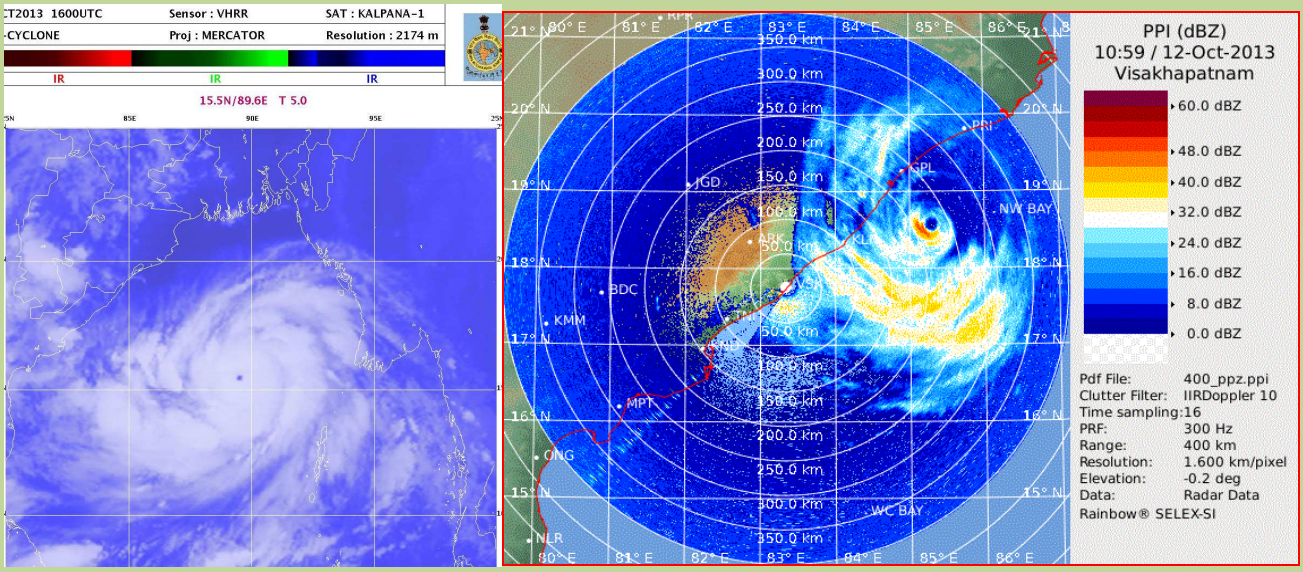
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
EARTH SYSTEM SCIENCE ORGANISATION
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm, PHAILIN over the Bay of Bengal (08-14 October 2013) : A Report



Satellite imagery and Doppler Weather Radar imagery of VSCS PHAILIN

Cyclone Warning Division

India Meteorological Department

New Delhi

October 2013

Very Severe Cyclonic Storm (VSCS) PHAILIN over the Bay of Bengal
(08-14 October 2013)

1. Introduction

A Very Severe Cyclonic Storm (VSCS) PHAILIN originated from a remnant cyclonic circulation from the South China Sea. The cyclonic circulation lay as a low pressure are over Tenasserim coast on 6th October 2013. It lay over north Andaman Sea as a well marked low pressure area on 7th October. It concentrated into a depression over the same region on 8th October near latitude 12.0^0N and longitude 96.0^0E. Moving west-northwestwards, it intensified into a deep depression on 9th morning and further into cyclonic storm (CS), '**PHAILIN'** in the same day evening. Moving northwestwards, it further intensified into a severe cyclonic storm (SCS) in the morning and into a VSCS in the forenoon of 10th Oct. over east central Bay of Bengal.

The VSCS, **PHAILIN** crossed Odisha & adjoining north Andhra Pradesh coast near Gopalpur (Odisha) around 2230 hrs IST of 12th October 2013 with a sustained maximum surface wind speed of 200-210 kmph gusting to 220 kmph. The salient features of this storm are as follows.

i. VSCS PHAILIN is the most intense cyclone that crossed India coast after Odisha Super Cyclone of 29th October 1999.
ii. There was rapid intensification of the system from 10th Oct. morning to 11th October morning leading to an increase in wind speed from 45 knots to 115 knots.
iii. At the time of landfall on 12th Oct, maximum sustained surface wind speed in association with the cyclone was about 115 knots (215 kmph) and estimated central pressure was 940 hPa with pressure drop of 66 hPa at the centre compared to surroundings.
iv. It caused very heavy to extremely heavy rainfall over Odisha leading to floods, and strong gale wind leading to large scale structural damage and storm surge leading to coastal inundation over Odisha.
v. Maximum rainfall occurred over northeast sector of the system centre at the time of landfall. Maximum 24 hr cumulative rainfall of 38 cm has been reported over Banki in Cuttack district of Odisha.
vi. Based on post-cyclone survey report, maximum of storm surge of 2-2.5 meters above the astronomical tide has been estimated in the low lying areas of Ganjam district of Odisha in association with the cyclone and the in-land inundation of saline water extended upto about one kilometer from the coast.

vii. The numerical weather prediction (NWP) and dynamical statistical models provided good guidance with respect to its genesis, track and intensity. Though there was divergence in model guidance with respect to landfall point in the initial stage, the consensus among the models emerged as the cyclone moved closer to the coast.

viii. IMD accurately predicted the genesis, intensity, track and point & time of landfall and also the adverse weather like heavy rainfall, gale wind and storm surge 4 to 5 days in advance.

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

2. Brief life history

2.1. Genesis

A Very Severe Cyclonic Storm (VSCS) PHAILIN originated from a remnant cyclonic circulation from the South China Sea. The cyclonic circulation lay as a low pressure are over Tenasserim coast on 6th October 2013. It lay over north Andaman Sea as a well marked low pressure area on 7th October.

On 8th October, scatterometry data indicated the cyclonic circulation over the region and associated wind speed to be about 25-30 knots. The wind speed was relatively higher in southern sector in association with cross equatorial flow. According to satellite observation, intense to very intense convection was seen over Andaman Sea and adjoining area between lat 8.5^{0}N to 14.5^{0}N and east of long 88.5^{0}E to Tenasserim coast at 0530 hrs IST of 8th October. The associated convection increased gradually with respect to height and organisation during past 24 hrs. The lowest cloud top temperature (CTT) was about -70^{0}C. The convective cloud clusters came closer and merged with each other during past 24 hrs ending at 0530 hrs IST of 8th October. According to Dvorak's intensity scale, the intensity of the system was T 1.5. The system showed shear pattern with convection shifted to the west of low level circulation centre. Considering all these, the well marked low pressure area was upgraded as a depression over the north Andaman Sea at 0530 hrs IST of 8th with its centre near latitude 12.0^{0}N and longitude 96.0^{0}E. Maximum sustained surface wind speed was estimated to be about 25 knots gusting to 35 knots around the system centre.

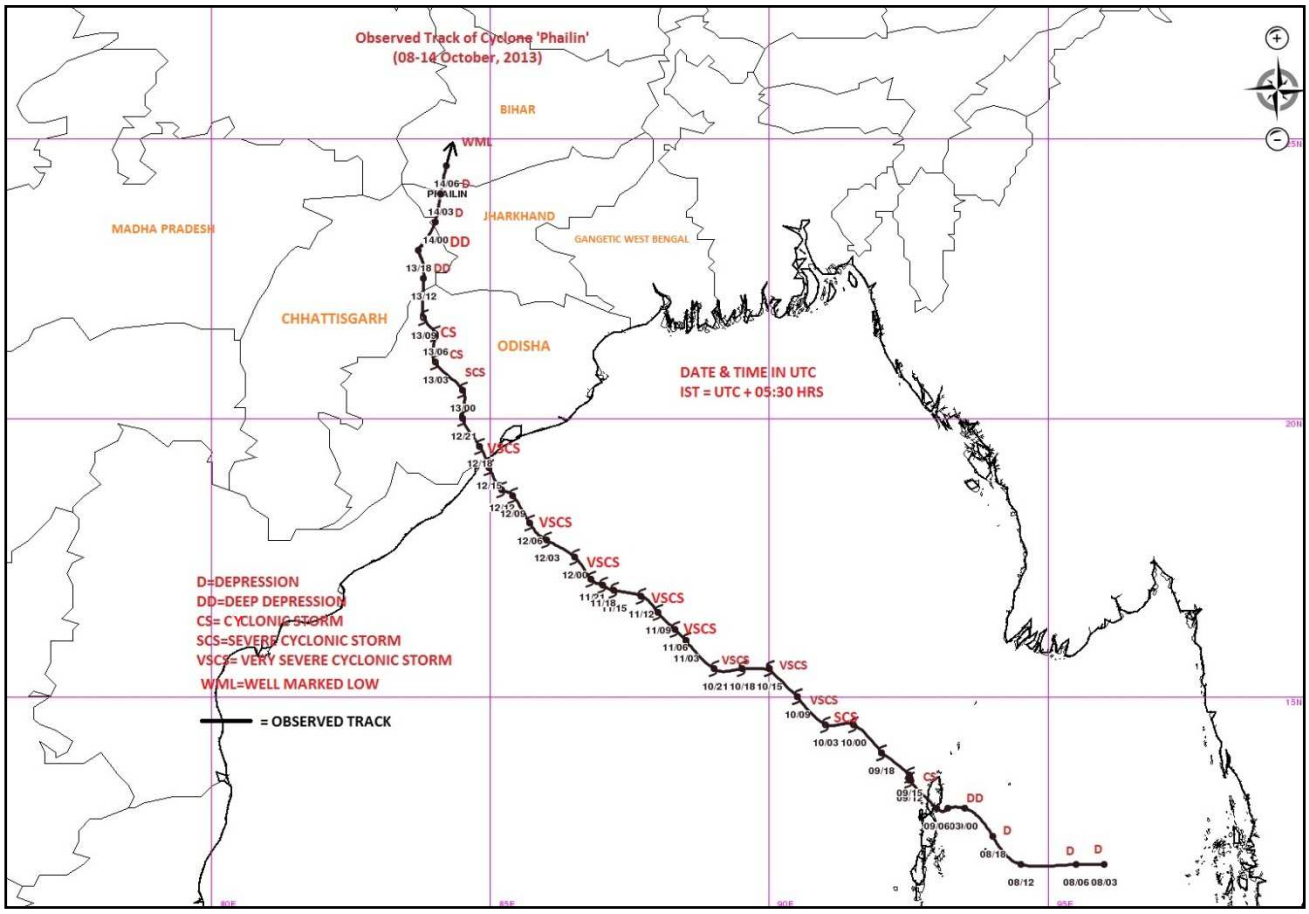


Fig.1 Observed track of VSCS PHAILIN during 8th-14th October 2013.

2.2. Intensification and movement

The upper tropospheric ridge at 200 hPa level ran along 21^0N in the morning of 8th October and was providing poleward out flow in association with the anticyclonic circulation over central India and another to the northeast of the system centre. Hence upper level divergence was favourable for intensification. The low level convergence along with low level relative vorticity increased in past 24 hrs ending at 0530 hrs IST of 8th October. The sea surface temperature based on satellite and available buoys and ships observation was about $28\text{-}29^0$C and ocean thermal energy was about 60-80 KJ/cm^2. The sea height anomaly was about 5-10 metre. The vertical wind shear of horizontal wind has decreased and was about 10-20 knots (low to moderate). The Madden Jullian oscillation (MJO) index lay over phase 6 with amplitude greater than 1. All these environmental, atmospheric and oceanic conditions suggested further intensification. Accordingly the depression moved northwestwards and intensified into a deep depression at 0530 hrs IST of 9th Oct. near 13.0^0N and 93.5^0E. Moving west-northwestwards, it crossed Andaman Islands near Mayabandar at 1430 hrs IST of 9th Oct. It moved slowly over east central Bay of Bengal and intensified into a Cyclonic Storm (CS), **PHAILIN** at 1730 hrs IST of 9th Oct. Most of the NWP models suggested west-northwestward to northwestward movement during next 72 hrs towards north Andhra Pradesh and Odisha coast. The NWP guidance including IMD's dynamical statistical model also suggested intensification of the system into a severe cyclonic storm.

Tracking over an area of high sea surface temperatures and Ocean thermal energy and especially low vertical wind shear (5-10 knots), rapid intensification ensued from 10th Oct. morning. Moving westwards, the CS intensified further into an SCS at 0830 hrs IST and further into VSCS at 1130 hrs IST of 10th Oct. over east central Bay of Bengal. The system intensified further and attained its maximum intensity of 115 knots in the morning of 11th October. Thus there was a rapid intensification of the system by about 70 knots during morning of 10th to morning of 11th October. The VSCS continued to move northwestwards at a speed of about 15 kmph and crossed Andhra Pradesh & Odisha coast near Gopalpur around 2230 hrs IST of 12th Oct. 2013. However, northerly component of the movement increased gradually, about 12 hrs before landfall. It continued to move north-northwestwards after the landfall for some time and then northward and finally north-northeastwards upto southwest Bihar. The system weakened gradually into an SCS at 0830 hrs IST of 13th Oct. and into a CS over south Odisha at 1130 hrs IST of same day. It further weakened into a deep depression over north Chhattisgarh and adjoining Odisha & Jharkhand at 1730 hrs IST of 13th Oct and into a depression at 0300 UTC of 14th Oct over southwest Bihar. It weakened into a well marked low pressure area at 1430 hrs IST of 14th over southwest Bihar and neighbourhood. The observed track of the system is shown in fig.1. The best track parameters are shown in Table 1.

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm 'Phailin' over the Bay of Bengal during 08-14 October, 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
08-10-2013	0300	12.0/96.0	1.5	1004	25	3	D
	0600	12.0/95.5	1.5	1004	25	3	D
	1200	12.0/94.5	1.5	1003	25	4	D
	1800	12.5/94.0	1.5	1003	25	4	D
09-10-2013	0000	13.0/93.5	2.0	1002	30	5	DD
	0300	13.0/93.5	2.0	1001	30	5	DD
	0600	13.0/93.0	2.0	1000	30	6	DD
	0900	13.5/92.5	2.0	1000	30	6	DD
	1200	13.5/92.5	2.5	999	35	7	CS
	1500	13.6/92.5	2.5	999	35	7	CS
	1800	14.0/92.0	2.5	998	40	8	CS
	2100	14.0/92.0	2.5	998	40	8	CS
10-10-2013	0000	14.5/91.5	3.0	996	45	10	CS
	0300	14.5/91.0	3.5	990	55	15	SCS
	0600	15.0/90.5	4.0	984	65	22	VSCS
	0900	15.0/90.5	4.0	982	70	24	VSCS
	1200	15.5/90.0	4.5	976	75	30	VSCS

	1500	15.5/90.0	5.0	966	90	40	VSCS
	1800	15.5/89.5	5.0	960	95	46	VSCS
	2100	15.5/89.0	5.5	954	100	52	VSCS
11-10-2013	0000	16.0/88.5	5.5	946	110	60	VSCS
	0300	16.0/88.5	6.0	940	115	66	VSCS
	0600	16.2/88.3	6.0	940	115	66	VSCS
	0900	16.5/88.0	6.0	940	115	66	VSCS
	1200	16.8/87.7	6.0	940	115	66	VSCS
	1500	16.9/87.2	6.0	940	115	66	VSCS
	1800	17.0/87.0	6.0	940	115	66	VSCS
	2100	17.1/86.8	6.0	940	115	66	VSCS
12-10-2013	0000	17.5/86.5	6.0	940	115	66	VSCS
	0300	17.8/86.0	6.0	940	115	66	VSCS
	0600	18.1/85.7	6.0	940	115	66	VSCS
	0900	18.6/85.4	6.0	940	115	66	VSCS
	1200	18.7/85.2	6.0	940	115	66	VSCS
	1500	19.1/85.2	6.0	940	115	66	VSCS
	The VSCS crossed Odisha & adjoining north Andhra Pradesh coast near Gopalpur around 1700 UTC (landfall point : 19.2^0N and 84.9^0E)						
	1800	19.5/84.8	-	956	100	50	VSCS
	2100	20.0/84.5	-	966	90	40	VSCS
13-10-2013	0000	20.5/84.5	-	976	75	30	VSCS
	0300	21.0/84.0	-	990	55	15	SCS
	0600	21.5/84.0	-	996	40	10	CS
	0900	21.8/83.8	-	998	35	8	CS
	1200	22.5/83.8	-	998	35	8	CS
	1800	23.0/83.5	-	1002	30	6	DD
14-10-2013	0000	23.5/84.0	-	1002	30	6	DD
	0300	24.0.84.1	-	1004	25	3	D
	0600	24.5/84.2		1005	25	3	D
	0900	Weakened into a well marked low pressure area over southwest Bihar and neighbourhood					

3. Monitoring of VSCS, PHAILIN

The VSCS PHAILIN was monitored & predicted continuously since its inception by the India Meteorological Department. The forecast of its genesis on 8th, its track, intensity, point & time of landfall, as well as associated adverse weather like heavy rain, gale wind & storm surge were predicted exceedingly well with sufficient lead time which helped the disaster managers to maximize the management of cyclone in an exemplary manner.

At the genesis stage, the system was monitored mainly with satellite observations, supported by meteorological buoys and coastal and island observations. As the system entered into the east central Bay of Bengal moving away from Andaman & Nicobar Islands, it was mainly monitored by satellite observations supported by buoys. On 12th October, when the

system lay within radar range, the DWR at Visakhapatnam was utilized and continuous monitoring by this radar started from 0630 hrs IST of 12th when the system was at about 310 km east-southeast of Visakhapatnam coast and continued till 2330 hrs IST of that date. In addition, the observations from satellite and coastal observations conventional observatories and Automatic Weather Stations (AWS) ware used. While coastal surface observations were taken on hourly basis, the half hourly INSAT/ Kalpana imageries and every 10 minute DWR imageries, available microwave imageries and scatterometry products were used for monitoring of Phailin.

Various national and international NWP models and dynamical-statistical models including IMD's global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track, intensity and rapid intensification of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

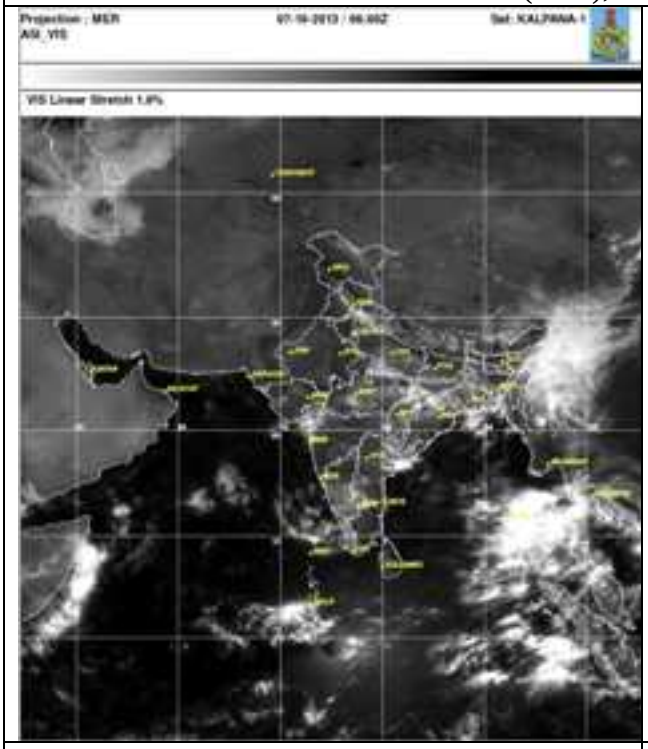
4. Characteristic features of PHAILIN

4.1. Features observed through satellite

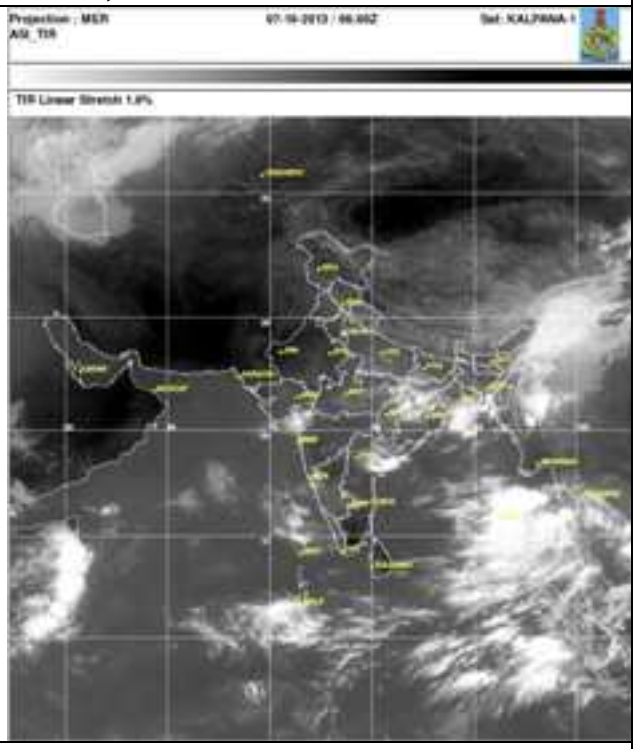
A low level circulation developed over Andaman Sea on 06 October 2013 at 2100UTC. It intensified into a vortex with intensity T1.0 and centre 12.0°N/98.5°E at 0600 UTC of 7th October. The pattern was of shear type at this stage. Initially it moved in westerly direction. The system intensified again at 0300 UTC of 8th October with centre 12.0°N/96.0°E and intensity T1.5. Moving in the west-northwesterly direction it intensified with intensity of T2.0 and centre 12.5°N/94.0°E at 2100 UTC on the same day. The intensity became T 2.5 at 1000 UTC of 9th October with centre near 13.5°N/92.5°E. At this time it was of curved band pattern and the band wrapped 0.5 degree in the logarithmic spiral. It remained with intensity of T2.5 for 11 hours and intensified very rapidly then to T3.5 within just after 5 hours. The eye was visible at this time but ragged. Intensification to T4.0 occurred at 0600UTC of 10th October as the spiral bands were more organized and centre at this time was 15.1°N/90.6°E, eye temperature was -42 deg C and diameter of the eye was 12 km (Table 2). very rapid intensification occurred after this upto T6.0 at 0300 UTC of 11th October 2013, because of continuous organization of eye and spiral bands. System continued to move northwestwards till landfall near 19.26°N/84.82°E (near Gopalpur, Odisha) at 1600 UTC of 12th October 2013. Typical satellite imageries of the system are shown in fig.2.

Satellite (Kalpana-1) imageries at different stages of the VSCS (Phailin)

Formation of well marked Low (T1.0), 0600 UTC, 07.10.2013 Centre 12.0N/98.5E

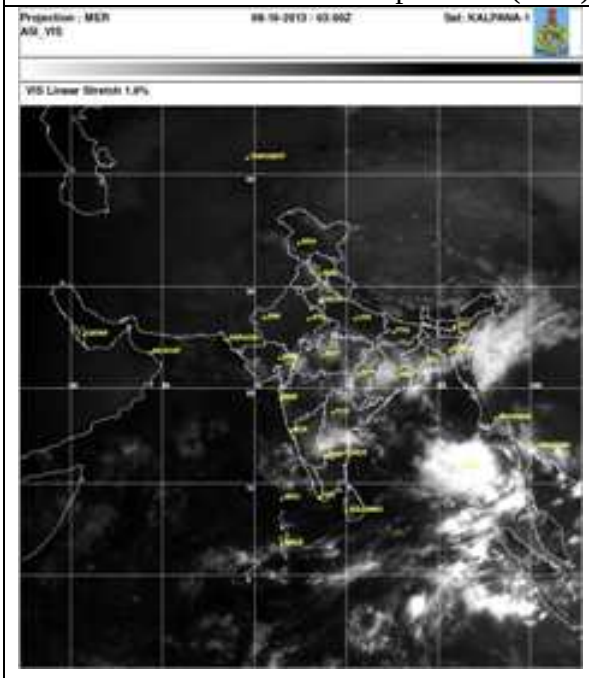


Visible imagery

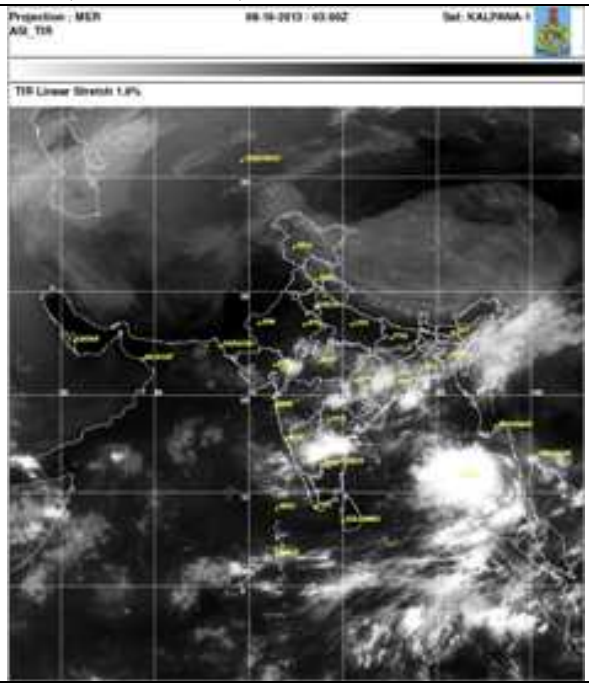


IR Imagery

Intensification into Depression (T1.5),0300 UTC, 08.10.2013 , Centre 12.0N/96.0E



Visible imagery



IR Imagery

Fig.2 (a) Typical satellite imageries in different stages in cyclone, PHAILIN

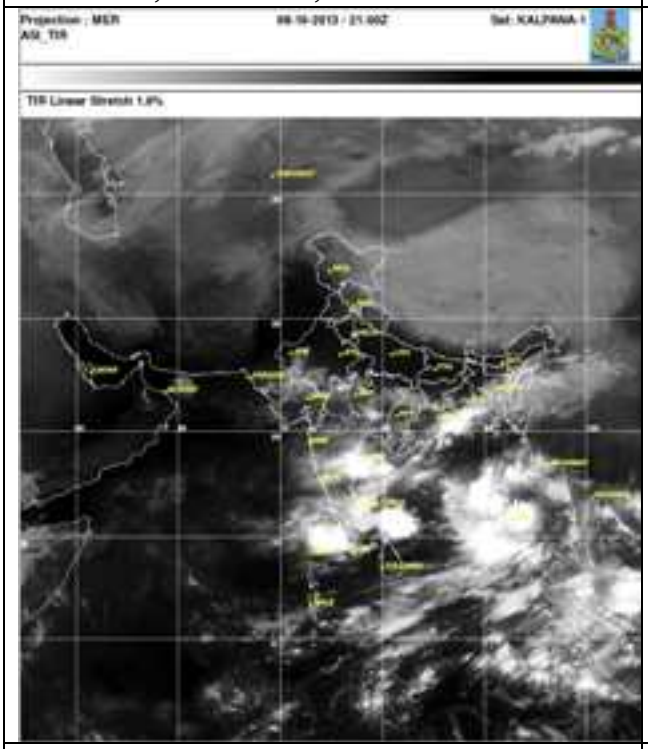
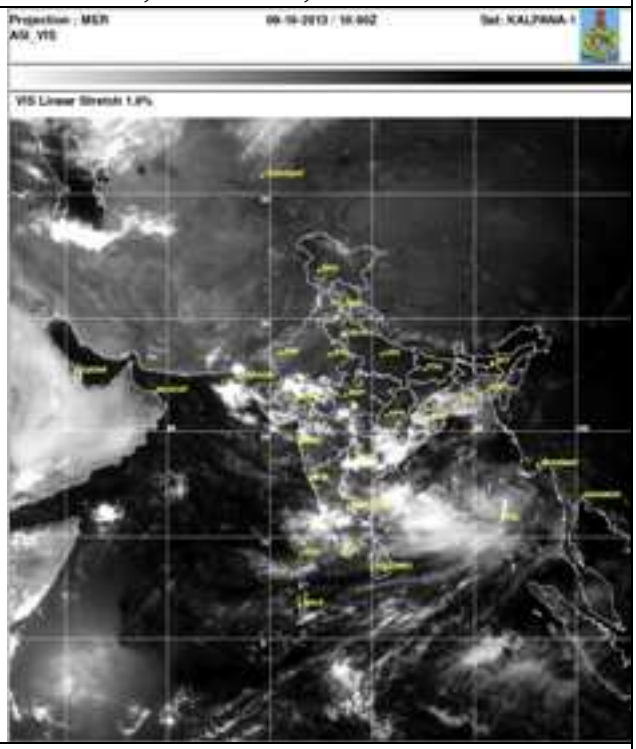
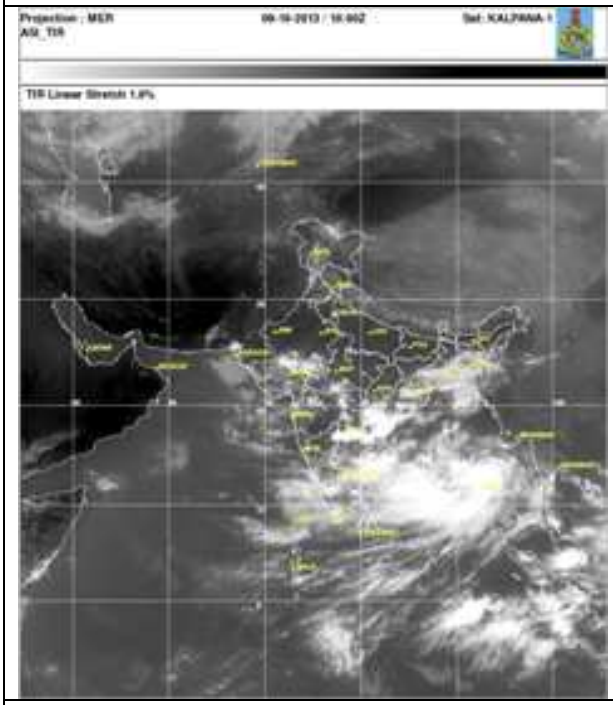
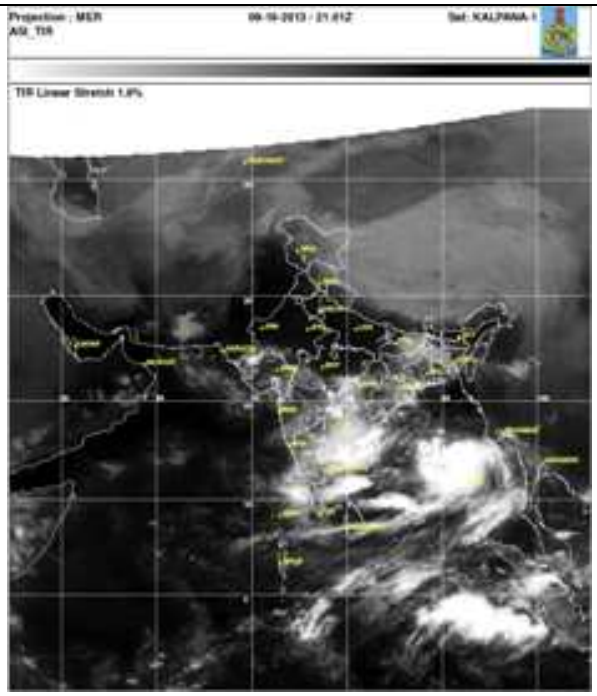
Intensification into Deep Depression (T2.0) 2100 UTC, 08.10.2013, Centre 12.5N/94.0E	Formation of tropical cyclone (Phailin), T2.5, 1000 UTC, 09.10.2013, Centre 13.5N/92.5E
	
IR Imagery	Visible imagery
Formation of tropical cyclone (Phailin), T2.5, 1000 UTC, 09.10.2013, Centre 13.5N/92.5E	Further intensification of the tropical cyclone (T3.0), 2100 UTC, 09.10.2013, Centre 14.1N/91.8E
	
IR Imagery	IR Imagery

Fig.2 (b) Typical satellite imageries in different stages in cyclone, PHAILIN

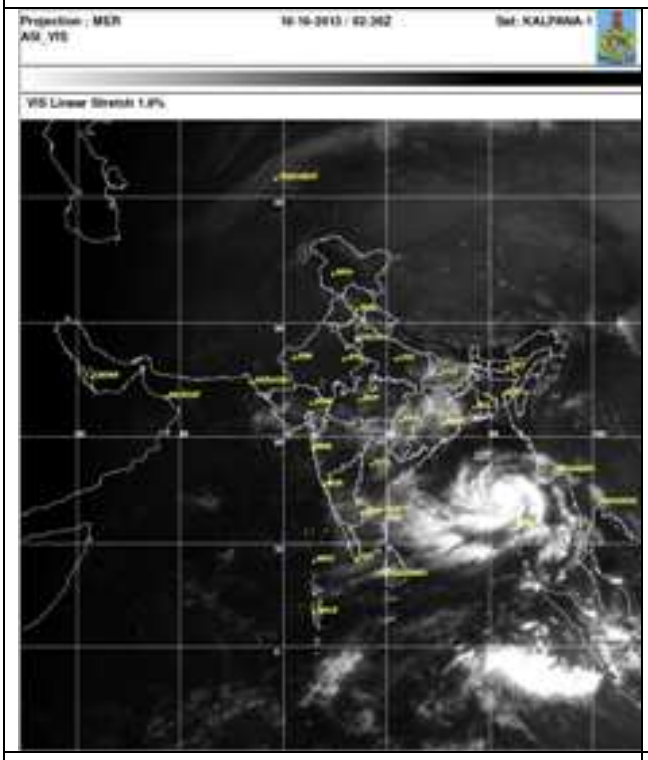
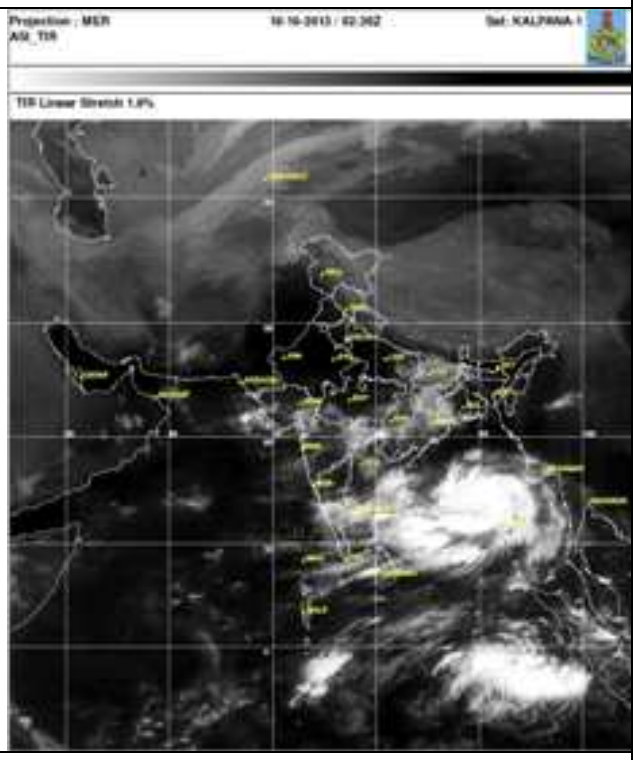
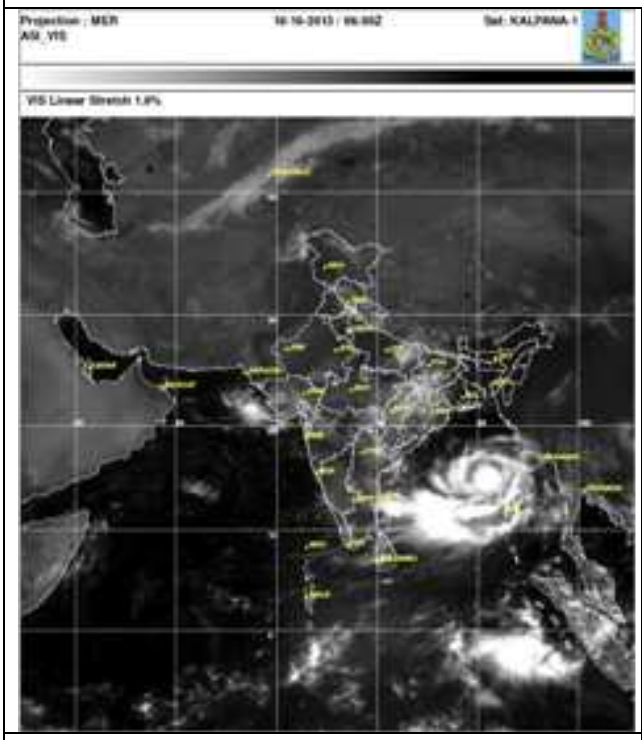
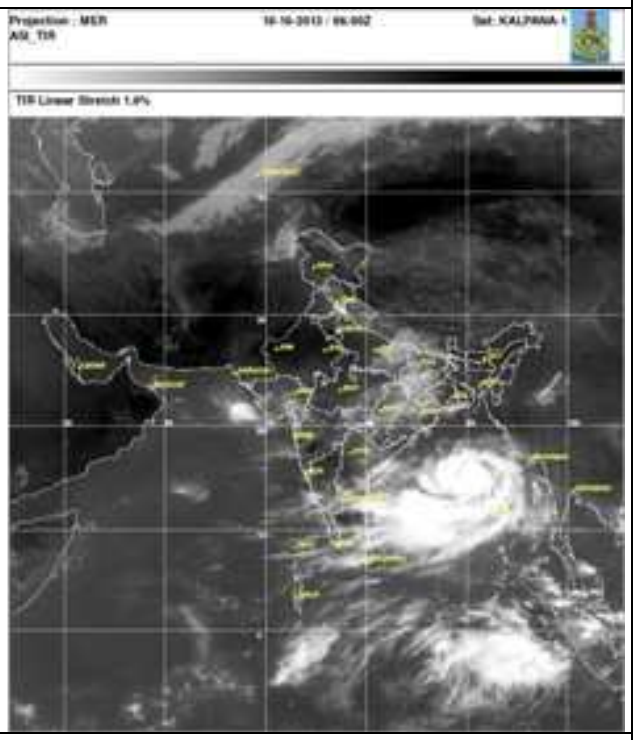
Intensification into Severe Cyclonic Storm (T3.5), 0230 UTC 10.10.2013, Centre 14.7N/91.1E	
	
Visible imagery	IR Imagery
Intensification in Very Severe Cyclonic Storm (T4.0). 0600 UTC, 10.10.2013, Centre 15.1N/90.6E	
	
Visible imagery	IR Imagery

Fig.2 (c) Typical satellite imageries in different stages in cyclone, PHAILIN

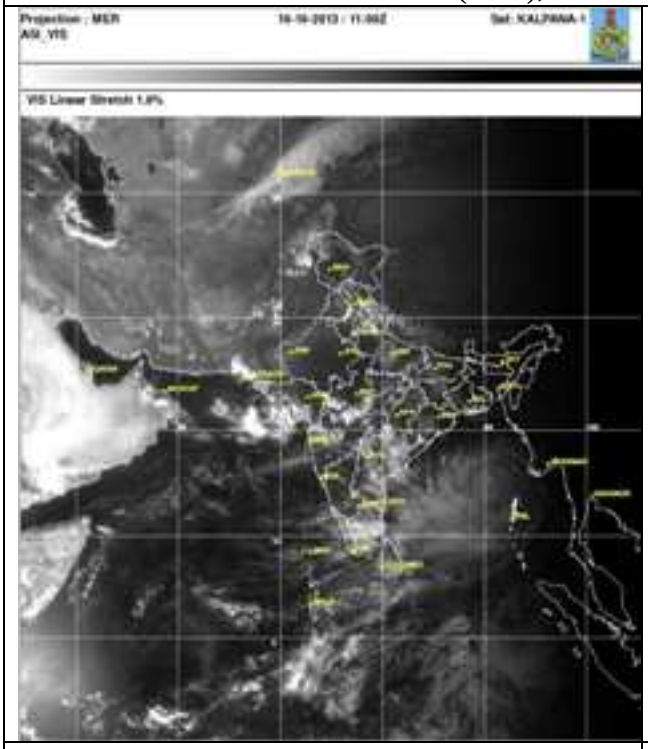
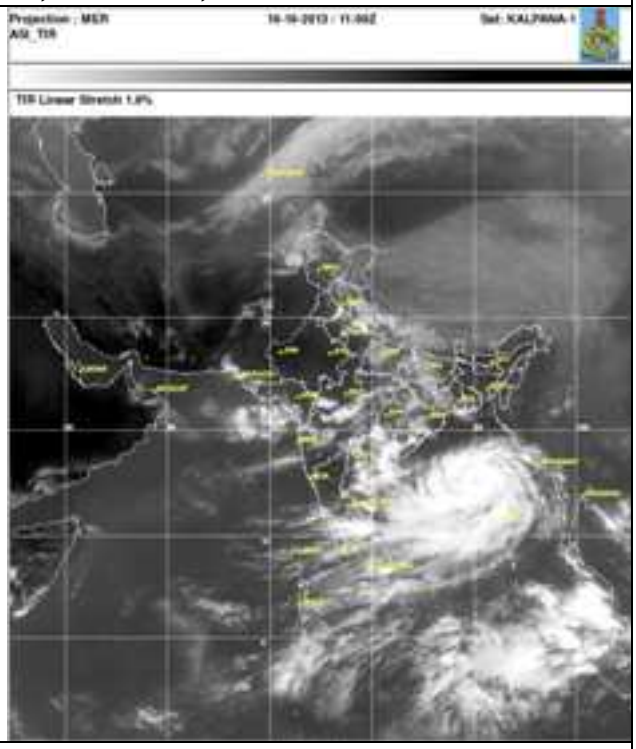
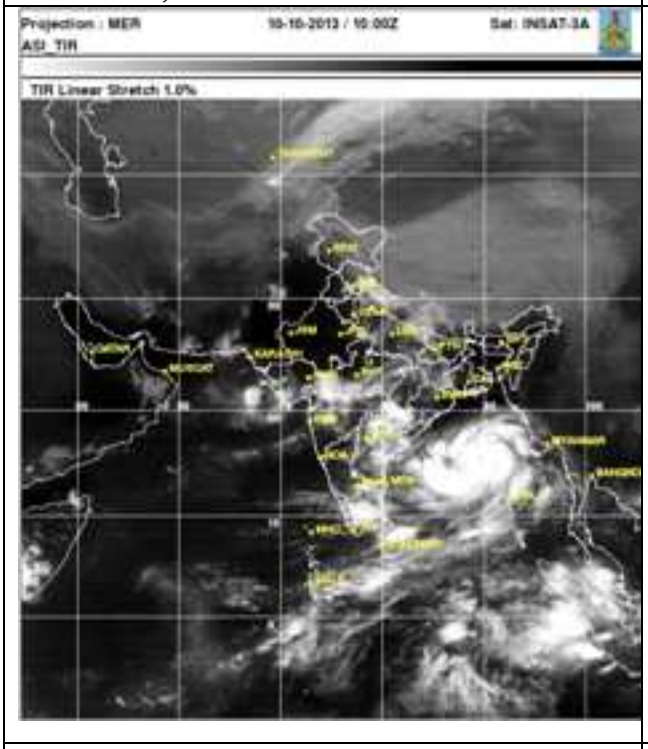
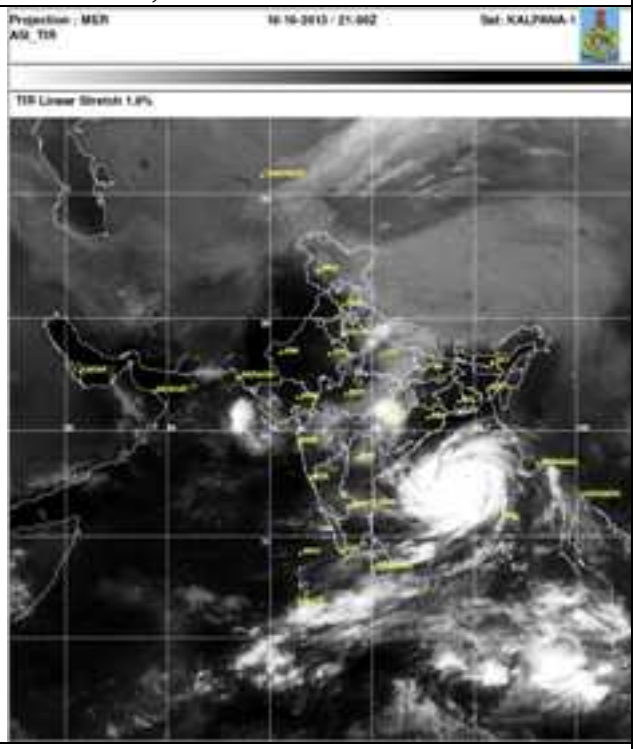
Further Intensification (T4.5), 1100 UTC, 10.10.2013, Centre 15.3N/90.2E	
	
Visible imagery	IR Imagery
Further Intensification (T5.0), 1500 UTC, 10.10.2013, Centre 15.5N/89.7E	Further Intensification (T5.5), 2100 UTC, 10.10.2013, Centre 15.6N/89.2E
	
IR Imagery (INSAT-3A)	IR Imagery

Fig.2 (d) Typical satellite imageries in different stages in cyclone, PHAILIN

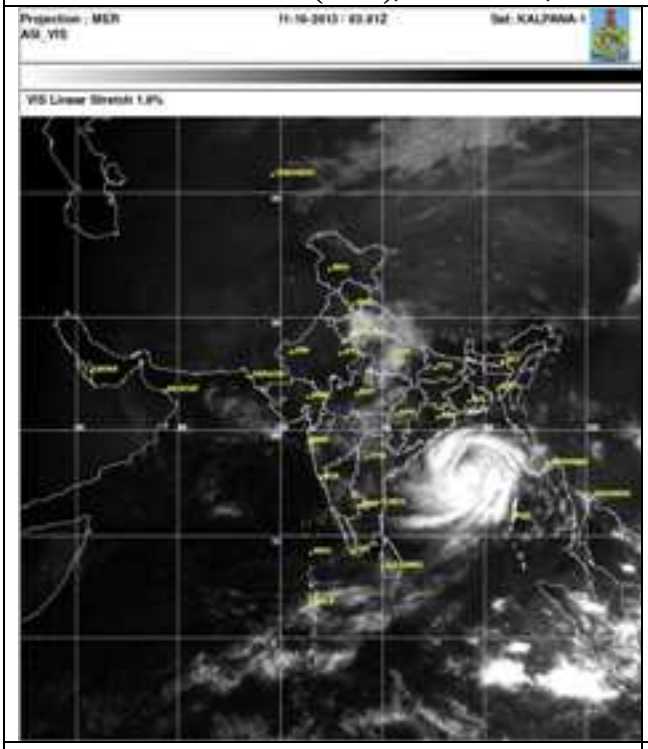
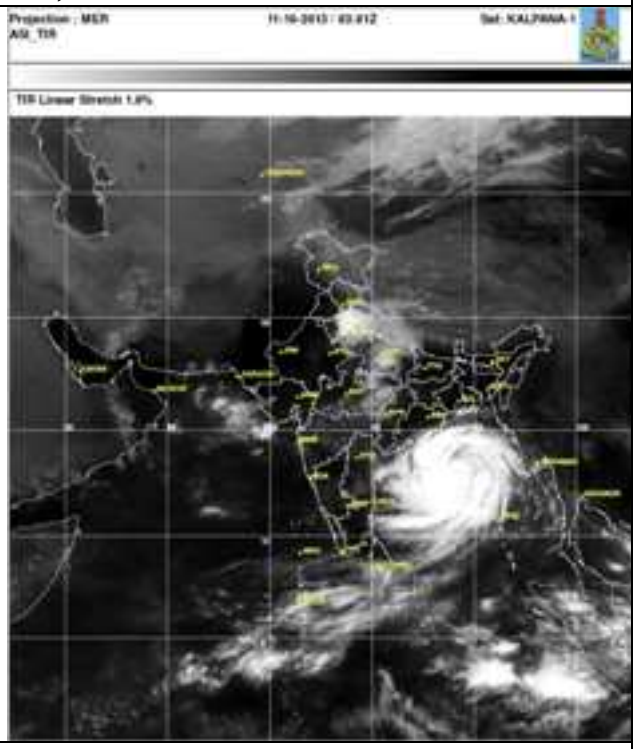
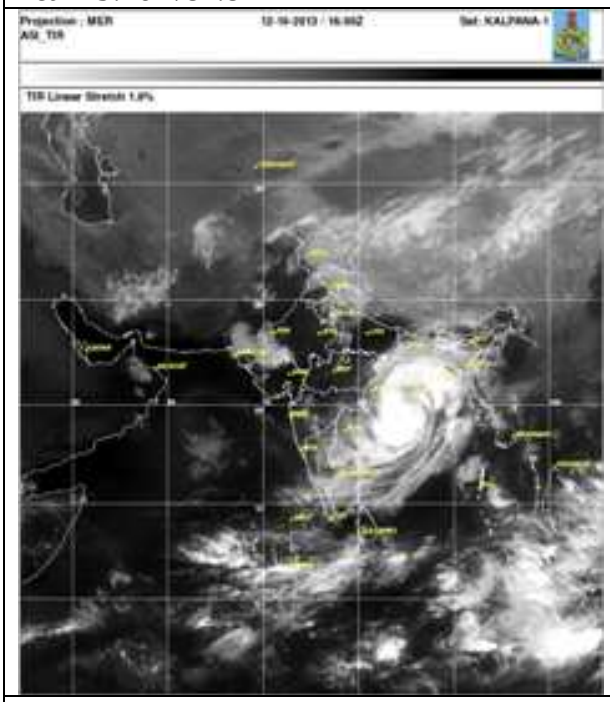
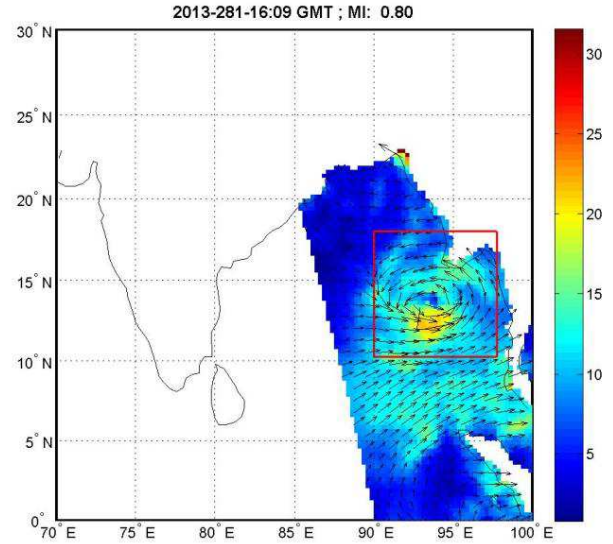
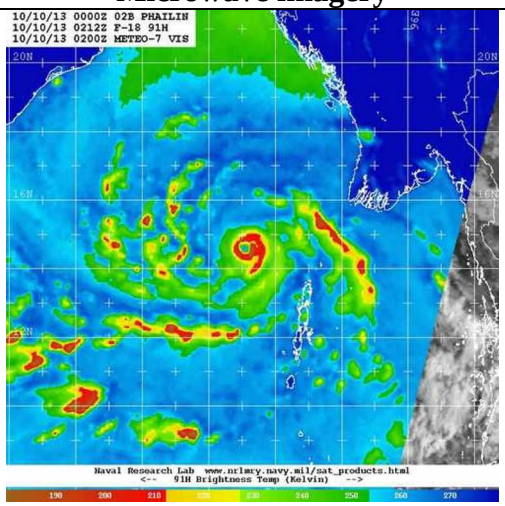
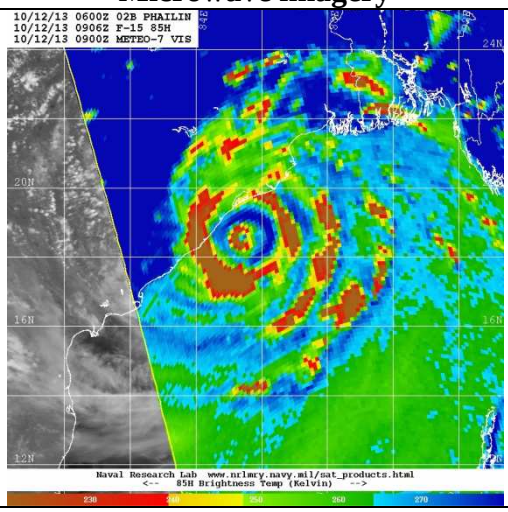
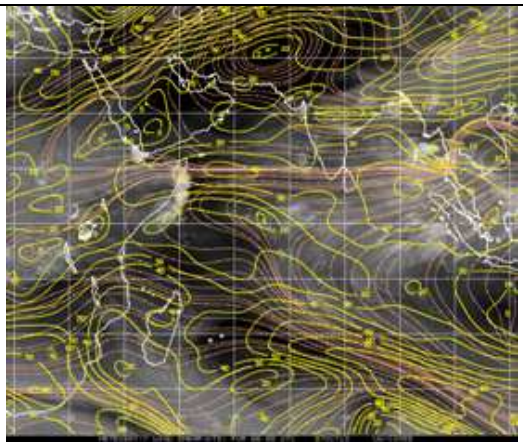
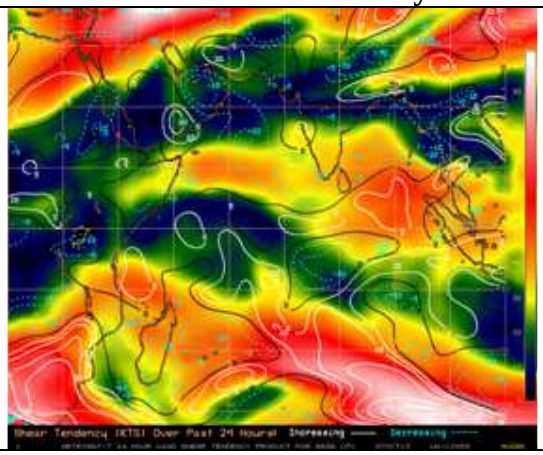
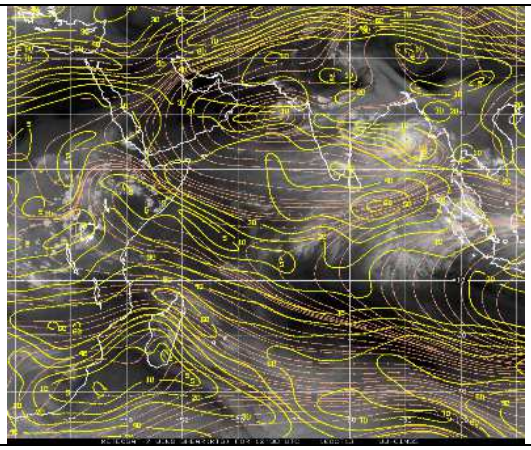
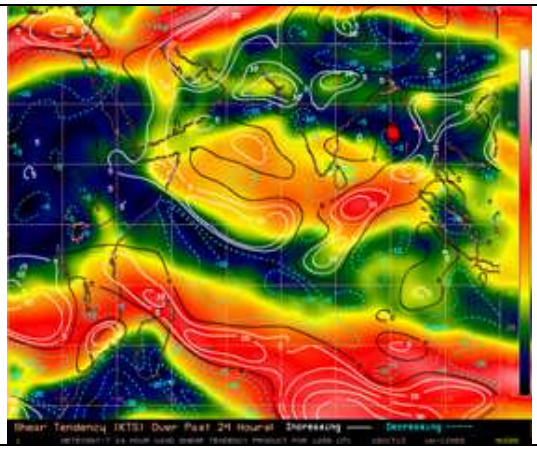
Further Intensification (T6.0), 0300 UTC, 11.10.2013, Centre 16.0N/88.5E	
	
Visible imagery	IR Imagery
Landfall of the cyclone 1600UTC, 12.10.2013 near 19.26N/84.82E	**Cyclogenesis predicted formation of Tropical cyclone**
	
IR Imagery	1609 UTC, 08.10.2013

Fig.2 (e) Typical satellite imageries in different stages in cyclone, PHAILIN

Microwave imagery	Microwave imagery
	
0212 UTC , 10.10.2013	0906 UTC, 12.10.2013
Wind Shear	**24 hrs Shear Tendency**
	
0600 UTC, 07.10.2013	0600 UITC, 07.10.2013
	
1200 UTC, 10.10.2013	1200 UTC, 10.10.2013
Fig.2(f). Typical microwave imageries, wind shear and shear tendency on 10 October 2013	

As the buoys were away from the track of the system, satellite observations played a vital role in tracking of the system. After the landfall also Satellite Application Unit of Satellite

Meteorology Division provided centre and expected intensity for better monitoring of the system. Monitoring of the system was mainly done by using half hourly Kalpana-1 imageries but satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered.

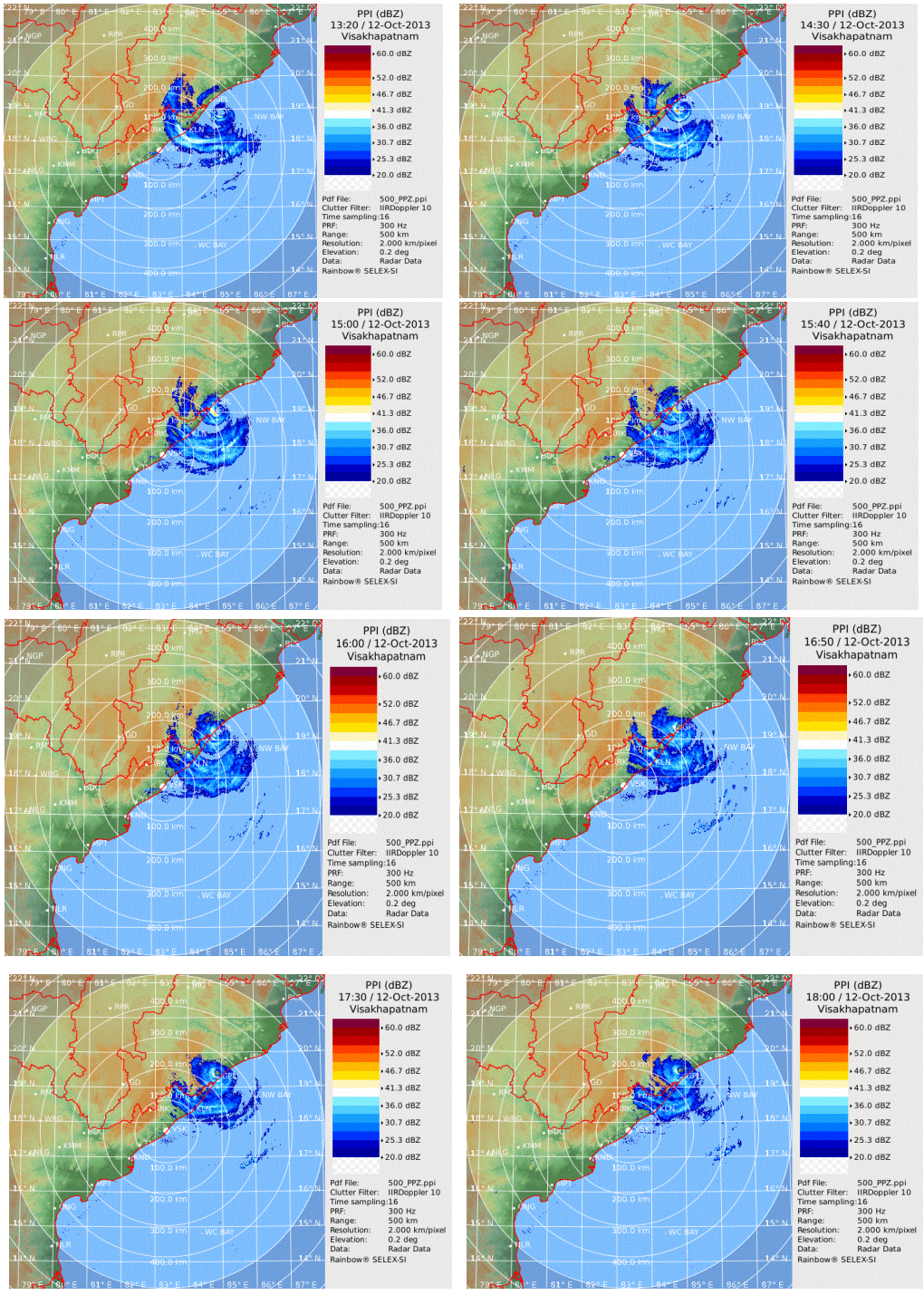


Fig. 3 : Visakhapatnam RADAR imageries based on 1320,1430, 1500, 1540 UTC, 1600 , 1650, 1730, 1800 UTC of 12th October 2013

4.2. Features observed through Radar

The initial cloud echoes observed at 2100UTC of 11th October, 2013 in Special 400 PPI Scan. The Eye appeared first at 0000UTC of 12th. The first radar based bulletin was issued by Doppler Weather Radar (DWR) station, Visakhapatnam at 0100UTC and bulletins continued at 30 minutes interval till the VSCS PHAILIN crossed the Odisha coast near Gopalpur. The bulletins were issued based on maximum reflectivity (Max. Z) product with effect from 0730 UTC of 12th October. The Maximum wind speed of 60mps at 4Kms height was reported at 1410 UTC (Table 3). A few DWR imageries are shown in Fig.3. The eye was visible during 0120 UTC to 1755 UTC of 12 October 2013. The eye diameter gradually decreased and was about 15-20 km at the time of landfall.

Table 3. Position Of Cyclone Phailin based on DWR, Visakhapatnam

SN	Date and time(UTC)	Lat deg N	Long deg E	Range kms	Azimuth deg	Radial wind speed (mps)/eye dia (km)	Shape of eye & confidence
1	12.10.13 0120z	17.647	86.258	309	91.5	-/NA	Almost closed eye fair
2	12.10.13 0220z	17.794	86.094	291	88.4	-/NA	Almost closed eye Good
3	12.10.13 0320z	17.868	85.950	277	86.7	-/NA	Almost closed eye Good
4	12.10.13 0350z	17.912	85.899	270	85.6	-/36.5KM	Almost closed eye Good
5	12.10.13 0420z	17.927	85.838	265	85.2	-/33.0KM	Almost closed eye Good
6	12.10.13 0450z	17.971	85.778	258	84.0	-/32.0KM	Almost closed eye Good
7	12.10.13 0520z	17.971	85.748	255	83.9	-/27.2KM	Almost closed eye Good
8	12.10.13 0600z	18.058	85.734	255	81.7	40/30.0KM	Almost closed eye Good
9	12.10.13 0640z	18.145	85.720	255	79.5	40/30.0KM	Almost closed eye Good
10	12.10.13 0800z	18.420	85.587	248	72.0	40/NA	Almost closed eye Good
11	12.10.13 0950z	18.599	85.261	223	64.7	58/24.0KM	Almost closed eye Good
12	12.10.13 1100z	18.599	85.261	223	64.7	58/26.0KM	Almost closed eye Good
13	12.10.13 1140z	18.671	85.262	227	62.9	57/27.5KM	Almost closed eye Good

14	12.10.13 1200z	18.679	85.262	227	62.9	57/26.0KM	Almost closed eye Good
15	12.10.13 1310z	18.897	85.208	234	56.7	57/24.0KM	Almost closed eye Good
16	12.10.13 1410z	18.997	85.094	231	52.8	60/18.0KM	Almost closed eye Good
17	12.10.13 1455z	19.071	85.032	231	50.3	58/18.0KM	Almost closed eye Good
18	12.10.13 1525z	19.144	85.024	235	48.5	57/20.0KM	Almost closed eye Good
19	12.10.13 1555z	19.192	84.982	236	46.7	51/20.0KM	Almost closed eye Good
20	12.10.13 1635z	19.282	84.934	238	44.1	45/16.0KM	Eye over land Good
21	12.10.13 1725z	19.415	84.853	243	40.5	42/NA	Eye over land Fair
22	12.10.13 1755z	19.454	84.842	48 (from the coast)	-	42/NA	Eye over land Fair

4.3. Estimated Central Pressure and Maximum Wind

The estimated central pressure of the system gradually decreased from genesis stage on 8th October to 10th morning. There was sharp decrease then till 11th morning due to rapid intensification of the system. It became lowest (940 hPa) at 0300 UTC of 11th October and continued so till the landfall (Table 1). During decay, the rise in central pressure was rather rapid than that in genesis stage. Similar was the variation in estimated maximum wind, as it gradually increased from 8th to 10th morning and then rapidly increased till 11th morning. It reached maximum value of 115 knots at 0300 UTC of 11th and continued so till the landfall.

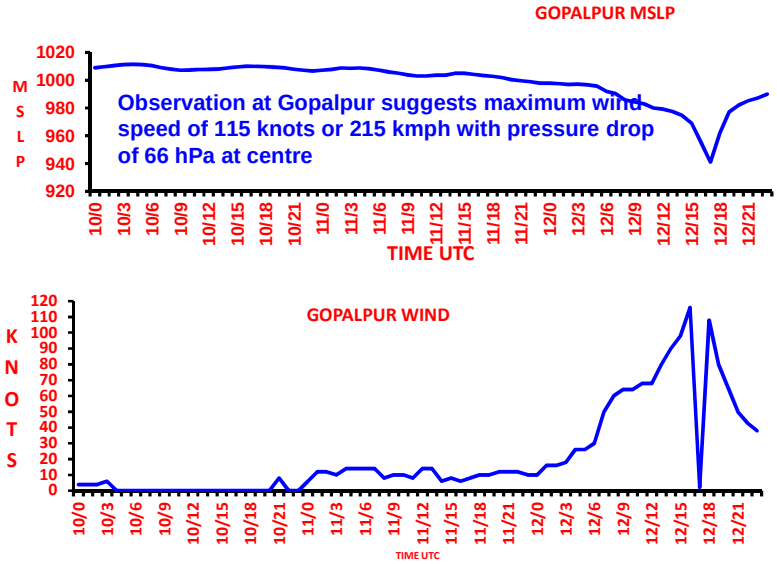


Fig.4. Variation of mean sea level pressure and wind over Gopalpur during the passage of cyclone

The pressure and wind variation over Gopalpur (point of landfall) are shown in Fig.4. It is worth mentioning that the eye of the cyclone passed over Gopalpur around 1700 UTC, when it experienced variable wind of about 2 knots for a few minutes followed by strong gale wind due to rear sector of the cyclone lying over the station. The estimated maximum wind speed over Gopalpur was about 115 knots (215 kmph) at the time of landfall.

5. Realized Weather:

5.1 Heavy rainfall due to PHAILIN:

The VSCS, PHAILIN caused very heavy to extremely heavy rainfall over Andaman & Nicobar Islands, Odisha and isolated heavy to very heavy rainfall over North Coastal AP, West Bengal, Jharkhand, Bihar, Chhattisgarh and Sikkim. Maximum rainfall occurred over Odisha. The rainfall was higher over north Odisha than over south Odisha (Fig.5). The rainfall departures over central and northeastern India during the period of 12-14 October 2013 are shown in Fig.6. It indicates that the rainfall extended upto sub-Himalayan West Bengal and Sikkim.

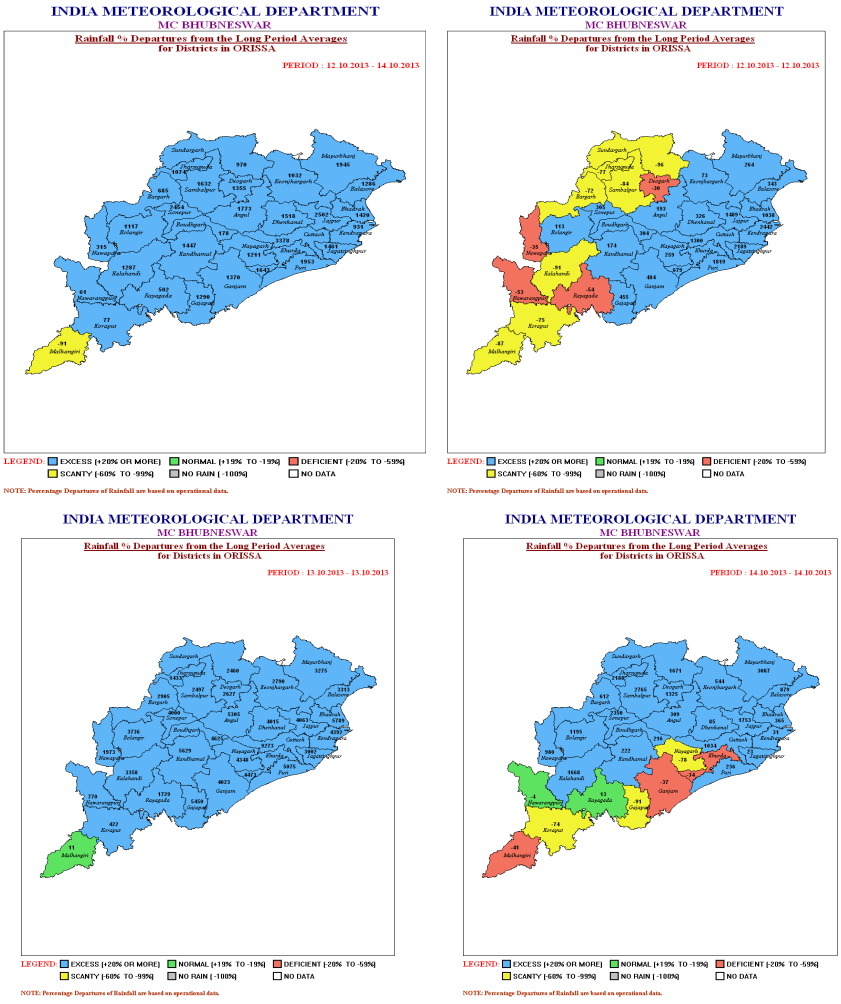


Fig.5. Rainfall departure over Odisha during 12-14 October 2013

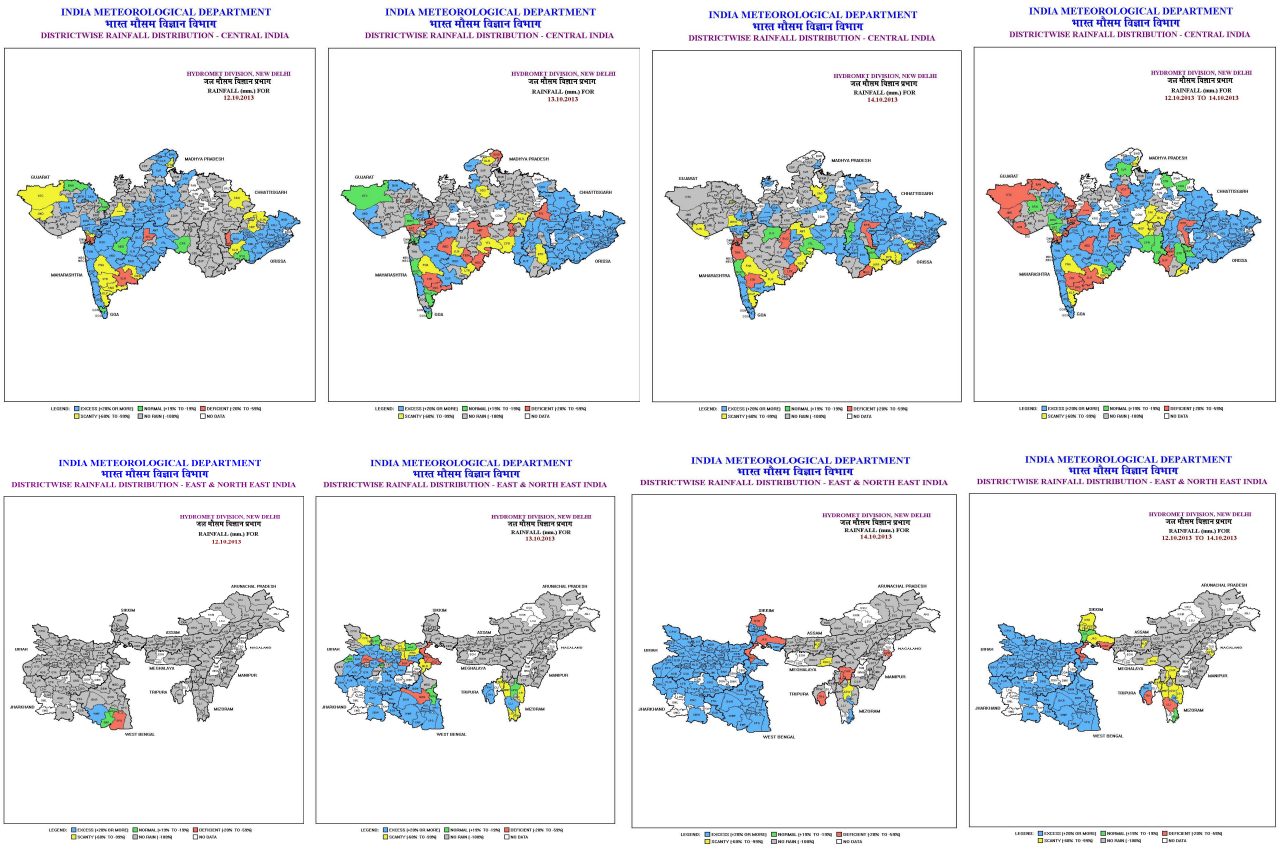


Fig 6. Rainfall departure over central and northeast India during 12-14 October 2013

The station-wise daily 24 hr cumulative rainfall (7 cm or more) during 8-15 October recorded in districts of different states at 0830 hrs IST of date are given below. States and districts are highlighted.

Date: 08-10-2013

(i) Odisha

Bargarh - Bijepur, Paikmal – 8 each, Ambabhona - 11, **Jharsuguda -** Kolabira (ARG) – 8,

Puri: Puri - 11

(ii) Chhattisgarh

Janjgir : Champa – 8, **Jashpur:** Jashpurnagar-**7, Korba : K**atghora- 8, **Raigarh: S**arangarh-9

(iii) Jharkhand

Latehar : Balumath – 9,

(iv) Andaman & Nicobar Islands

North & Middle Andaman- Maya bandar – 24, **South Andaman-** Port Blair – 9

(v) Gangetic West Bengal

Hooghly- Harinkhola – 10, **North 24 Parganas-** Barrackpur (IAF) -7,

09-10-2013

(i) Odisha

Kendrapara- Derabis (ARG), Dattamundai-9 each, **Mayurbhanj-** Baripada -9, **Puri -** Satyabadi ARG) -7

(ii) Andaman & Nicobar Islands

North & Middle Andaman - Long Island, Maya Bandar – 34 each

South Andaman - Port Blair -7

10-10-2013

(i) Odisha

Ganjam - Belaguntha (Arg), Jagannath Prasad (ARG)- 9 each, **Keonjhargarh - S**wam-Patna - 8, **Sonepur - U**llunda (ARG) -7

(ii) Coastal Andhra Pradesh

Krishna - Vijayawada (A.P).-8,**Vizianagaram**- Srungavarapukota -8, **West Godavari -** Narsapuram- 8

(iii) Andaman & Nicobar Islands

A & N Island - Iaf Carnicobar – 8, Car Nicobar - 10,

North & Middle Andaman - Maya Bandar - 16

11-10-2013

(i) Telangana

Adilabad- Chinnoor – 7, **Karimnagar-** Kaleswaram - 7

12-10-2013

(ii) Odisha

Balasore - Soro -7, **Bhadrak** - Akhuapada – 8, **Jagatsinghpur** - Jagatsinghpur (AWS), Kujanga (AWS)-9 each, J**ajpur**-Korei (AWS)-8, **Puri-** Puri -7, Brahmagiri (AWS)-8,

13-10-2013

(i) Odisha

Angul - Banarpal (ARG), Chendipada-8 each, Kaniha (ARG)-9, Angul, Athmalik -11 each, Talcher- 12, Pallahara, Tikarpara-17 each, **Balasore -** Balasore-11, Nh5 Gobindpur-13, Jaipur-26, Rajghat-92, **Bargarh -** Bijepur-7, Chandbali-12, Akhuapada-14, **Cuttack -** Niali (ARG), Mahanga (ARG), Tigiria (ARG)-9 each, Cuttack, Salepur (ARG), Nischintakoili (ARG)-11each,

Athgarh- 12, Naraj-13, Narsinghpur-14, Mundali-25, Banki (ARG)-38, **Deogarh** -Reamal-9, **Dhenkanal** -Altuma (CWC)-7,Hindol-23, **Gajapati** - Nuagada Arg, R.Udaigiri-19 each,Mohana-20, **Ganjam** - Rambha (AWS)-14, Purushottampur-18, (Gopalpur reported rainfall till 0900 UTC of 12th Oct. and cumulative rainfall was about 09 cm till 1330 IST and after that reading could not be taken due to damage of raingauge by cyclone.) **Jagatsinghpur**- Raghunathpur (ARG)-7, Balikuda (ARG), Paradeep Cwr-.8 each, Jagatsinghpur (AWS) , Tirtol (ARG)-9 each**,** Alipingal- 10, **Jajpur**- Jajpur-7, Sukinda, Binjharpur Arg-9 each, Jenapur- 10, Bari (ARG) -12, Chandikhol (ARG) - 15, Danagadi (ARG) , Korei (ARG) -19 each,

Kalahandi - Madanpur Rampur-11, Lanjigarh-12, Narla (ARG) -13, **Kandhamal** - Kotagarh- 8, G Udayagiri (AWS), Tikabali- 13 each, Phulbani, K Nuagaon (ARG) -14 each, Raikia (ARG) - 15 , Phiringia Arg-16, Daringibadi-17, Baliguda-9, **Kendrapara –** Rajkanika- 9, Derabis (ARG), Kendrapara- 11 each, Pattamundai-15, **Keonjhargarh** -Harichandanpur (ARG)-7, Champua-9, Swam-Patna, Telkoi-10 each, Anandpur-11, Jhumpura, Ghatagaon-14 each, Keonjhargarh-15, Daitari-16, , Joda (ARG)-19, **Khurda** - Barmul-13, Bhubaneswar (Aero), Bolagarh (ARG), Balipatna (ARG)-17 each, Banpur-20, **Mayurbhanj** - Jamsolaghat-11,Thakurmunda-13, Baripada, Rairangpur-14 each, Tiring, Betanati (ARG), Udala- 15 each, Samakhunta(AWS)-17, Bangiriposi-21, Balimundali-31, **District: Nayagarh -** Gania (ARG) - 12, Daspalla- 14, Khandapara-17, Nayagarh- 18, Odagaon Arg -21, Ranpur- 30 **Puri -** Puri-12, Nimpara - 15, **Rayagada -** Muniguda (ARG) - 8, **District: Sambalpur -** Batagaon, Jujumura (ARG), Airakhol-11each.

(ii) Coastal Andhra Pradesh

Srikakulam- Mandasa, Palasa -10 each, Sompeta – 11, Itchapuram -20,

Jharkhand

Bokaro - Tenughat – 7, **Dhanbad**- Papunki – 7, **Giridih**- Dumri- 9, **Pakur** - Hiranpur - 7

Ranchi - Ranchi Aero – 7, **West Singbhum** - Chaibasa - 20

(iii) Gangetic West Bengal

Purulia- Phulberia – 7,

14-10-2013

(i) Odisha

Balasore-Jaipur-9, **Cuttack**- Salepur Arg-9, **Jajpur**-Chandikhol Arg-9, Korei Arg-16

Mayurbhanj - Balimundali, Thakurmunda- 9 each, Bangiriposi, Baripada-11 each, Jamsolaghat-14, **Sundargarh**-Tensa-11

(ii) Jharkhand

Bokaro - Bokaro, Tenughat- 15 each, **Dhanbad -** Panchet , Putki -10 each, Papunki -16, **East Singbhum-**Jamshedpur, Jamshedpur Aero – 10 each, **Giridih -** Maithon -9, Nandadih – 11, Barkisuriya - 16, **Hazaribag-**Barhi – 9, **Jamtara-**Jamtara – 15, **Pakur -** Pakur, Pakuria – 7 each, Maheshpur -8, Hiranpur -9, **Palamu -** Japla -11, Panki- 13

(iii) Bihar

Araria - Forbesganj – 7, Araria - 10, **Arwal-** Kuratha – 10, Kinjar - 11, Arwal - 12, **Aurangabad-**Palmerganj – 9, **Banka-**Banka – 13, **Begusarai-** Sahebpur Kanal – 13, Kodawanpur/C.Bii -22, **Bhagalpur-** Sabour – 9 Bhagalpur-11, Colgaon - 12, **Bhojpur-**Koilwar – 9, **Darbhanga-** Kamtaul- 10, Hayaghat- 14, **Gaya -** Gaya Aero -15,Bodh Gaya- 17, **Jahanabad –** Makhdumpur-8, Jahanabad -9, **Jamui -** Sono-9, Jamui-12, Garhi-13, Jhajha - 14, **Katihar** - KatiharNorth, Manihari- 10 each,K**hagaria-** Khagadia-10, Baltara -12, **Madhepura-** Murliganj-10, Udai Kishanganj-15 **Madhubani-**Jhanjharpur-10, **Monghyr -** Monghyr-13, **Muzaffarpur -** Sahebganj , Saraiya – 8 each, Rewaghat, Minapur-9 each, Benibad, Muzaffarpur-11each, **Nalanda-**Bihar Shrif-9, Ekangersarai -12, **Nawada-**Hisua, Nawada-7 each, Rajauli- 9, **Patna-**Patna Aerodrome-8, Sripalpur-9, **Purnea-** Purnea – 11, **Rohtas-** Dehri – 9, **Saharsa-**Sirmari B. Pur – 10, **Samastipur-** Samastipur-11, Rosera-14, Hasanpur - 16, **Saran-** Chapra-11, **Sheikhpura-**Barbigha-8, **Sitamarhi-**Belsand-9, **Siwan-**Siswan-8, **Supaul-** Bhimnagar, Nirmali-8 each, Basua-10, **Vaishali-**Vaishali-9,

(iv) Sub-Himalayan West Bengal and Sikkim (SHWB & SIKKIM)

Malda-Ratua Arg 7

(v) Gangetic West Bengal

Bankura- Bankura- 10, Bankura(Cwc) - 10 Kansabati Dam – 7, **Burdwan-** Asansol(Cwc) – 12, **Hooghly-** Bagati – 9, **Kolkata-** Alipore – 8, **North 24 Parganas -** Barrackpur(Iaf) – 8, **Purulia-** Phulberia - 9, Kharidwar - 13, Simula , Tusuma -15 each, Purihansa - 18, **West Midnapore-** D.P.Ghat – 9

15-10-2013

Bihar: Katihar/North-24, Kursela-24, Purnea-23, Madhipura-17, Murliganj-16, Barahara-15, Chargharia-15, Udai Kishanganj-14, Bhagalpur-14, Colgaon-12, Araria-11, Manihari-11, Sabour-11, Chanpatia-10, Phulparas-8, Koilwar-7, Ramnagar-7, Taibpur-7, Jainagar-7, Basua-7,

Sub-Himalayan West Bengal & Sikkim: Gangarampur (ARG)-22, Darjeeling-18, Bagrakote-16, Champasari-13, Murti-13, Kalimpong-13, Pedong-13, Malda-13, Siliguri (ARG)-13, Jalpaiguri-12, Dinhata (ARG)-12, Gajoldoba-12, Namchi (AWS)-12, Domohani-11, Gangtok-11, Sevoke-11, Soreng (ARG)-11, Bagdogra Iaf-10, Damthang-10, Khanitar-9,

Neora-9, Mekhliganj (ARG)-9, Mathabhanga-9, Singla Bazar-9, Tadong-8, Chepan-8, Nagarkata-8, Gyalsing (AWS)-8, Cooch Behar-7, Pundibari (AWS)-7,

Gangetic West Bengal: Narayanpur-7,

Odisha: Astaranga (ARG)-9,

5.2 Gale Wind

Maximum wind 115 knots (215 kmph) has been estimated to have occurred over the region near landfall based on the observations from the Doppler weather Radar, Visakhapatnam and the observations from Gopalpur and Puri in Odisha.

5.3. Storm Surge

According to survey report, maximum storm surge of 2-2.5 meters above the astronomical tide has been reported in the coastal areas of Ganjam district. The coastal inundation has been reported maximum upto 500 metre to one km in the low lying areas of Ganjam district.

6. Damage due to Cyclone 'Phailin'

The VSCS, PHAILIN mainly affected Odisha and coastal Andhra Pradesh. Details of the damage are given below.

6.1. Odisha

Districts Affected: Angul Balasore, Bhadrak, Bolangir, Cuttak, Ganjapati, Ganjam, Jagatsinghpur, Jajpur, Kamdhamal, Kendrapara, Keonjhar, Khurda, Koraput, Mayurbhanj, Nayagarh, Puri

Block Affected (Nos.)	: 151
GPs Affected(Nos.)	: 2015
Village Affected(Nos.)	: 18117
ULB Affected (Nos.)	: 43
Population Affected (Nos.) due to flood & cyclone	: 12396065
Human Casualty due to cyclone	: 21
Human Casualty due to flood	: 17
Crop area affected (hect)	: 668268
Person evacuated due to cyclone	: 983642
Person evacuated due to flood	: 171083

Cattle evacuated : 31062

House damaged : 419052

6.2. Coastal Andhra Pradesh

Districts affected : Srikakulam, Vizainagaram, Visakhapatnam

Village affected : 294

Human death : 01

Persons evacuated : 134,426

Paddy crop inundated : 6192 Ha

7. NWP model forecast performance

India Meteorological Department (IMD) operationally runs two regional models, WRF and Quasi-Lagrangian Model (QLM) for short-range prediction and one Global model T574L64 for medium range prediction (7 days). The WRF-Var model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^{o} S to 45^{o} N 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. The QLM model (resolution 40 km) is used for cyclone track prediction in case of cyclone situation in the north Indian Ocean. IMD also makes use of NWP products prepared by some other operational NWP Centres like, ECMWF (European Centre for Medium Range Weather Forecasting), UKMO, GFS (NCEP), JMA (Japan Meteorological Agency), Meteo-France. A multi-model ensemble (MME) for predicting the track of tropical cyclones for the Indian Seas is developed. The MME is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, QLM, GFS (NCEP), UKMO and JMA. In addition to the above NWP models, IMD also run operationally the SCIP model for 12 hourly intensity predictions up to 72-h and Genesis potential parameter (GPP) for potential of cyclogenesis and forecast for potential cyclogenesis zone. Recently the Hurricane WRF (HWRF) model and Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones and a rapid intensification index (RII) is developed for the probability forecast of rapid intensification (RI). The NWP guidance based on WRF model with 27 km resolution from IIT, Bhubaneswar were also received on real time. The performances of all these models during PHAILIN are presented below.

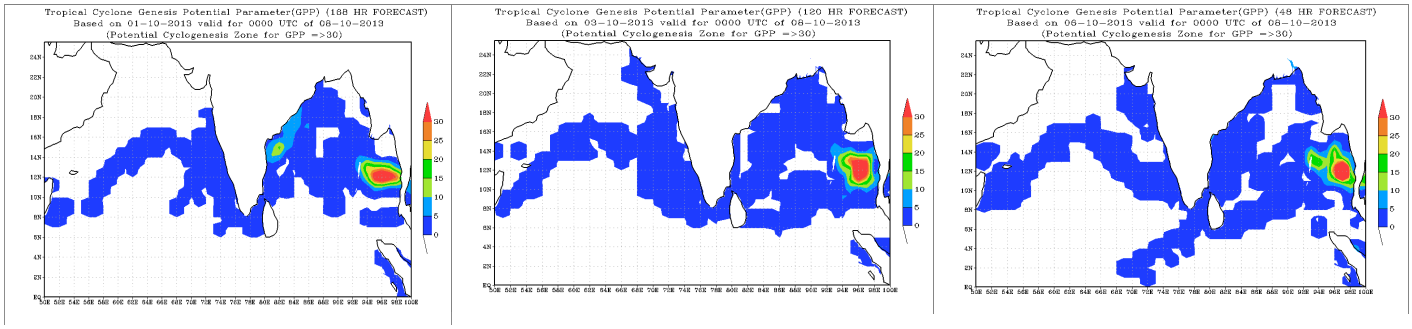


Fig.7. Genesis potential parameter based on 01, 03 and 05 October 2013 valid for 8 Oct. 2013

7.1. Genesis

The guidance available from dynamical-statistical model suggesting genesis potential provided good guidance about the genesis of the storm based on even 1st October. A few examples are shown in Fig.7. The Area average Genesis potential parameter (GPP) for different dates are shown in Fig.8. It also indicated genesis of the cyclone with T3.0 or more.

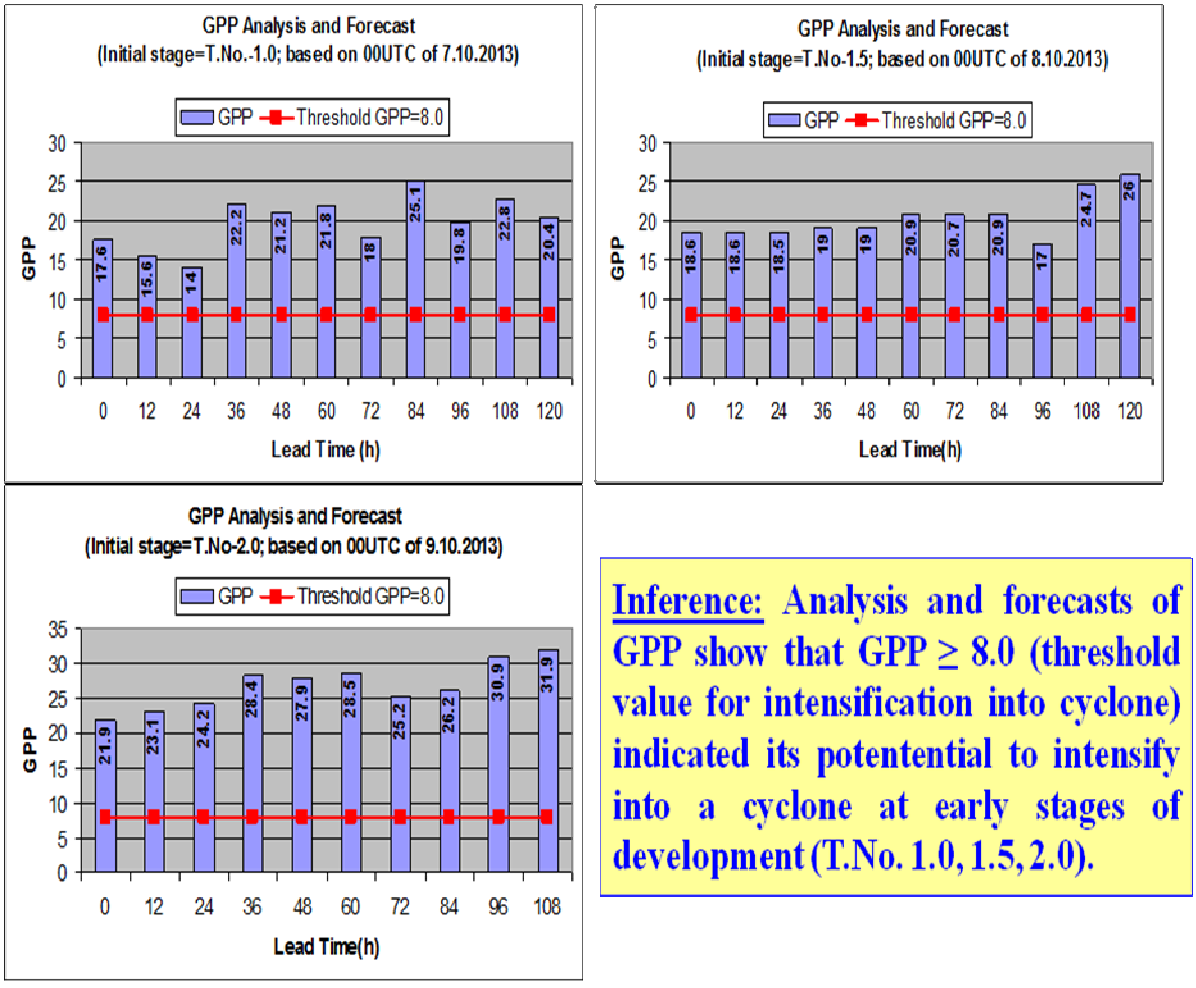


Fig. 8. Area average Genesis potential parameter (GPP)

7.2. Track forecast by NWP models

NWP model and consensus NWP (Multi-model ensemble) track forecasts based on different initial conditions starting from 08 October 2013 are shown in Fig.9. The model landfall point forecasts varied from Visakhapatnam to Paradip on 8th October, Visakhapatnam to Sagar Island on 9th October, Kalingapatnam to Paradip on 10th and 11th October. They mostly converged on 12th October. Comparing all the models, the forecast was most accurate for MME technique of IMD. The average track forecast errors of different models are shown in Table 4. On comparison, it is found that the performance of UKMO was better upto 48 hrs lead time and that of NCEP-GFS model was better for 60-108 hrs lead time and MME-IMD for 120 hrs lead

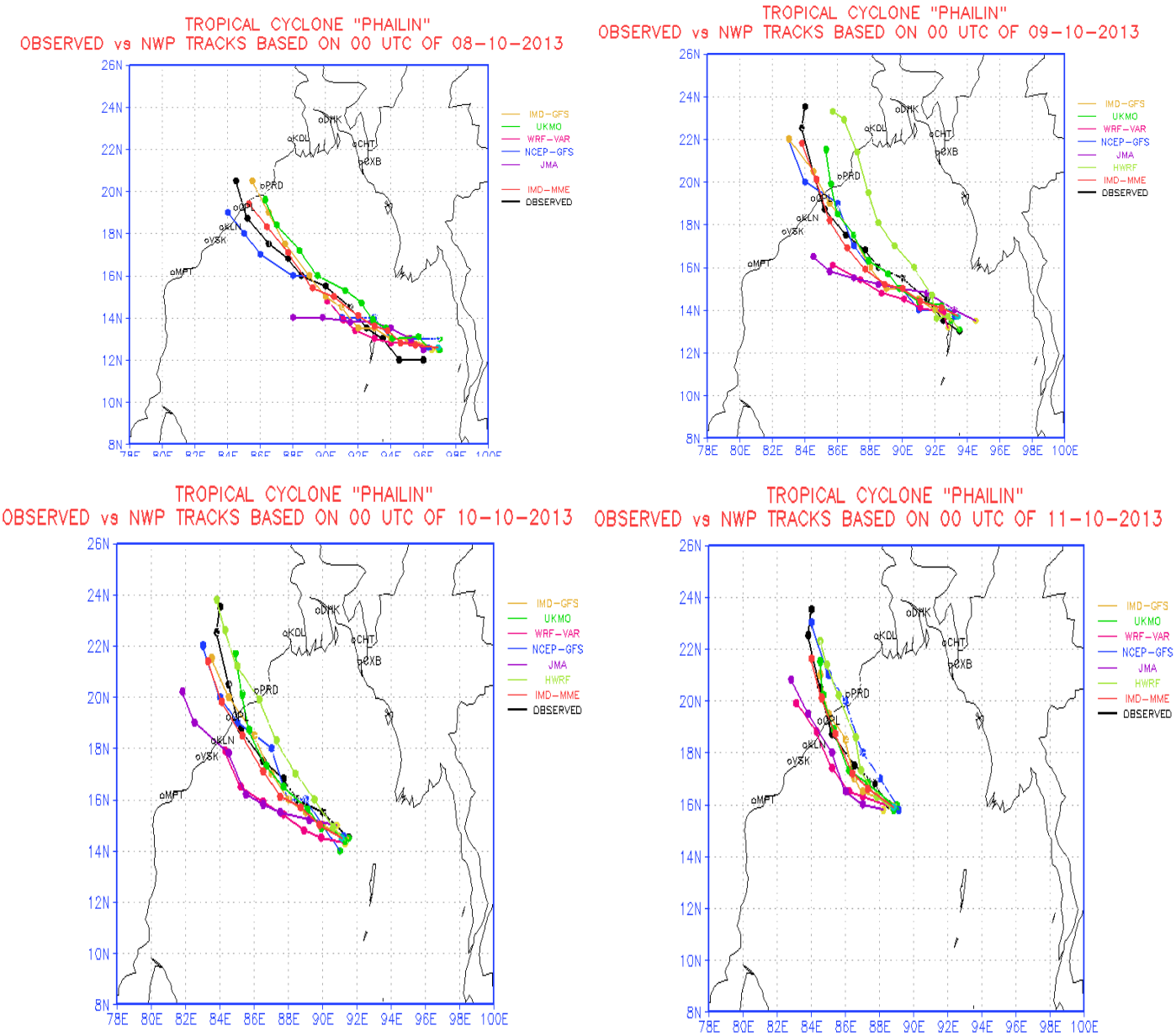
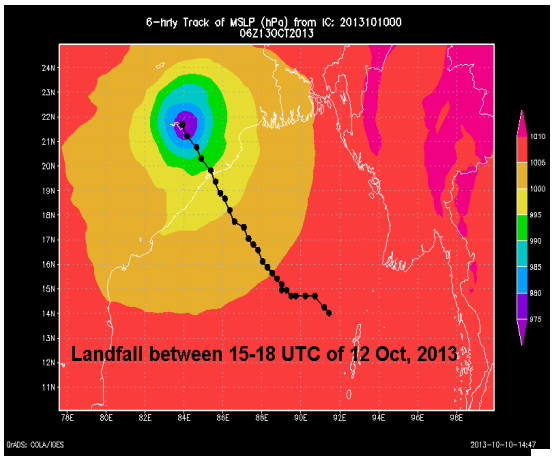
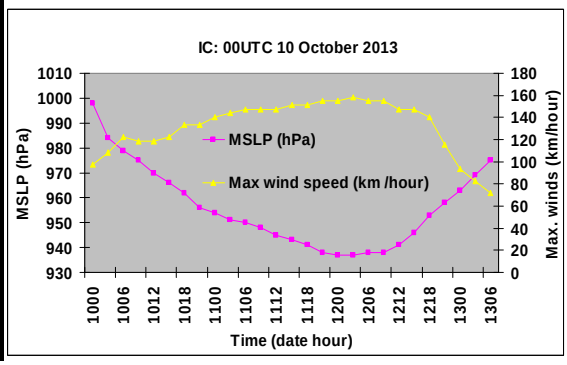
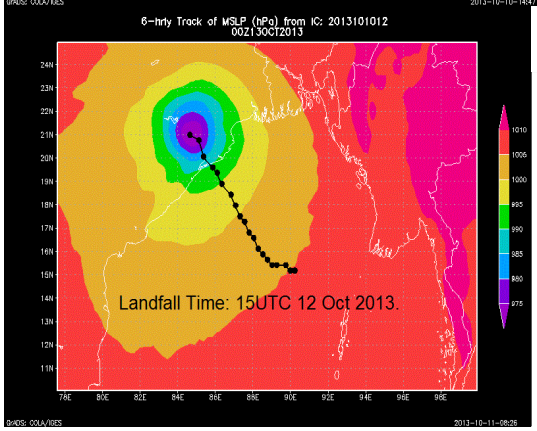
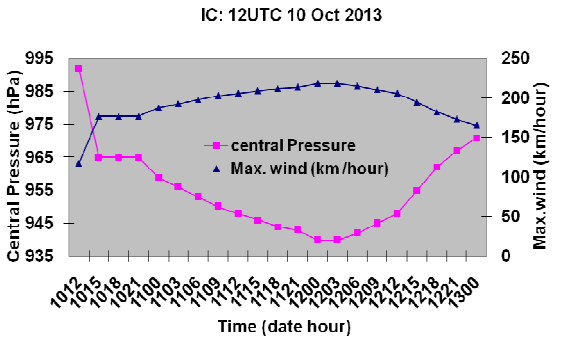


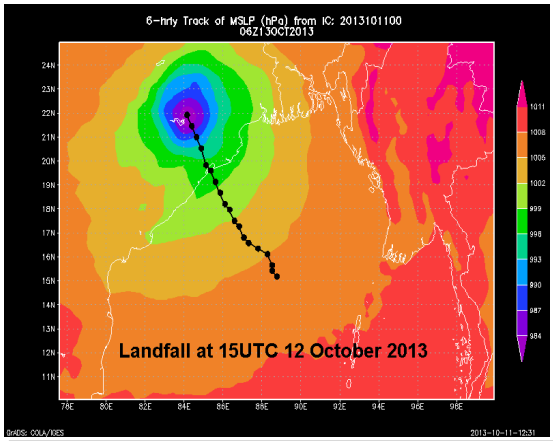
Fig.9 (a). Observed vs NWP Tracks based on 00UTC of 8th -11th Oct 2013.

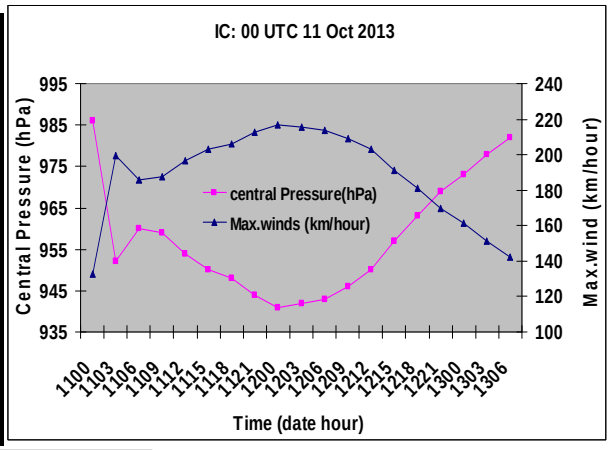












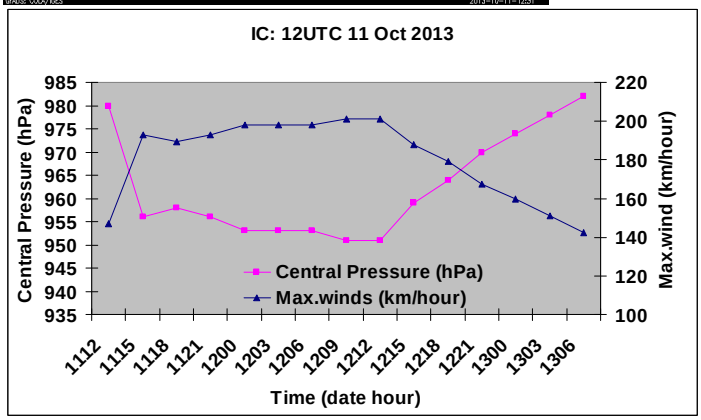


Fig. 9(b). WRF ARW model guidance from IIT, Bhubaneswar

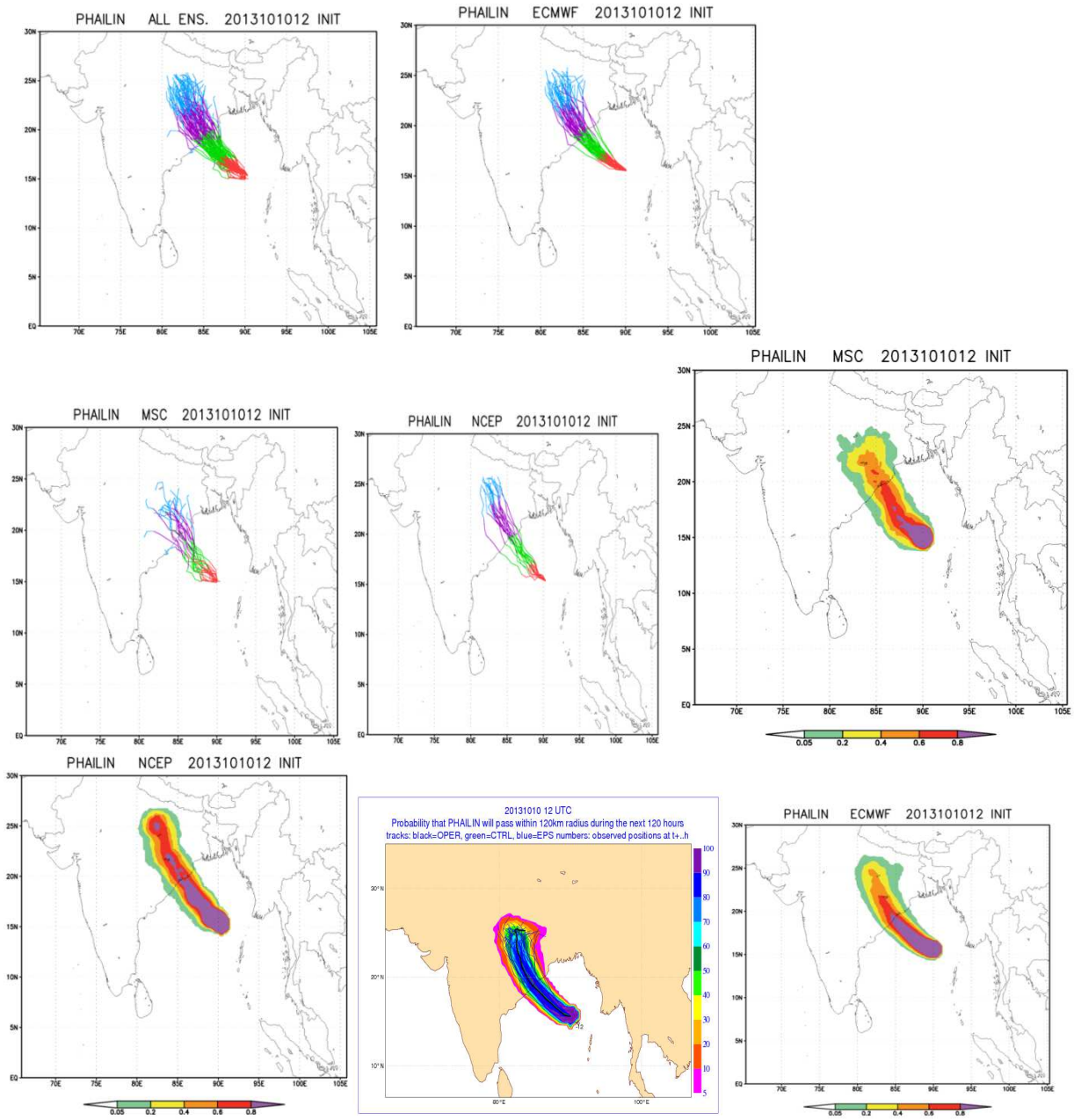


Fig.9(c). Ensemble prediction system (EPS) guidance with respect to cyclone, Phailin based on 1200 UTC of 10th October 2013.

WRF-ARW based NWP guidance was also received from IIT, Bhubaneswar. A typical example of the product received from IIT, Bhubaneswar is shown in Fig.9 (b). The ensemble prediction system available from various agencies are also utilised to predict the track and strike probability of the cyclone. A typical example of the EPS products is shown in Fig.9c.

Table 4. Average track forecast errors (DPE) in km (Number of forecasts verified)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-GFS	98(9)	107(9)	129(9)	173(8)	132(6)	115(5)	109(4)	92(3)	120(2)	104(1)
IMD-WRF	97(9)	150(9)	167(9)	193(8)	234(6)	266(5)	-	-	-	-
JMA	86(9)	97(9)	114(9)	149(8)	185(6)	239(5)	304(4)	-	-	-
NCEP-GFS	69(9)	63(9)	91(9)	87(8)	91(6)	61(5)	90(4)	84(3)	90(2)	175(1)
UKMO	63(9)	62(9)	71(9)	77(8)	104(6)	134(5)	134(4)	168(3)	191(2)	213(1)
IMD-MME	64(9)	67(9)	81(9)	95(8)	103(6)	119(5)	139(4)	112(3)	106(2)	148(1)
IMD-HWRF	49(8)	111(8)	169(8)	176(7)	183(6)	170(5)	154(4)	159(3)	187(2)	182(1)
IMD (Official)	63 (21)	98 (19)	91(17)	91(15)	90(13)	77(11)	95(07)	136(05)	112(03)	78(01)

7.3. Landfall forecast by NWP models

The landfall forecasts by various models are shown in Fig.10. The forecast was most accurate for MME. MME landfall forecast errors were consistently low at all lead time.

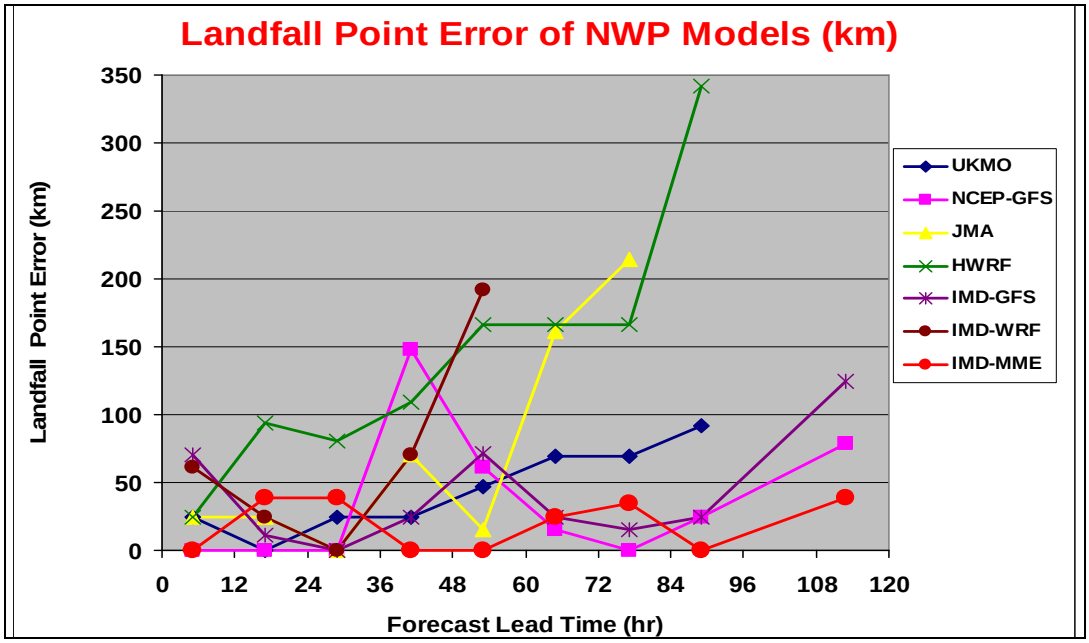


Fig.10 (a). Landfall Point Error (km) of NWP Models

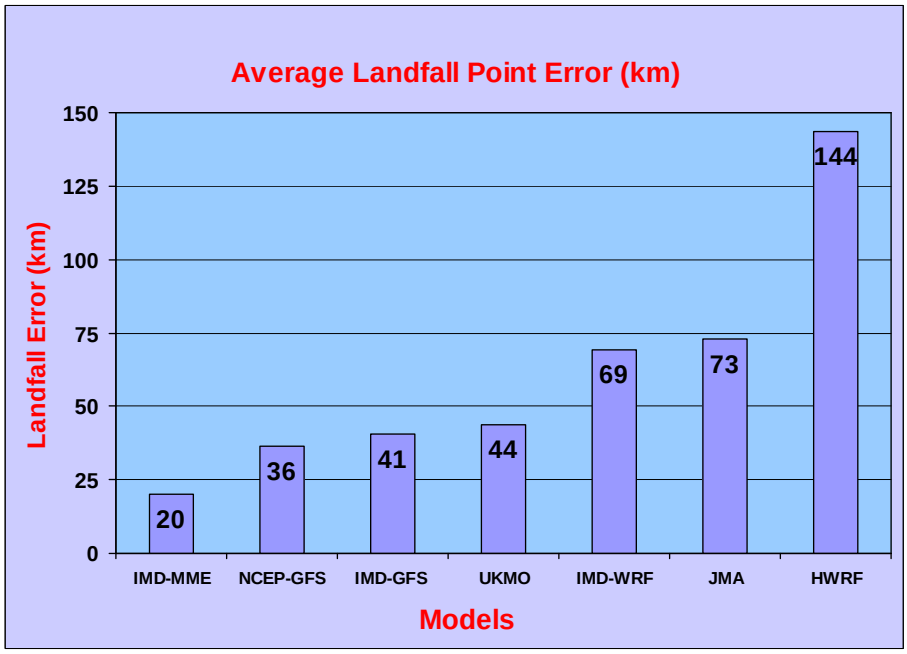


Fig.10 (b). Average landfall forecast error was lowest for MME

7.4. Intensity prediction by models

Statistical cyclone intensity prediction (SCIP) Model could able to predict the very severe stage of the PHAILIN at all stages of forecast (Fig.11). However, it predicted the peak intensity of 133 knots at the time of landfall against the actual of 115 knots. HWRF Model could be able to predict the very severe stage of the PHAILIN at all stages of forecast. However, it was under-estimating the intensity at landfall slightly (Fig.12).

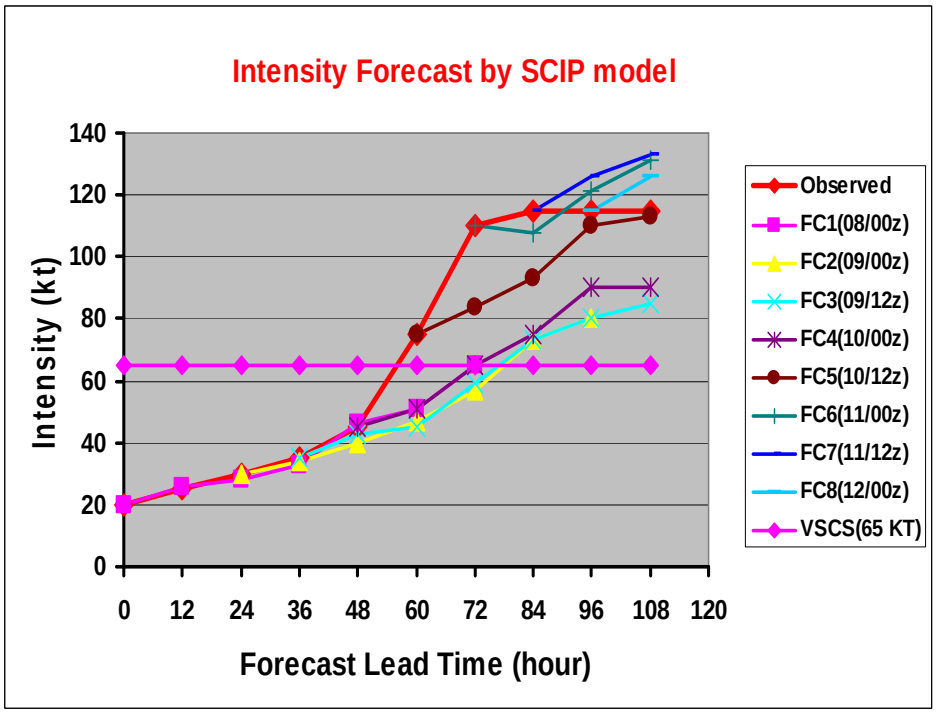


Fig.11 Tropical Cyclone Intensity Prediction by SCIP model

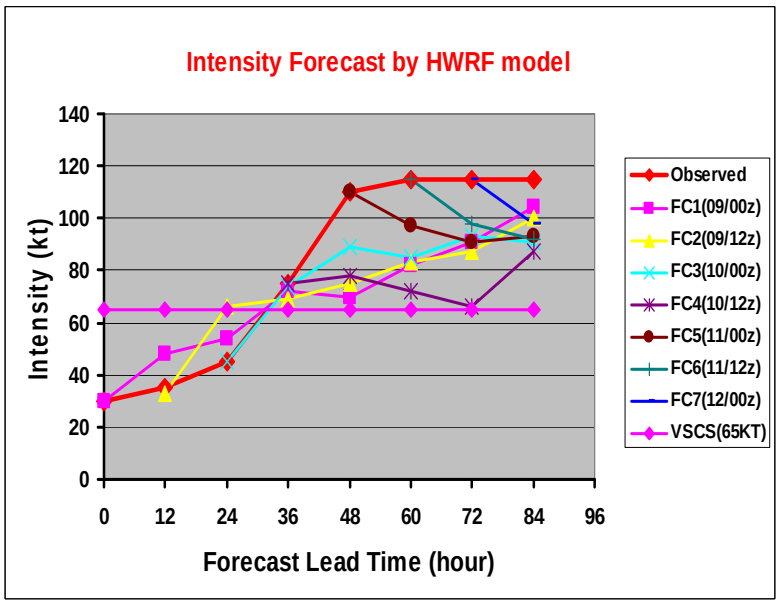


Fig.12. Intensity Prediction by HWRF model

Rapid Intensification (RI) is defined as intensity increase by 30 knots or more in 24 hrs period. Probability of rapid intensification was also provided by dynamical statistical model. It suggested rapid intensification from 12 UTC of 10th to 12 UTC of 11th against the actual occurrence of 00 UTC of 10th to 00 UTC of 11th. The RI probability is shown in Table 5 for different dates.

Table 5. Prediction of Rapid Intensification of PHAILIN

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Occurrence
00 UTC/08.10.2013	9.4 %	VERY LOW	NO
00 UTC/09.10.2013	9.4 %	VERY LOW	NO
12 UTC/09.10.2013	9.4 %	VERY LOW	YES
00 UTC/10.10.2013	72.7 %	HIGH	YES
12 UTC/10.10.2013	72.7 %	HIGH	YES
00 UTC/11.10.2013	72.7 %	HIGH	NO
12 UTC/11.10.2013	32.0 %	MODERATE	NO

Decay model of IMD also could predict the decaying nature of the PHAILIN after landfall to a reasonable accuracy.

7.5. Heavy rainfall

The heavy rainfall guidance from various models was also used for heavy rainfall warning. An example of HWRF model is shown in Fig.13 and that of IMD-GFS and WRF in Fig.14 and 15 respectively.

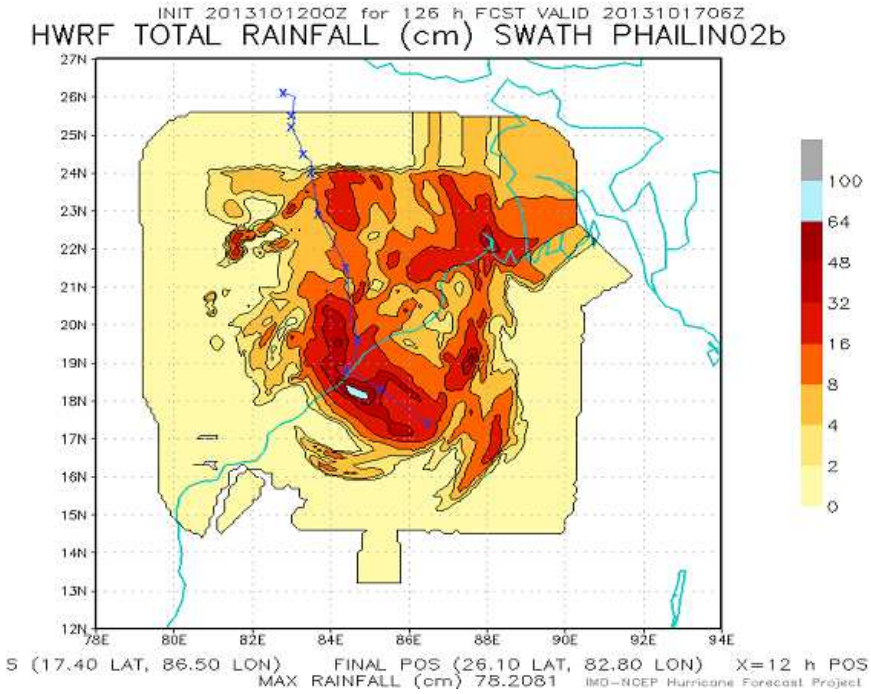


Fig.13. Rainfall guidance from HWRF model.

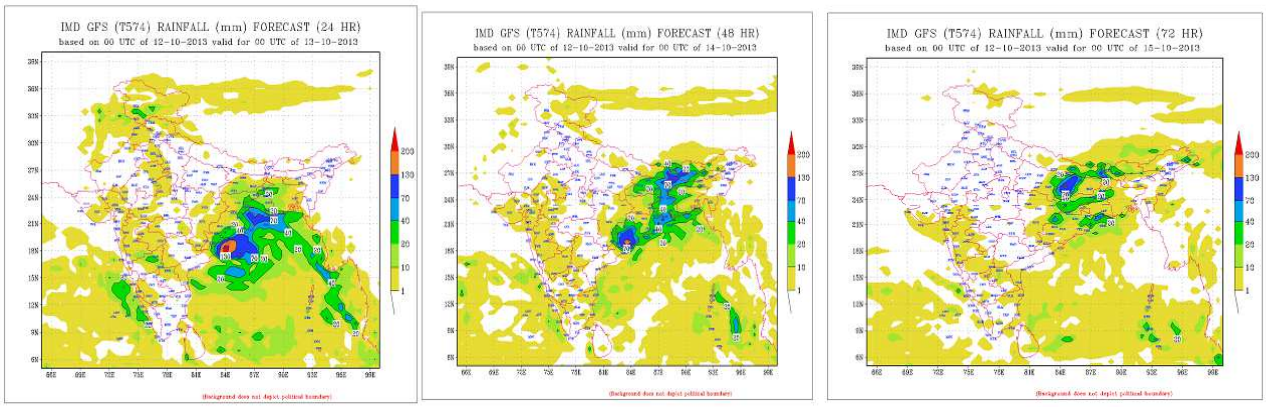


Fig.14. 24 hr rainfall forecast of IMD-GFS model basewd on 00 UTC of 12th valid upto 00 UTC of 15th Oct. 2013

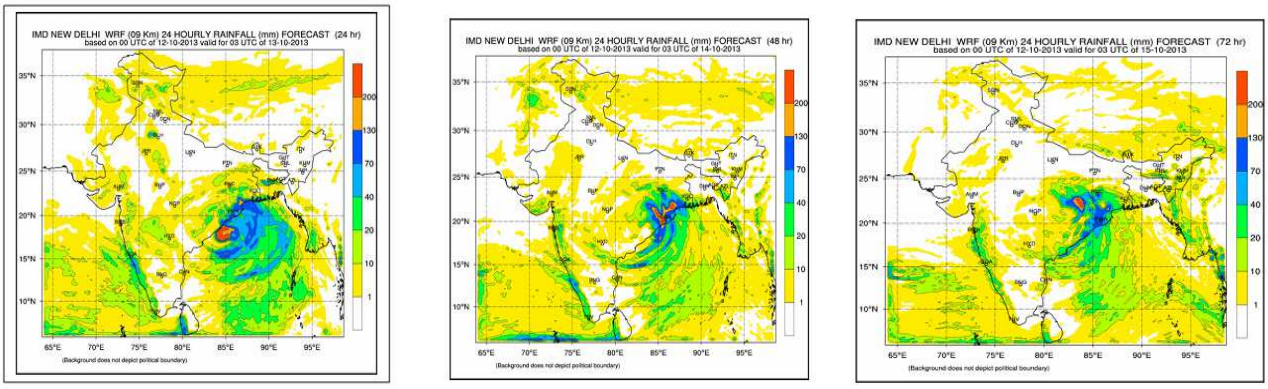


Fig.15. 24 hr rainfall forecast of WRF-IMD model based on 00 UTC of 12th valid upto 00 UTC of 15th Oct. 2013

7.6. Storm surge forecast

The storm surge models of INCOIS and IIT, Delhi provided prediction storm surge of 2-3 meters (Fig.16). The model run by IIT, Bhubaneswar predicted a surge of 3.5 meters above astronomical tide (not shown).

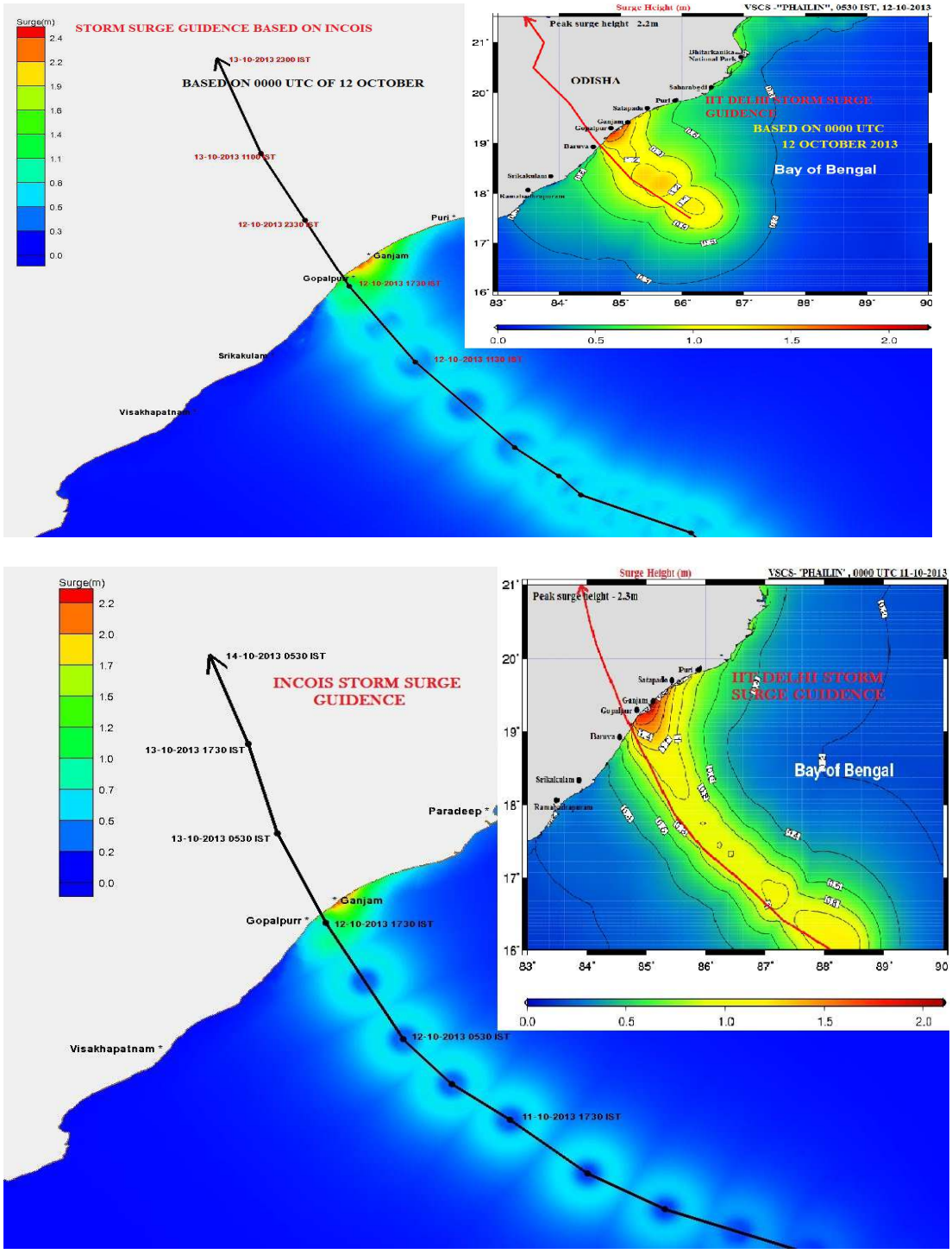


Fig.16. Storm surge guidance from INCOIS and IIT, Delhi model based on 0000 UTC of 11 and 12 October initial condition

8. Bulletins issued by IMD

8.1 Bulletins issued by cyclonic division Delhi

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

S.N.	Bulletin	No. of Bulletins
1	Press Release	03
2	No. of Press Conferences	06
3	Personal Briefings to higher officials	Daily
4	National Bulletin	45
5	RSMC Bulletin	27
6	DGM's Bulletin to higher Officials at national and state level	04
7	TCAC Bulletin (Text & Graphics)	19
8	ADRR Bulletin to Hong Kong website	18
9	TC vitals	10
10	Quadrant Wind	07
11	SMS to Senior Govt. Officials at national and state level	02

Press Releases were put up on IMD website and emailed to Senior Officers of NDMA, NDM, NDRF, MoHA, Senior Officers of MoES, IMD Modelling Groups- IIT-DLH & BBN, NCMRWF, INCOIS RMC-KOL, MUM, CHN, ACWC-CHN, MUM, KOL, CWC-BBN, VZK, MC-BBN, AGT, RANCHI, RAIPUR, HYD, MO-Port Blair, VZK, MUM. **DGM Bulletin was** Faxed and e-mailed to Cabinet Secretary, Principal Secretary to PM, P.S. to Hon'ble Minister

for S & T and MoES, Secretary- Ministry of Home Affairs, Ministry of Defence, Ministry of Agriculture, Ministry of I & B, MoES, DST, Ministry of Shipping & Surface Transport, Director General, Shipping, Central Relief Commissioner, Ministry of Home Affairs Control Room, NDM, Ministry of Home Affairs, Director Of Punctuality, Indian Railways, Director Central Water Commission, Director General, Doordarshan, AIR, Chief Secretary-Govt. of Andhra Pradesh, Govt. of Puducherry, Andaman & Nicobar Islands, DDGM(WF) Pune, ACWC-Chennai, Kolkata, CWC VZK, MO-VZK. Six **Press Conferences were held during 10-12 October 2013**. **Personal Briefings were provided to** Crisis Management Committee, Cabinet Secretary, Secy. MHA, VC NDMA for Disaster Management, Central Water Commission through Secy MHA for Hirakud Reservoir Management, Chief Secretary og Odisha and Andhra Pradesh. **National Bulletins** were updated daily on IMD website and faxed and sent by e-mail to Control Room NDM, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Dir. Indian Railways, Indian Navy, IAF, Chief Secretary-Govt. of Andhra Pradesh, Puducherry, Andaman & Nicobar Islands, West Bengal, Chhattisgarh, Jharkhand, Odisha, Bihar, Sikkim, Uttar Pradesh, Command Meteorological Office, Visakhapatnam,

Bulletins for WMO/ESCAP Panel countries were updated daily on IMD website and transmitted to All WMO/ESCAP member countries, Indian Navy, IAF, through global telecommunication system (GTS) and e-mail. For civil aviation purpose, the the Tropical Cyclone Advisory Centre located at cyclone warning Division of IMD, New Delhi issued **Text & Graphics bulletin as per requirement of International Civil Aviation Organization** and were updated daily on IMD website & transmitted through GTS / ftp to Meteorological watch Offices for issue of significant weather warning and to Aviation Disaster Risk Reduction Centre of WMO at Hong Kong through ftp. **TC vitals and Quadrant Winds were provided t**hrough ftp/email to modeling group-NCMRWF, IIT, INCOIS, IMD NWP and through e-mail to NCMRWF, IIT, INCOIS, IMD NWP for generation of synthetic cyclones in their models and hence to improve the model forecast performance.

8.1.1 Triggering for Water management

The full reservoir level of Hirakud Dam is 630 ft. DGM IMD advised on 9TH October to Hirakud Dam authorities through MHA to release water in view of potential threat due to cyclone. Due to release, water level came down to 621 ft. on 11th October. As the released water was increasing over the plain area of coastal Odisha, DGM, IMD further advised to stop releasing water on 11th October, As a result the reservoir was well managed. Due to extremely

heavy rain over Mahandi catchment the reservoir level increased from 621ft on 11th to 629ft after the cyclone. As it was within the full capacity, it did not worsen the flood situation in Mahanadi

8.2. Bulletins issued by Cyclone Warning Centre Bhubaneswar

Number of warnings issued with time are given below.

i) Number of Informatory message issued: 01 (One) at 081230ef

ii) Number of Cyclone watch issued : 02(Two) at 081430ef and 082030ef

iii) Number of Cyclone Alert issued: 06 (Six) at 091000ef, 091230ef, 091630ef, 092030ef, 092330ef, 100900ef.

iv)Number of Cyclone warning issued : 21 (Twenty One) at
101230ef, 101530ef, 101730ef, 102000ef, 102330ef, 110530ef, 110730ef, 111000ef, 111230ef, 111430ef, 111730ef, 112030ef, 112330ef, 140430ef, 120630ef, 120830ef, 121230ef, 121430ef, 121700ef, 122030ef, 122330ef.

v) Number of post landfall warning issued :- 08 (Eight) at 130430ef, 130630ef, 130900ef, 131230ef, 131530ef, 132100ef, 141230ef, 142000ef

vi)Press/AIR/Doordarshan/other TV Channel Bulletin issued : 38 (Thirty eight)
Time of issue:- 081230ef, 081430ef, 082030ef, 091000ef, 091230ef, 091630ef, 092030ef, 092330ef, 100900ef. 101230ef, 101530ef, 101730ef, 102000ef, 102330ef, 110530ef, 110730ef, 111000ef, 111230ef, 111430ef, 111730ef, 112030ef, 112330ef, 140430ef, 120630ef, 120830ef, 121230ef, 121430ef, 121700ef, 122030ef, 122330ef, 130430ef, 130630ef, 130900ef, 131230ef, 131530ef, 132100ef, 141230ef, 142000ef .

vi. Number of Port Warning issued :- 36 (Thirty six) and one de-warning
DC-I. 081230ef, 082030ef, 090530ef, 091000ef, 091230ef.
DW-II. 092030ef, 092330ef, 100430ef, 100600ef, 100900ef, 101230ef, 101530ef, 101730ef, 102000ef, 102330ef, 110530ef, 110730ef.
LC-III. 111000ef, 111230ef, 111430ef, 111700ef, 112030ef, 112330ef, 120430ef.
GD-X. Gopalpur,Puri and GD-IX Paradip, Chandbali Ports at 120630ef, 120830ef, 121230ef, 121430ef, 121700ef, 122020ef, 122330ef, 130430ef.
LC-III. 130630ef, 130930ef, 131230ef, 132100ef.
De-warning:- 141230ef.

viii. Fishermen Warning:- 28 (Twenty eight) at
082130ef,
090530ef, 091345ef, 091500ef, 092130ef.

100535ef, 101428ef, 101600ef, 102217ef.

110530ef, 111323ef, 111500ef, 112145ef.

120535ef, 121400ef, 121500ef, 122320ef.

130535ef, 131425ef, 131630ef, 132130ef.

140535ef, 141405ef, 141500ef, 142130ef.

150530ef, 151310ef, 151500ef.

viii. Heavy Rainfall Warning:-

08.10.2013:- Heavy rainfall may occur at one or two places over Odisha

09.10.2013: - Heavy rainfall may occur at one or two places over Odisha.

10.10.2013: - Heavy rainfall may occur at one or two places over Odisha.

11.10.2013:- heavy to very heavy rainfall would occur at one or two places over South Odisha and Heavy rainfall and one or two places over north Odisha

12.10.2013 :- Heavy to very heavy rainfall at a few places with isolated extremely heavy rainfall would occur over the districts of Gajapati, Ganjam, Khurda, Puri, Jagatsinghpur, Nayagarh, Cuttack, Bhadrak, and Kendrapada in Coastal Odisha.

13.10.2013 :- Heavy to very heavy rainfall at a few places with extremely heavy rainfall would occur over North Odisha and heavy rainfall would occur at one or two places over South Odisha.

8.3. Bulletins issued by Area Cyclone Warning Centre, Kolkata

i. Port Warning : 17
ii. Fisherman warning : 12
iii. Heavy rainfall warning : 12

8.4. Bulletins issued by Cyclone Warning Centre, Visakhapatnam

i. Cyclone Alert Bulletins-3(To State Govt officials)
ii. Cyclone Warning Bulletins-20(To State Govt officials)
iii. Port warnings-12
iv. Fishermen warnings-17
v. CWDS Bulletins-20(ACWC CHENNAI)
vi. Air bulletins-20
vii. Air news cycle-4
viii. Press bulletins

8.5. **Bulletins issued by Area Cyclone Warning Centre, Chennai**

i. Fishermen warnings- 20

ii. Port warning- 09

9. Forecast Performance

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

(i) 3rd October: Forecast of Formation of low pressure area on low pressure over North Andaman Sea around 6th October.

(ii) 7 October : Forecast for intensification of low over Andaman Sea.

(iii) 8 October: Depression formed and regular special bulletin commenced. Forecast for further intensification into a cyclonic storm by 9th October and move towards North Andhra Pradesh and Odisha Coast during next 72 hrs.

(iv) 9th October (morning): Forecast for Cyclonic Storm to intensify further to a very severe cyclonic storm with a wind speed of 175-185 kmph gusting to 200 kmph at the time of landfall between Kalingapatnam and Paradip by night of 12th October . **The forecast track indicated the landfall near Gopalpur (Fig.17)**

(v) 11th October 2013 : Forecast wind intensity was increased to 210-220 kmph at the time of landfall

9.1. Operational landfall forecast error

The operational landfall forecast error varied from 3 to 13 km for 12 to 72 hrs forecast (Table 6). Considering the size of the eye of the cyclone as 15-20 km, the landfall error was negligible for all forecast time scales. The landfall time error was also very less varying from 1 to 3 hrs.

Table 6. Operational landfall point and time forecast errors of PHAILIN

Lead Time (Hrs)	Landfall Point Error (km)	Landfall Time Error (hrs)	Long period average landfall point error(km)	Long period average landfall time error(hrs)
12	3	3 hr delay	41.6	2.5
24	13	3 hr delay	90.8	5.5
36	5	3 hr delay	102.7	8.5
48	11	3 hr delay	95.8	7.3
60	2	3 hr delay	67.7	2.2
72	6	01 hr early	134.8	1.2
84	41	01 hr early	-	-

Observed and Forecast Track based on 1200 UTC of 09 October 2013

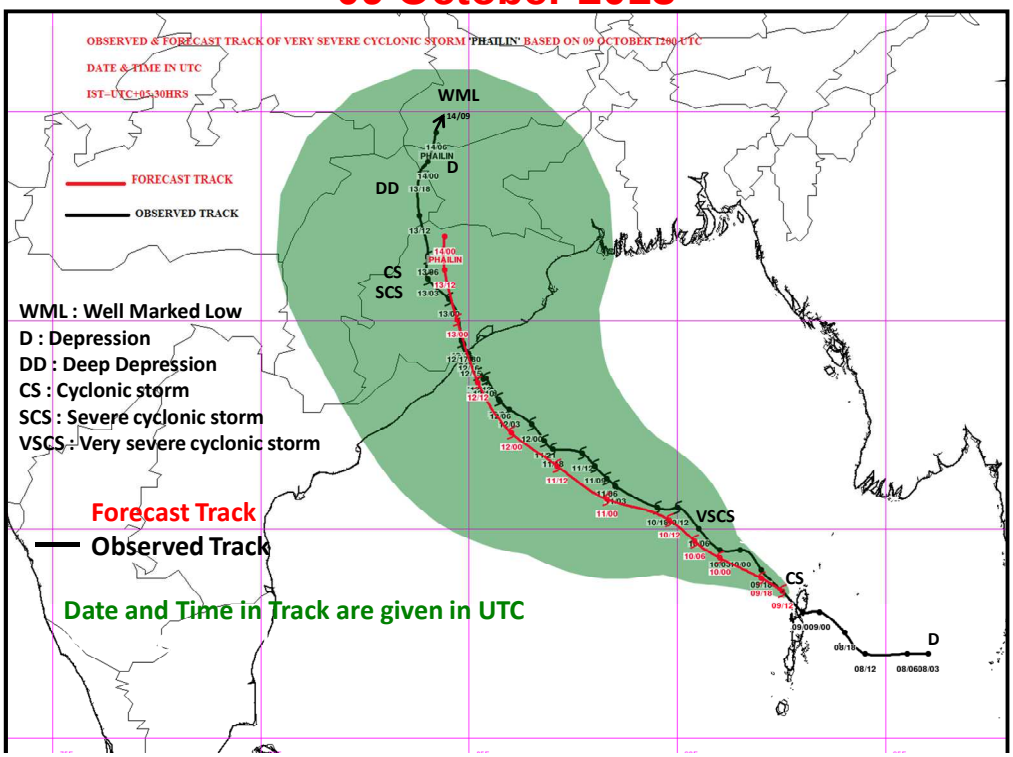


Fig.17. An example of forecast track along with cone of uncertainty issued on 9th October 2013.

9.2. Operational track forecast error and skill

The operational track forecast errors are shown in Table 7. It was less than 100 km for all forecast time scales upto 84(Table 7). It was also significantly less for 96-120 hr forecast times. The track forecast skill varied from 25% to 80 % for various time scales and was significantly higher than long period average (Table 8).

Table 7. Operational Track Forecast Error (km) of PHAILIN

Lead period (hrs)	Track forecast error	Long period average (2008-2012)
12	62.6	75.4
24	98.4	132.6
36	90.6	190.2
48	91.0	253.6
60	90.0	308.9
72	76.7	376.1
84	94.8	-
96	135.8	-
108	112.4	-
120	77.8	-

120 hr forecast has been introduced in 2013. Hence, no long period average is available for 84-120 hrs.

Table 8. Operational Track Forecast Skill (%)

Lead period (hrs)	Track forecast skill	Long period skill (2008-2012)
12	25.7	23.1
24	25.7	34.8
36	52.3	35.1
48	65.4	41.8
60	73.1	47.4
72	81.4	50.0
84	79.8	-
96	75.1	-
108	77.7	-
120	71.4	-

120 hr forecast has been introduced in 2013. Hence, no long period average is available for 84-120 hrs.

9.3. 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 9. The AE varied from about 2 knots to 19 knots in different time scales. The error was higher than the long period average based on 2008-2012 by about 5 knots. The slightly higher error in intensity may be attributed to rapid intensification of cyclone on 10th October 2013. However, comparing the skill, the skill in intensity forecast compared to persistence forecast 44% to 97% (Table 10).

Table 9. Intensity Forecast error (knots)

Lead period (hrs)	Absolute Error (knots)	RMS Error (knots	Long period Average (2008-2012):Absolute Error (knots)	Long period Average (2008-2012): RMS Error (knots)
12	9.1	12.8	7.3	9.9
24	14.9	21.0	10.4	13.5
36	17.4	22.2	12.7	16.1
48	18.7	22.9	13.4	17.8
60	17.7	20.5	13.4	15.3
72	11.1	13.9	19.0	24.0
84	19.7	31.2	-	-
96	10.5	16.5	-	-
108	1.8	2.2	-	-
120	5.4	5.4	-	-

120 hr forecast has been introduced in 2013. Hence, no long period average is available for 84-120 hrs.

Table 10. Operational Intensity Forecast skill (%)

Lead period (hrs)	Absolute Error (knots)	RMS Error (knots
12	44.3	50.0
24	62.1	55.6
36	70.9	65.1
48	77.9	75.5
60	75.3	84.2
72	91.7	91.6
84	80.4	80.4
96	87.3	85.4
108	97.0	96.6
120	89.6	89.7

9.4. Adverse weather forecast verification

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Table 11-13. It is found that all the three types of adverse weather were predicted very accurately and well in advance.

Table 11 .Verification of Heavy Rainfall Forecast

Date/ Time(IST)	Forecast Rainfall	Observed Rainfall
08.10.13/ 0830	Andaman and Nicobar Islands during next 48 hrs: Heavy to very heavy rainfall at a few places with isolated extremely heavy falls (≥ 25cm)	**Andaman & Nicobar Islands:** 08 October: scattered heavy to very heavy rainfall. 09 October: scattered heavy to very heavy rainfall with isolated extremely heavy. 10 October: isolated heavy to very heavy rainfall. **Odisha**
09.10.13/ 0830	Andaman and Nicobar Islands during next 24 hrs: Heavy to very heavy rainfall at a few places with isolated extremely heavy falls (≥ 25cm)	
09.10.13/ 1730	Andaman and Nicobar Islands during next 12 hrs: Heavy to very heavy rainfall at a few places with isolated extremely	

	heavy falls (≥ 25cm)	12 October: Isolated heavy over coastal Odisha
10.10.13/ 0830	Odisha : heavy to very heavy falls at a few places with isolated extremely heavy falls (≥ 25cm) would occur over coastal Odisha commencing from 12th October 2013 morning. It would continue and extend to interior Odisha and coastal areas of Gangetic West Bengal from 13th morning. North Coastal Andhra Pradesh : Heavy to very heavy rainfall would also occur at a few places over north coastal Andhra Pradesh commencing from 12th Oct 2013	13 October: scattered heavy to very heavy with isolated extremely heavy. 14 October: Isolated heavy 15 October : Isolated heavy **Coastal Andhra Pradesh** 13 October : isolated heavy to very heavy rainfall **Chhattisgarh** 13 October: Isolated heavy rainfall. **Gangetic West Bengal** 13 October: Isolated heavy 14 October: Isolated heavy to very heavy 15 October : Isolated heavy **SHWB & Sikkim** 14 October: Isolated heavy rainfall. 15 October: Isolated heavy to very heavy rainfall. **Jharkhand** 13 & 14 October: Isolated heavy to very heavy rainfall. **Bihar** 14 & 15 October: Isolated heavy to very heavy rainfall.
11.10.13/ 0830	Commencement of rainfall over coastal Odisha, changed to 11th night, Interior Odisha from 12th evening and West Bengal 12th night. Others remained same	
12.10.13/ 0830	Isolated heavy falls over north Chhattisgarh and Jharkhand, next 48 hrs	
13.10.13/ 0830	Isolated heavy to very heavy falls would occur over Bihar, Sub-Himalayan West Bengal & Sikkim during next 48 hours.	
14.10.13/ 0830	Isolated heavy to very heavy falls would occur over Bihar including Kosi and Gandak river catchments during next 24 hour and over Sub-Himalayan West Bengal & Sikkim including Teesta river catchment during next 48 hours. Isolated heavy falls over north Jharkhand during next 24 hours.	

Table 12. Verification of Gale Wind Forecast

Date/ Time(IST)	Forecast Wind	Observed Wind
Andaman and Nicobar Islands		
08.10.13/ 0830	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would prevail over Andaman Nicobar Islands and adjoining sea areas during next 48 hours. Sea condition will be rough to very rough along and off Nicobar Islands during this period.	Observed maximum wind is about 50-60 kmph
09.10.13/ 0830	Squally/Gale winds speed reaching 60-70 kmph gusting to 80 kmph would prevail over Andaman Nicobar Islands and adjoining sea areas during next 48 hours. Sea condition will be very rough to high along and off Andaman and Nicobar Islands during next 24 hrs.	
09.10.13/ 1730	Squally winds speed reaching 50-60kmph gusting to 70 kmph would prevail over Andaman Nicobar Islands and adjoining sea areas during next 24 hours. Sea condition will be very rough along and off Andaman and Nicobar Islands during next 24 hrs.	
East Coast		
10.10.13/ 0830	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would commence along and off Odisha and north Andhra Pradesh coast from 11th morning. It would increase in intensity with gale wind speed reaching 175-185 kmph along and off coastal districts of north coastal Andhra Pradesh and south Odisha at the time of landfall.	Observed maximum wind is about 115 Knots (200-210 gusting to 220 kmph)
11.10.13/ 0830	Squally winds speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Odisha and north Andhra Pradesh coast during next 12 hrs. It would increase in intensity thereafter with gale wind speed reaching 210-220 kmph along and off coastal districts of north coastal Andhra Pradesh and south Odisha at the time of landfall.	

Table 13. Verification of Storm Surge Forecast issued by IMD

Date/Time(IST)	Forecast Surge	Observed Surge
10.10.13/1730	Storm surge with height of around 1.5-2.0 m above astronomical tide would inundate low lying areas of Ganjam, Khurda, Puri and Jagatsinghpur districts of Odisha and Srikakulam district of Andhra Pradesh during landfall.	2-2.5 metres with coastal inundation upto 500 meter to one km in low lying areas of Ganjam district
11.10.13/1730	Storm surge with height of 3.0 to 3.5 mt. above astronomical tide would inundate low lying areas of Ganjam, Khurda, Puri and Jagatsinghpur districts of Odisha and Srikakulam district of Andhra Pradesh during landfall.	
12.10.13/1730	Storm surge with height of 3.0 to 3.5 metre. above astronomical tide would inundate low lying areas of Ganjam, Khurda, Puri and Jagatsinghpur districts of Odisha and Srikakulam district of Andhra Pradesh during landfall.	