry along with the lowest pressure and maximum sustained surface wind over Puducherry clearly suggested landfall close to north of Puducherry by 1930 IST.

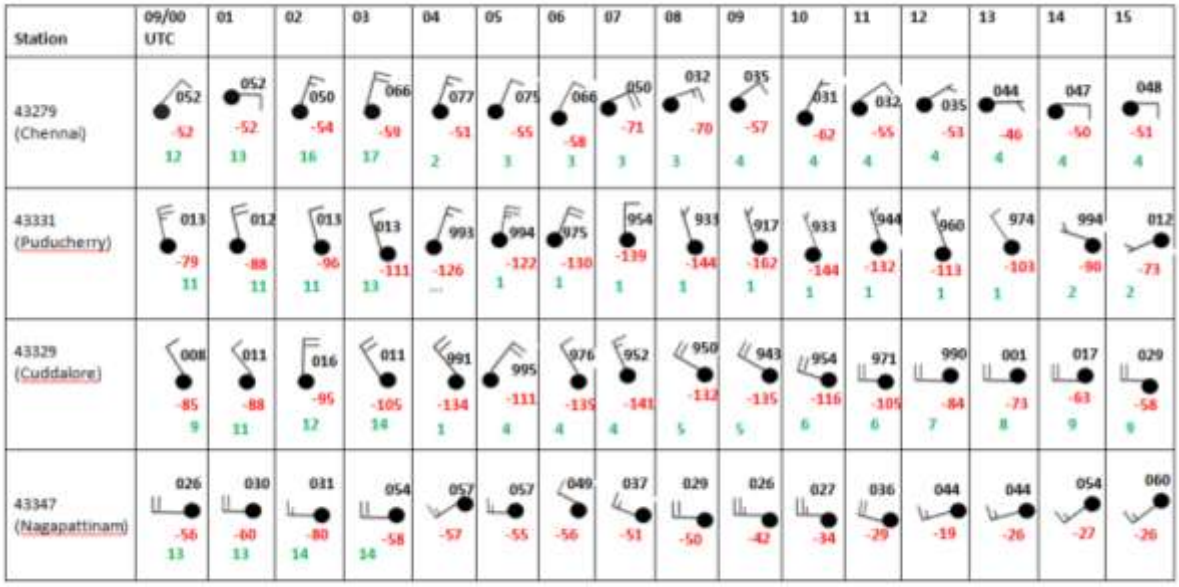


Fig. 4: Hourly observations from coastal stations on 09th November 2015

At 0600 UTC of 09th, the system centre was located about 40-50 km south-southeast of Puducherry. The lowest MSLP of 997.5 hPa was recorded at Puducherry and the ECP was 996 hPa. At 1200 UTC of 09th, the system was located about 30 km east-northeast of Puducherry with 996 hPa MSLP over Puducherry and ECP also about 996 hPa. However, Puducherry recorded the lowest MSLP of 991.7 hPa at 0900 UTC (1430 IST) of 09th thus indicating slight intensification of the system during this time. However, this intensity did not sustain as seen from increase in MSLP over Puducherry from 1000 UTC onwards indicating signs of weakening of the system just prior to landfall.

5. Maximum Sustained Surface Wind speed and estimated central pressure at the time of landfall:

The MSW in association with a cyclonic disturbance 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. As the system crossed north Tamil Nadu coast north of Puducherry, the MSW associated with it at the time of landfall is determined from coastal observations as well as wind speed recorded by the HWSR at Chennai and Karaikal. The DWRs at Karaikal and Chennai also continuously monitored the MSW in terms of radial velocity. Based on satellite imagery, intensity is estimated in terms of T number using Dvorak technique and using the empirical relation between the T.No and MSW, the corresponding MSW is estimated. Further, surface observatories along North Tamil Nadu and Puducherry coasts has continuously monitored the Mean Sea Level Pressure (MSLP) on the day of landfall, the 09th November. Based on the observation of the pressure drop at the centre, MSW is estimated using the empirical pressure-wind relationship (MSW= 14.2* √ pressure drop at the centre).

5.1 Estimated central pressure

The lowest MSLP of 991.7 hPa was recorded at Puducherry, located close to the point of landfall at 09th/0900 UTC. Hourly MSLP recorded at Puducherry on the day of landfall is shown in Fig.5a. At 0600 UTC, MSLP over Puducherry was 997.5 hPa and the ECP was 996 hPa and at 1200 UTC, the corresponding values were 996 hPa each. During the period from 0600 UTC to 0900 UTC, MSLP over Puducherry fell from 997.5 hPa to 991.7 hPa after which it started rising gradually as the system started moving slightly northwards along the coastline for some time before the landfall over north of Puducherry around 1400 UTC of 09th November.

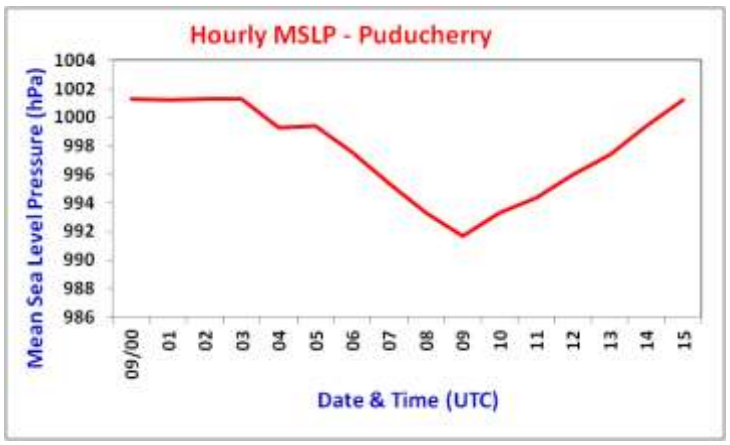


Fig.5a: Hourly MSLP recorded at Puducherry during 0000-1500 UTC of 09th November 2015

5.2. MSW based on coastal observations:

As the system was located very close to the coast when the system maintained the intensity of a deep depression, wind speeds recorded by hourly coastal observations

provided the crucial input for determination of MSW during the time of landfall. Fig.5b depicts the wind speed recorded at Cuddalore, Puducherry and Chennai (Meenambakkam) during 0000 UTC to 1500 UTC on 09th November 2015, the day of landfall. As seen, highest wind speed of 25 knots has been recorded by Puducherry observatory at 0000 and 0500 UTC of 09th. Wind speed over Puducherry decreased to less than 05 kts at 0800 UTC and continued to remain around 5 knots until landfall as the system centre was located close to Puducherry during the period 0800 to 1400 UTC prior to landfall.

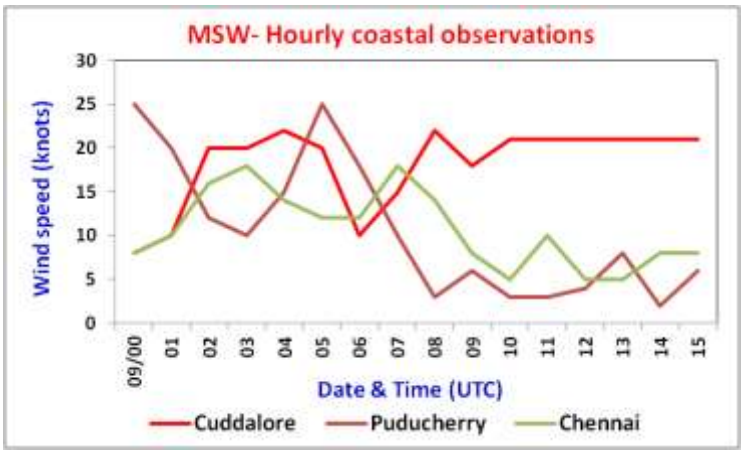


Fig.5b: Hourly wind speeds recorded by coastal observatories during 0000-1500 UTC of 09th November 2015

5.2. MSW based on HWSR:

HWSR Karaikal has recorded one -minute average MSW of 22 kts wind at around 0200 UTC (0730 IST) of 09th and HWSR Chennai, 20 kts at about 0530 UTC (1100 IST). The 3-minute average MSW (standard practice of IMD) was about 18 knots at Chennai around 1103 hours IST of 09th November 2015 (Fig.5c).

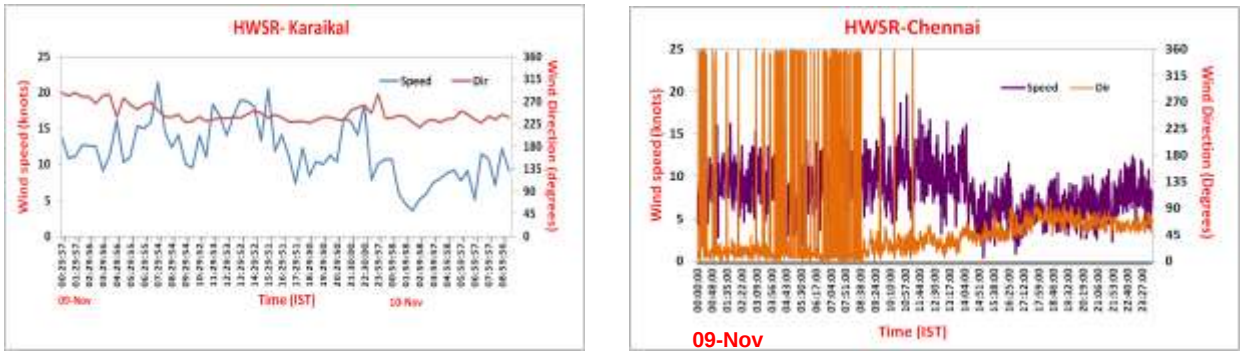


Fig.5c: Wind speed and direction recorded by Karaikal and Chennai High Wind Speed Recorders on 09th November 2015.

5.4. Satellite based MSW

As per IMD's intensity estimation based on Dvorak technique, maximum intensity of the system at the time of landfall was T2.0 which corresponds to an MSW of about 30 knots (55-60 kmph).

5.5 MSW based on satellite derived winds

NOAA satellite ASCAT winds indicate highest wind speeds of about 40 knots at around 0430 UTC of 09th (Fig.5d). This, when reduced to 3-min average wind, indicates MSW of about 30 knots.

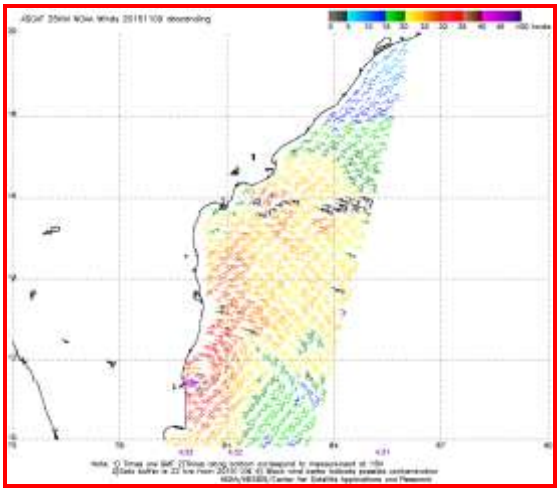


Fig.5d: NOAA-ASCAT winds at 0430 UTC of 09th November 2015

NOAA, NESDIS, Cooperative Institute for Research in Atmosphere (CIRA) multi-platform satellite wind analysis product indicated highest winds of 35 knots (one-minute average) on 08th/1800 UTC with stronger winds on the northeast and northwest sectors (Fig.5e).

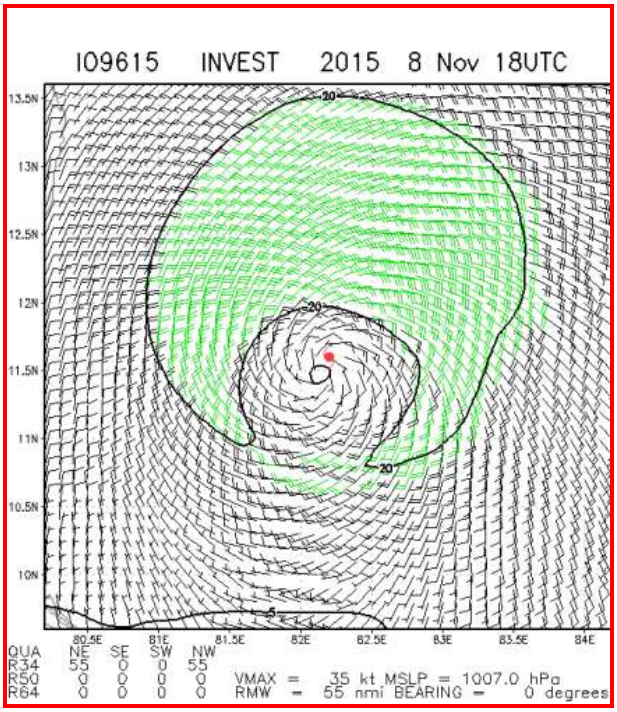


Fig.5e:CIRA-multiplatform satellite wind analysis product based on 08th/1800 UTC.

5.5. MSW based on radar

DWRs Karaikal and Chennai reported highest maximum radial winds on 09th at 0030 UTC and 0500 UTC respectively (Fig.5f). Highest maximum radial wind reported

by DWR Karaikal (at about 0030 UTC of 09th) works out to 42 knots radial wind (surface level, 3-min average) at a distance of about 40 km along 90° azimuth from the radar (Fig.5f). Highest maximum radial wind reported by DWR Chennai (at 0500 UTC of 09th) when reduced to surface level and corrected for 3-minute average works out to about 40 knots at a distance of about 150 km along 220° azimuth from the radar, near 12.0°N and 79.4°E (over land) (Fig.5f), against the surface wind of 25 knots reported by the nearest observatory, Puducherry at that time. The radar based winds also decreased gradually thereafter.

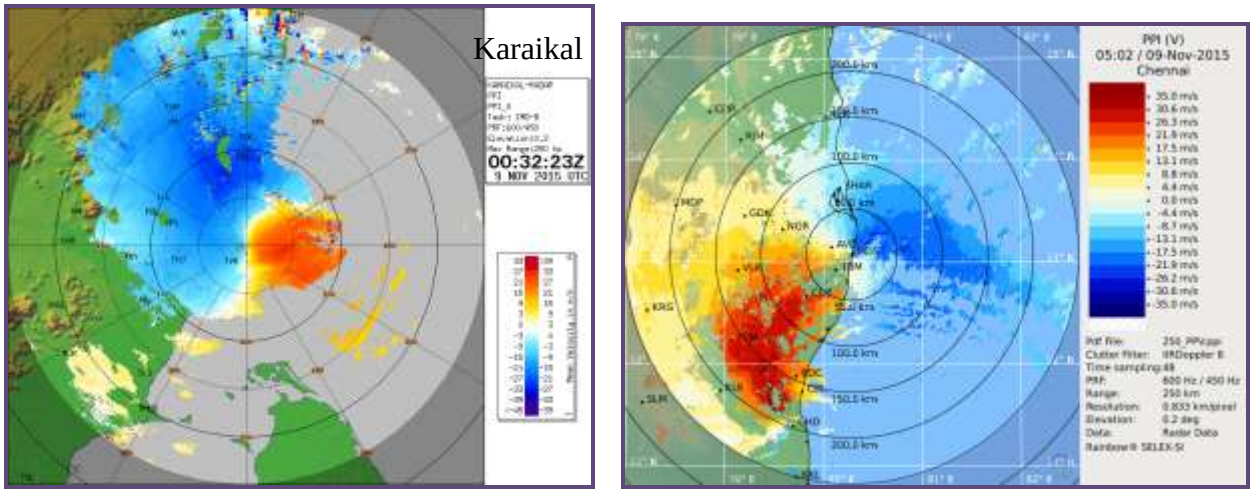


Fig.5f: DWR Karakal and DWR Chennai based radial wind observation at 0030 and 0500 UTC of 09th Nov 2015 respectively.

5.6. MSW based on pressure drop

According to the hourly coastal observations, the lowest MSLP of 991.7 hPa was recorded at Puducherry at 0900 UTC of 09th. Hence, the lowest central pressure could be considered as 991 hPa. Thus, the pressure drop at the centre could have been of the order of 11 hPa as the outermost pressure in the system was 1002 hPa. According to Mishra and Gupta formula, the MSW=14.2*SQRT (pressure drop) = 47 knots. Though this estimation ties in with radar estimation, recorded coastal wind observations do not indicate wind speeds greater than 25 knots.

5.7 Final estimate of MSW

Considering all these observations and estimates, it can be concluded that the system could have attained peak intensity of about 35-40 knots for a short while, around 0900 UTC of 09th. However, the MSW around the time of landfall was about 30 knots (55-60 kmph) based on coastal observations and satellite and radar based winds.

6. Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D imageries. Satellite imageries of international geostationary satellite Meteosat-7 and and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical INSAT-3D imageries representing the life cycle of the system are shown in Fig.6a-b.

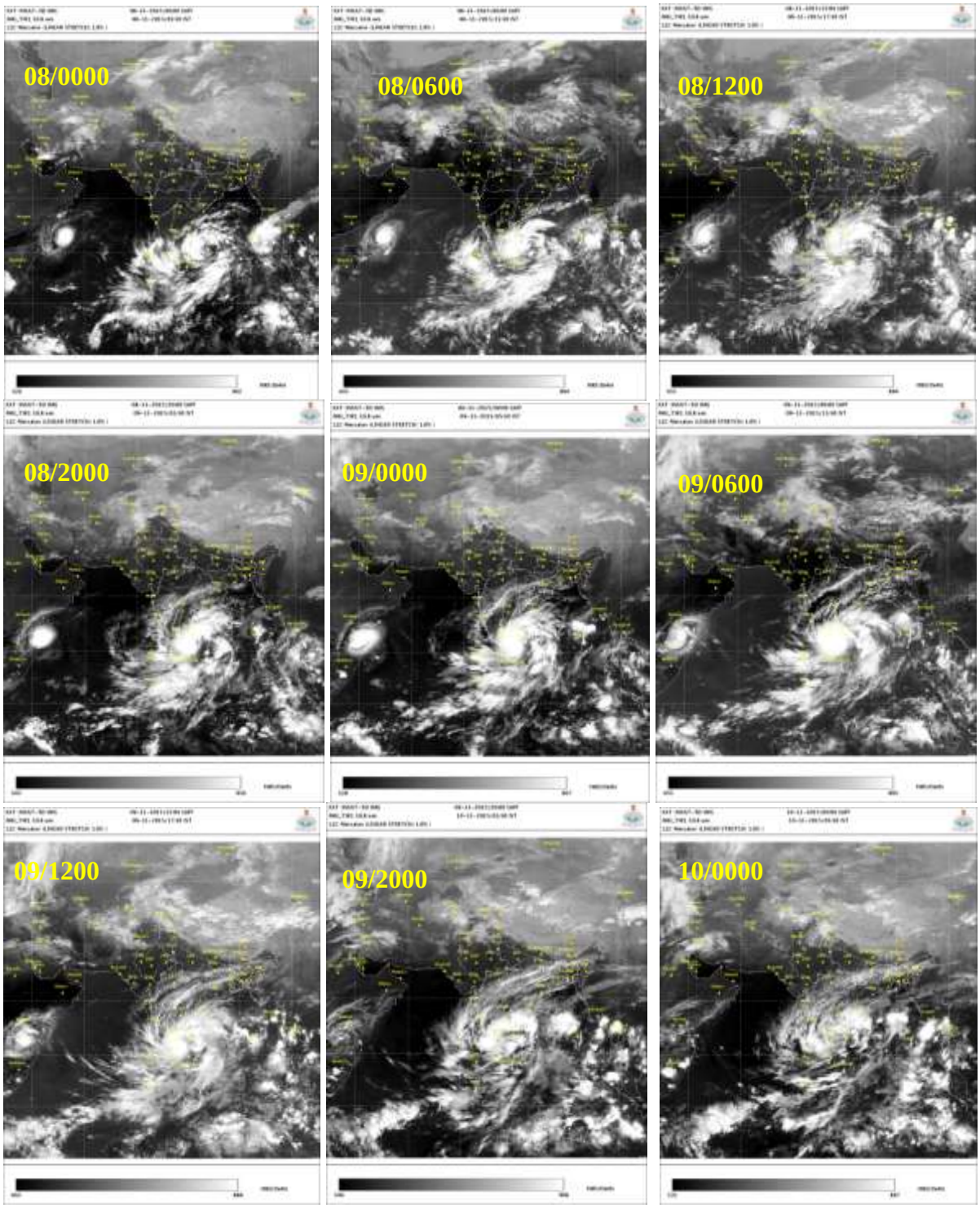


Fig. 6(a): Typical INSAT-3D Infra-red (IR) imageries in association with Deep Depression (08-10 November 2015)

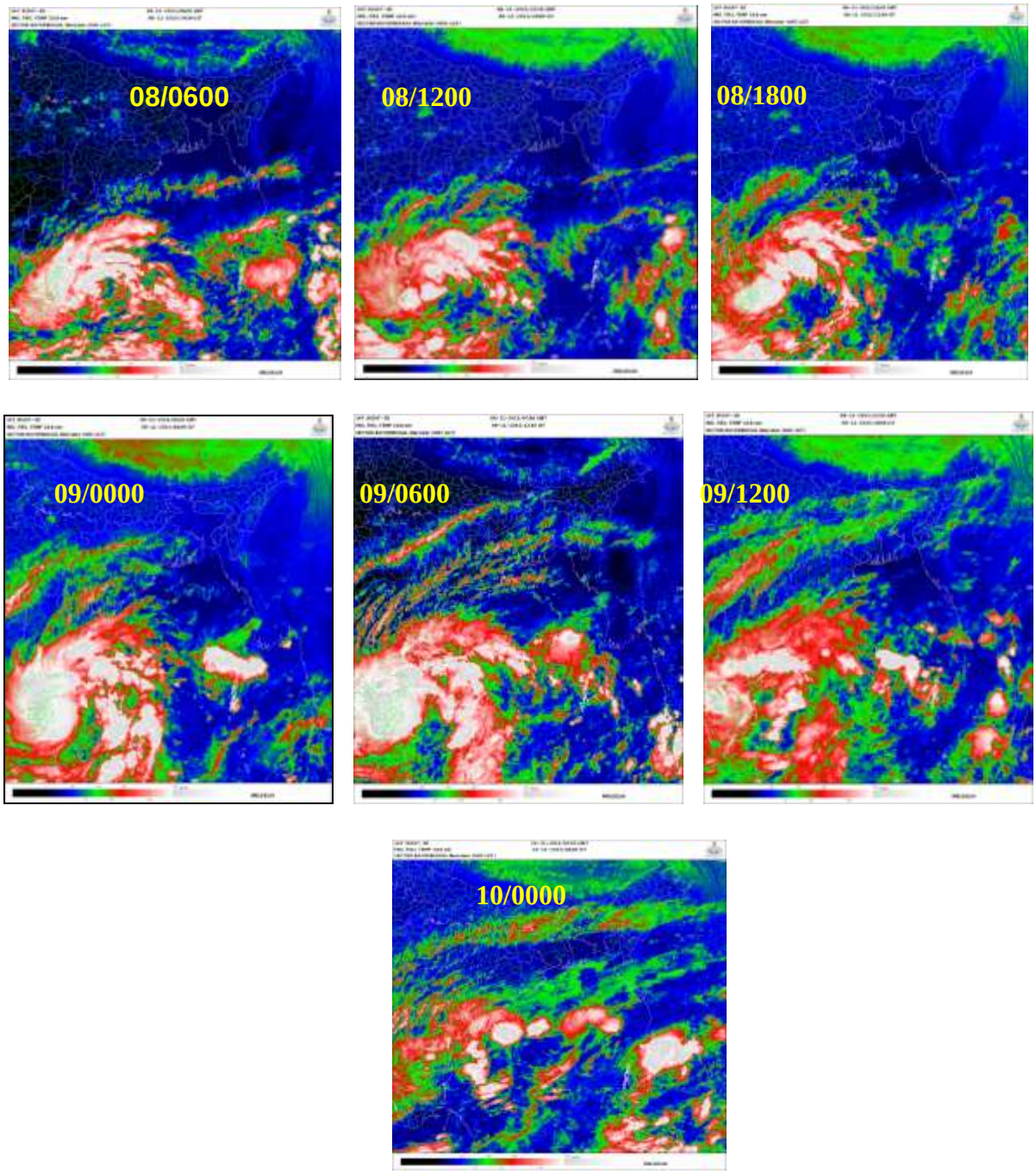


Fig. 6(b): Typical INSAT-3D enhanced Infra-red (IR) imageries in association with Deep Depression (08-10 November 2015)

According to INSAT-3D imageries and products, intensity of the system was T. 1.5 at 0300 UTC of 08th and convection showed shear pattern. Subsequently, the system intensified to T.2.0 at 1800 UTC of 08th and the convection showed curved band pattern. Lowest cloud top temperature associated with the system was -88.0°C. From 09th/0600 UTC onwards, intensity of the system could not be estimated as the system was located very close to land. Due to southwestward tilting of the system, the system centre, as observed through satellite, lay over land at about 0600 UTC of 9th.

7. Features observed through Radar

The Deep Depression (08-10 November 2015) was monitored by DWRs Karaikal and Chennai continuously when the system was within the range of these radars and hourly observations were taken. DWR Karaikal commenced hourly observations at 1800 UTC of 08th and DWR Chennai, at 09th/0000 UTC. Typical reflectivity products of both the radars, presented in Fig.7(a&b) indicate spiral band pattern. DWR Chennai reflectivity product based on 09th/1400 UTC also suggests landfall near north of Puducherry around 1400 UTC of 09th (Fig.7b).

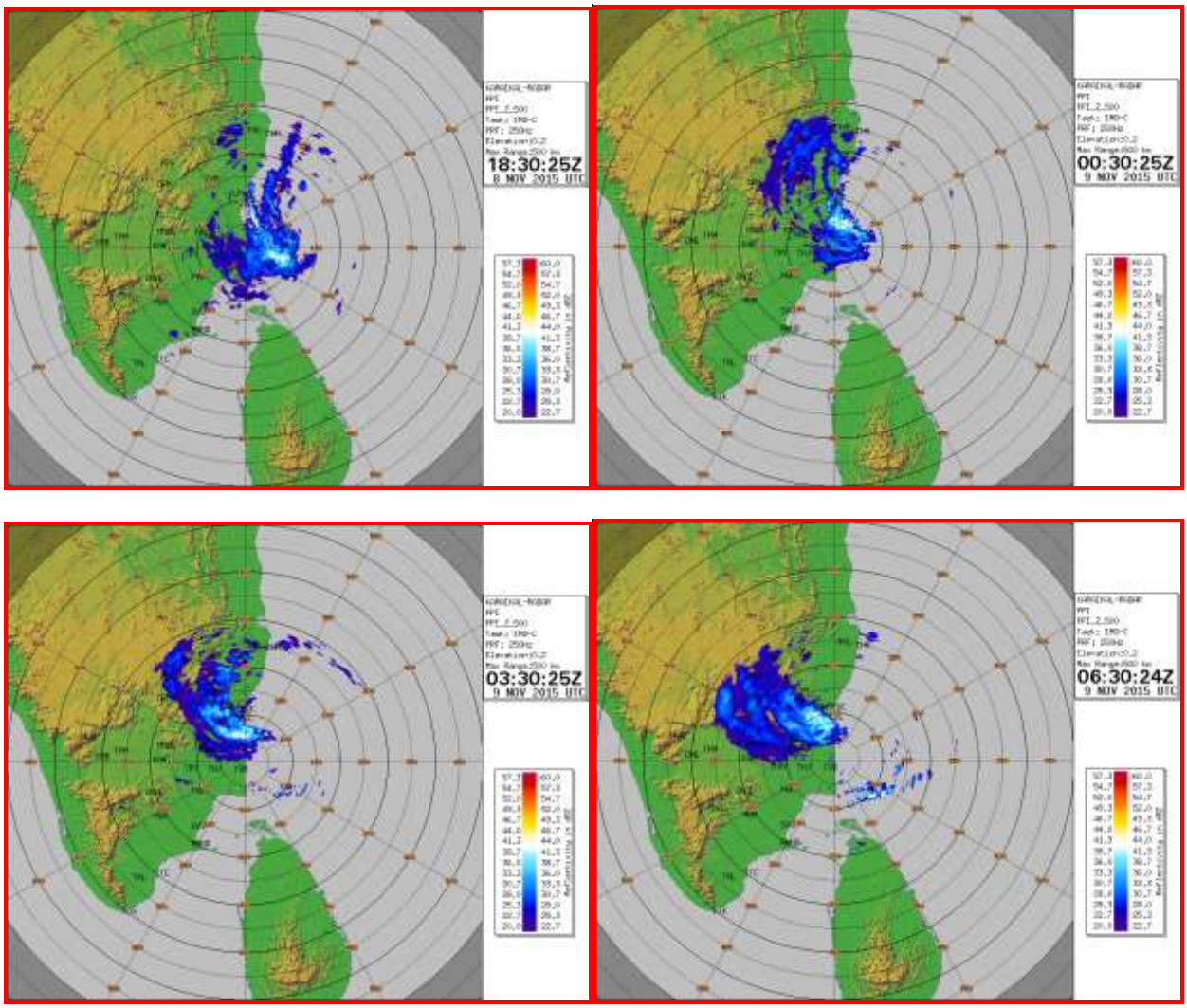


Fig.7a: DWR Karaikal imageries during 08th/1800 UTC to 09th/0600 UTC of November 2015

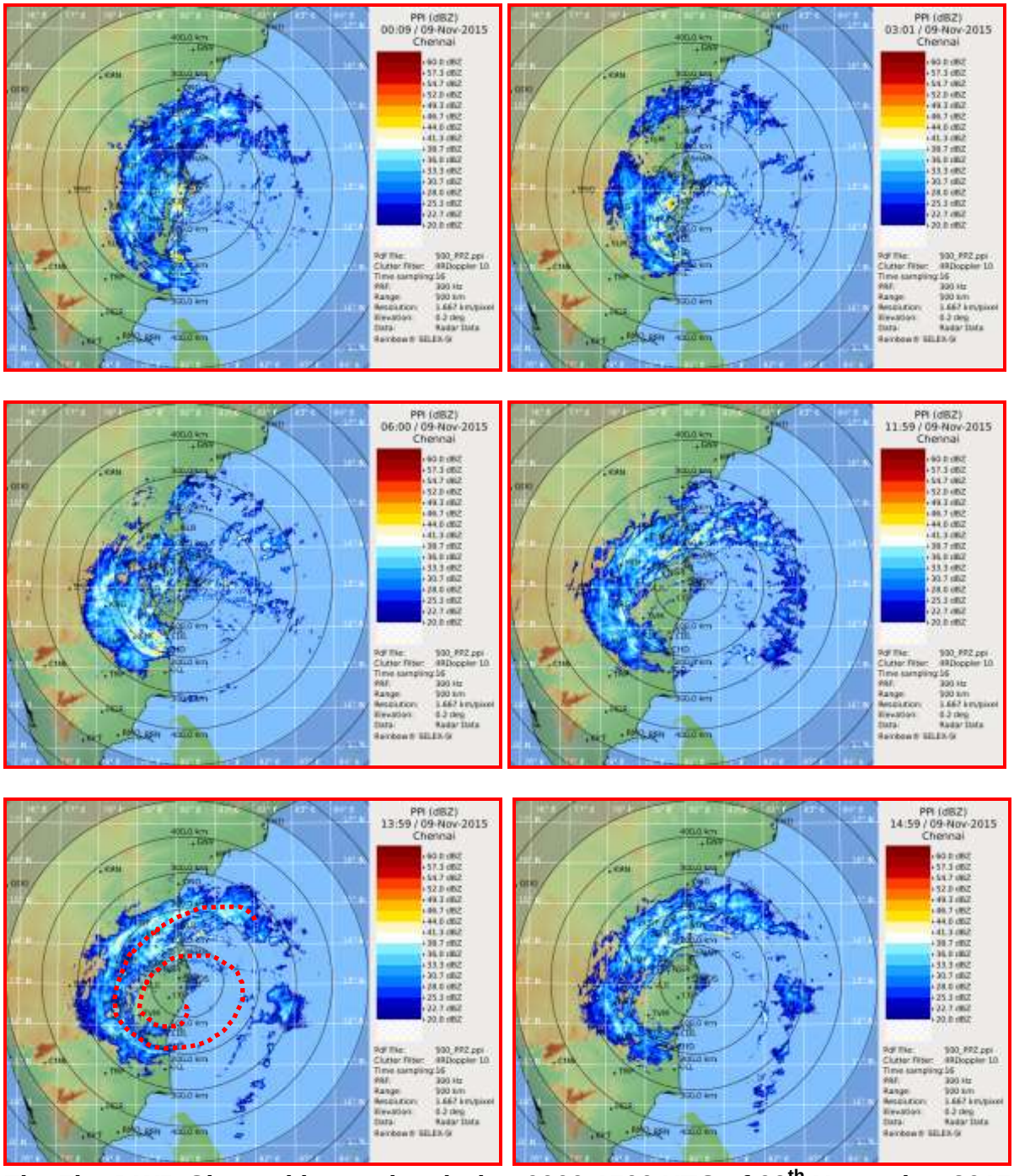
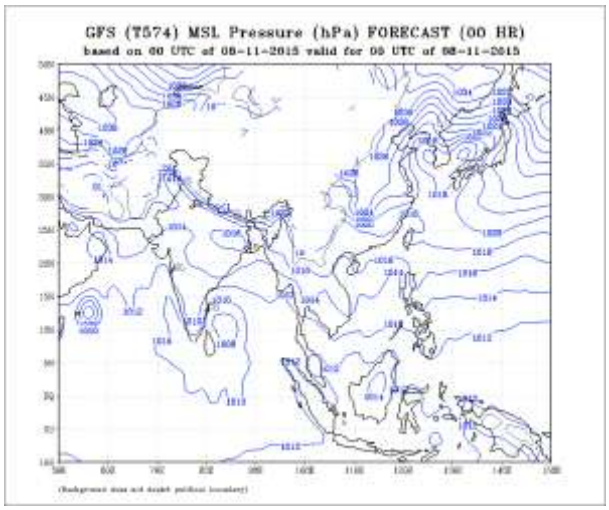
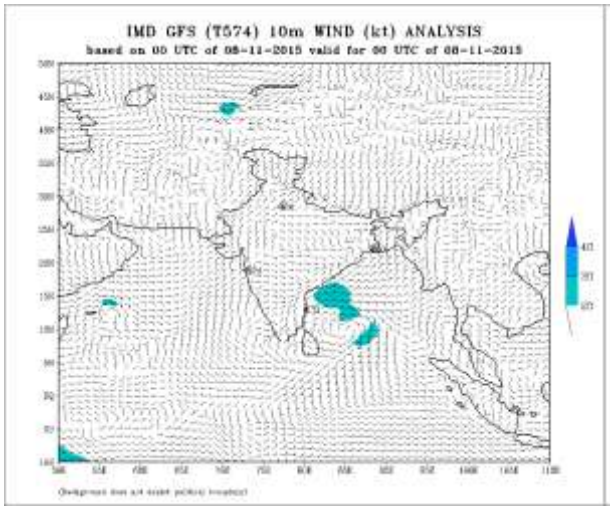


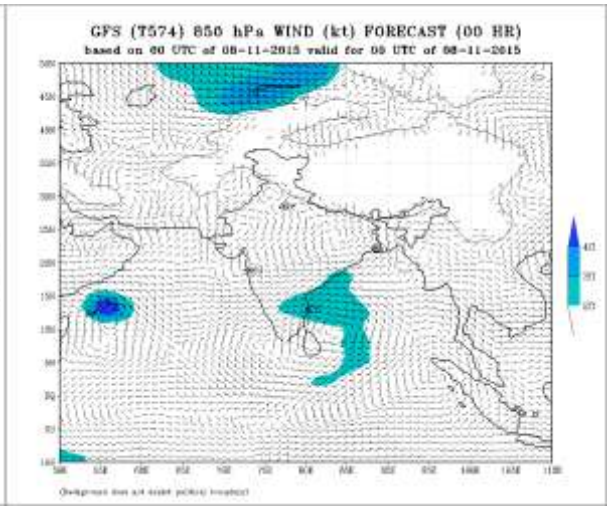
Fig. 7b: DWR Chennai imageries during 0000-1500 UTC of 09th November 2015

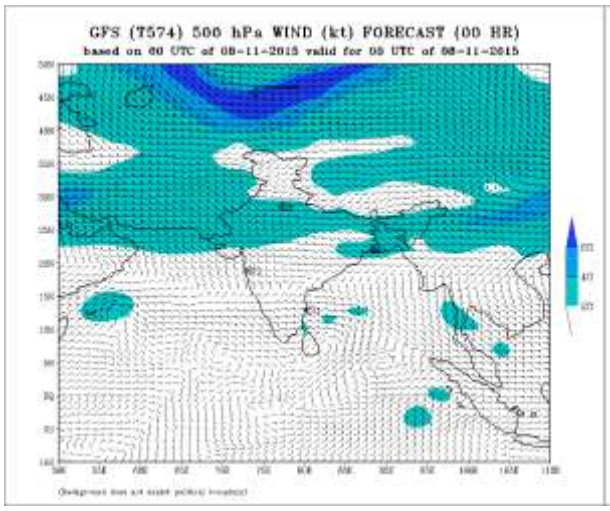
8. Dynamical features

Dynamical models captured the genesis, track and intensity of the system fairly well. Dynamical features associated with the system are discussed based on IMD-GFS analysis fields of Mean Sea Level Pressure (MSLP), surface winds at 10 m height and winds at 850 hPa, 500 hPa and 200 hPa levels based on initial conditions of 0000 UTC of 8-10 November 2015 (Fig.8).









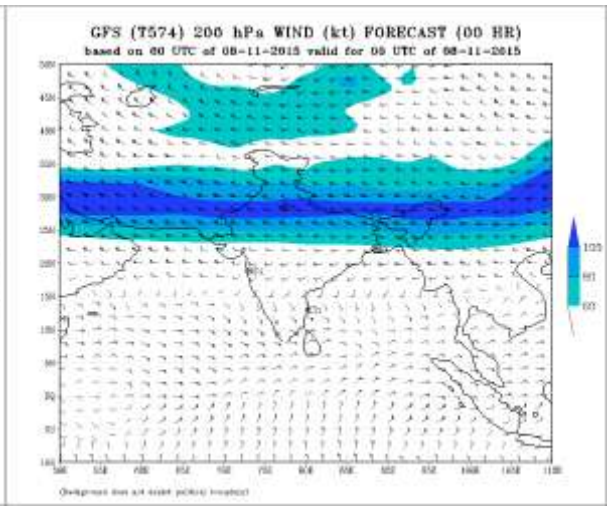
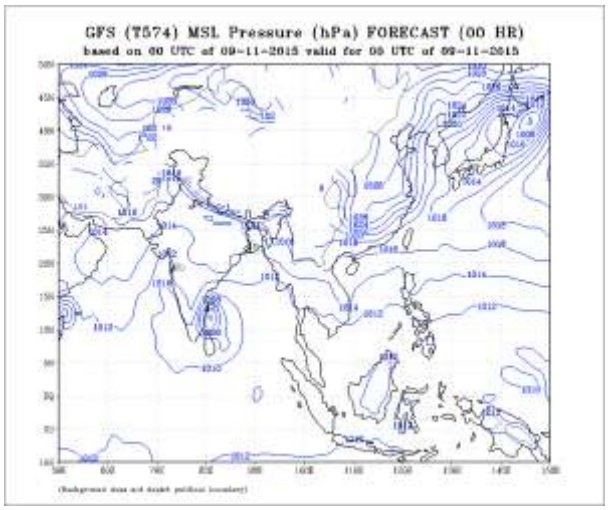


Fig. 8: IMD-GFS Analyses based on 0000 UTC of 8th November 2015 (a) MSLP (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



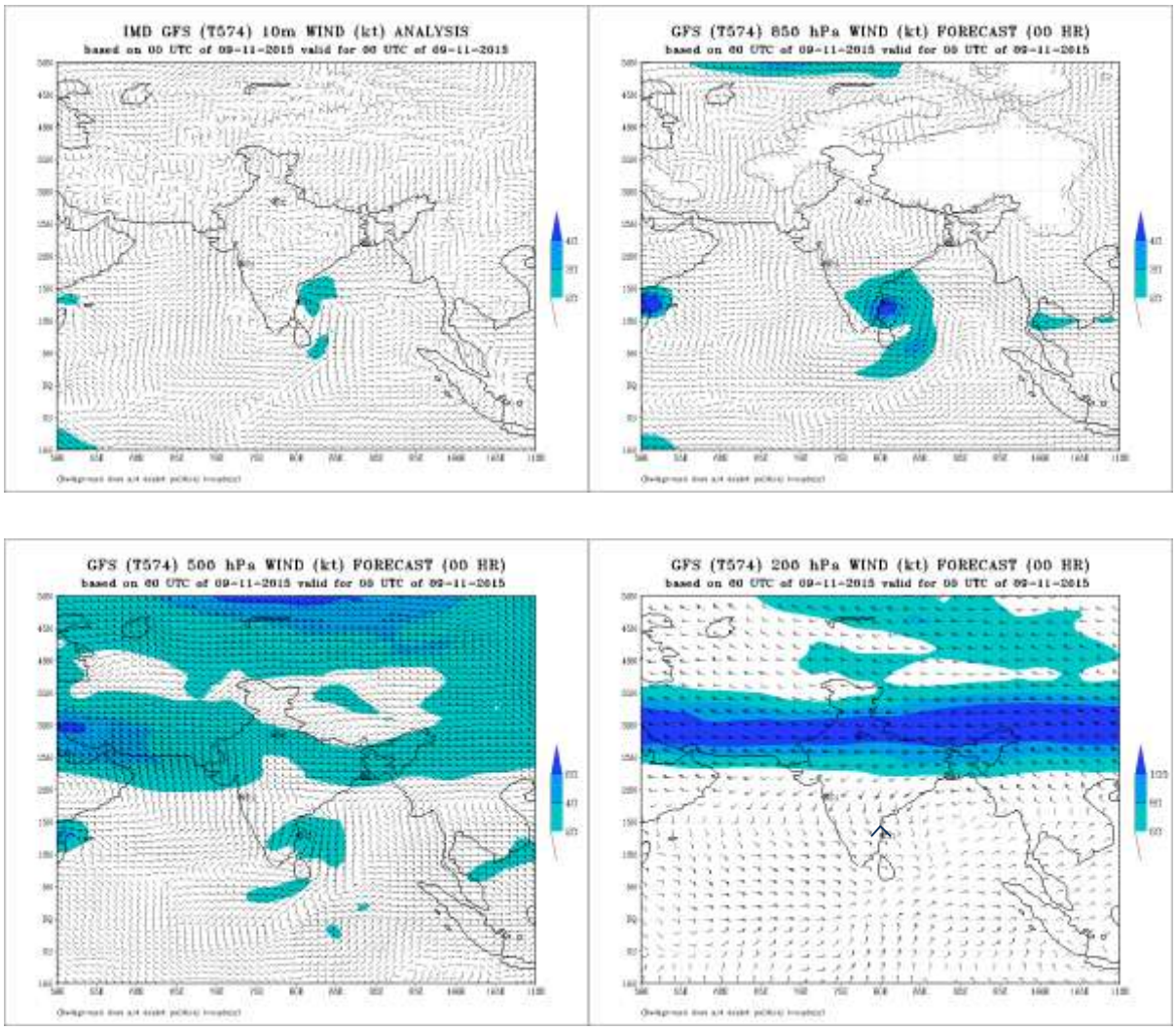
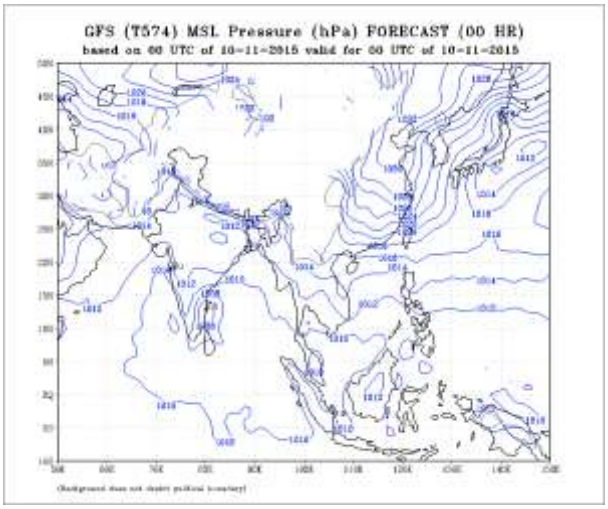


Fig. 8 (contd.): IMD-GFS Analyses based on 0000 UTC of 9th November 2015 (a) MSLP (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



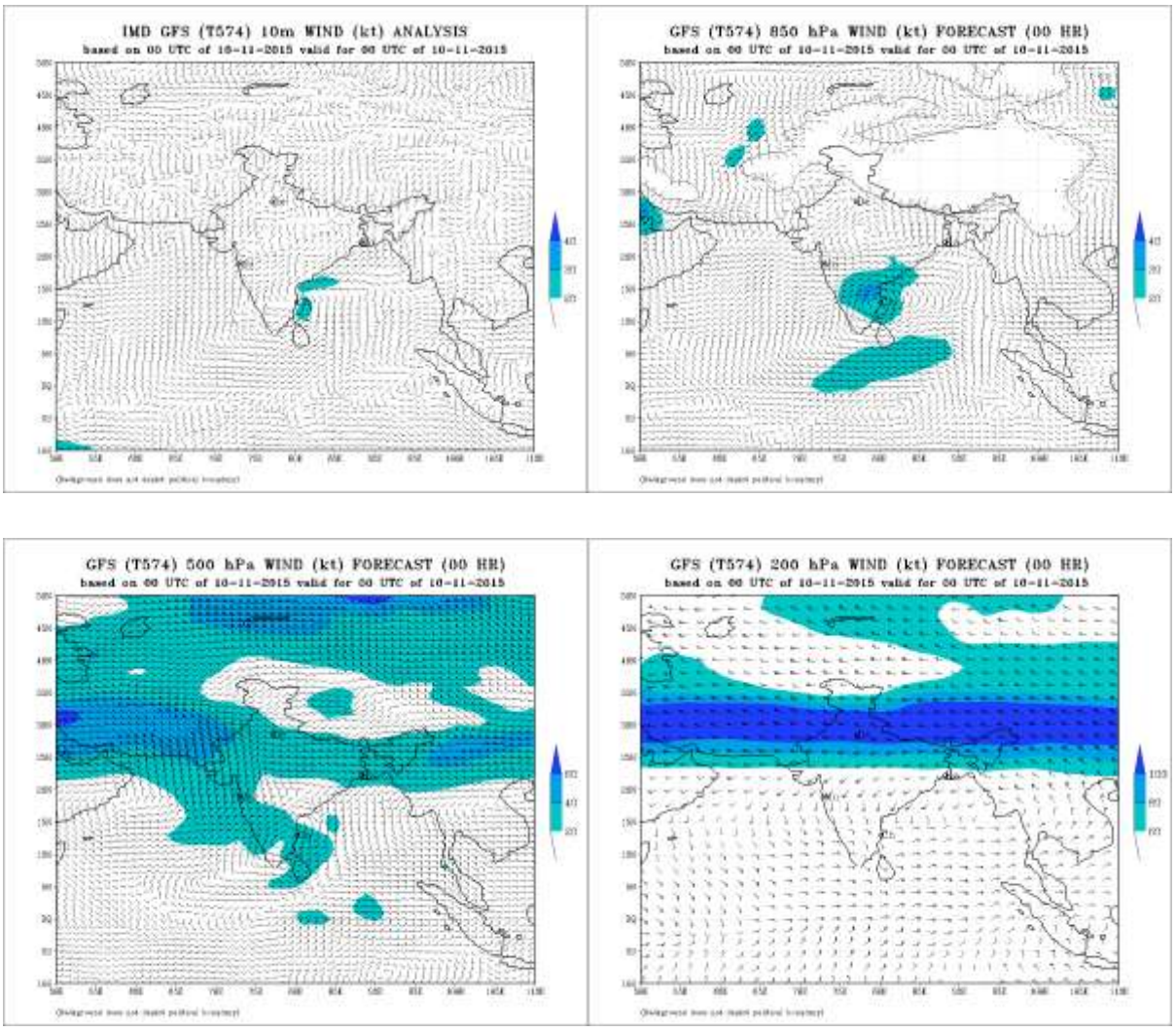


Fig. 8 (contd.): IMD-GFS Analyses based on 0000 UTC of 10th November 2015 (a) MSLP (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds

It is observed that genesis of the system took place over the east-west shear zone of the inter-tropical convergence zone (ITCZ). Winds are stronger over the northeastern sector at the surface which extends to southeastern sector also at 850 hPa level on 08th and 09th. Wind speeds of the order of 40 knots are seen off the north Tamil Nadu coast on 09th. An upper air anti-cyclone at 200 hPa level is observed to the east of the system centre on 09th and the system being located close to the ridge, at the western periphery of the eastern anti-cyclone, was steered very slowly northwards prior to the landfall on 09th.

9. Realised Weather:

9.1 Heavy rainfall:

North Tamil Nadu and adjoining Rayalaseema received heavy to extremely heavy rainfall on 09th. (Description of rainfall terminologies: *Rainfall amount*: ***Heavy***: 64.5 to 124.4 mm, ***Very Heavy***: 124.5 to 244.4 mm and ***Extremely Heavy***: ≥244.5 mm; *Spatial distribution*: ***Isolated (ISOL)***: 1-25% of stations reporting rainfall, ***Scattered (SCT / A few places)*** : 26-50% of stations reporting rainfall, ***Fairly WideSpread (FWS/ Many places)***: 51-75% of stations reporting rainfall and ***Widespread (WS/ Most places)***: 76-100% of stations reporting rainfall during the last 24 hours ending at 0300 UTC of every day).

Neyveli of Cuddalore district in north coastal Tamil Nadu recorded highest 24 hr rainfall amount of 48 cm ending at 10th/0300 IST. Tirumala in Rayalaseema recorded extremely heavy rainfall of 30 cm during the same period. The chief amounts of rainfall ≥ 7 cm (associated with the system) realised in 24 hours ending 0300 UTC of 9-12 November 2015 are furnished below.

:

Rainfall ≥ 7 cm recorded at 0830 IST of 09-12th November 2015:

NORTH COASTAL TAMIL NADU:

District:Tiruvallur

09th: Red Hills, Chembarabakkam, Puzhal -19 each, Poonamallee - 17, Cholavaram - 16, Poonamalle ARG - 16, Ponneri - 15, Chembarambakkam ARG - 14, Madavaram - 14, Ennore - 12, Thamaraipakkam, Tiruvallur -11 each, Poondi – 7.

10th: Pallipattu - 13, Ponneri - 11, Red Hills, Chembarabakkam, Tiruvallur, R.K.pet, Tiruttani, Thiruvalangadu, Puzhal – 9 each, Cholavaram, Thamaraipakkam – 8 each, Madavaram, Poondi, Ennore, Poonamalle -7 each.

District:Chennai

09th: Anna University - 16, Anna Univ ARG -15, Chennai(NBK) - 14, DGP Office - 13,

10th: Chennai(NBK) – 7.

District: Kancheepuram

09th: Kattukuppam - 20, Chengalpattu, Tambaram - 18 each, Mahabalipuram, Chennai AP, Kelambakkam – 17 each, Taramani, Kancheepuram, Kolapakkam, Cheyyur – 15 each, Sriperumbudur -14, Maduranthagam, Uthiramerur – 10 each, Satyabama Univ – 8.

10th: Uthiramerur - 16, Kancheepuram - 13, Chengalpattu - 11, Sriperumbudur -8, Tambaram - 7.

District:Villupuram

09th: Mylam - 12, Marakkanam - 10, Vilupuram - 7, Gingee, Tindivanam – 7 each,

10th: Thirukoilur - 21, Vilupuram - 18, Sankarapuram - 15, Kallakurichi -15, Gingee - 12, Ulundurpet - 11, Tindivanam – 10.

District:Cuddalore

09th: Chidambaram AWS - 19, Chidambaram - 15, Neyveli, Cuddalore -14 each, Parangipettai - 11, Sethiathope -8, Panruti – 7.

10th: Neyveli - 48, Panruti - 35, Sethiathope , Chidambaram – 34 each, Parangipettai - 33, Chidambaram AWS - 24, Virudachalam - 19, Cuddalore - 11, Tozhudur – 7.

Puducherry

09th: Karaikal -17, Puducherry – 13.

District:Nagapattinam

09th: Sirkali, Anaikaranchatram - 20, Nagapattinam -14, Mayiladuthurai -12, Vedaranyam -10, Tarangambadi- 7.

10th: Anaikaranchatram- 15, Tarangambadi- 10, Sirkali – 7.

District:Tiruvarur

09th: Tiruvarur, Nannilam – 10 each, Thiruthuraipoondi - 9, Valangaiman – 7.

District:Thanjavur

09th: Thiruvidaimaruthur, Kumbakonam, Aduthurai – 7 each.

NORTH INTERIOR TAMIL NADU:

District:Tiruvannamalai: **09th:** Cheyyar – 13.

10th: Sathanur Dam – 19.

District:Vellore

09th: Arakonam -7.

10th: Ambur - 19, Vaniaymbadi, Alangayam - 18 each, Tirupattur - 17, Vellore - 11, Kaveripakkam, Melalathur, Gudiyatham – 10 each, Kalavai - 9, Arakonam – 7.

District:Dharmapuri

10th: Dharamapuri - 21, Pappireddipatti - 17, Pennagaram, Harur – 15 each, Palacode - 14, Hogenekal, Marandahalli – 11 each.

District:Krishnagiri

10th: Uthangarai - 19, Barur - 15, Shoolagiri, Penucondapuram – 14 each, Pochampalli, Krishnagiri – 13 each, Hosur - 11, Anjatti - 10, Thali, Rayakottah, Denkanikottai -9 each.

District:Salem

10th: Yercaud - 25, Omalur - 13, Salem - 12, Vazhapadi - 10, Attur, Mettur - 8 each, Thammampatty – 7.

District:Namakkal- **10th:** Rasipuram - 10, Mangalapuram – 8.

District:Perambalur: **10th:** Perambalur – 7.

COASTAL ANDHRA PRADESH:

Nellore district:

10th: Venkatagiri-24, Gudur-20, Rapur-19, Atmakur-17, Podalakur-13, Vinjamur, Nellore-10 each, Tada-8, Sullurpeta, Udayagiri, Shar, Kavali-7 each.

11th: Atmakur-23, Rapur-20, Gudur-14, Nellore-8.

12th: Atmakur-9.

RAYALASEEMA:

Chittoor district:

09th: Tirumalla- 12, Satyavedu - 8, Puttur -7.

10th: Tirumala-30, Kalakada-15, Chittoor-14, Mandapalle, Pakala, Palamaner-13 each, Tirupati, Arogyavaram -12 each, Palasamudram, Tirupati Aero, Santhipuram, Thottambedu, Gurramkonda -11 each, Venkatagiri Kota -9

11th: Kalakada-9.

12th: Chittoor-7.

Cuddapah district:
09th: Kodur, Srikalahasti – 7 each.
10th: Kodur-23, Ananthrajpeta-20, Pullampeta-15, Rajampet-12, Penagaluru -11, Nagari, Kuppam, Punganur, Satyavedu, Srikalahasti -10 each, Chinnamandem, Royachoti -9 each.
11th: Rajampet-18, Sambepalle-17, Pullampeta-16, Penagaluru-13, Royachoti-8, Chinnamandem, Kodur, Lakkireddipalle -7 each.
Anantapur district:
11th: Nambulipulikunta-7
SOUTH INTERIOR KARNATAKA:
10th: M M Hills-18, Anekal-9, Kolar, Kanakapura, Yelandur, Chamarajanagar -7 each.

IMD-NCMRWF GPM gauge merged rainfall during the life period of the system are depicted in Fig.9(a&b). Fig.9a depicts the spatial distribution of rainfall occurrence over the Indian region during the above period and Fig.9b depicts the spatial distribution of heavy rainfall amounts (at 24-hr ending 0300 UTC of the date indicated in the plots) associated with the system.

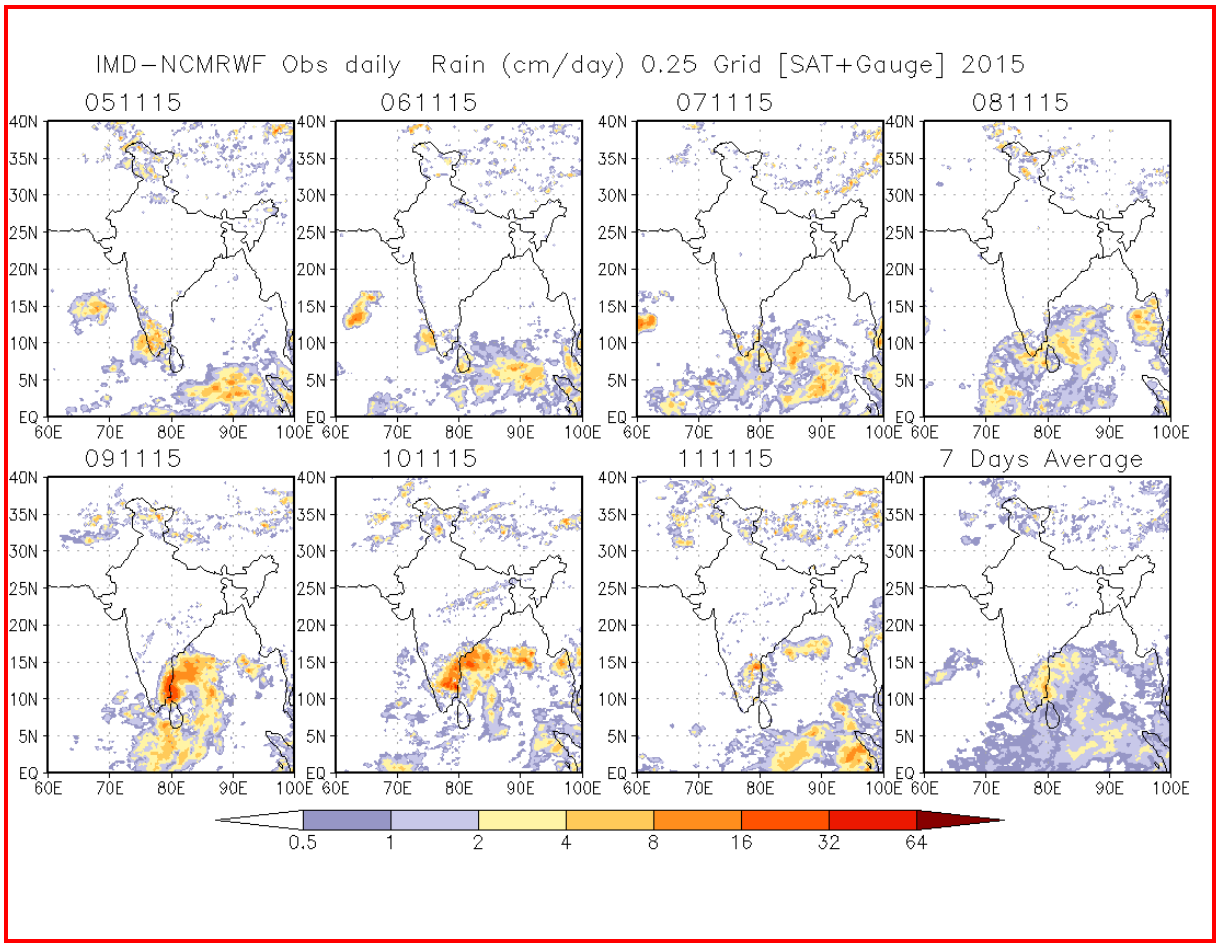


Fig.9a IMD-NCMRWF GPM gauge merged rainfall during the life period of the Deep Depression (08-10 November 2015)

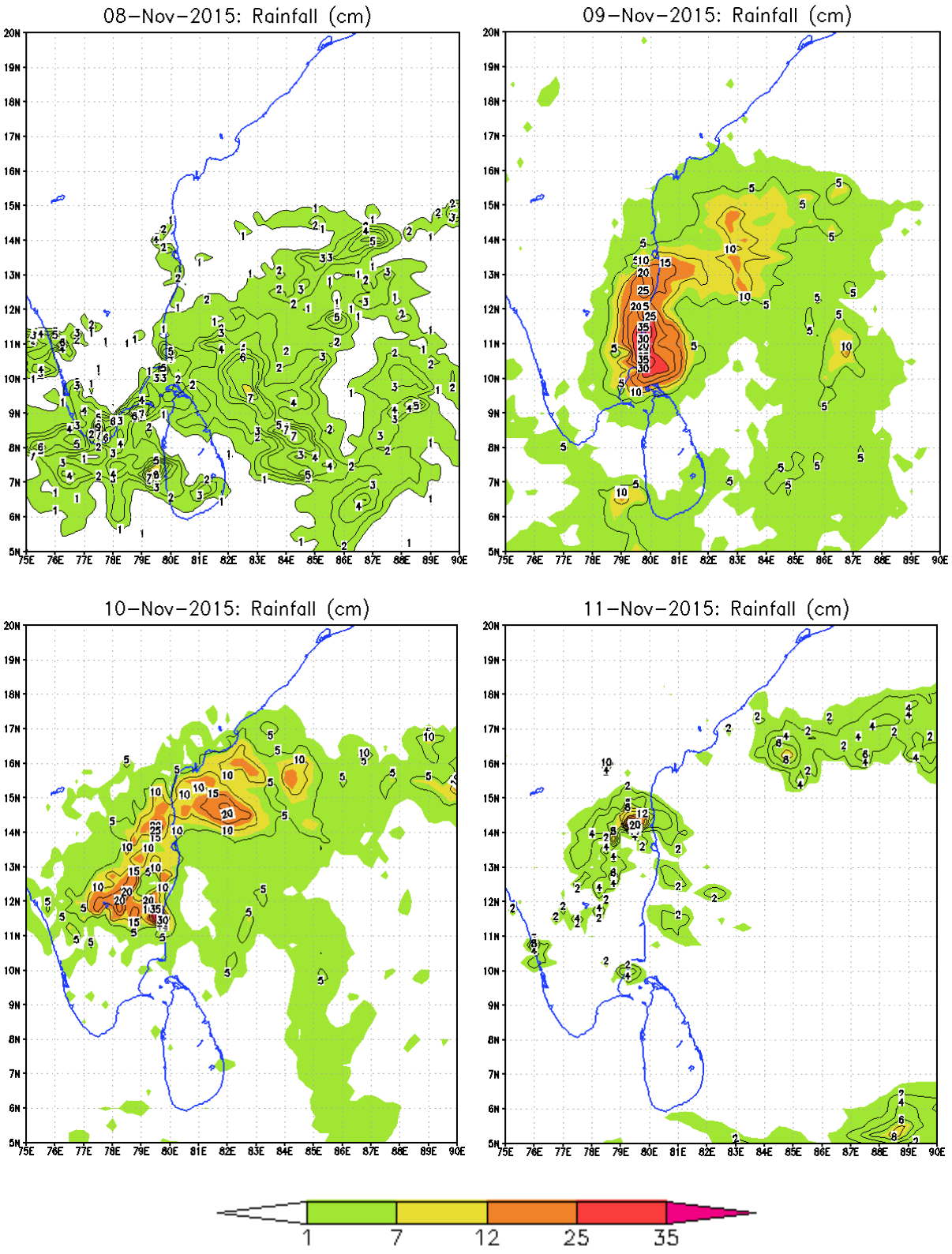


Fig.9b IMD-NCMRWF GPM gauge merged rainfall depicting heavy rainfall occurences in association with the Deep Depression (08-10 November 2015) (24-hr ending 0300 UTC as on the date indicated in each plot).

The above rainfall figures indicate that extremely heavy rainfall (≥ 25 cm) is observed along coastal districts of north Tamil Nadu between 10°N to 11.5°N as on 09th/0300 UTC. Rainfall > 35 cm is observed near 10.4°N and 79.7°E. Rainfall amount decreases sharply over the interior parts thus suggesting role of frictional convergence along the coast in enhancing the rainfall along the coastal districts.

9.2 Strong Wind

Strong winds of the order of 25-30 knots prevailed along and off north Tamil Nadu coast on 08th and 09th November 2015. Winds were stronger over the northeastern sector due to the northeast monsoon seasonal flow. NOAA-NESDIS- CIRA, Multi-platform satellite wind analysis based on 0000 UTC of 08th and 09th depicting prevalence of strong winds of the order of 30 knots (55-60 kmph) along and off the north Tamil Nadu coast on 09th are presented in Fig.10.

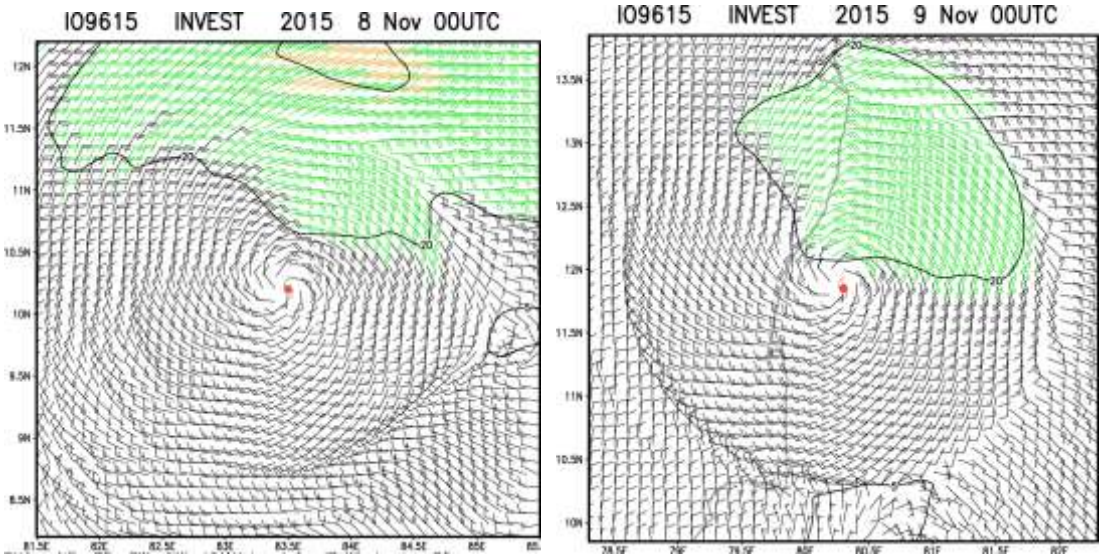


Fig.10: Multi-platform satellite wind analysis based on 0000 UTC of 08th and 09th.
(Source: NOAA-NESDIS-Coperative Institute for Research in Atmosphere (CIRA))

9.3. Storm Surge

No storm surge has been reported in association with the system as it was a deep depression.

10. Damages due to Deep Depression (08-10 November 2015)

As the system caused extremely heavy rainfall, it caused extensive inland flooding over coastal districts of north coastal Tamil Nadu. IMD's issued warnings on 09th morning (based on 09/0830 IST) regarding expected damages - Minor damage to banana trees and near coastal agriculture due to salt spray. Damage to ripe paddy crops. Some breaches in Kutcha road due to flooding. Minor damage to Kutcha embankments. Minor damage to loose / unsecured structures.

About 31 deaths were reported in Tamil Nadu and Puducherry in association with the damages caused by the system (flood related casualities and due to wall collapses

in kutcha houses). A few photographs depicting the flood situation in north Tamil Nadu are shown in Fig.11.

Fig.11 A few damage photographs due to the Deep Depression (08-10 November 2015)

11. NWP model forecast performance

NWP system

IMD operationally runs regional models, WRF for short-range prediction and one Global model GFS (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 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 recently for 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 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). Decay model is used for prediction of intensity after landfall.

NCMRWF provided forecasts based on NGFS (T574L64), NCMRWF Unified Model (NCUM) adopted from UK Meteorological Office and NGEFS (T190L28; 20-member ensemble prediction system) for the DD over BOB during 08-10 November 2015. 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.

The model forecast integration are carried out at respective centers and the only forecast output is analyzed for verification and intercomparison.

Verification of IMD NWP model performance

(i) Prediction of cyclogenesis (Genesis Potential Parameter (GPP))

a. Grid point analysis and forecast of GPP

Grid point analysis and forecast of GPP is used to identify potential zone of cyclogenesis. Fig.12 (a-g) below shows the predicted zone of cyclogenesis.

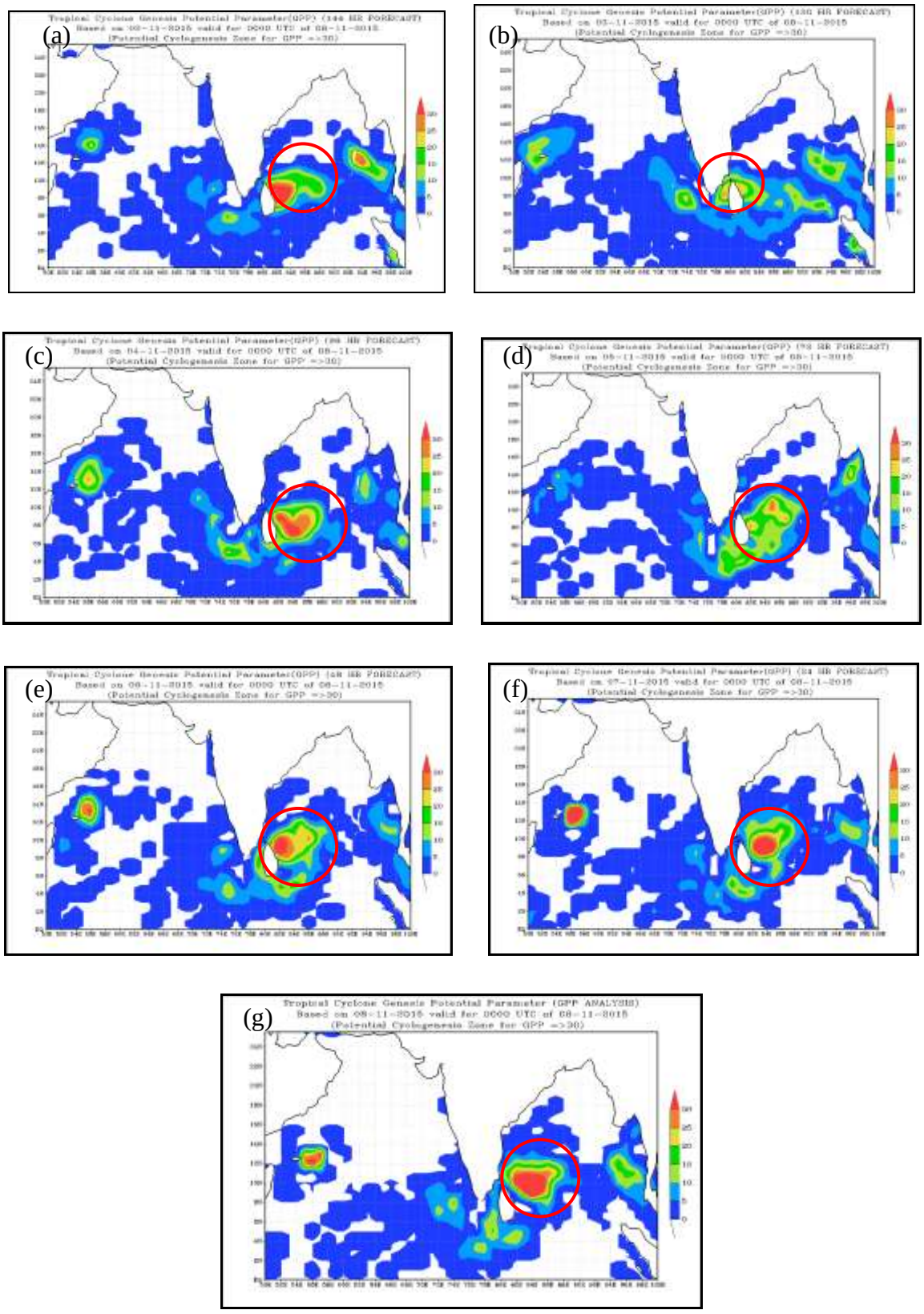


Fig. 12a-g: Predicted zone of cyclogenesis.

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. For developing systems (T 3.0), threshold value of area average GPP ≥ 8.0 and for non-developing system, area average GPP < 8.0. Analysis and forecasts of area averaged GPP (Fig.13) indicated formation of cyclone and gradual weakening of the system at early stages of development.

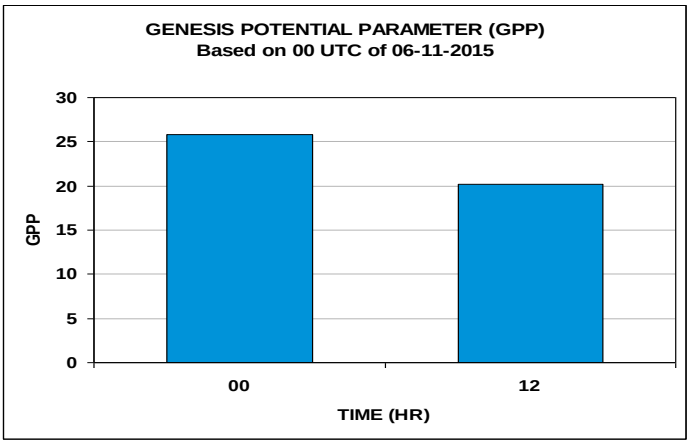


Fig.13 Area average analysis and forecasts of GPP based on 0000 UTC of 06.11.2015

(ii) Track and intensity forecast verification

IMD's MME track forecast and SCIP intensity predictions based on 1200 UTC of 08.11.2015 and 0000 UTC of 09th are presented in Fig.14a&b.

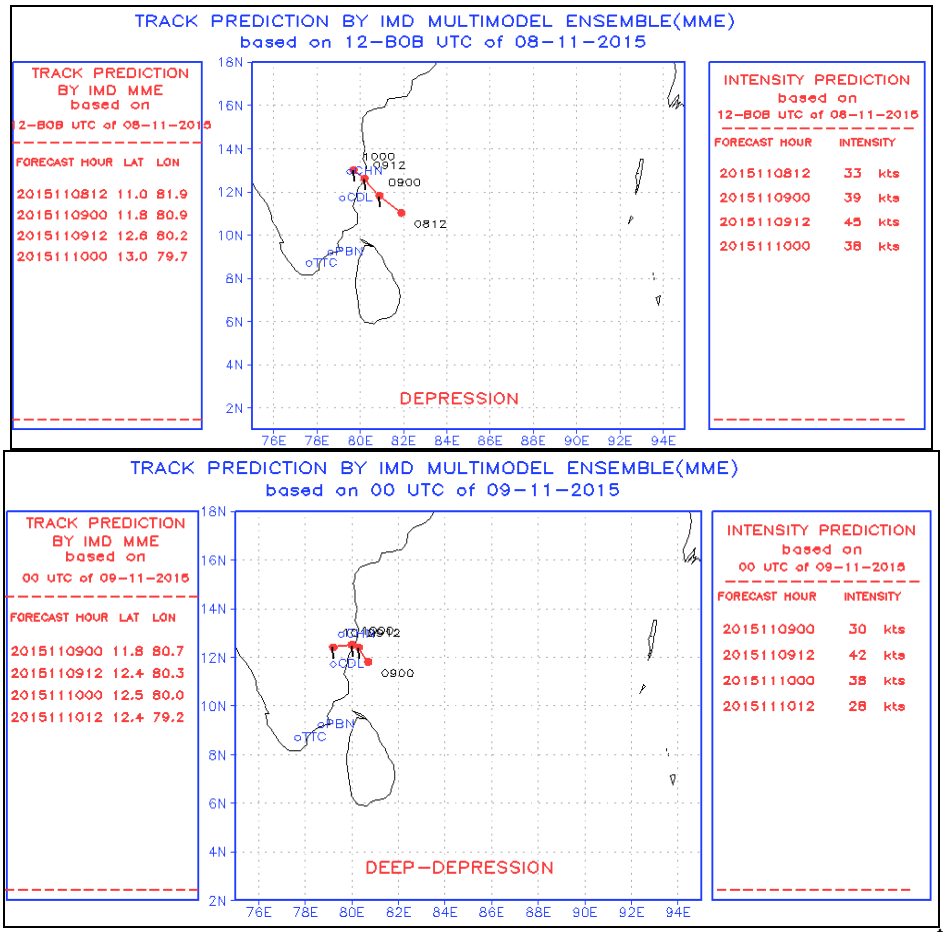


Fig.14a&b: IMD's MME Track and SCIP intensity predictions based on 08th/1200 and 09th/0000 UTC of November 2015

Track forecasts by various global and regional models based on 1200 UTC of 08.11.2015 and 0000 UTC of 09th are presented in Fig.15a&b. Errors in track and landfall point and time forecasts of various models are presented in Table 2, Table-3a and Table-3b respectively. Errors in SCIP intensity prediction model are presented in Table-4.

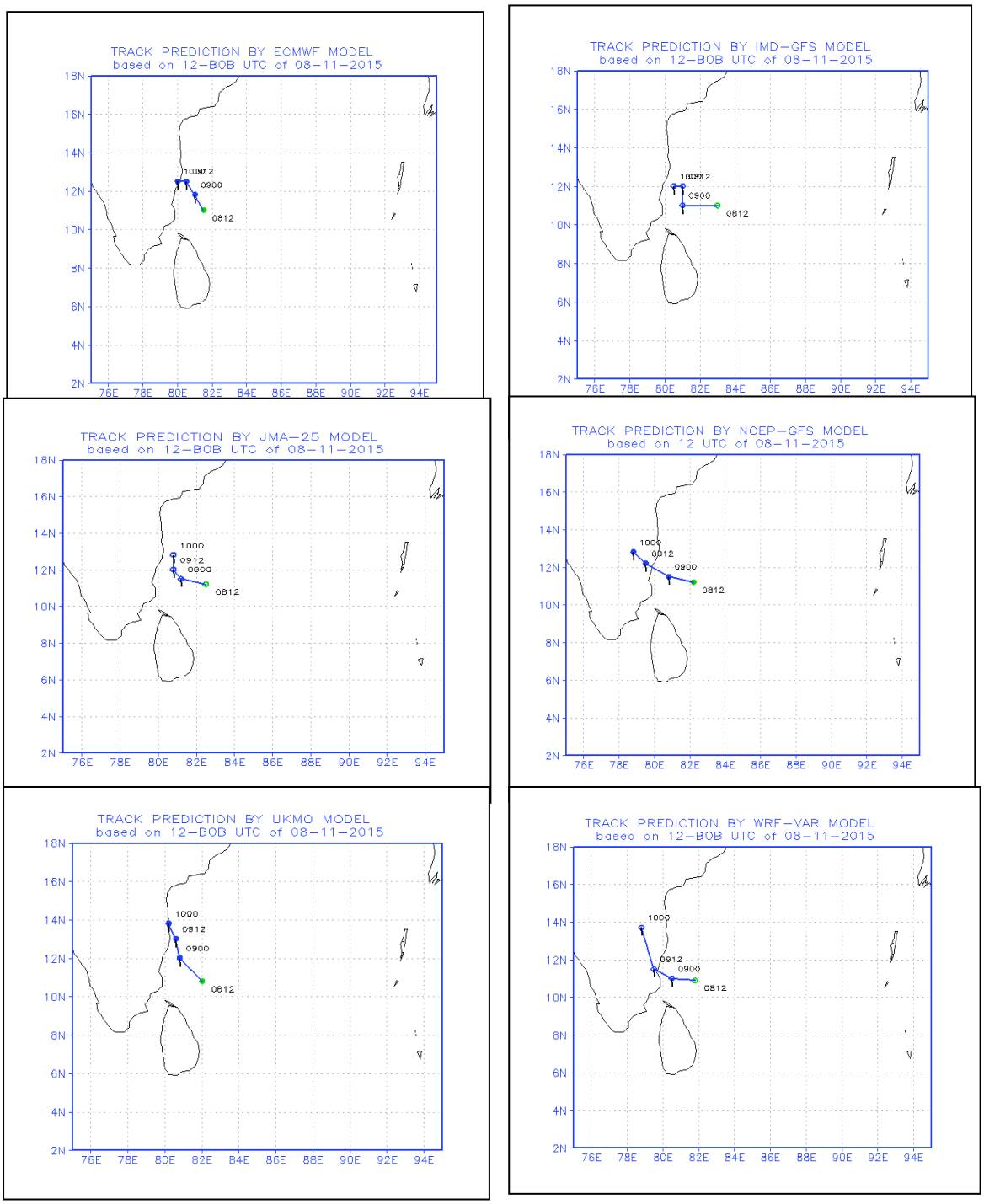


Fig.15a: Track prediction by various global and regional models based on initial conditions of 08th/1200 UTC.

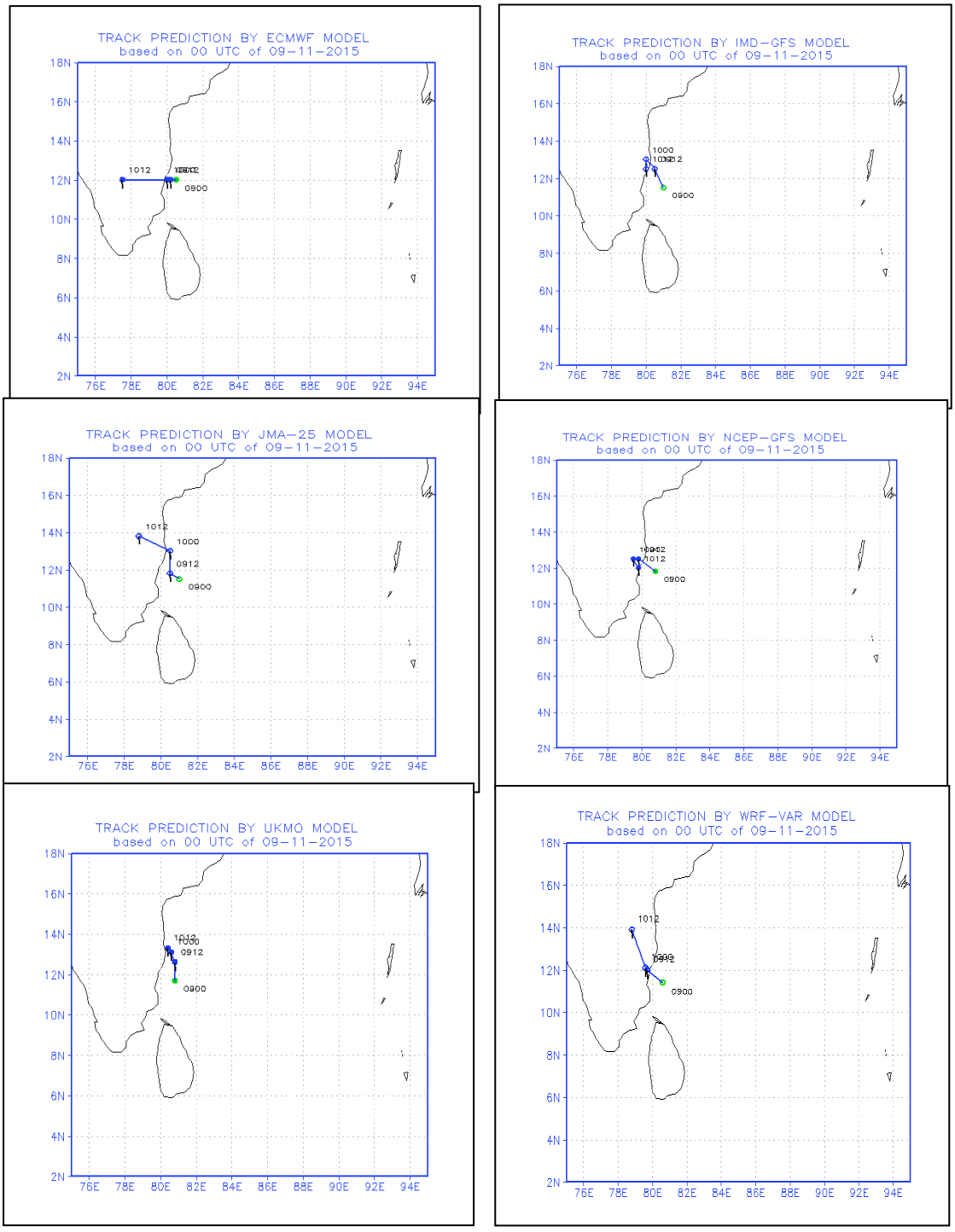


Fig.15b: Track prediction by various global and regional models based on initial conditions of 08th/0000 UTC

By and large, ECMWF track and landfall point forecasts were better than those by other models. However, for 24-hr lead time, NCEP-GFS and IMD-MME have less track forecast errors than that of ECMWF. Regarding landfall time forecasts, IMD-MME had least errors.

Table-2. Average track forecast errors (Direct Position Error) in km

Lead time →	12 hr	24 hr	36 hr
IMD-GFS	63(2)	94(2)	107(1)
IMD-WRF	42(2)	60(2)	168(1)
JMA	60(2)	103(2)	138(1)
NCEP-GFS	33(2)	35(2)	97(1)
UKMO	85(2)	126(2)	169(1)
ECMWF	40(2)	66(2)	45(1)
IMD-MME	48(2)	52(2)	60(1)

Figures in brackets: Number of forecasts verified

Table-3a. Landfall point forecast errors (km) of NWP Models at different lead time (hour)

Forecast Lead Time (hour) →	14hr	26hr
IMD-GFS	70	**
IMD-WRF	31	114
JMA	91	**
NCEP-GFS	31	112
UKMO	113	81
ECMWF	25	33
IMD-MME	39	49

Table-3b. Landfall time forecast errors (hour) at different lead time (hr)
('+' indicates delayed landfall, '-' indicates early landfall)

Forecast Lead Time (hour) →	14hr	26hr
IMD-GFS	+4	**
IMD-WRF	-2	-3
JMA	+11	**
NCEP-GFS	-4	-5
UKMO	+24	+10
ECMWF	+10	+10
IMD-MME	-2	-2

Table-4 Average absolute errors (AAE) and Root Mean Square (RMSE) errors of SCIP model (Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr
IMD-SCIP (AAE)	+10.5(2)	+11.5(2)	+8.0(1)
IMD-SCIP (RMSE)	10.6	12.0	8.0

Figures in brackets: Number of forecasts verified

Verification of forecast tracks are presented for NCMRWF's NGFS (T574L64), NCMRWF Unified Model (NCUM) and NGEFS (T190L28; 20-member ensemble prediction system). In addition to tracks NGEFS members are used to estimate strike probability based on the 20 members. Forecast track verification is presented for all the models against the IMD best track data. Table-5 presents the track forecast verification. Some conclusions based on the performance of these models in predicting the tracks for this case are:

1. Lowest initial position error is seen in NGFS (~30 km). The highest initial position error
is seen in NGEFS (~94 km).
2. NGFS shows the lowest DPE till 24 hr forecast and NCUM shows the highest error. NGEFS shows the lowest DPE in the 48 hour forecast and NGFS shows the highest.
3. NCUM shows the lowest along track error (ATE) values as compared to the other two models.
4. ATE values are always positive indicating that the forecast tracks are always moving faster than the observations.
5. NCUM shows the highest cross track error (CTE) values in the 24 hour forecast whereas NGEFS has the owest CTE values (~0).

Table- 5 Forecast Track Errors in km for the model products of NCMRWF

	00hr	24hr	48hr
NGFS	30.5	112.5	338
NCUM	35	268.5	319
NGEFS	94	162.5	241
No. of forecasts	2	2	1

12. Bulletins issued by IMD

IMD continuously monitored the system from the pre-genesis stage onwards. Based on 0300 UTC of 06th November, a probabilistic forecast on possible cyclogenesis over Bay of Bengal within 48-72 hrs was issued. 6-hrly bulletins were issued from the Depression stage onwards (08th/0830 IST). As the system was expected to intensify into a marginal cyclonic storm, a pre-cyclone watch bulletin was issued on 08th/1200 IST based on 08th/0830 IST analysis. As the system formed close to the coast and made landfall within 36 hours of formation, bulletins containing track & intensity forecast was issued upto 36 hrs at +06, +12, +18, +24, +36, hrs. The 24-hr forecast of track (alongwith the cone of uncertainty) and intensity was issued at 09th/0530 IST and further updated bulletins were issued at 3-hrly intervals based on 09th/0830, 1130, 1430 and 1730 IST prior to the landfall. The radius of winds ≥ 28 knot in four quadrants of the system was also mentioned in these bulletins. 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 system were described in the RSMC bulletins. Bulletins issued by Cyclone Warning services of IMD in association with the Deep Depression over the BOB during 08-10 November 2015 are given in Tables 6-10.

Table-6: Bulletins issued by Cyclone Warning Division, New Delhi

Bulletins issued by Cyclone Warning Division, New Delhi in association with Deep Depression Over Bay of Bengal (8th to 10th November), 2015			
S.No.	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	10	1. IMD's website 2. FAX and email to Control Room NDM, PMO- Minister of Sc. & Tech, Cabinet Secretariat, Secretary MoES, DST, HQ Integrated Defence Staff, Doordarshan, All India Radio, National Disaster Response Force, Indian Railways, Indian Navy, IAF, Chief Secretary- Andhra Pradesh, Tamil Nadu Kerala, Karnataka.
2	RSMC Bulletin	18	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	3	1. IMD's website 2. Emails to : press and electronic media
4	DGM's Bulletin	3	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
5	SMS	4 times Total SMS 244 4 times Total SMS 1655/262501 21795- by AFMU Karaikal & 53330 by AFMU Ooty	1. Disaster management officers at central & State Level (Andhra Pradesh, Tamil Nadu & Puducherry,Kerala and Karnataka,) 2. Registered general public of Andhra Pradesh, Tamil Nadu & Puducherry,Kerala and Karnataka, 3. Farmers through Kisan portal
6	CAP feed for Google Public Alert (Experimental)	1	General public

Table-7: Bulletins issued by Area Cyclone Warning Centre, Chennai:

S.No.	Type of Bulletins	No. of Bulletins issued
1.	Sea Area Bulletins	6
2.	Coastal Weather Bulletins	6
3.	Fishermen Warnings issued	12
4.	Port Warnings	4
5.	Heavy Rainfall Warning	12
6.	Squall Wind Warning	12
7.	State of sea forecast	12
8.	Information and Warning issued to State Government and other Agencies	12

Table-8: Bulletins issued by Cyclone Warning Centre, Visakhapatnam

S.No.	Type of Bulletin Number	No. of Bulletins issued
1.	Coastal Weather Bulletins	6
2.	Fishermen Warnings issued	14
3.	Port Warnings	4
4.	Heavy Rainfall Warning	4
5.	Gale /squall Wind Warning	4
6.	Information & Warning issued to State Government and other Agencies (Pre-cyclone watch, informatory message e)	4
7.	SMS to disaster managers	50

Table-9: Bulletins issued by Area Cyclone Warning Centre, Kolkata

Sr.No.	Type of Bulletin	No. of Bulletins issued
1.	Sea Area Bulletins	05
2.	Coastal Weather Bulletins	I) WB Coast-04 II) A & N Coast-04
3.	Port Warnings	I) Hooghly Ports & Sagar Ids Port- 03 II) Port Blair Port-03

Table-10: Bulletins issued by Cyclone Warning Centre, Bhubaneswar

S.No.	Type of Bulletin Number	No. of Bulletins issued
1.	Coastal Weather Bulletins	4
2.	Port Warnings	3
3.	Information & Warning issued to State Government and other Agencies (Pre-cyclone watch, informatory message etc.)	4

13. Operational Forecast Performance

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

(i) 7th November (morning):

Forecast for formation of a depression by 8th November over southwest Bay of Bengal and subsequent intensification and movement towards Tamil Nadu coast by 07th.

(ii) 8th November (morning):

(a) Depression formed in the morning of 8th November over southwest Bay of Bengal. Forecast was issued for further intensification into a deep depression within 24 hours and further into a cyclonic storm and cross north Tamil Nadu coast between Karaikal and Chennai near Puducherry by 09th mid-night.

(b) Warning for heavy to very heavy rainfall occurrence over north Tamil Nadu and Puducherry with isolated extremely heavy rainfall on 09th was issued.

(c) Squally wind warning for north Tamil Nadu, Puducherry and adjoining Pudukkottai and Ramanathapuram districts of south Tamil Nadu coasts with speed reaching 40-50 kmph gusting to 60 kmph during next 24 hrs 55-65 kmph gusting to 75 kmph during the subsequent 24 hrs was issued.

13.1. Operational landfall forecast error

Operational forecast errors in landfall location and time for 12-, 24- and 36- hr lead times are shown in Table-11.The operational landfall forecast position error (LPE) was about 50 km and landfall time error (LTE) was -6 hrs. Delay in the landfall time than the one predicted was due to the northward movement of the system close to the coast from 0600 UTC of 09th until the landfall around 1400 UTC of 09th. An example of forecast & actual track showing prediction of landfall point & time is shown in Fig.16.

Table-11. Operational landfall point and landfall time forecast errors

Lead Period (hrs)	N	Actual Landfall point and time	Forecast Landfall point and time	Operational Landfall Error in	
				LPE(km)	LTE(hours)
12	1	12.2^{0}N/80.0^{0}E at 1400 UTC of 9th	11.8^{0}N/79.8^{0}E at 0800 UTC of 9th	49	-6.0
24	1		Near Puducherry around 1630 UTC of 09th	41	+2.0
36	1		Near Puducherry around 1830 UTC of 09th	41	+4.5

LTE : Landfall forecast time – Actual landfall time,

LPE : Landfall forecast point – Actual landfall point, N: No. of observations verified

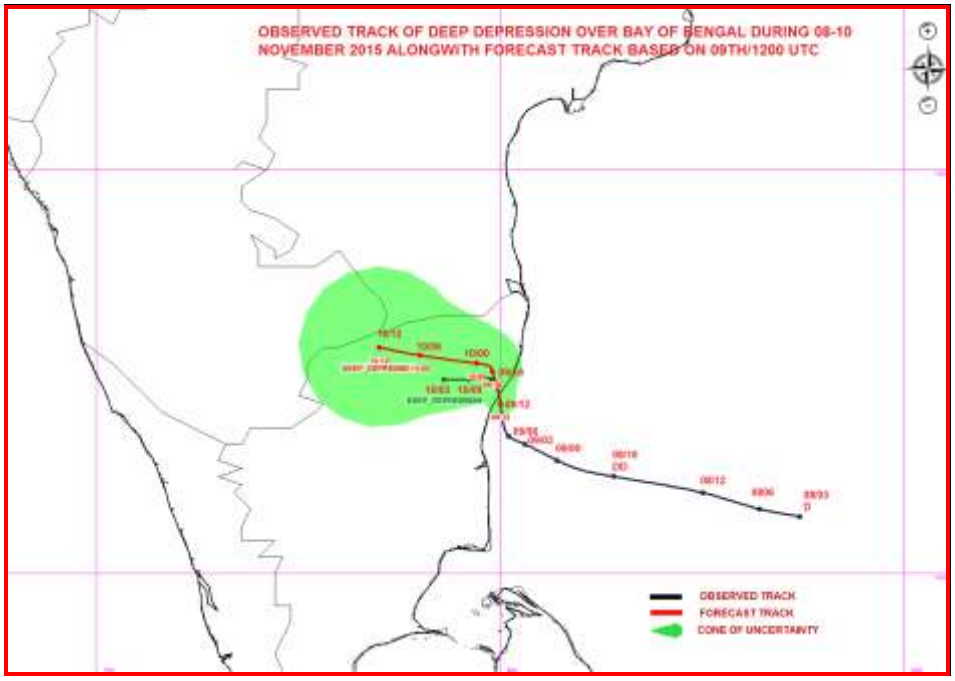


Fig.16. Actual track of the Deep Depression (08-10 November 2015) and the forecast track along with cone of uncertainty based on 1200 UTC of 9th November 2015.

13.2. Operational track forecast error and skill

The operational average track forecast errors are shown in Table-12. The track forecast for 12- and 24-hr forecasts were skilful as seen from the table.

Table- 12. Operational Track Forecast Error and Skill

Lead Period (hrs)	N	Direct Positional Error (km)		Skill (%)
		Operational	CLIPER	
12	3	83.8	135.1	38.0
24	1	187.3	308.2	39.2

N: No. of forecasts verified

13.3. 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 13. 24-hr intensity forecast performance was quite qood with 70% skill against persistence forecast.

Table-17. Operational Intensity forecast errors and skill

Lead Period (hrs)	N	Operational Error (knot)		Persistence based Error (knot)		Operational skill against Persistence forecast (%)	
		AE	RMSE	AE	RMSE	AE	RMSE
12	3	1.7	2.0	1.7	2.9	0	31.0
24	1	3.0	3.0	10.0	10.0	70.3	70.3

N: No. of forecasts verified;

AE: Absolute Error; RMSE: Root Mean Square Error

13.4. Adverse weather warning verification

Verification of heavy rainfall warnings issued by IMD, and skill scores for 24 and 48 hr forecast are presented in Table 18(a-b). Verification of strong wind forecast is given in Table 19. It may be noted that both the adverse weather conditions were predicted by IMD in advance. No storm surge forecast was issued. It shows that the warnings were highly skilful with probability of detection (POD) of 1.0 and Heidke skill score of 0.5 for 24 hr forecast.

Table – 18a .Verification of Heavy Rainfall warning

Date/ Time(IST)	**Forecast Rainfall**	**Observed Rainfall (24 hr ending)**
08.11.15/ 0830	Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (25 cm or more) over north coastal Tamil Nadu and Puducherry during next 24 hours and north Tamil Nadu and Puducherry during subsequent 24 hours.	**09 November 2015/ 0300 UTC:** (a) Heavy to very heavy rainfall at a few places over north

	Isolated heavy falls over south and north interior Tamil Nadu during next 24 hours and over south Tamil Nadu, Rayalseema, south coastal Andhra Pradesh, south interior Karnataka and Kerala during subsequent 24 hours.	coastal Tamil Nadu and north interior Tamil Nadu and Chittoor district of Rayalaseema. (b) Isolated heavy rainfall in Cuddapah district of Rayalaseema. **10 November 2015/ 0300 UTC:** (a) Heavy to very heavy rainfall at a few places over north coastal, north interior Tamil Nadu and Chittoor and Cuddapah districts of Rayalaseema. extremely heavy falls at isolated places over north coastal Tamil Nadu (Cuddalore district) and at isolated place in Chittoor district of Rayalaseema. (b) Isolated heavy to very heavy rainfall over south interior Karnataka **11 November 2015/ 0300 UTC:** Heavy to very heavy falls at a few places over Cuddapah distraict of Rayalaseema and Nellore district of south coastal Andhra Pradesh and at isolated places over Chittoor and Anantapur districts of Rayalaseema. **12 November 2015 /0300 UTC:** Heavy rainfall at isolated places over Nellore districat of south coastal Andhra Pradesh and Chittoor district of Rayalaseema.
09.11.15/ 0830	Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (25 cm or more) over north Tamil Nadu and Puducherry during next 24 hours. Isolated heavy to very heavy falls would occur over south Tamil Nadu, Rayalseema, south coastal Andhra Pradesh during next 24 hrs and over coastal & south interior Karnataka and Kerala during next 48 hours.	
10.11.15/ 0830	Heavy to very heavy rainfall at a isolated places over north Tamil Nadu, Puducherry and Rayalaseema, and isolated heavy rainfall over coastal Andhra Pradesh during next 24 hours. Heavy to very heavy rainfall at a isolated places over coastal & south interior Karnataka and Kerala during next 48 hours.	

Table – 18b : Skill scores for 24 and 48 hr heavy rainfall forecast

Skill Parameter	24 hr forecast	48 hr forecast
Probability of detection(POD)	1.0	0.6
False alarm rate (FAR)	0.3	0.6
Missing rate (MR)	0.0	0.4
Correct non-occurrence (C-NON)	0.5	0.5
Critical success index (CSI)	0.7	0.3
Bias for occurrence	1.5	1.3
Percentage correct (PC)	75.0	54.2
Heidke skill score (HSS)	0.5	0.1

Table-19: Squally wind forecast verification

Date/ Time(IST)	Strong wind forecast	Recorded wind
08.11.15/ 0830	Squally wind speed reaching 40-50 kmph gusting to 60 kmph would prevail along and off north Tamil Nadu, Puducherry and adjoining Pudukkottai and Ramanathapuram districts of south Tamil Nadu coasts during next 24 hrs. It would increase gradually becoming 55-65 kmph gusting to 75 kmph along and off above coasts from tomorrow.	**08 November2015:** 50kmph winds prevailed along and off north Tamil nadu, Puducherry and adjoining Pudukottai and Ramanathapuram districts **09 November 2015:** 55-65 kmph winds prevailed along and off north Tamil nadu, Puducherry and adjoining Pudukottai and Ramanathapuram districts

14. Summary

The Deep Depression over the Bay of Bengal during 08-10 November 2015 was the first cyclonic disturbance over the BOB during the post-monsoon season (October-December) of 2015. It formed from a low pressure area that lay over southwest BOB on 06th, concentrating into a depression over southwest BOB close to north Tamil Nadu and Sri Lanka coasts around 0300 UTC of 08th and intensifying into a Deep Depression around 08th/1800 UTC. Moving initially west-northwestward and then northwestwards, it crossed north Tamil Nadu close to north of Puducherry coasts on 09th / 1400 UTC near latitude 12.2°N/80.0°E. Due to its proximity to the coast throughout the day, it caused exceptionally heavy rainfall over north Tamil Nadu and Puducherry on 9th.

Even though it a was a short lived system, crossing coast within 36 hrs of formation, IMD predicted, in advance, the genesis, intensity, track and point & time of

landfall of the system as well as the associated adverse weather like heavy rainfall and squally wind. When the system was very close to the coast, about 50-60 km from Puducherry, it underwent changes in speed and direction of movement as well as in intensity. Such changes pose great challenges to early warning system which need further investigation.

Acknowledgements

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