**GOVERNMENT OF INDIA**

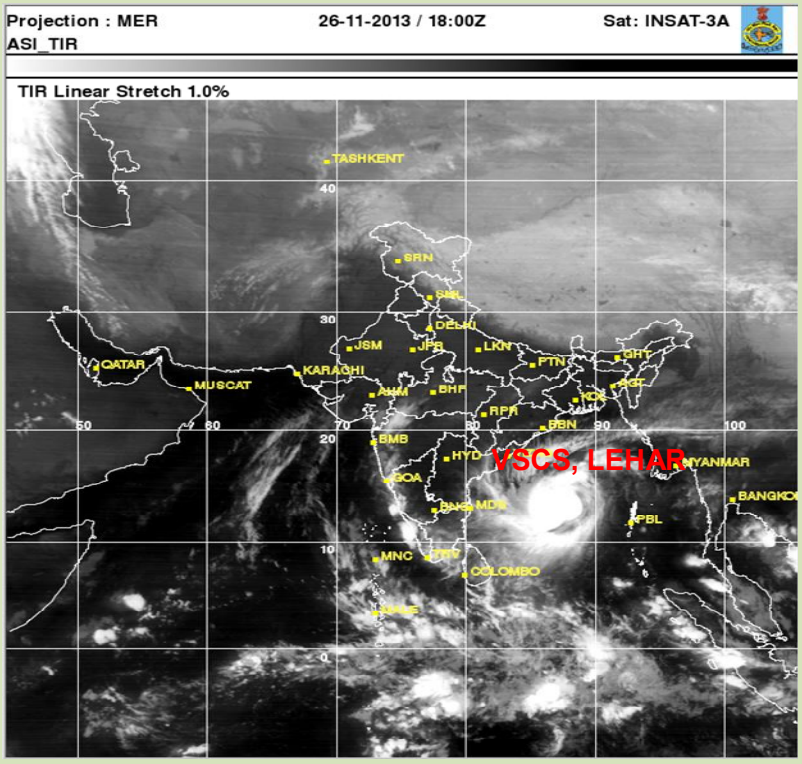
**MINISTRY OF EARTH SCIENCES**

**EARTH SYSTEM SCIENCE ORGANIZATION**

**INDIA METEOROLOGICAL DEPARTMENT**

# A Preliminary Report on Very Severe Cyclonic Storm 'LEHAR' over the Bay of Bengal

**(23 – 28 November, 2013)**




# CYCLONE WARNING DIVISION, NEW DELHI

**FEBRUARY, 2014**

Very Severe Cyclonic Storm VSCS ÷Leharø
(23-28 November, 2013)

## 1. Introduction

A depression formed over south Andaman sea on 23rd evening and it intensified into a cyclonic storm, **Lehar** in the early morning of 24th November 2013 near Latitude 10.0°N and longitude 95.0°E. Moving northwestward, it crossed Andaman & Nicobar Islands near Port- Blair around 0000 UTC of 25th November as a severe cyclonic storm. On 25th morning it emerged into southeast Bay of Bengal and moved west-northwestward, intensified into a very severe cyclonic storm in the early hours of 26th Nov. However while moving west-northwestwards over westcentral Bay of Bengal, it rapidly weakened from 27th afternoon and crossed Andhra Pradesh coast close to south of Machilipatnam around 0830 UTC of 28th Nov. 2013 as a depression.

The salient features of this system are given below:

(i) It was the first severe cyclonic storm to cross Andaman and Nicobar Islands after November, 1989.

(ii) It had second landfall near Machilipatnam as a depression.

(iii) It rapidly weakened over the sea from the stage of very severe cyclonic storm to depression in 18 hrs.

Brief life history and other characteristics of the system are described below:

## 2. Monitoring and Prediction:

The very severe cyclonic storm, ÷LEHARø was monitored mainly with satellite supported by meteorological buoys, coastal and island observations and Doppler Weather Radar(DWR), Machilipatnam. The half hourly INSAT/KALPANA imageries, hourly coastal observations and every 10 minutes DWR imageries and products were used for monitoring of cyclonic storm.

Various numerical weather prediction (NWP) models and dynamical-statistical models including IMDøs global and meso-scale models were utilized to predict the track and intensity of the storm. The Tropical Cyclone Module in the digitized forecasting system of IMD was utilized for analysis and comparison of various NWP models and decision making process. However, there was large divergence in NWP model guidance with

respect to genesis and intensification of the system. There was more unanimity in the NWP models with respect to track prediction.

## 3. Genesis:

A remnant of tropical depression over south China Sea moved across Malay peninsula and lay as a low pressure area over south Andaman Sea on 21st November, 2013. It became well marked over the same area on 22nd and concentrated into a depression over south Andaman Sea near latitude 08.5°N and longitude 96.5°E about 550 km south-southeast of Port Blair at 1200 UTC of 23rd November, 2013. The genesis was detected with the Ocean Sat-II winds and the observation from the coast of Thailand in addition to satellite imageries. The genesis was associated with upper troposphere ridge which ran along 13° N and provided adequate upper level divergence through Poleward outflow. The lower level convergence and relative vorticity increased over the area from 22nd to 23rd November. The sea surface temperature was 28-29°C and Ocean thermal energy was 60-80 kJ/cm$^2$. The vertical wind shear of horizontal wind was moderate (10-20 knots). The Madden Julian oscillation (MJO) index lay in Phase 3 i.e. over east equatorial Indian Ocean. Past studies indicate that the Phase 3 is favorable for genesis of depression.

## 4. Intensification and movement:

Due to the favourable atmospheric and Oceanic condition as mentioned above, the depression over south Andaman Sea moved northwestwards, intensified into a deep depression at 1800 UTC of 23rd and further into a cyclonic storm, 'Lehar' at 0300 UTC of 24th November and lay centred near latitude 10.0°N and longitude 95.0° E. It further intensified into a severe cyclonic storm, continued to move northwestwards and crossed Andaman & Nicobar Island near Port Blair around 0000 UTC of 25th November, 2013. It then emerged into southeast Bay of Bengal, moved west-northwestwards and intensified into a very severe cyclonic storm at 2100 UTC of 26th November, 2013 over southeast Bay of Bengal near latitude 12.5° N and longitude 91.0°E. It attained the maximum intensity of 75 knots at 1800 UTC of 26th November, 2013 and the same intensity continued till 0300 UTC of 27th November, 2013 when it lay over central Bay of Bengal.

As the westcentral Bay of Bengal was colder with Ocean thermal energy less than 50 KJ/cm$^2$ and there was entrainment of dry and cold air from central and northern parts of India into the cyclone field and vertical wind shear of horizontal wind increased and became high, the very severe cyclonic storm started to weaken rapidly from the afternoon of 27$^{th}$ November, 2013. It weakened into a severe cyclonic storm at 1200 UTC of 27$^{th}$ November and lay centred near latitude 14.5°N and longitude 85.0°E. It further weakened into a cyclonic storm at 1800 UTC of 27$^{th}$ November, 2013 with centre near latitude 15.0°N and longitude 84.0°E over westcentral Bay of Bengal. It weakened into a deep depression at 0000 UTC of 28$^{th}$ November, 2013 with centre near latitude 15.5°N and longitude 82.0°E. At this time the vertical wind shear was high (about 20 knots). It weakened into a depression and crossed Andhra Pradesh coast near latitude 15.9°N and longitude 81.1°E (close to south of Machilipatnam) around 0830 UTC of 28$^{th}$ November, 2013. It weakened into a well marked low pressure area over coastal Andhra Pradesh and adjoining Telengana at 1800 UTC of 28$^{th}$ November, 2013.

The system moved northwestwards/west-northwestwards as it lay to the south of the upper tropospheric steering ridge which moved northward from its position near latitude 13.0°N on the day of genesis to latitude 17°N on the day of landfall. The best track position and other parameters of the Very Severe Cyclonic Storm 'Lehar' over the Bay of Bengal is given in Table 1 and the track of the very severe cyclonic storm 'Lehar' is given in Fig. 1. Visakhapatnam & Machilipatnam RADAR imageries, Satellite imageries and IMD GFS MSLP and wind at 850, 500 and 200 hPa levels are shown in Fig. 2, 3 & 4 respectively. The position of the cyclone 'Lehar' based on DWR, Visakhapatnam is shown in Table 2.

**Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm 'Lehar' over the Bay of Bengal during 23-28 November, 2013**

| 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 |
|---|---|---|---|---|---|---|---|
| 23-11-2013 | 1200 | 8.5/96.5 | 1.5 | 1004 | 25 | 3 | D |
| | 1800 | 9.0/96.0 | 2.0 | 1002 | 30 | 5 | DD |
| 24-11-2013 | 0000 | 10.0/95.0 | 2.5 | 999 | 35 | 7 | CS |
| | 0300 | 10.0/95.0 | 2.5 | 998 | 40 | 8 | CS |
| | 0600 | 10.5/94.5 | 2.5 | 998 | 40 | 8 | CS |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0900 | 10.7/94.0 | 3.0 | 996 | 45 | 10 | CS |
| | 1200 | 11.0/93.5 | 3.0 | 996 | 45 | 10 | CS |
| | 1500 | 11.0/93.5 | 3.0 | 996 | 45 | 10 | CS |
| | 1800 | 11.5/93.0 | 3.0 | 996 | 45 | 10 | CS |
| | 2100 | 11.5/92.5 | 3.0 | 996 | 45 | 12 | CS |
| 25-11-2013 | The system crossed Andaman & Nicobar island, south of Port Blair around 0000 UTC | | | | | | |
| | 0000 | 12.0/92.5 | 3.5 | 992 | 55 | 15 | SCS |
| | 0600 | 12.0/91.5 | 3.5 | 988 | 55 | 17 | SCS |
| | 0900 | 12.0/91.5 | 3.5 | 988 | 60 | 17 | SCS |
| | 1200 | 12.5/91.5 | 3.5 | 988 | 60 | 17 | SCS |
| | 1500 | 12.5/91.0 | 3.5 | 988 | 60 | 17 | SCS |
| | 1800 | 12.5/91.0 | 3.5 | 988 | 55 | 17 | SCS |
| | 2100 | 12.5/91.0 | 4.0 | 984 | 65 | 22 | VSCS |
| 26-11-2013 | 0000 | 12.5/90.5 | 4.0 | 982 | 70 | 24 | VSCS |
| | 0300 | 12.5/90.0 | 4.0 | 982 | 70 | 24 | VSCS |
| | 0600 | 12.5/89.5 | 4.0 | 982 | 70 | 24 | VSCS |
| | 0900 | 13.0/89.0 | 4.0 | 982 | 70 | 24 | VSCS |
| | 1200 | 13.0/88.5 | 4.0 | 982 | 70 | 24 | VSCS |
| | 1500 | 13.0/88.5 | 4.0 | 982 | 70 | 24 | VSCS |
| | 1800 | 13.1/88.0 | 4.0 | 980 | 75 | 26 | VSCS |
| | 2100 | 13.2/87.5 | 4.0 | 980 | 75 | 26 | VSCS |
| 27-11-2013 | 0000 | 13.5/87.0 | 4.0 | 980 | 75 | 26 | VSCS |
| | 0300 | 13.5/86.5 | 4.0 | 980 | 75 | 26 | VSCS |
| | 0600 | 14.0/86.0 | 4.0 | 982 | 70 | 24 | VSCS |
| | 0900 | 14.0/85.5 | 4.0 | 984 | 65 | 22 | VSCS |
| | 1200 | 14.5/85.0 | 3.5 | 988 | 55 | 17 | SCS |
| | 1500 | 14.5/84.5 | 3.5 | 988 | 55 | 17 | SCS |
| | 1800 | 15.0/84.0 | 3.0 | 996 | 45 | 10 | CS |
| | 2100 | 15.0/83.5 | 2.5 | 998 | 40 | 8 | CS |
| 28-11-2013 | 0000 | 15.5/82.0 | 2.0 | 1000 | 30 | 5 | DD |
| | 0300 | 15.7/81.7 | 2.0 | 1000 | 30 | 5 | DD |
| | 0600 | 15.7/81.3 | 2.0 | 1000 | 30 | 5 | DD |
| | The system crossed Andhra Pradesh close to south of Machilipatnam near $15.9^0$N/$81.1^0$ E around 0830 UTC | | | | | | |
| | 0900 | 15.9/81.0 | - | 1002 | 25 | 4 | D |
| | 1200 | 16.0/80.8 | - | 1004 | 20 | 3 | D |
| | 1800 | Weakened into a well marked low pressure area over coastal Andhra Pradesh and adjoining Telengana. | | | | | |

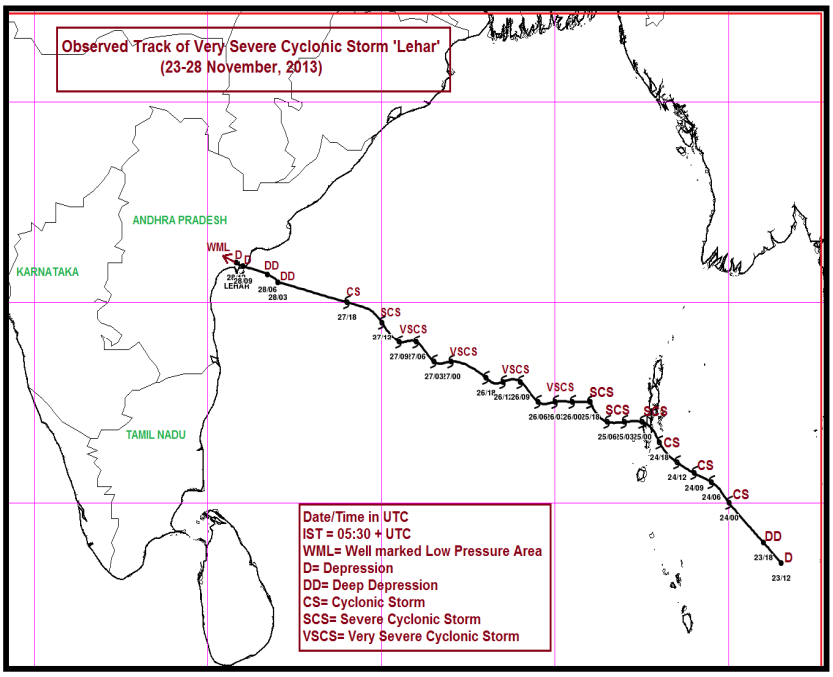
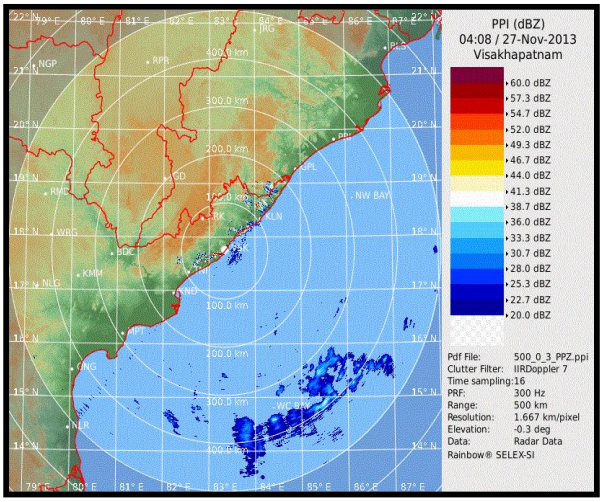


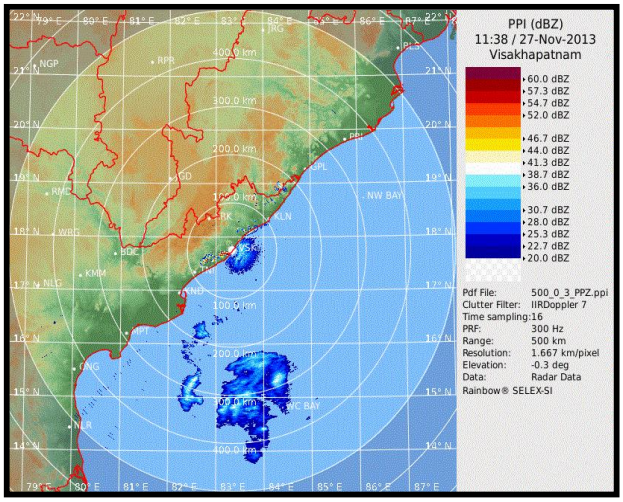

**Fig.1. Track of Very Severe Cyclonic Storm 'Lehar' over the Bay of Bengal**

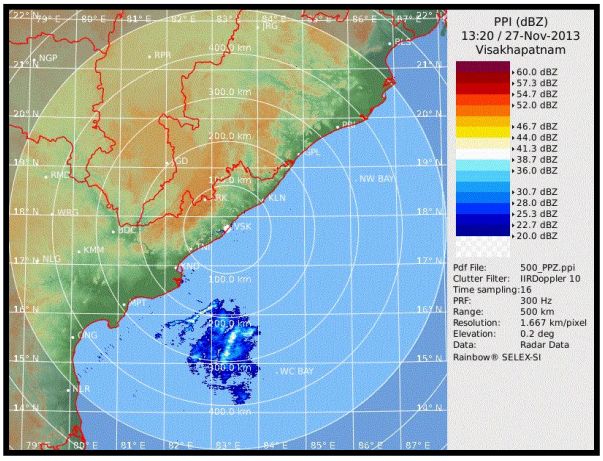
**Table 2. Position of Very Severe Cyclonic Storm 'LEHAR' based on DWR Visakhapatnam**

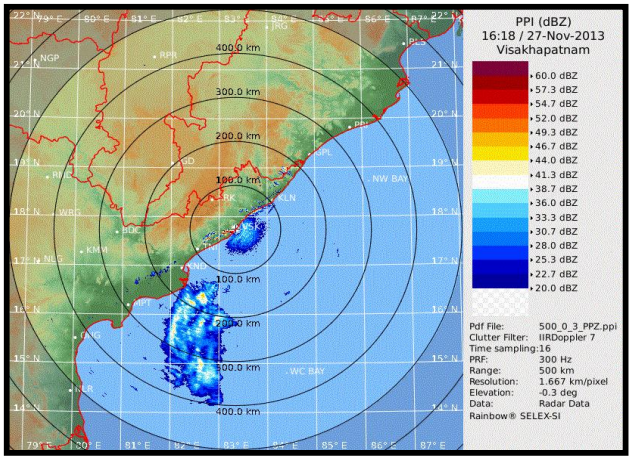
| Date | Time (UTC) | Intensity | Lat $^{o}$N | Long $^{o}$E |
|---|---|---|---|---|
| 23.11.13 | 1200 | D | 08.5 | 96.5 |
| | 1800 | DD | 09.0 | 96.0 |
| | 2100 | DD | --- | --- |
| 24.11.13 | 0000 | CS | 10.0 | 95.0 |
| | 0300 | CS | 10.0 | 95.0 |
| | 0600 | CS | 10.5 | 94.5 |
| | 0900 | CS | 10.5 | 94.0 |
| | 1200 | CS | 11.0 | 93.5 |
| | 1800 | CS | 11.5 | 93.0 |
| | 2100 | CS | 11.5 | 92.5 |
| 25.11.13 | 0000 | SCS | 12.0 | 92.5 |
| | 0300 | SCS | 12.0 | 92.0 |
| | 0600 | SCS | 12.0 | 91.5 |

| | | | | |
|---|---|---|---|---|
| | 0900 | SCS | 12.0 | 91.5 |
| | 1200 | SCS | 12.5 | 91.0 |
| | 1500 | SCS | 12.5 | 91 .0 |
| | 1800 | SCS | 12.5 | 91.0 |
| | 2100 | VSCS | 12.5 | 91.0. |
| 26.11.13 | 0000 | VSCS | 12.5 | 90.5 |
| | 0300 | VSCS | 12.5 | 90.0 |
| | 0600 | VSCS | 12.6 | 89.5 |
| | 0900 | VSCS | 13.0 | 89.0 |
| | 1200 | VSCS | 13.0 | 88.5 |
| | 1500 | VSCS | 13.0 | 88.5 |
| | 1800 | VSCS | 13.0 | 88.0 |
| | 2100 | VSCS | 13.2 | 87.5 |
| 27.11.13 | 0000 | VSCS | 13.5 | 87.0 |
| | 0300 | VSCS | 13.5 | 86.5 |
| | 0600 | VSCS | 14.0 | 86.0 |
| | 0900 | VSCS | 14.0 | 85.5 |
| | 1200 | SCS | 14.5 | 85.0 |
| | 1500 | SCS | 14.5 | 84.5 |
| | 1800 | CS | 15.0 | 84.0 |
| | 2100 | CS | 15.0 | 83.5 |
| 28.11.13 | 0000 | DD | 15.5 | 82.0 |
| | 0300 | DD | 15.7 | 81.7 |
| | 0600 | DD | 15.7 | 81.3 |
| | 0900 | D | 15.9 | 81.1 |



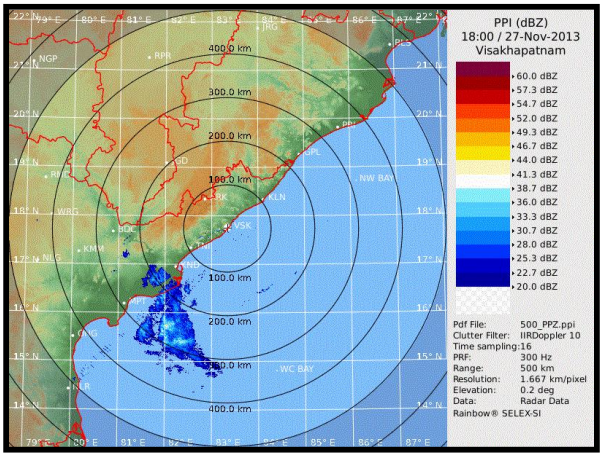




**Fig. 2(a) Visakhapatnam RADAR imageries based on 0400,1140,1320,1620 & 1800 UTC of 27th November, 2013**

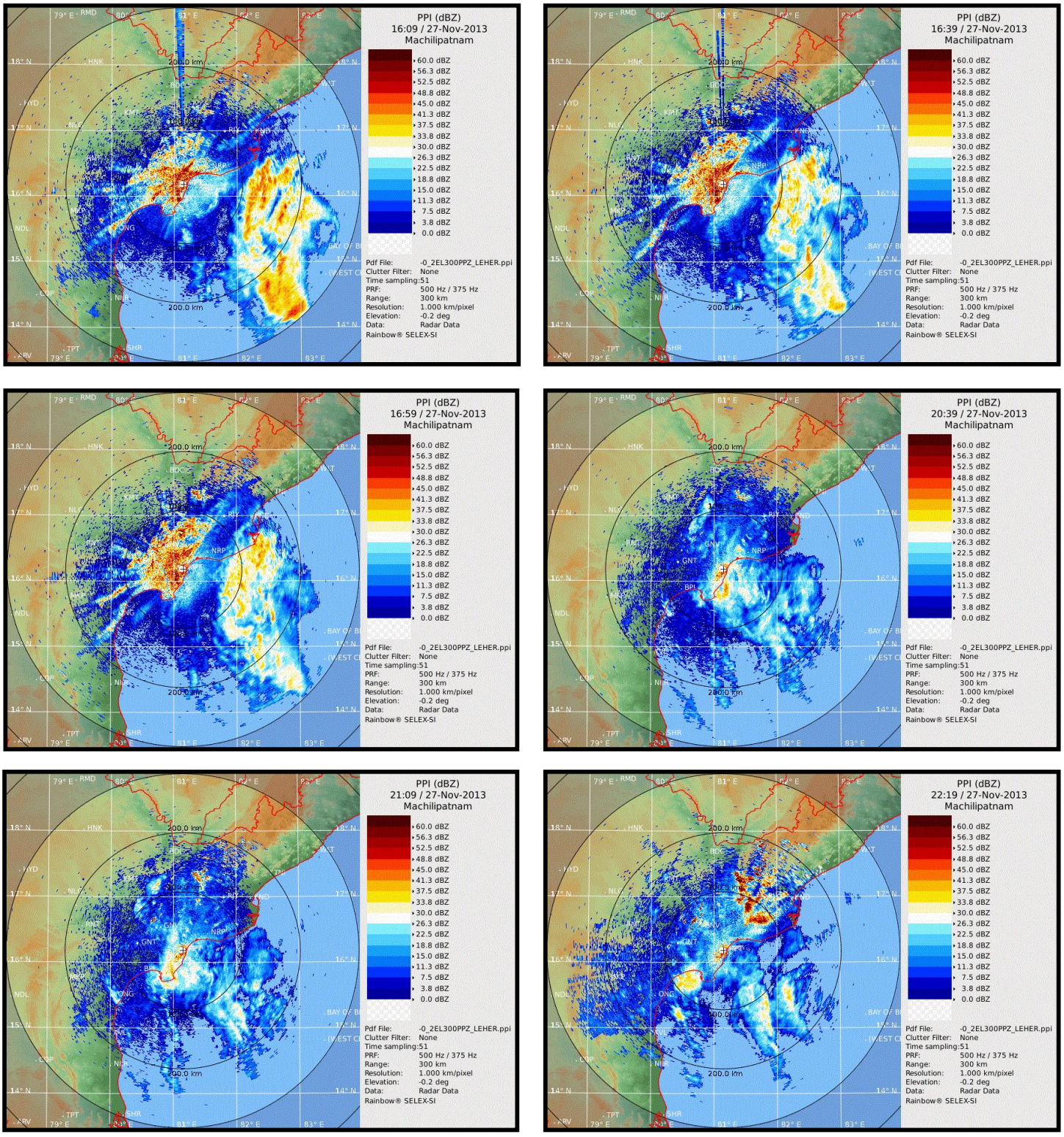
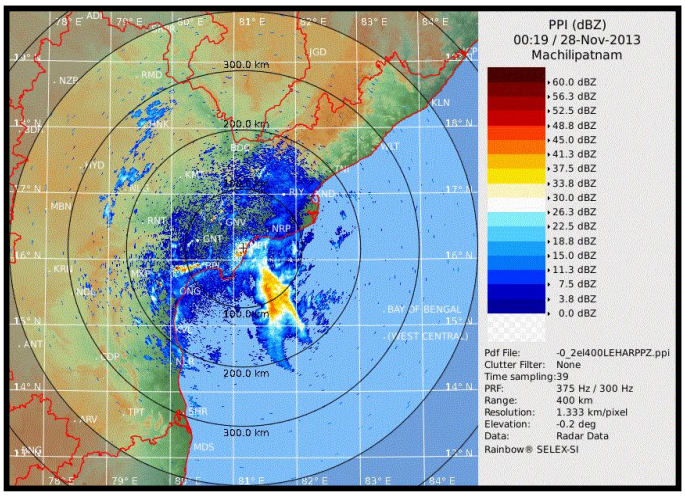
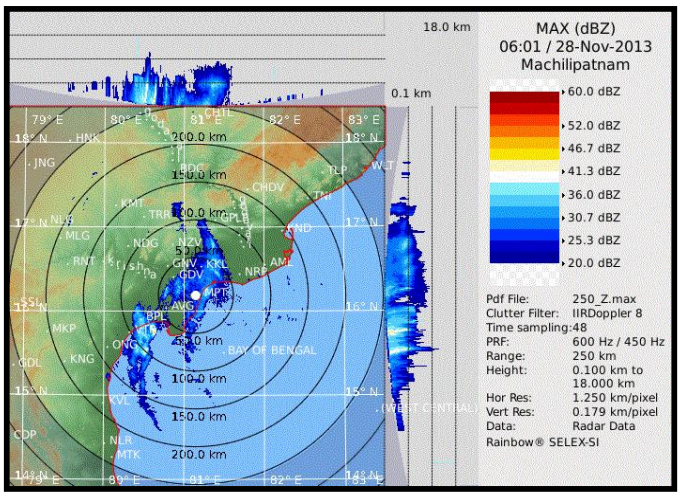
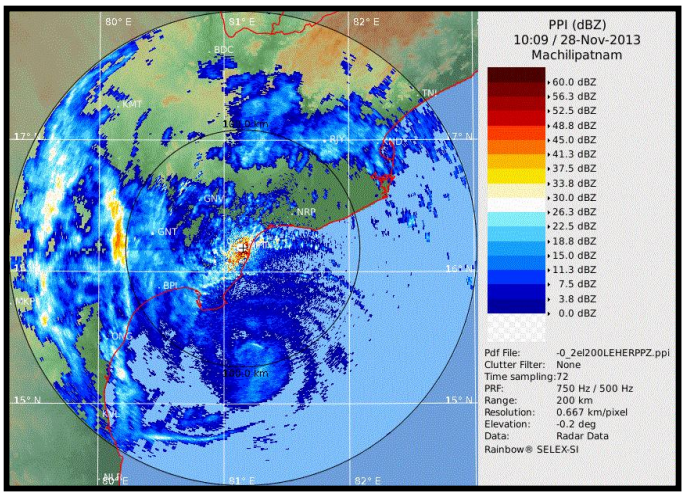
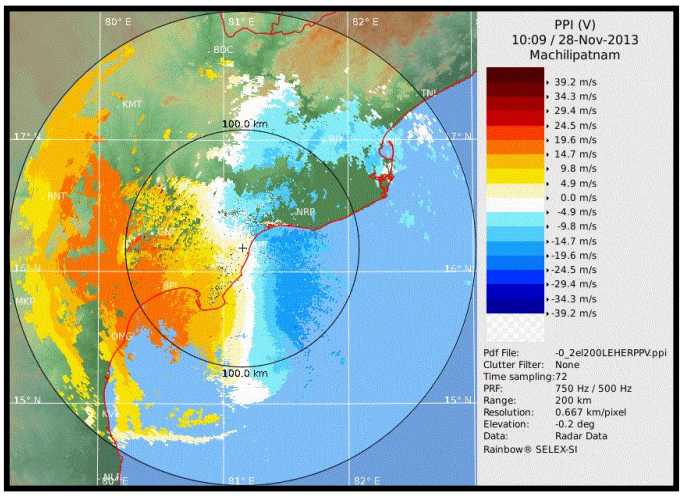



**Fig. 2(b) Machilipatnam RADAR imageries on 27th November, 2013**



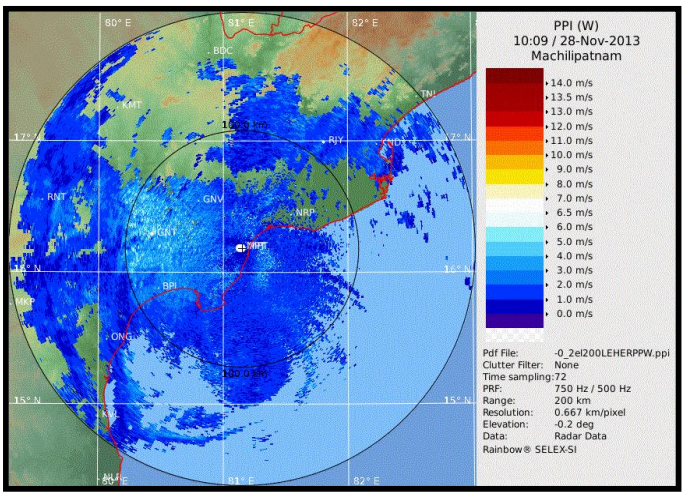
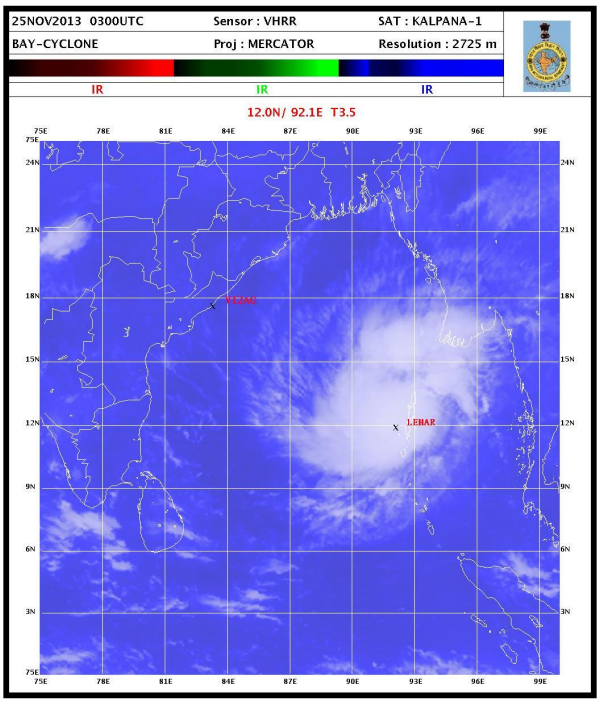
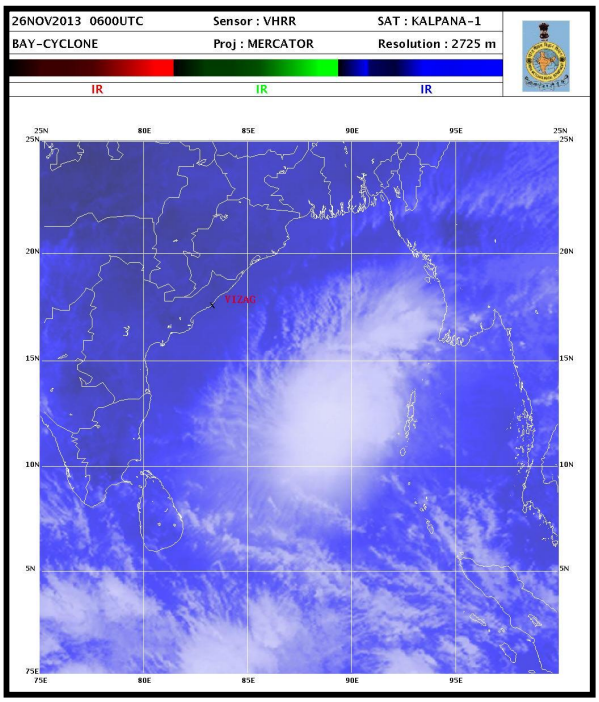
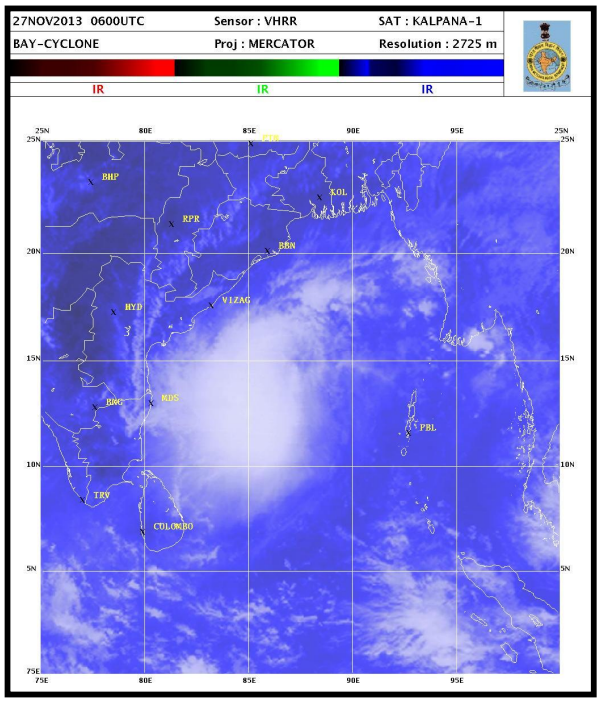




**Fig. 2(c) Machilipatnam RADAR imageries on 28th November, 2013**



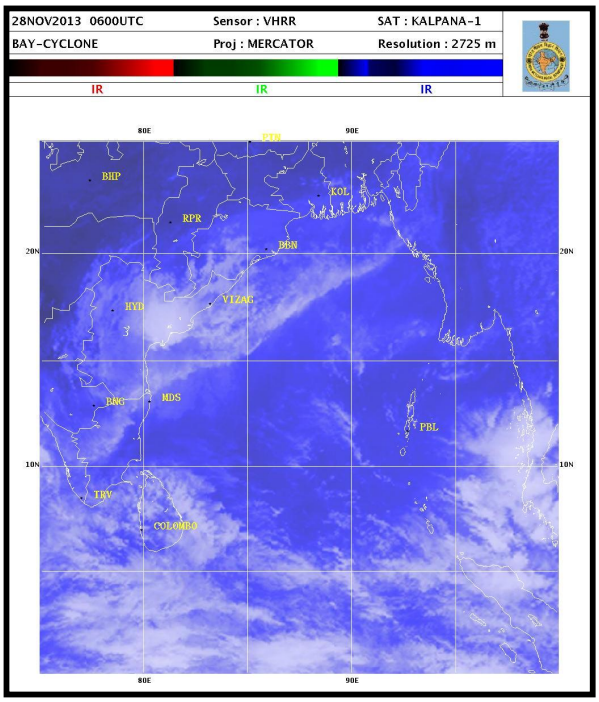
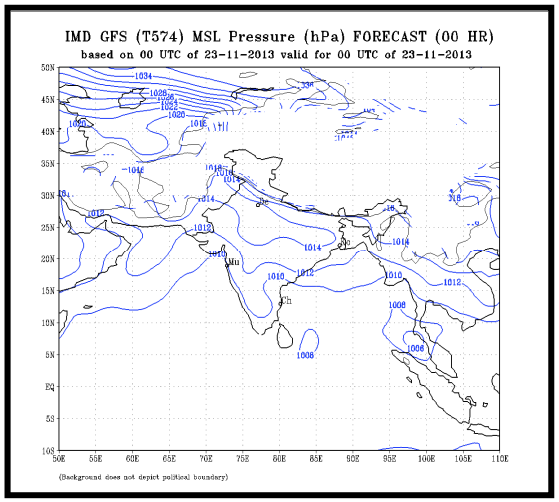
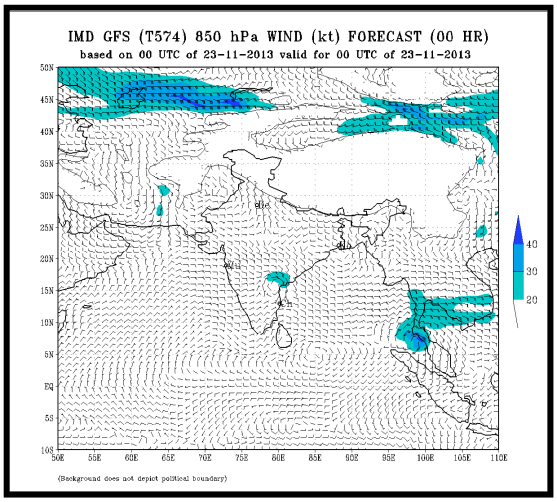
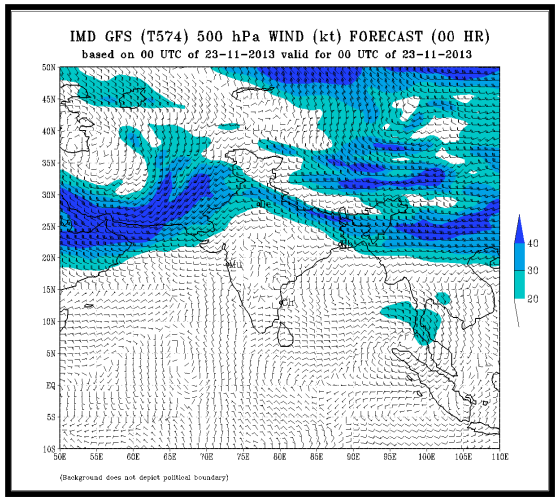
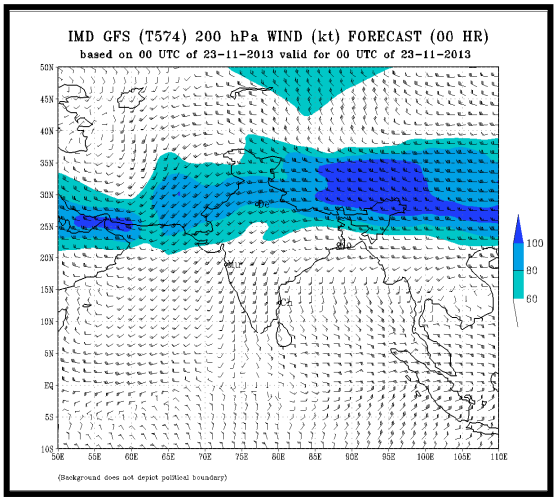




**Fig. 3: Satellite imageries based on 0300 UTC of 25th and 0600 UTC of 26th, 27th and 28th November, 2013**



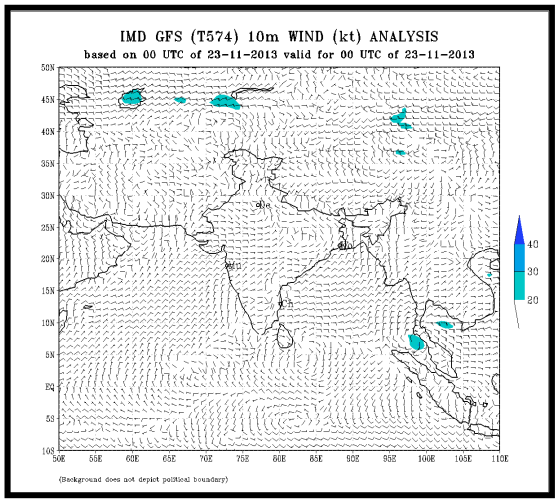
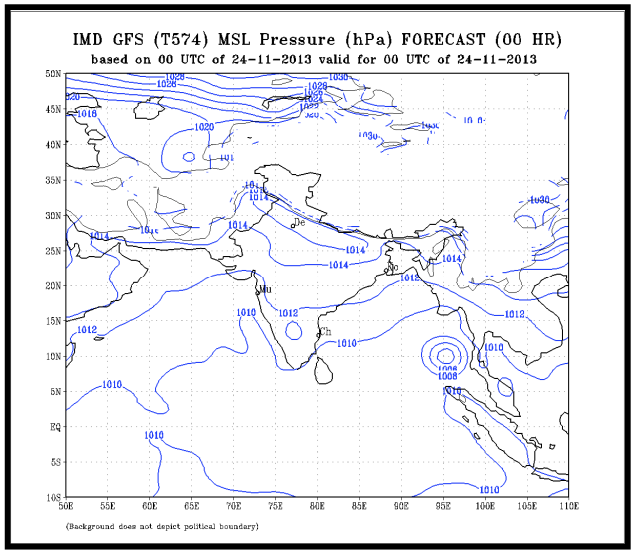
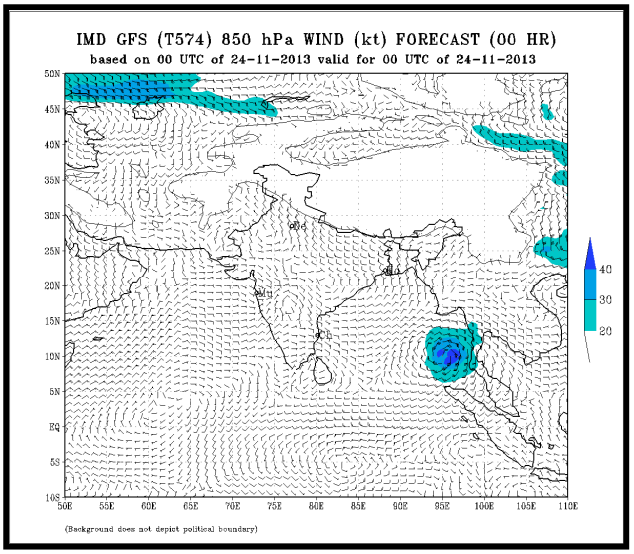
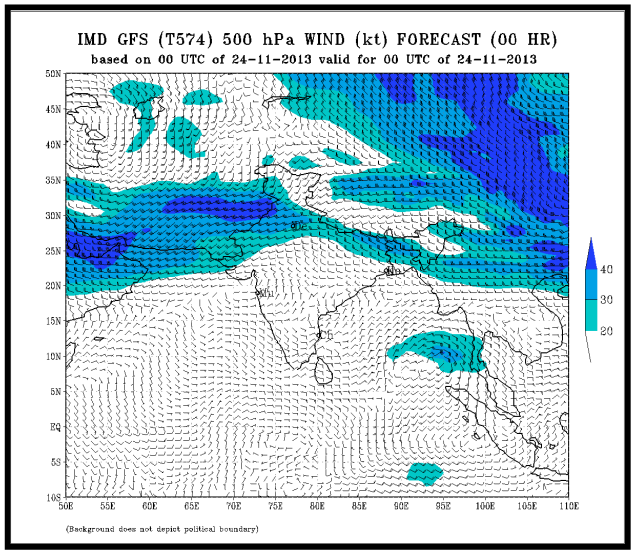
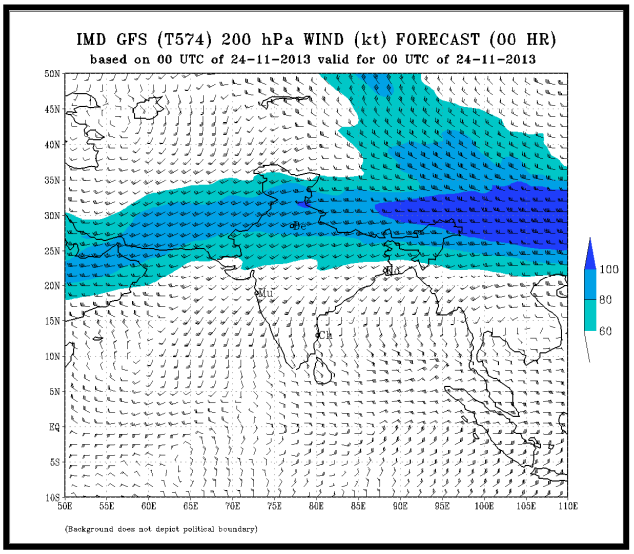




**Fig.4 (a) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 23rd November, 2013.**



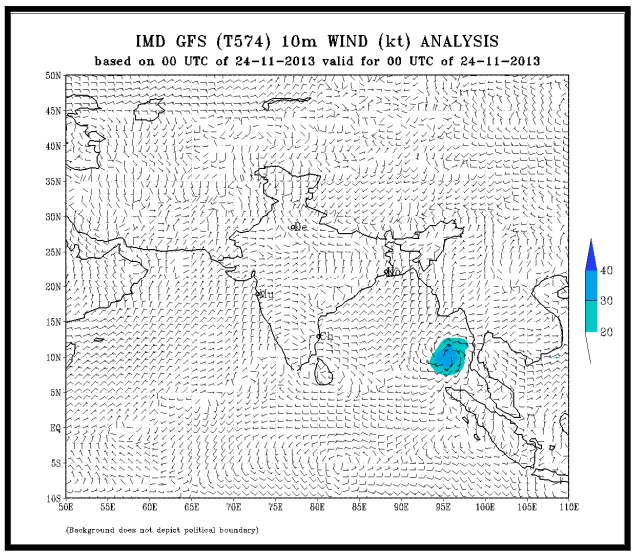
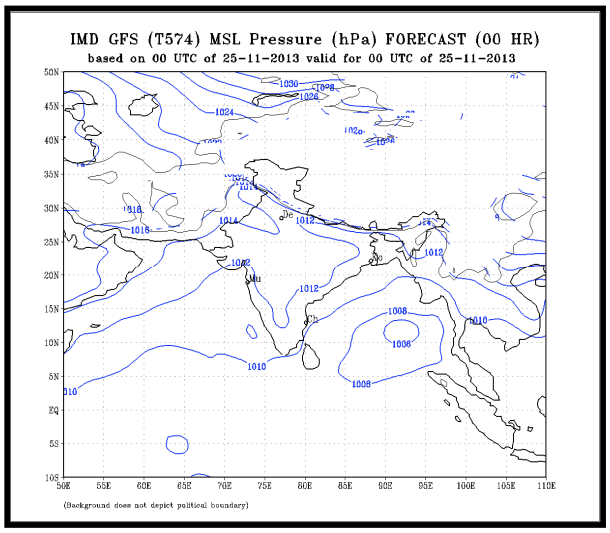
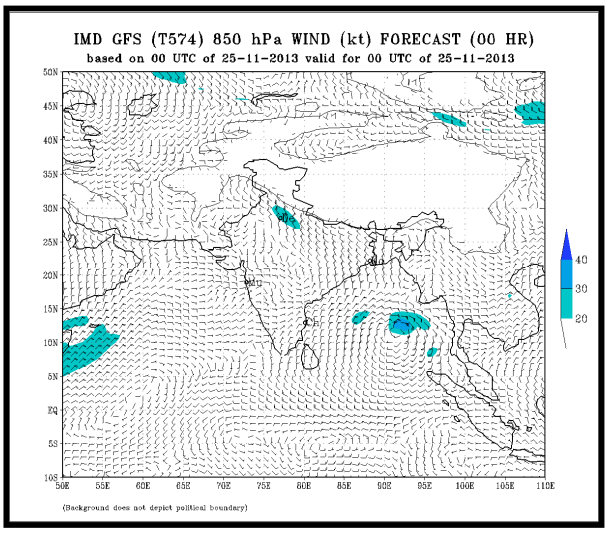
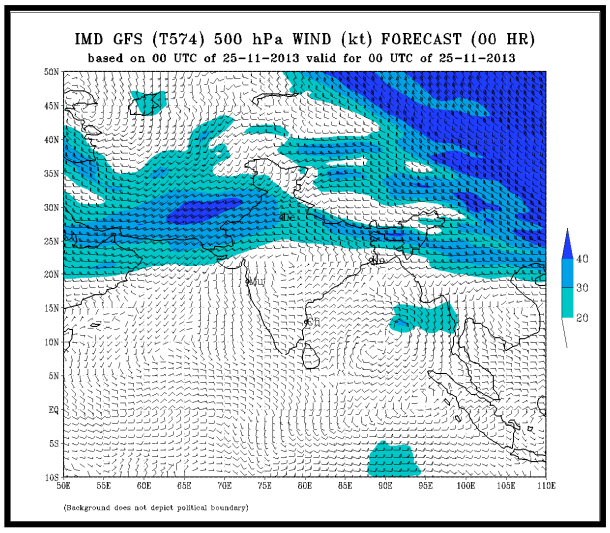
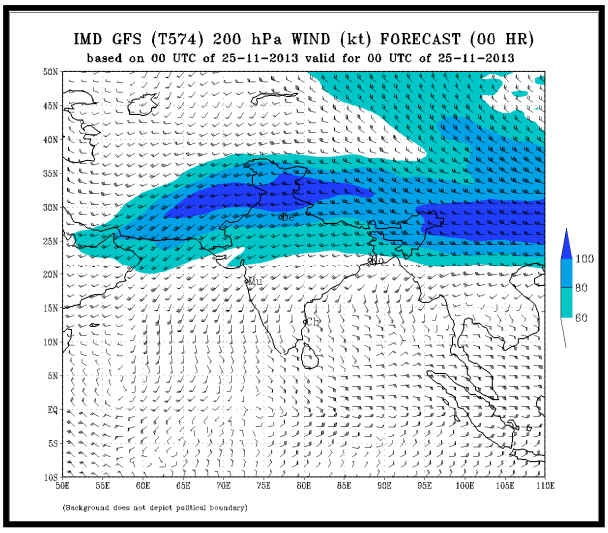




**Fig.4 (b) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 24th November, 2013.**



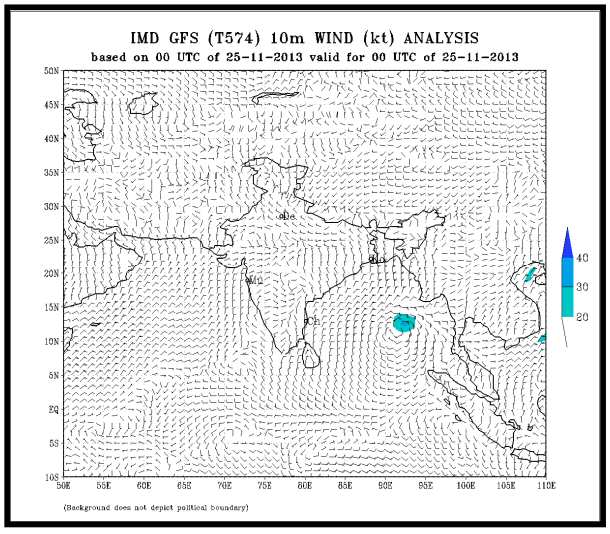




**Fig.4 (c) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 25th November, 2013.**

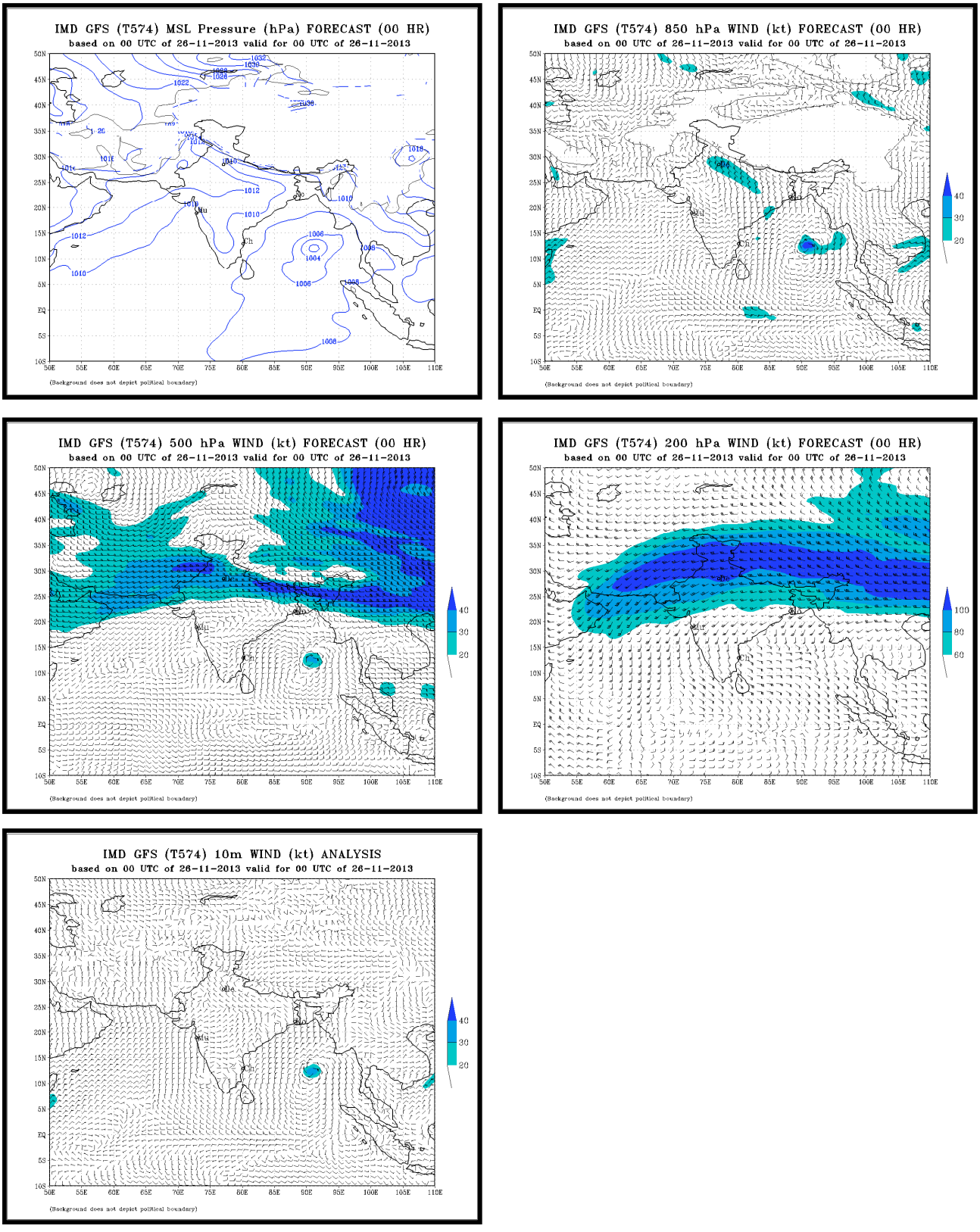



**Fig.4 (d) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 26th November, 2013.**

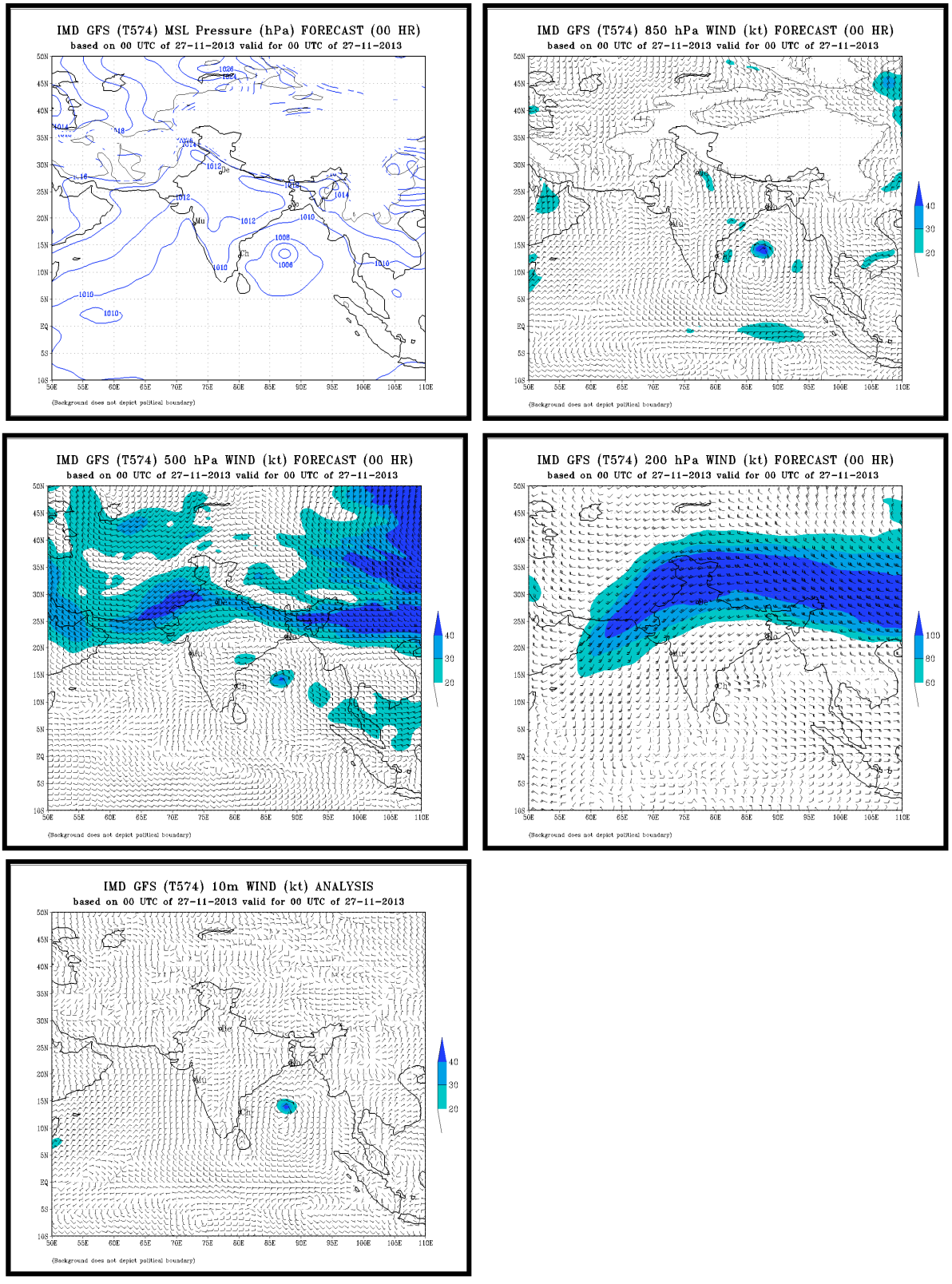
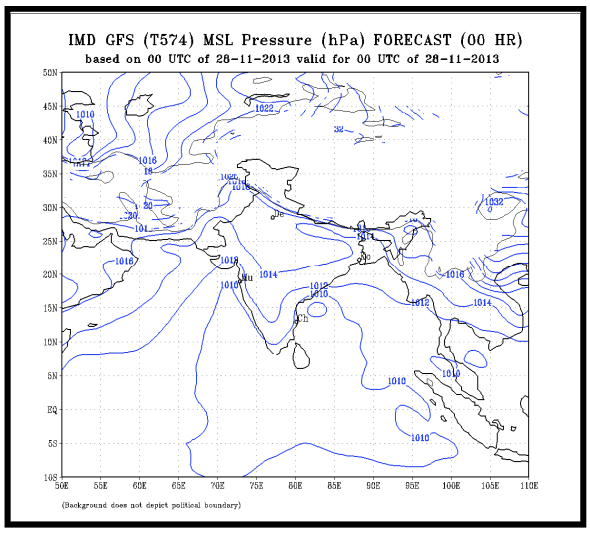
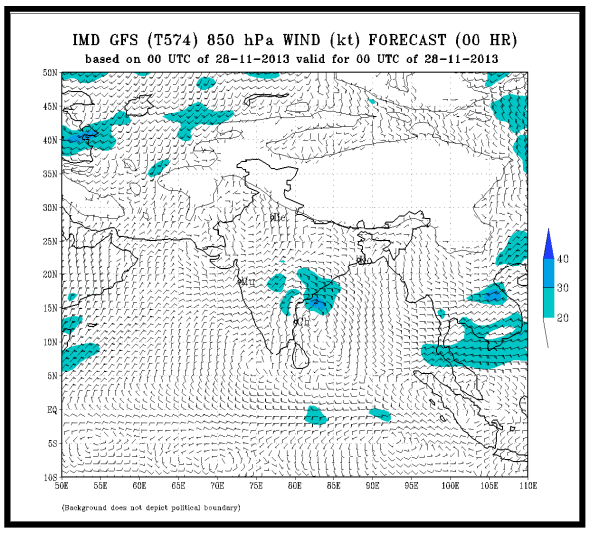
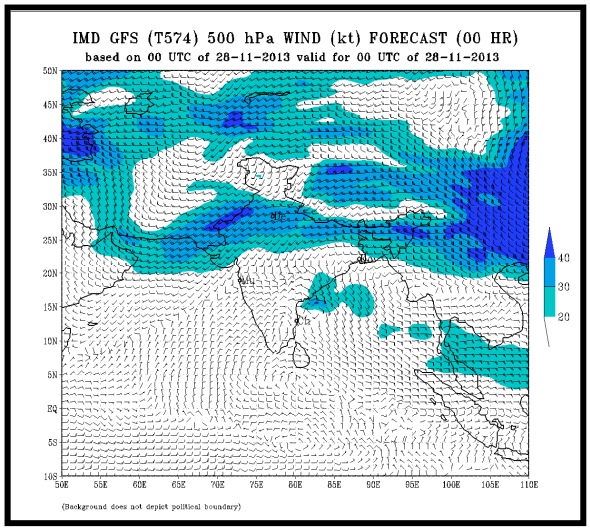
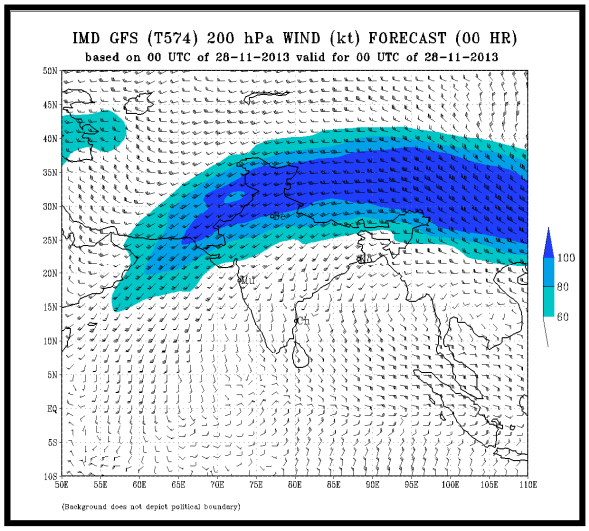



**Fig.4 (e) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 27th November, 2013.**



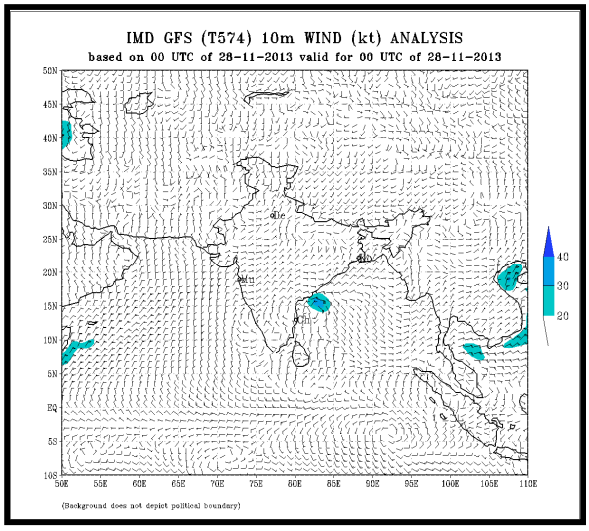




**Fig.4 (f) IMD GFS MSLP and winds at 850, 500 & 200 hpa levels analysis and 10meter wind based on 00 UTC of 28th November, 2013.**

## 5. Warning services

The Cyclone Warning Division/ Regional Specialised Meteorological Centre (RSMC)-Tropical Cyclone, IMD, New Delhi mobilised all its resources for monitoring and prediction of cyclonic storm, **LEHAR**. It issued 3/6 hourly warning/advisory bulletins to national disaster management agencies. It issued forecast and warning bulletins to various national and international disaster management agencies including National Disaster Management (NDM), Ministry of Home Affairs (MHA), National Disaster Management Authority (NDMA), concerned state Govts. and other users in regular intervals. It also issued advisories to World Meteorological Organisation (WMO)/Economic and Social Cooperation for Asia and the Pacific (ESCAP) Panel member countries including Bangladesh, Myanmar, Thailand, Pakistan, Oman, Sri Lanka and Maldives during cyclone period. As Tropical Cyclone Advisory Centre (TCAC), it also issued tropical cyclone advisories with effect from the stage of cyclone for international civil aviation purpose as per the requirement of International Civil Aviation Organization (ICAO). The TCAC bulletin was also sent to Aviation Disaster Risk reduction (ADRR) centre of WMO at Hong Kong like previous year.

The cone of uncertainty in the track forecast was also given. The radius of maximum wind and radius of Ó34 knots, Ó50 knots and Ó64 knots wind in four quadrants of cyclone was also issued 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 IMD's website regularly. The prognostics and diagnostics of the systems were described in the special tropical weather outlook and tropical cyclone advisory bulletins. Tropical cyclone vitals were prepared every six hourly from deep depression stage onwards and provided to various NWP modeling groups in India for synthetic vortex generation in NWP models.

The numbered warning bulletins were issued by Cyclone Warning Division, IMD, New Delhi since 23rd November, 2013. The bulletins were issued every three hourly since the cyclonic storm stage, i.e. from early morning of 24th Nov 2013. The number of bulletins issued by the Regional Specialised Meteorological Centre and Cyclone Warning Division, New Delhi, are given in Table 3.

| **Table 3.** Bulletins issued by the Regional Specialised Meteorological Centre and Cyclone Warning Division, New Delhi | | |
|---|---|---|
| S.N. | Bulletins | No. of Bulletins |
| 1. | Press Release | 6 |
| 2. | No. of Press conferences | 1 |
| 3. | National Bulletin | 40 |
| 4. | RSMC Bulletin | 36 |
| 5. | DGMôs Bulletin to higher officials at national and state level | 5 |
| 6. | TCAC Bulletin (Text & Graphics) | 18 |
| 7. | ADRR Bulletin to Hong Kong | 18 |
| 8. | TC Vitals | 14 |
| 9. | Quadrant Wind | 14 |
| 10. | Frequency of SMS to senior Govt. officials at national and state level | 7 |

In addition, special e-mails about the cyclone were also sent to all concerned offices. The warning bulletins were issued to various disaster management agencies in the national level and to Govt. of Andaman & Nicobar Islands, Andhra Pradesh and Tamil Nadu states.

| **Table 4. No. of bulletins issued during VSCS 'Lehar' by CWC Visakhapatnam** | | | |
|---|---|---|---|
| S. No. | Name of the Bulletin | Bulletins issued to | Number of bulletins |
| 1 | Cyclone Alert Bulletin | State Government Officials (Chief Secretary, Commissioner, Disaster Management, Collectors Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam and Nellore Districts) | 2 |
| 2 | Cyclone Warning Bulletin | State Government Officials (Chief Secretary, Commissioner, Disaster Management, Collectors Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam and Nellore Districts) | 13 |

| Table 5. No. of bulletins issued during VSCS 'Lehar' by CWC Bhubaneswar | | |
|---|---|---|
| S. No. | Name of the Bulletin | Number of bulletins |
| 1 | Number of Informatory message issued | 39 |
| 2 | Number of Port Warning issued | 36 |
| 3 | Fishermen Warning | 18 |
| 4 | Press/AIR/Doordarshan/other TV Channel Bulletin issued | 39 |

**6. Realized Weather:**

Chief amounts of 24 hrs. Rainfall (7 cm or more) ending at 0300 UTC from 23rd November to 29th November, 2013 are given below:

**23 November 2013 - Nil**

**24 November 2013 – Nil**

**25 November 2013**

Andaman & Nicobar Islands: Maya Bandar-24, Port Blair-21, Long Island-11,

**26 November 2013 – Nil**

**27 November 2013 – Nil**

**28 November 2013**

Kerala: Angadippuram-8,

**29 November 2013**

Coastal Andhra Pradesh: Macharla-7

## 7. Forecast verification

### (a) Track forecast error

In the first bulletin issued in the evening of 23rd November 2013 (five days in advance of landfall), when the system was a depression over south Andaman sea, it was predicted that the system would intensify into a cyclonic storm and move northwestward and cross Andaman & Nicobar Islands between Hurt Bay and Long island, close to Port Blair as a cyclonic storm. In the third bulletin issued in the morning of 24th November 2013, it was

predicted that the system would intensify into a very severe cyclonic storm and move towards Andhra Pradesh coast.

The average track forecast error and skill is shown in Table 6 and Table 7 respectively. The track forecast error was 92,133 and 140 km respectively for 24, 48 and 72 hrs. forecast period against the long period average of 133, 254 and 376 km for the *per*iod of 2008-2012.

**Table 6. Operational track forecast error of LEHAR**

| Lead period (hrs) | Track Forecast Error in km | Long period average (2008-2012) |
|---|---|---|
| 12 | 56.9 (18) | 75.4 |
| 24 | 92.4 (16) | 132.6 |
| 36 | 111.3 (14) | 190.2 |
| 48 | 132.9 (12) | 253.6 |
| 60 | 141.0 (10) | 308.9 |
| 72 | 139.7 (08) | 376.1 |
| 84 | 134.4 (06) | - |
| 96 | 142.7 (04) | - |
| 108 | 169.2 (02) | - |
| 120 | - | - |

**Table 7. Operational Track Forecast Skill (%)**

| Lead period (hrs) | Track forecast skill | Long period skill (2008-2012) |
|---|---|---|
| 12 | 47.0 | 23.1 |
| 24 | 53.7 | 34.8 |
| 36 | 62.1 | 35.1 |
| 48 | 63.0 | 41.8 |
| 60 | 75.3 | 47.4 |
| 72 | 77.8 | 50.0 |
| 84 | 82.0 | - |
| 96 | 81.7 | - |
| 108 | 85.0 | - |
| 120 | - | - |

The track forecast skill was about 54%, 63% and 78% for 24, 48 and 72 hrs forecast respectively. They were significantly higher than long period average (Table 7).

### (b) Landfall forecast error

Considering the landfall forecast error, the landfall on Andhra Pradesh coast, near Machilipatnam was predicted in the fourth bulletin itself. The landfall point forecast errors 5 days before the landfall was about 162 km. It was 20, 83, and 156 km for 24, 48 and 72 hrs forecast period before landfall respectively.

**Table.8. Operational Landfall forecast error of LEHAR**

| Lead Period | Landfall point and time forecast error (Difference of forecast landfall point and time and actual landfall point and time) | | | |
|---|---|---|---|---|
| | Landfall point Error (km) (Forecast landfall point- Actual landfall point) | Landfall Time Error (Forecast landfall time- Actual landfall time) (hrs) | Long period average landfall point error(km) during 2008-2012 | Long period average landfall time error(hrs) during 2008-2012 |
| 12 | 50 | -½ | 41.6 | 2.5 |
| 24 | 20 | +5 ½ | 90.8 | 5.5 |
| 36 | 52 | +½ | 102.7 | 8.5 |
| 48 | 83 | +2 ½ | 95.8 | 7.3 |
| 60 | 156 | +½ | 67.7 | 2.2 |
| 72 | 156 | -2 ½ | 134.8 | 1.2 |
| 84 | 156 | -2 ½ | - | - |
| 96 | 156 | -1 | - | - |
| 108 | 162 | -1½ hr | - | - |

### (c) Intensity forecast error

The intensity forecast error (average absolute error (AAE) and root mean square error (RMSE)) of IMD for very severe cyclonic storm, Lehar are shown in Table 9. The AAE was about 18, 29 & 41 knots against the long period average of 10, 13 and 19 knots based on the period of 2008-2012. The RMSE was about 25, 38 and 47 knots against the long period average of 13, 18 and 24 knots. Hence, both the AAE and RMSE are above the long period average. It is due to the rapid weakening of the cyclone on 27$^{th}$ November which could not be predicted well. Considering the skill in intensity forecast compared to persistence, there was positive skill for all forecast times except 12 & 24 hrs forecast. The poor skill in 12 & 24 hrs forecast is mainly due to sudden weakening of the cyclone on 27$^{th}$ November over the sea.

| Table 9. Operational average intensity forecast error of LEHAR | | | | |
|---|---|---|---|---|
| Lead Period | Intensity Forecast Error (knots) | | Long period Average (2008-2012):Absolute Error (knots) | Long period Average (2008-2012): RMS Error (knots) |
| | Absolute error | Root mean square error | | |
| 12 | 10.2 | 13.4 | 7.3 | 9.9 |
| 24 | 18.4 | 24.5 | 10.4 | 13.5 |
| 36 | 25.5 | 33.1 | 12.7 | 16.1 |
| 48 | 29.2 | 38.0 | 13.4 | 17.8 |
| 60 | 32.4 | 39.3 | 13.4 | 15.3 |
| 72 | 41.0 | 47.3 | 19.0 | 24.0 |
| 84 | 47.0 | 49.6 | - | - |
| 96 | 48.5 | 54.3 | - | - |
| 108 | 34.5 | 36.9 | - | - |
| 120 | - | - | - | - |

**Table 10. Operational Intensity Forecast skill (%)**

| Lead period (hrs) | Skill in term of Absolute Error (%) | Skill in term of RMS Error (%) |
|---|---|---|
| 12 | -14.3 | -22.3 |
| 24 | -27.5 | -14.0 |
| 36 | 2.5 | 07.5 |
| 48 | 0.9 | 09.4 |
| 60 | 10.1 | 14.4 |
| 72 | 17.8 | 15.0 |
| 84 | 25.9 | 27.5 |
| 96 | 33.0 | 33.2 |
| 108 | 54.7 | 54.7 |
| 120 | -- | |

## (d) Gale and squally wind forecast

The warning for gale and squally wind issued by IMD along with the actual wind is given in Table 11.

Table 11: Gale and squally wind forecast verification

| Date & time | Warning issued | Realised wind |
|---|---|---|
| 23rd November 1200 UTC | **Squally winds** - Squally winds speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Andaman & Nicobar island. The wind speed would gradually increase and become 80-90 kmph gusting to 100kmph from 24th evening along and off this coast. | Port Blear reported 120 kmph at the time of landfall.<br>Maximum surface wind speed was about 45-55 kmph at the time of landfall near Machilipatnam. |
| 24th November 0300 UTC | Squally winds speed reaching 50-60 kmph gusting to 70 kmph would prevail along and off Andaman & Nicobar Islands. The wind speed would gradually increase and become 80-90 kmph gusting to 100 kmph from 24th evening along and off this coast. | |
| 25th November 0300 UTC | Gale winds speed reaching 80-90 kmph gusting to 100 kmph would prevail along and off Andaman & Nicobar Islands during next 6 hrs and gradually decrease thereafter. | |
| 26th November 0300 UTC | Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Andhra Pradesh and south Odisha coasts from 27th evening. It would increase in intensity with gale wind speed reaching 170-180 kmph gusting to 200 kmph along and off coastal districts of Krishna, west & east Godavari and Vishakhapatnam districts and 120-130 kmph gusting to 140 kmph over Vizianagarm, Srikakulam and Guntur districts of coastal Andhra Pradesh at the time of landfall. Squally winds speed reaching 55-65 kmph gusting to 75 kmph would prevail along and off remaining districts of Andhra Pradesh and south Odisha at the time of landfall. | |

| | | |
|---|---|---|
| 27th November 0300 UTC | Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Andhra Pradesh from 27th evening. It would increase in intensity with gale wind speed reaching 150-160 kmph gusting to 170 kmph along and off coastal districts of Guntur, Krishna, west & east Godavari and Vishakhapatnam districts of Andhra Pradesh and Yanam district of Puducherry and 100-110 kmph gusting to 120 kmph over Vizianagaram and Prakasham districts of coastal Andhra Pradesh at the time of landfall. Squally winds speed reaching 55-65 kmph gusting to 75 kmph would prevail along and off remaining districts of Andhra Pradesh at the time of landfall. Squally winds speed reaching 40-50 kmph gusting to 60kmph would prevail along and off south coastal Odisha on 28th Nov 2013. | |
| 27th November 1200 UTC | Squally winds speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Andhra Pradesh during next 24 hours. It would increase in intensity with gale wind speed reaching 70-80 kmph gusting to 90 kmph along and off coastal districts of Guntur, Krishna, west & east Godavari and adjoining areas of Vishakhapatnam districts of Andhra Pradesh and Yanam district of Puducherry at the time of landfall. | |
| 28th November 0300 UTC | Squally winds speed reaching 50-60 kmph gusting to 70 kmph would prevail along and off Andhra Pradesh during next 12 hours. | |

### (e) Rainfall forecast

The heavy rainfall warning issued by IMD along with the actual heavy rainfall is given in Table 12.

Table 12: Heavy rainfall forecast verification

| Date & time | Warning issued | 24 hr heavy rainfall realised at 0300UTC of date |
|---|---|---|
| 23rd November 1200 UTC | Heavy to very heavy rainfall at a few places with isolated extremely heavy falls (25 cm or more) would occur over Andaman & Nicobar Islands during 48 hrs. | **25th November, 2013**<br>**Heavy to very heavy rainfall at a few places –** Andaman & Nicobar Island<br><br>**28th November, 2013**<br><br>**Isolated Heavy rainfall -** Kerala<br><br>**29th November, 2013**<br><br>**Isolated Heavy rainfall –** Coastal Andhra Pradesh |
| 24th November 0300 UTC | Heavy to very heavy rainfall at a few places with isolated extremely heavy falls (25 cm or more) would occur over Andaman & Nicobar Islands during 48 hrs. | |
| 25th November 0300 UTC | Isolated heavy to very heavy rainfall would occur over Andaman & Nicobar Islands during next 24 hrs. and intensity would decrease thereafter. | |
| 26th November 0300 UTC | Heavy to very heavy falls at a few places and isolated extremely heavy falls over north coastal Andhra Pradesh on 28th and isolated heavy rainfall over south Odisha and south coastal Andhra Pradesh. | |
| 27th November 0300 UTC | Heavy to very heavy falls at a few places and isolated extremely heavy falls over coastal Andhra Pradesh and Yanam district of Puducherry on 28th November and isolated heavy to very heavy rainfall over these regions on 29th November 2013. Isolated heavy to very heavy falls would also occur over Telangana on 28th and 29th Nov 2013. | |
| 28th November 0300 UTC | Isolated heavy to very heavy falls would occur over coastal Andhra Pradesh and Yanam district of Puducherry during next 24 hours. Isolated heavy to very heavy falls would also occur over Telangana during next 36 hours. | |

## (f) Storm Surge forecast

| Table.13. Storm surge forecast varification | | |
|---|---|---|
| Date & time | Storm Surge warning issued | Storm Surge reported |
| 24th November 0300 UTC | Storm surge of about 1 to 1.5 metre height above astronomical tide would inundate the low lying areas of Andaman & Nicobar Islands within 100 km from the landfall point. | No storm surge report has received. |
| 25th November 0300 UTC | Storm surge of about 0.5-1.0 metre height above astronomical tide would inundate the low lying areas of Andaman & Nicobar Islands within 100 km from the landfall point during next six hours and decrease thereafter. | |
| 26th November 0300 UTC | Storm surge of height about 2.0-3.0 metres above astronomical tide would inundate low lying areas of west and east Godavari, Vishakhapatnam and Krishna districts at the time of landfall. | |
| 27th November 0300 UTC | Storm surge of height about 2.0-3.0 metres above astronomical tide would inundate low lying areas of west and east Godavari, Guntur and Krishna districts of Andhra Pradesh and Yanam district of Puducherry and about 1 metre near Visakhapatnam district at the time of landfall. | |

**3. Damage:** No damage has been reported due to this system

-----x-----