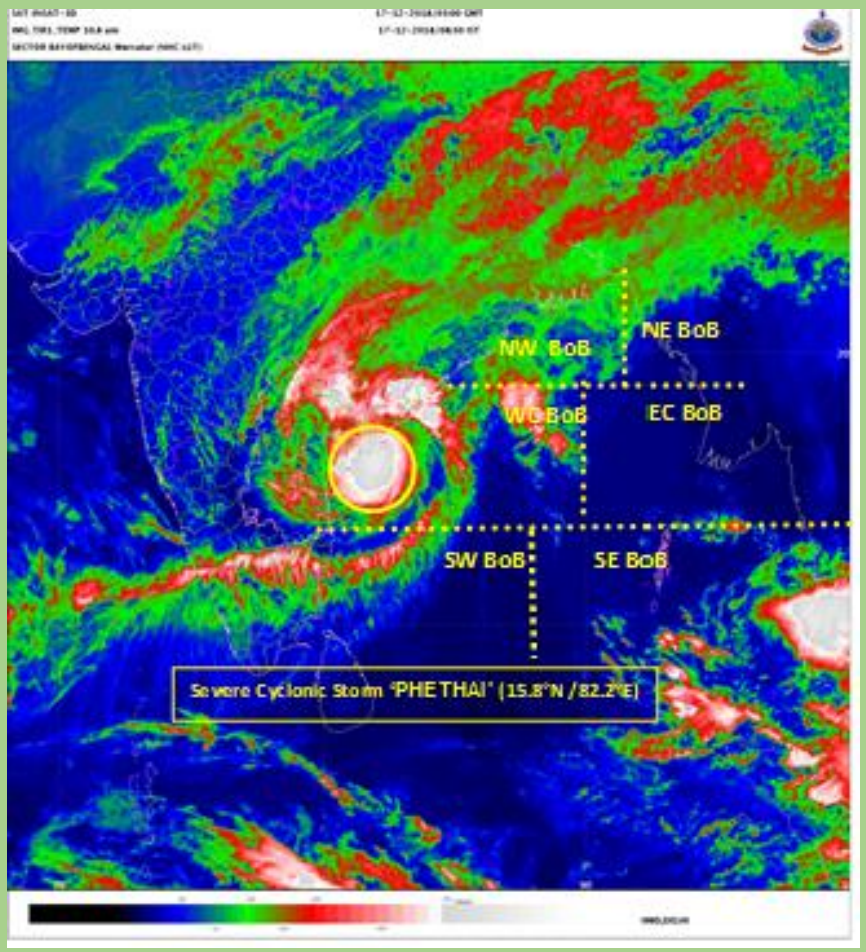
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Severe Cyclonic Storm, 'PHETHAI' over southeast Bay of Bengal (13 – 18 December 2018): A Report



INSAT-3D enhanced colored IR imagery of 17th December, 2018

Cyclone Warning Division

India Meteorological Department

New Delhi

January, 2019

Severe Cyclonic Storm "PHETHAI" over southeast Bay of Bengal (13-18 December 2018)

1. Introduction

The Severe Cyclonic Storm (SCS) Phethai originated from a low pressure area (LPA) which formed over Equatorial Indian Ocean (EIO) and adjoining central parts of south Bay of Bengal (BoB) in the evening (1730 IST) of 9th December. It lay as a well-marked low pressure area (WML) over central parts of south BoB and adjoining EIO in the morning (0830 IST) of 11th December. Under favorable environmental conditions, it concentrated into a Depression (D) over southeast BoB in the early morning (0530 IST) of 13th December. Moving north-northwestwards, it intensified into a deep depression (DD) over southeast BoB in the same mid-night (2330 IST) of 13th December. It intensified into a cyclonic storm (CS) **"Phethai**" (Pronounced as Pay-ti) in the evening (1730 IST) of 15th December and into a severe cyclonic storm (SCS) in the afternoon of 16th December. It maintained its intensity of SCS till early morning (0530 IST) of 17th December and weakened into a CS in the same morning (0830 IST). Continuing to move north-northwestwards and then northwards it crossed Andhra Pradesh coast near 16.55^0N and 82.25^0E (close to south of Yanam and 40 km south of Kakinada) during 17th afternoon (1330-1430 IST) as a cyclonic storm with maximum sustained wind speed of 75-85 kmph gusting to 95 kmph. After landfall, it moved north-northeastwards and weakened rapidly into a deep depression over westcentral BoB off Kakinada coast in the evening (1730 IST) of 17th December. Continuing to move north-northeastwards, it crossed again Andhra Pradesh coast close to Tuni during 1930-2030 IST and weakened into a depression over coastal Andhra Pradesh during same midnight (2330 IST). It further weakened into a WML over northwest and adjoining westcentral BoB & coastal Odisha in the early morning (0530 IST) and into a low pressure area over northwest BoB and adjoining Odisha in the morning (0830 IST) of 18th December.

2. Salient Features:

The salient features of the system were as follows:

- SCS Phethai was the seventh cyclone over north Indian Ocean during 2018 against normal frequency of about 4.5 cyclones per year during the satellite era (1961 onwards).
- Earlier such occurrence of 7 cyclones in a year was witnessed in 1985.
- It was a recurving cyclone with northeastward recurvature during and after the landfall.
- The track length of the system was 1525 km.
- The severe cyclonic storm intensity of the system was short lived (about 15 hrs).
- The system weakened slightly before landfall from the stage of SCS to CS.
- The peak maximum sustained surface wind speed (MSW) of the cyclone was 100-110 kmph gusting to 120 kmph (55 knots) during 1200 to 2100 UTC of 16th. The lowest estimated central pressure was 992 hPa during the same period with pressure drop of 15 hPa.

- The life period (D to D) of the system was 120 hours (5 days) against long period average (LPA) (1990-2013) of 98 hours for SCS category over Bay of Bengal during post monsoon season.
- It moved with normal speed, as the 12 hour average translational speed of the cyclone was 13.5 kmph against LPA (1990-2013) of 14.7 kmph for SCS category over north Bay of Bengal.
- The Velocity Flux, Accumulated Cyclone Energy (ACE) and Power Dissipation Index (PDI) were 3.6 X102 knots, 1.67 X 104 knots2 and 0.79 X106 knots3 respectively.

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

3. Monitoring of SCS, 'PHETHAI'

The cyclone was monitored & predicted continuously by India Meteorological Department (IMD) prior to its genesis as low pressure area over BoB from 7th December onwards. The observed track of the cyclone over BoB during 13-18 December is shown in **Fig.1**. The best track parameters of the systems are presented in **Table 1.**

The system was monitored mainly with satellite observations from INSAT 3D and 3DR, SCAT Sat, polar orbiting satellites, scatterometer observations, Doppler Weather Radar (DWR) Visakhapatnam and Chennai and available ships & buoy observations in the region. The system came under Radar surveillance from the morning of 16th night. Various national and international numerical weather prediction models and dynamical-statistical models were utilized to predict the genesis, track and intensity of the cyclone. 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. IMD issued regular bulletins to WMO/ESCAP Panel member countries including Bangladesh, Myanmar, Sri Lanka, National & State Disaster Management Agencies, general public and media since inception of the system over BOB.

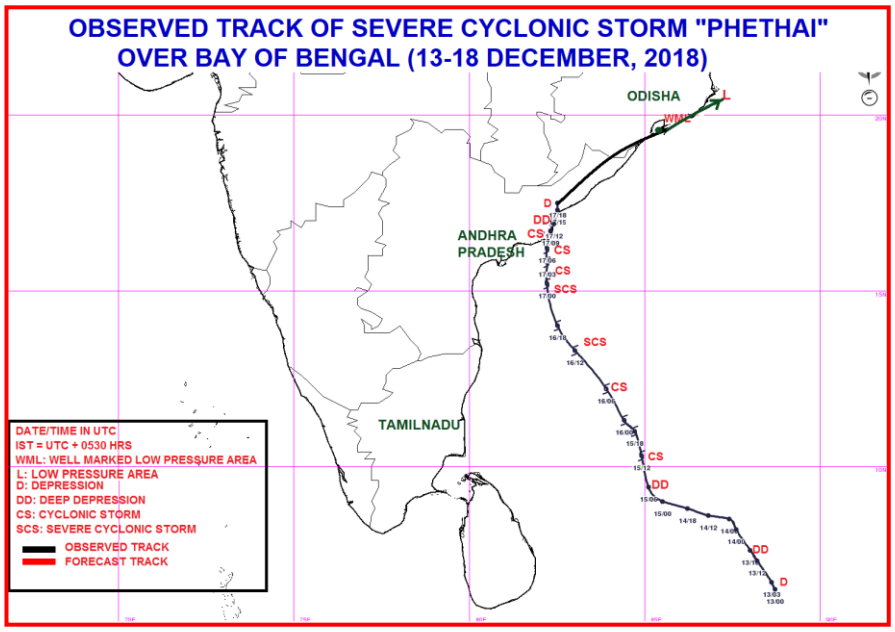


Fig.1 Observed track of SCS PHETHAI (13-18 December, 2018) over Bay of Bengal

Table 1: Best track positions and other parameters of the Severe Cyclonic Storm, 'Phethai' over the southeast Bay of Bengal during 13-18 December, 2018

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
13/12/2018	0000	6.5	88.7	1.5	1004	25	3	**D**
	0300	6.7	88.6	1.5	1004	25	3	**D**
	0600	6.8	88.5	1.5	1003	25	4	D
	1200	7.3	88.2	1.5	1003	25	4	D
	1800	7.6	88.0	2.0	1002	30	5	**DD**
14/12/2018	0000	8.2	87.6	2.0	1002	30	5	DD
	0300	8.5	87.4	2.0	1002	30	5	DD
	0600	8.5	87.4	2.0	1002	30	5	DD
	1200	8.6	86.8	2.0	1002	30	5	DD
	1800	8.8	86.2	2.0	1002	30	5	DD
15/12/2018	0000	9.0	85.5	2.0	1002	30	5	DD
	0300	9.2	85.2	2.0	1001	30	6	DD
	0600	9.4	85.1	2.0	1001	30	6	DD
	1200	10.3	84.9	2.5	1000	35	7	**CS**
	1500	10.7	84.7	2.5	1000	35	7	CS
	1800	11.0	84.6	2.5	1000	35	7	CS
	2100	11.1	84.5	2.5	1000	35	7	CS
16/12/2018	0000	11.3	84.3	3.0	998	40	8	CS
	0300	11.8	84.1	3.0	996	45	10	CS
	0600	12.2	83.9	3.0	996	45	10	CS
	0900	12..6	83.6	3.0	994	50	13	**SCS**
	1200	13.3	83	3.5	992	55	15	**SCS**
	1500	13.8	82.7	3.5	992	55	15	**SCS**
	1800	14.0	82.5	3.5	992	55	15	**SCS**
	2100	14.5	82.2	3.5	992	55	15	**SCS**
17/12/2018	0000	15.2	82.2	3.0	994	50	13	**SCS**
	0300	15.8	82.2	3.0	997	45	10	**CS**
	0600	16.2	82.2	3.0	997	45	10	CS
		Crossed Andhra Pradesh coast near 16.55^{0}N and 82.25^{0}E 25 km south of Yanam and 40 km south of Kakinada during 0800 to 0900 UTC						
	0900	16.7	82.3	-	998	40	8	CS
	1200	16.9	82.4	2.0	1001	30	6	**DD**
		Crossed Andhra Pradesh coast close to TUNI during 1400 to 1500 UTC						
	1500	17.3	82.5	-	1004	30	5	DD
	1800	17.5	82.5	-	1006	25	3	D
18/12/2018	0000	**Weakened into a well marked low pressure area over northwest and adjoining west central Bay of Bengal and coastal Odisha.**						

4. Brief life history

4.1. Genesis

On 9th December, the Madden Julian Oscillation (MJO) index lay in phase 3 with amplitude more than 1. Forecast indicated that it would continue in same phase with amplitude greater than 1 for next 4 days. Thereafter it would move to phase 4 with amplitude remaining more than 1. Thus, MJO phase and amplitude were favourable for enhancement of convection over BoB region. Considering the environmental conditions, the sea surface temperature (SST) was 29-31˚C over southeast BoB and adjoining EIO region. It was decreasing slightly becoming 27-28˚C towards west of 82°E and north of 8˚N. The tropical cyclone heat Potential was more than 100 KJ/cm^2 over central parts of south BoB and adjoining EIO. It was around 60-80 KJ/cm^2 over major parts of south BoB and adjoining EIO. However, it was less than 40 KJ/cm^2 over western parts of BoB along the east coast of India and Sri Lanka. The low level relative vorticity was east-west oriented and was around 60-80 x10^{-6} sec^{-1} over southeast BoB and adjoining EIO and was extending upto 500 hpa level. The lower level convergence and upper level divergence were about 15 x10^{-5} sec^{-1} and 20 x10^{-5} sec^{-1} over southeast BoB & adjoining EIO. The vertical wind shear was high (20-25 kt) over southeast BoB & adjoining EIO. The upper tropospheric ridge ran along 11°N.

Under the influence of these atmospheric & sea conditions and trough of low at mean sea level over EIO and adjoining central parts of south BoB, an LPA formed over the same region in the evening (1200 UTC) of 9th December. The favourable conditions continued and it the system lay as a WML over central parts of south BoB and adjoining EIO in the morning (0300 UTC) of 11th December.

At 0000 UTC of 13th December, similar sea conditions prevailed. The atmospheric conditions further consolidated. The lower level convergence increased significantly and was around 50x10^{-5} $second^{-1}$, the lower level vorticity was 130x10^{-6} $second^{-1}$, upper level divergence was 60x10^{-5} $second^{-1}$ and low vertical wind shear was moderate (10-15 knots) around the system centre. The upper tropospheric ridge ran along 11°N. Under these favourable environmental conditions, the system concentrated into a depression (D) over southeast BoB near latitude 6.5°N and longitude 88.7 °E about 850 km east-southeast of Triconmalee in the early morning (0000 UTC) of 13th December.

4.2. Intensification and movement

Moving north-northwestwards, it intensified into a deep depression (DD) over southeast BoB in the same mid-night (1800 UTC) of 13th December. Considering the environmental conditions, the sea surface temperature (SST) was 29-30˚C over southeast BoB and adjoining areas. The TCHP was more than 100 KJ/cm^2 over central parts of south BoB and adjoining EIO. It was around 60-80 KJ/cm^2 over remaining parts of southeast BoB. However, it was less than 40 KJ/cm^2 over western parts of BoB along the east coast of India and Srilanka. The lower level convergence was 30x10^{-5} $second^{-1}$, lower level vorticity was150x10^{-6} $second^{-1}$, upper level divergence was 40x10^{-5} $second^{-1}$ and low vertical wind shear was high (20-25 knots) over the system area and was increasing towards the northwest of the system area. The upper tropospheric ridge ran along 12°N. Under the influence of an anticyclone over southeast Asia, more northward component of movement was exhibited in movement.

At 1200 UTC of 15th, the MJO index lay in Phase 4 with amplitude more than 1. The SST was 28-29˚C around the system area. The tropical cyclone heat potential was around 60-80 KJ/cm^2 over the system area. However, it is less than 40 KJ/cm^2 over western parts of BoB along the east coast of India. The lower level convergence was 60x10^{-5} second^{-1} towards north-northwest of the system center. Lower level vorticity was 200x10^{-6} second^{-1} around the system center. Upper level divergence was 20x10^{-5} second^{-1} towards north-northwest of the system centre and vertical wind shear was moderate (15-20 knots) over the system area and was indicating increasing trend along the forecast track. The total precipitable water imagery indicated warm and moist air feeding into the core of the system from southeast sector and dry & cold air prevailed over peninsular India. The upper tropospheric ridge runs along 16°N. The system was guided by the anticyclone over southeast Asia. Under these conditions, the system intensified into cyclonic storm (CS) “Phethai” (Pronounced as Pay-ti) in the evening (1200 UTC) of 15th December and into a severe cyclonic storm (SCS) in the evening (1200 UTC) of 16th December. It maintained its intensity of SCS till early morning (0000 UTC) of 17th December.

At 0300 UTC of 17th, the SST was 28-29˚C around the system area. it is decreasing slightly becoming 26-28˚C towards westcentral BoB and along & off Andhra Pradesh coast. The tropical cyclone heat potential decreased and was around 35-50 KJ/cm^2 over the system area. However, it is less than 35 KJ/cm^2 over western parts of BoB along the east coast of India. The lower level convergence decreased significantly and was around 20x10^{-5} second^{-1} towards north-northeast of the system centre. The lower level vorticity was around 200x10^{-6} second^{-1} around the system center. The upper level divergence also decreased and was around 10x10-5 second^{-1} around the system center. The vertical wind shear increased over the system area and along the forecast track (around 20 knots). Wind shear tendency was positive over the system area as well as along the forecast track. The TPW imagery indicated warm and moist air feeding into the core of the system from north-northeast sector and dry & cold air prevailing over peninsular India. The upper tropospheric ridge ran along 17°N. An anticyclone lay over southeast Asia, and hence under it’s influence, the system moved north-northeastwards as it approached the coast and weakened into a CS in the same morning (0300 UTC) of 17th. Moving nearly northwards, it crossed Andhra Pradesh coast near 16.55^{0}N and 82.25^{0}E 25 km south of Yanam and 40 km south of Kakinada during 0800 to 0900 UTC of 17th.

At 1200 UTC of 17th, the system emerged into westcentral Arabian Sea. The lower level convergence was 30x10^{-5} second^{-1} towards east of the system centre. Upper level divergence was 20x10^{-5} second^{-1} towards northeast of the system center. Lower level vorticity was 150x10^{-6} second^{-1} to the south of the system centre. The upper tropospheric ridge ran along 16°N. The system was guided by the anticyclone over southeast Asia and a deep trough in upper tropospheric westerlies to the west. Under the combined effect of anticyclone and above trough, the upper level winds increased over northeast coast of India leading to an increase in increase in wind shear over the region. There was lower SST over the region, lower ocean heat content, land interactions and high wind shear. Under these circumstances, the system weakened into a deep depression over

westcentral BoB at 1200 UTC of 17th and moving nearly northwards crossed Andhra Pradesh coast close to TUNI during 1400 to 1500 UTC.

The unfavourable conditions continued and moving nearly northwards, it weakened into a depression at 1800 UTC of 17th over coastal Andhra Pradesh and into a well marked low pressure area over northwest and adjoining westcentral Bay of Bengal and coastal Odisha at 0000 UTCof 18th December.

The TPW imageries during 16-18 Dec. 2018 are presented in **Fig.2**. These imageries indicate continuous warm and moist air advection from the southeast sector into the system, till 16th December. However, as the system approached coast , there was land interaction and moisture supply also reduced relatively as evident from TPW imageries on 17th and 18th Dec . The TPW image also indicated cold air advection from central and peninsular India on 17th and 18th Dec helping in weakening of the system.

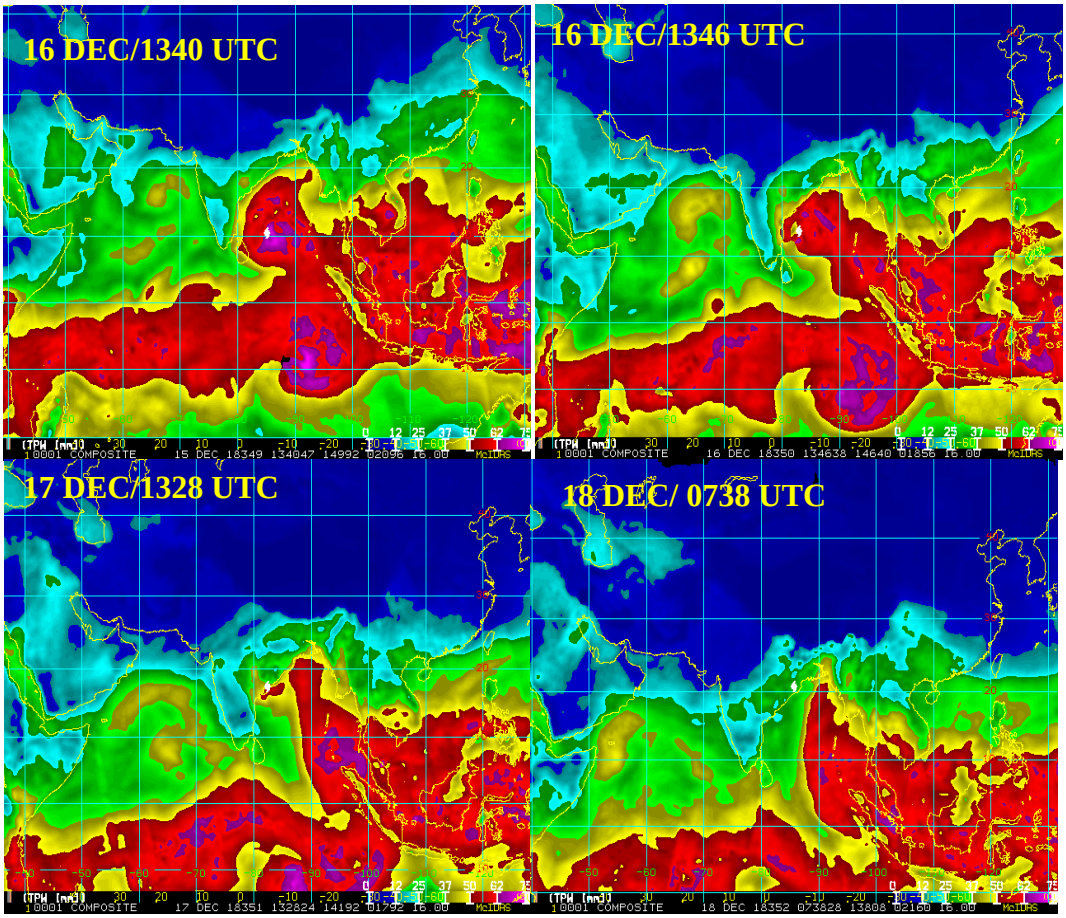


Fig. 2: Total Precipitable Water (TPW) imageries during 13-18 December, 2018

The wind speed in middle and deep layer around the system centre is presented in **Fig.3**. The wind shear around the system between 200 & 850 hPa levels remained moderate (10-20 knots) till 0000 UTC of 17th December. Thereafter, it increased becoming high (20-30 knots) till dissipation as the system came under the combined influence of anticyclone over southeast Asia and a deep trough in upper tropospheric westerlies to the west of system centre. The direction of 200-850 hPa wind shear was northwesterly during the period. It caused the convective cloud mass to be sheared to the southeast of the system centre.

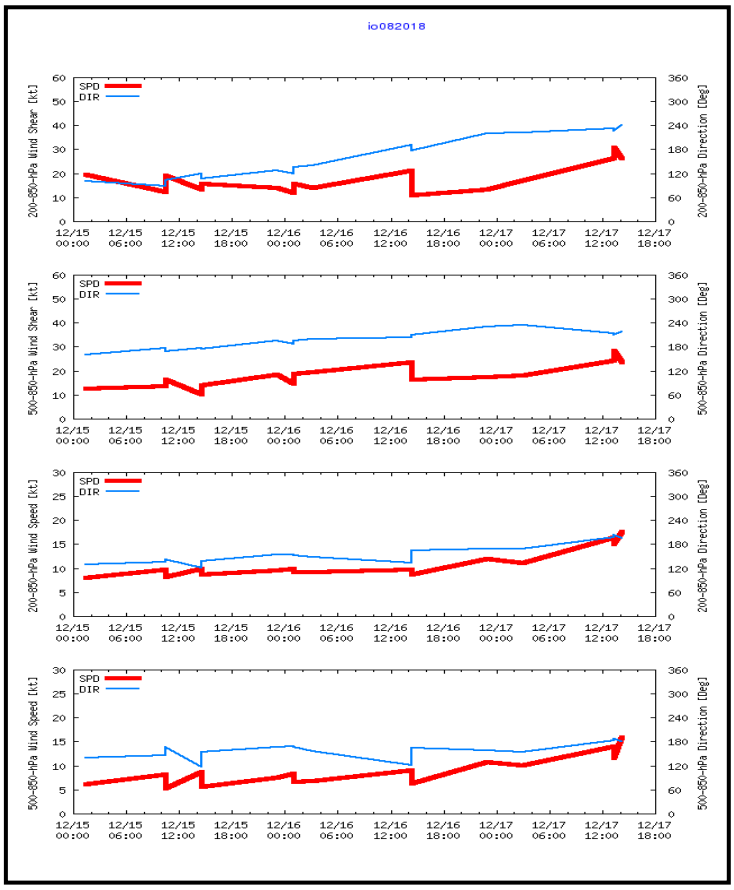


Fig.3 Wind shear and wind speed in the middle and deep layer around the system during 13-18 December 2018.

From **Fig.3**, it indicates that from the genesis stage, the mean deep layer winds between 200-850 hPa levels steered the system initially northwestwards till 00 UTC of 17th Dec and then northwards for 12 hours and then north-northeastwards. The twelve hourly movement of SCS Phethai is presented in **Fig.4**. The 6 hourly average translational speed of the cyclone was about 13.4 kmph and hence the cyclone was moving slower against the normal speed of 14.7 kmph..

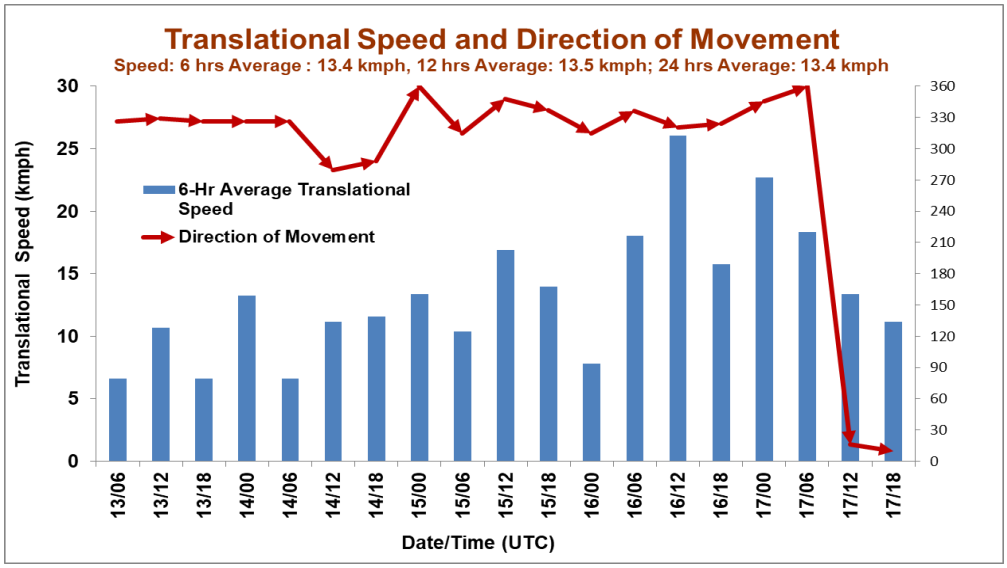


Fig.4 Six hourly average translational speed (kmph) and direction of movement in association with SCS Phethai

4.3 Maximum Sustained Surface Wind speed and estimated central pressure

The lowest estimated central pressure and the maximum sustained wind speed are presented in **Fig.5**. The lowest estimated central pressure had been 992 hPa during 1200-2100 UTC of 16th. The estimated maximum sustained surface wind speed (MSW) was 55 knots during the same period with pressure drop of 15 hPa.. At the time of landfall, the ECP was 997 hPa and MSW was 45 knots (cyclonic storm). During second landfall near Tuni the ECP was 1001 hPa and MSW was 30 knots (Deep Depression).

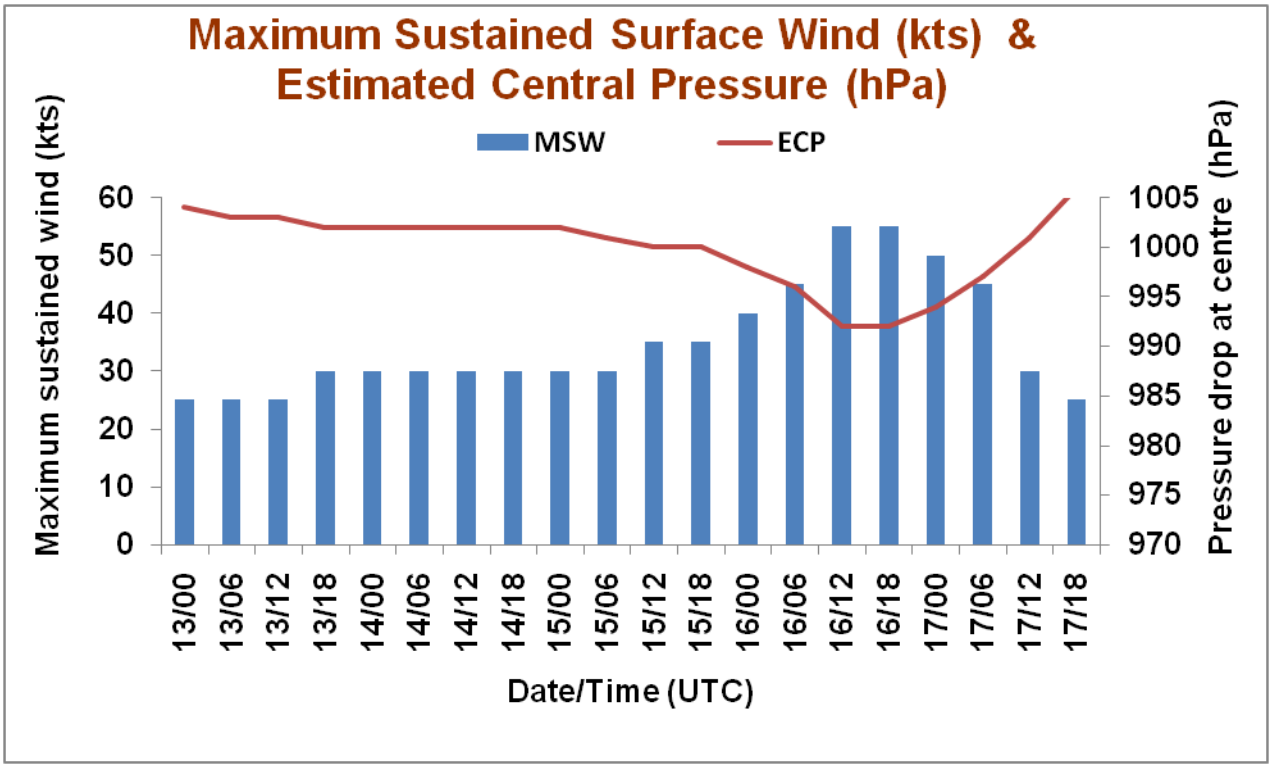


Fig.5. Lowest estimated central pressure and the maximum sustained wind speed

5. Monitoring

5. 1. Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D and 3DR imageries. Satellite imageries of international geostationary satellites Meteosat-8 & MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.6**. The system showed curved band pattern during genesis and groth stage upto the intensity of CS. It has central dense overcast (CDO) pattern during SCS stage. It showed sheared pattern after landfall .

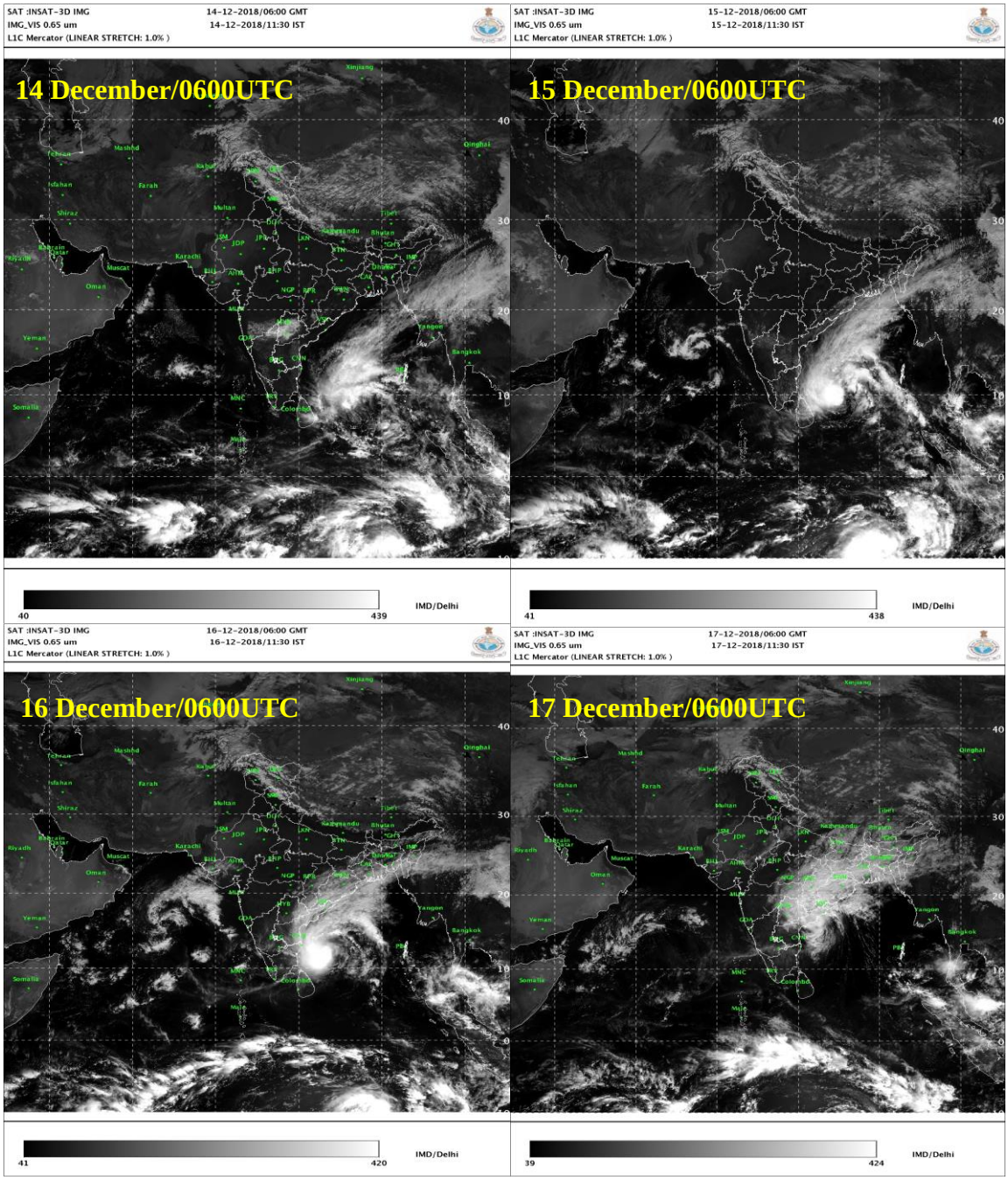


Fig. 6a: INSAT-3D visible imageries during life cycle of SCS PHETHAI (13-18 December, 2018

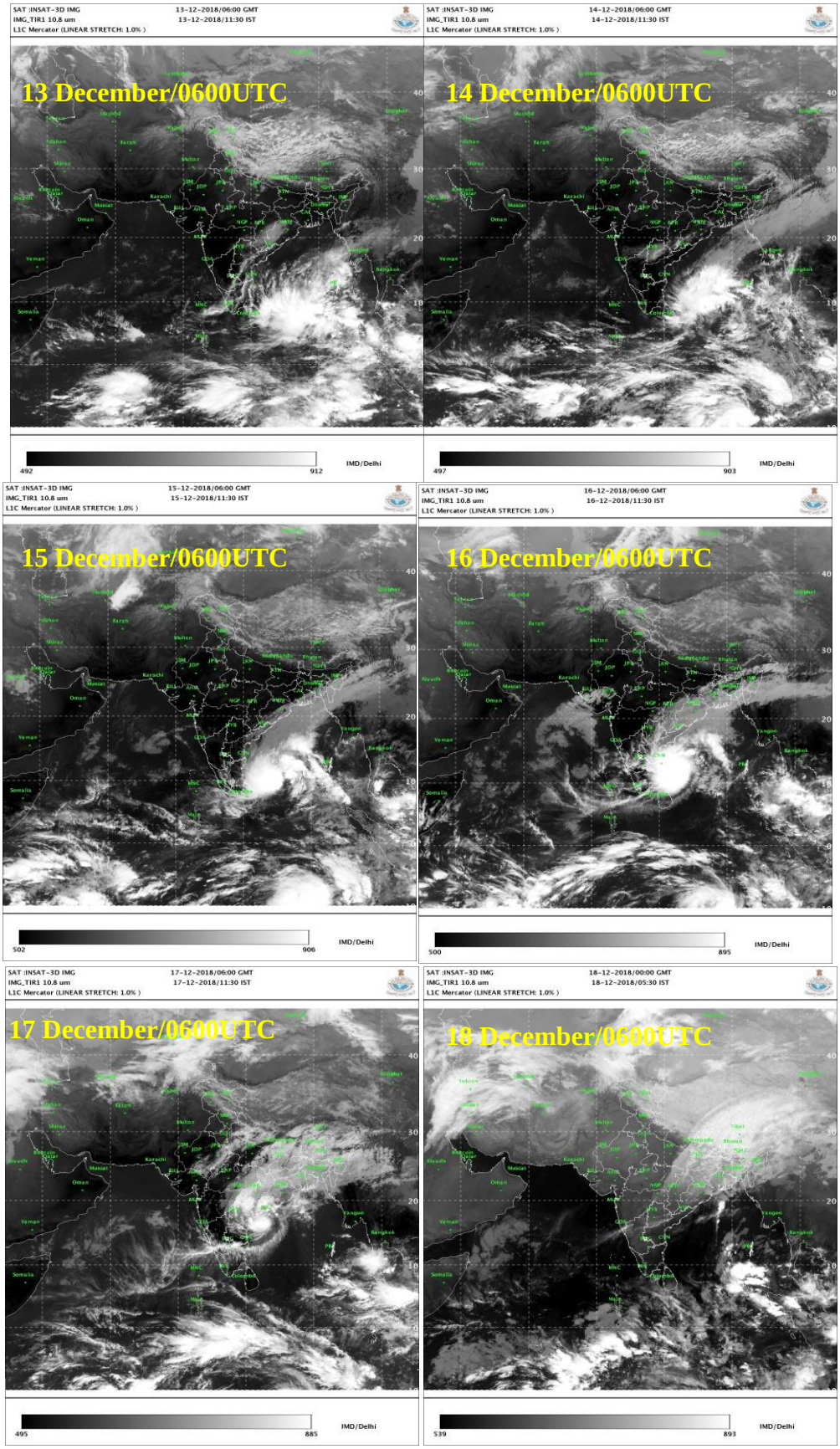


Fig. 6b: INSAT-3D IR imageries during life cycle of SCS PHETHAI (13-18 December, 2018)

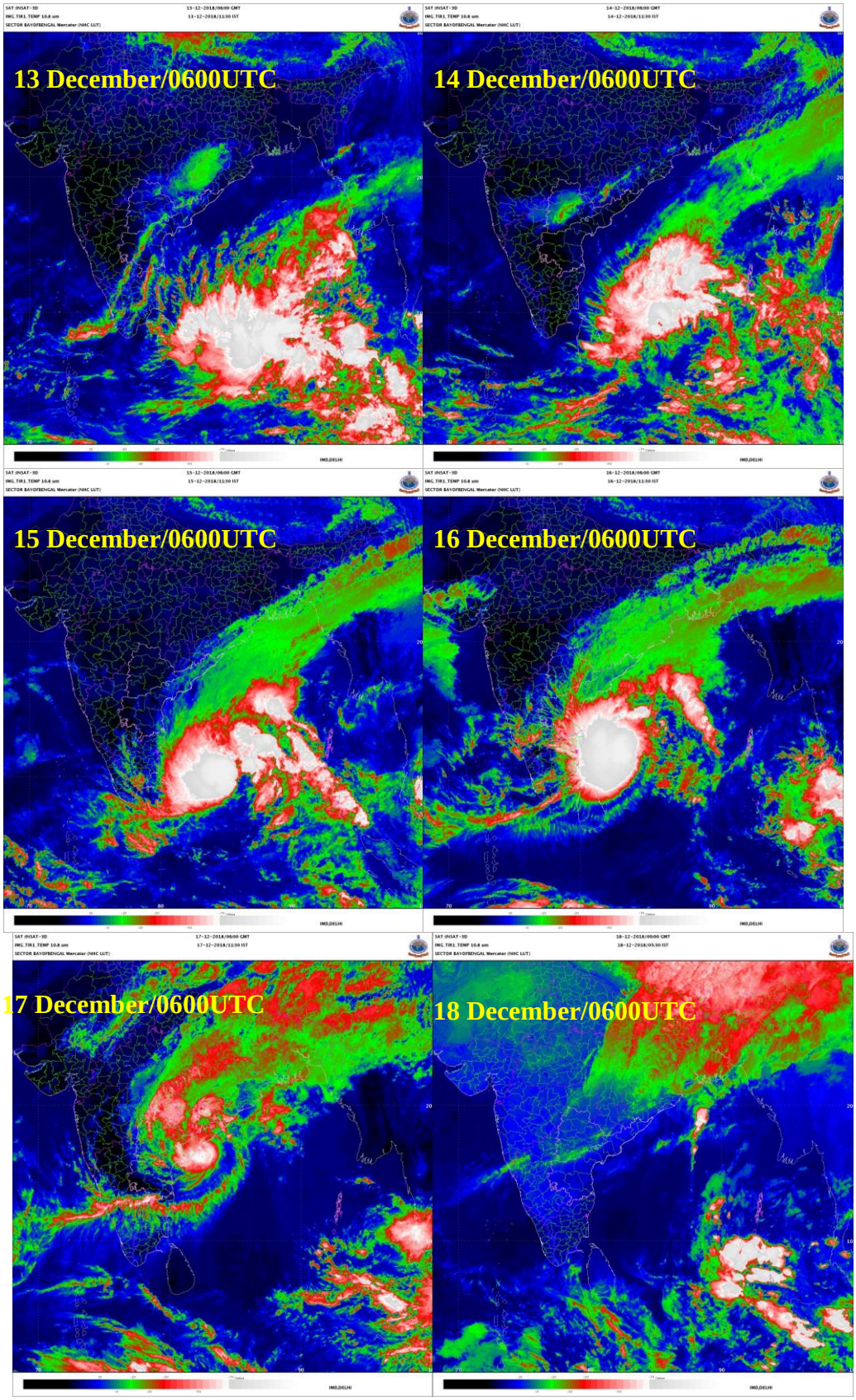


Fig. 6c: INSAT-3D enhanced colored imageries during life cycle of CS DAYE (19-22 September, 2018)

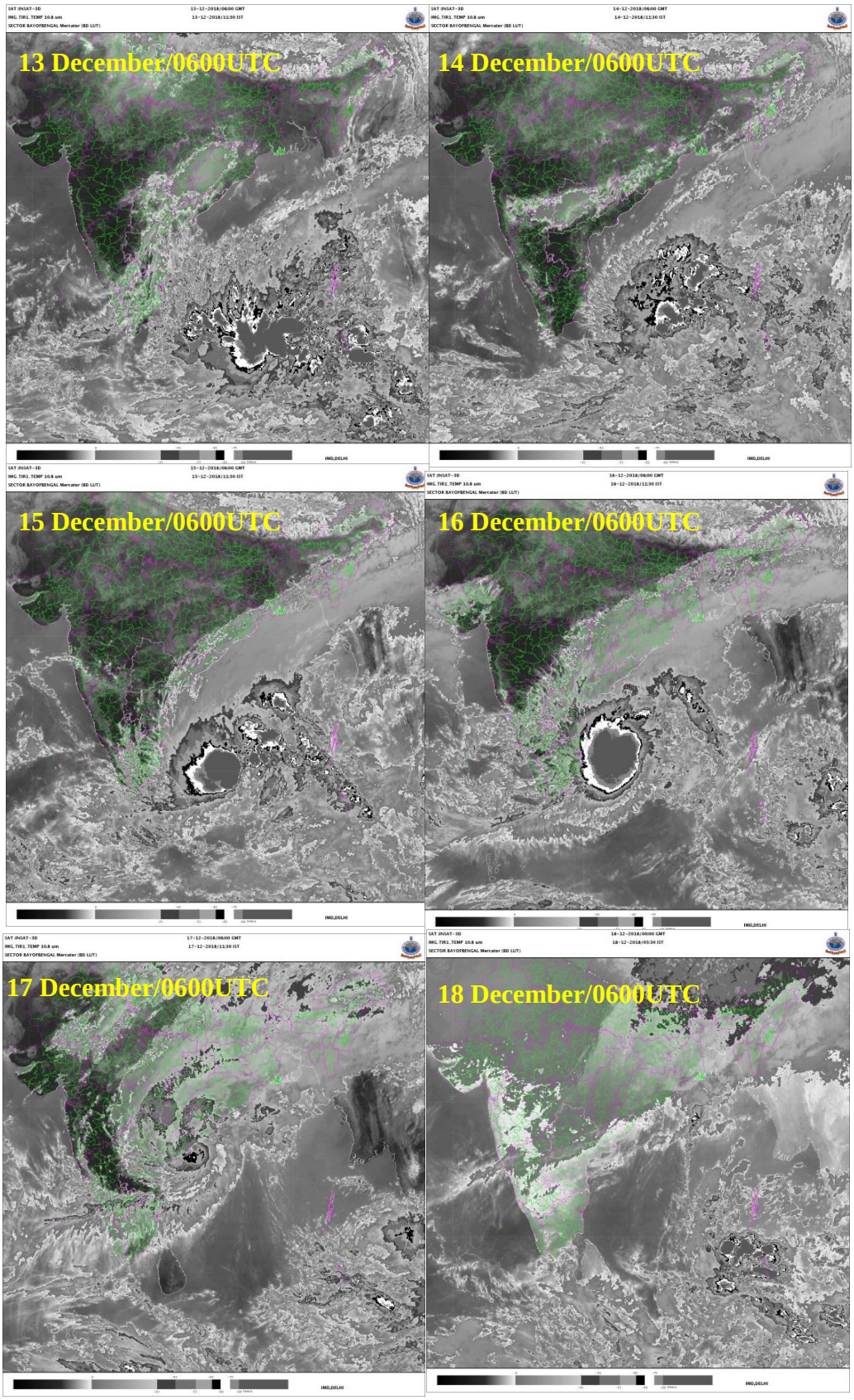


Fig. 6d: INSAT-3D cloud top brightness imageries during life cycle of SCS PHETHAI (13-18 December, 2018

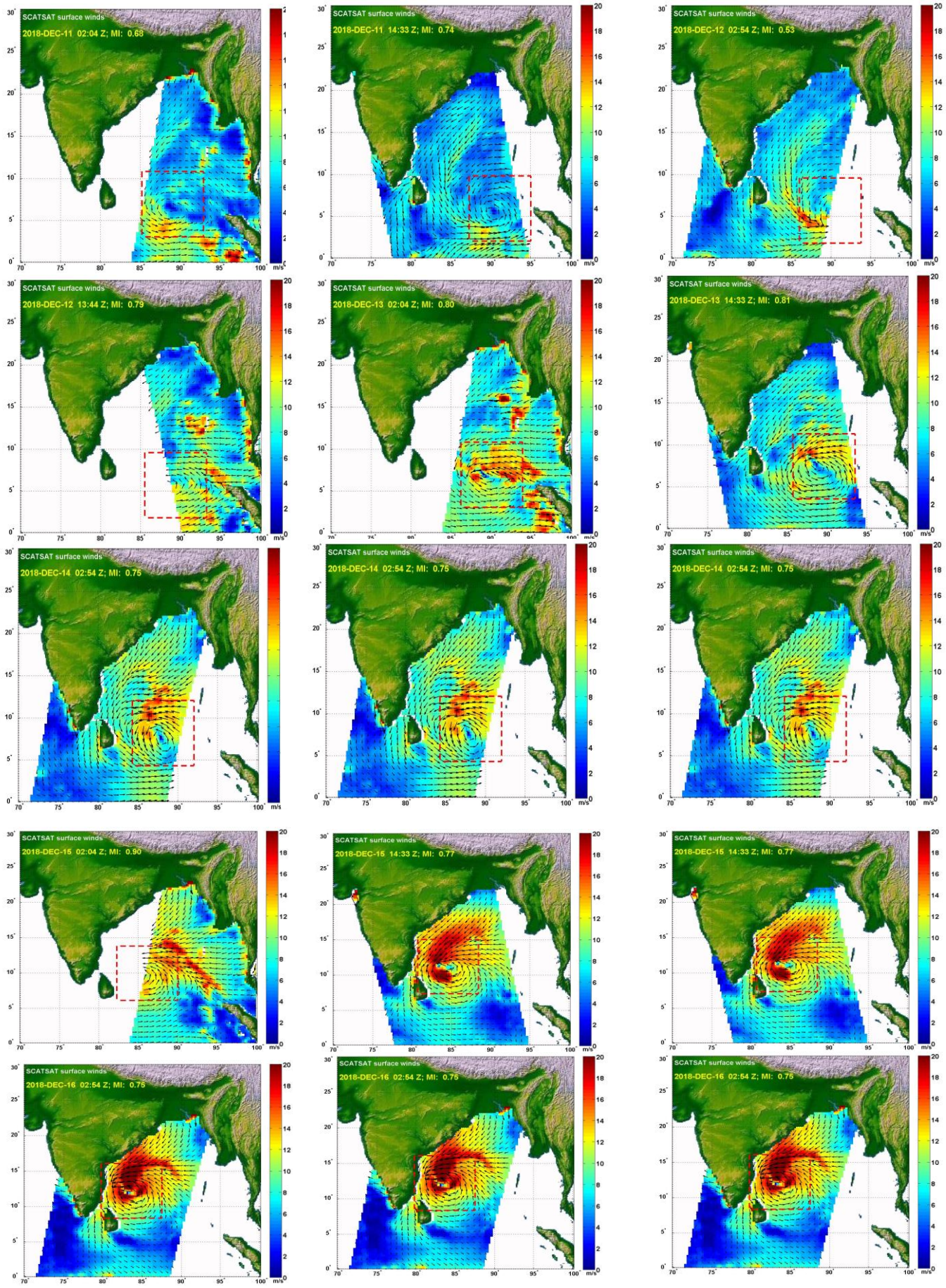


Fig. 6e: SCATSAT imageries during life cycle of SCS PHETHAI (13-18 December, 2018

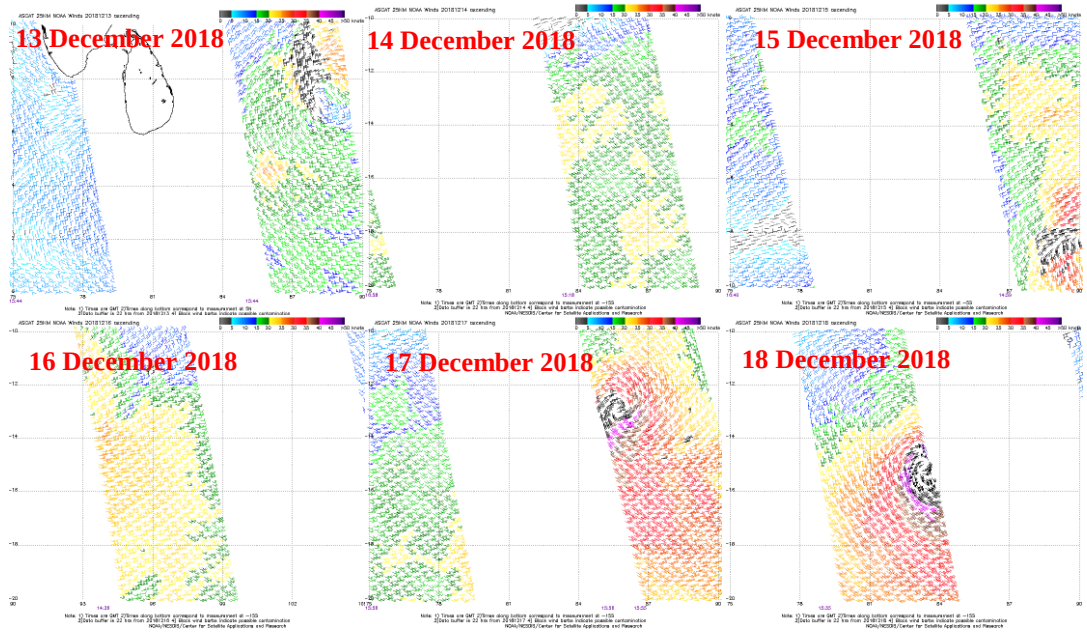


Fig. 6f: ASCAT imageries during life cycle of SCS PHETHAI (13-18 December, 2018

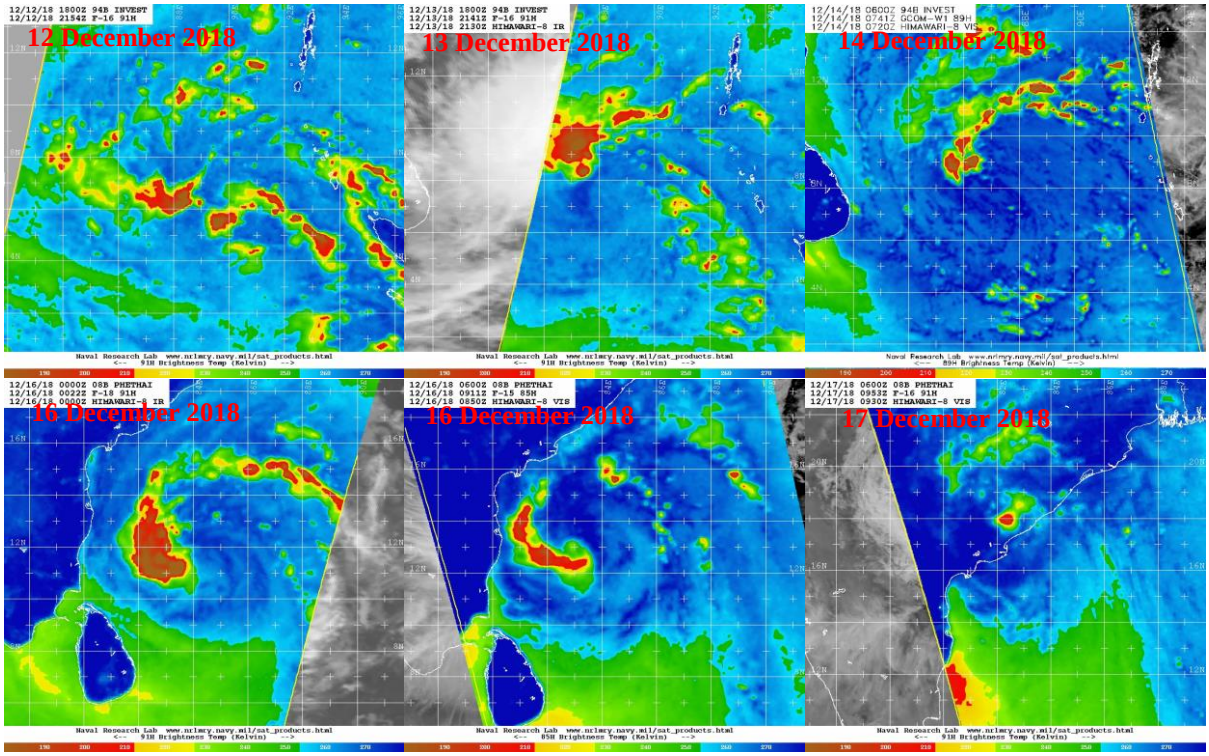


Fig. 6g: Microwave imageries during life cycle of SCS PHETHAI (13-18 December, 2018

5.2. Features observed through Radar

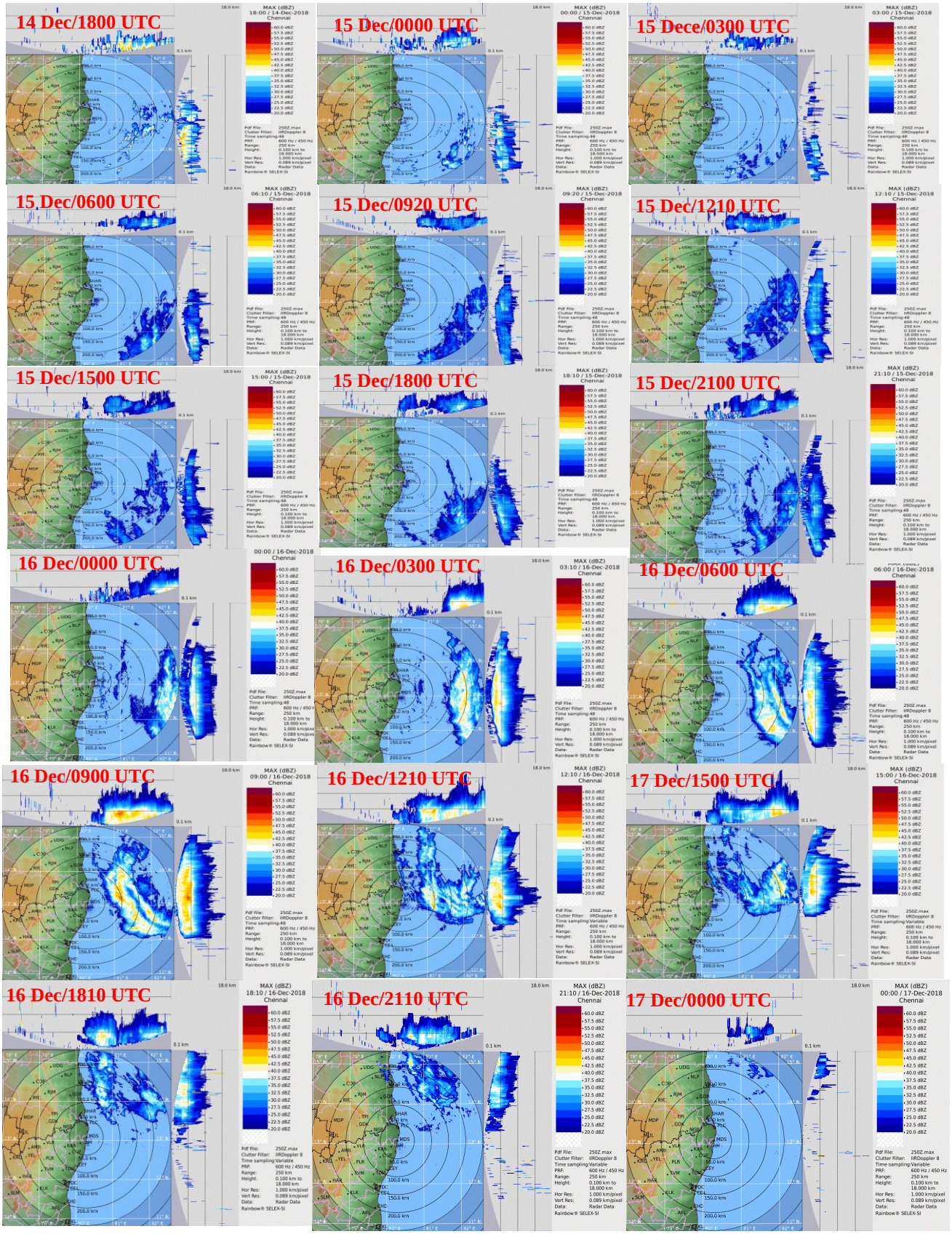


Fig.7(i): Typical Radar imagery MAX-Z from DWR Chennai From 13-18 Dec

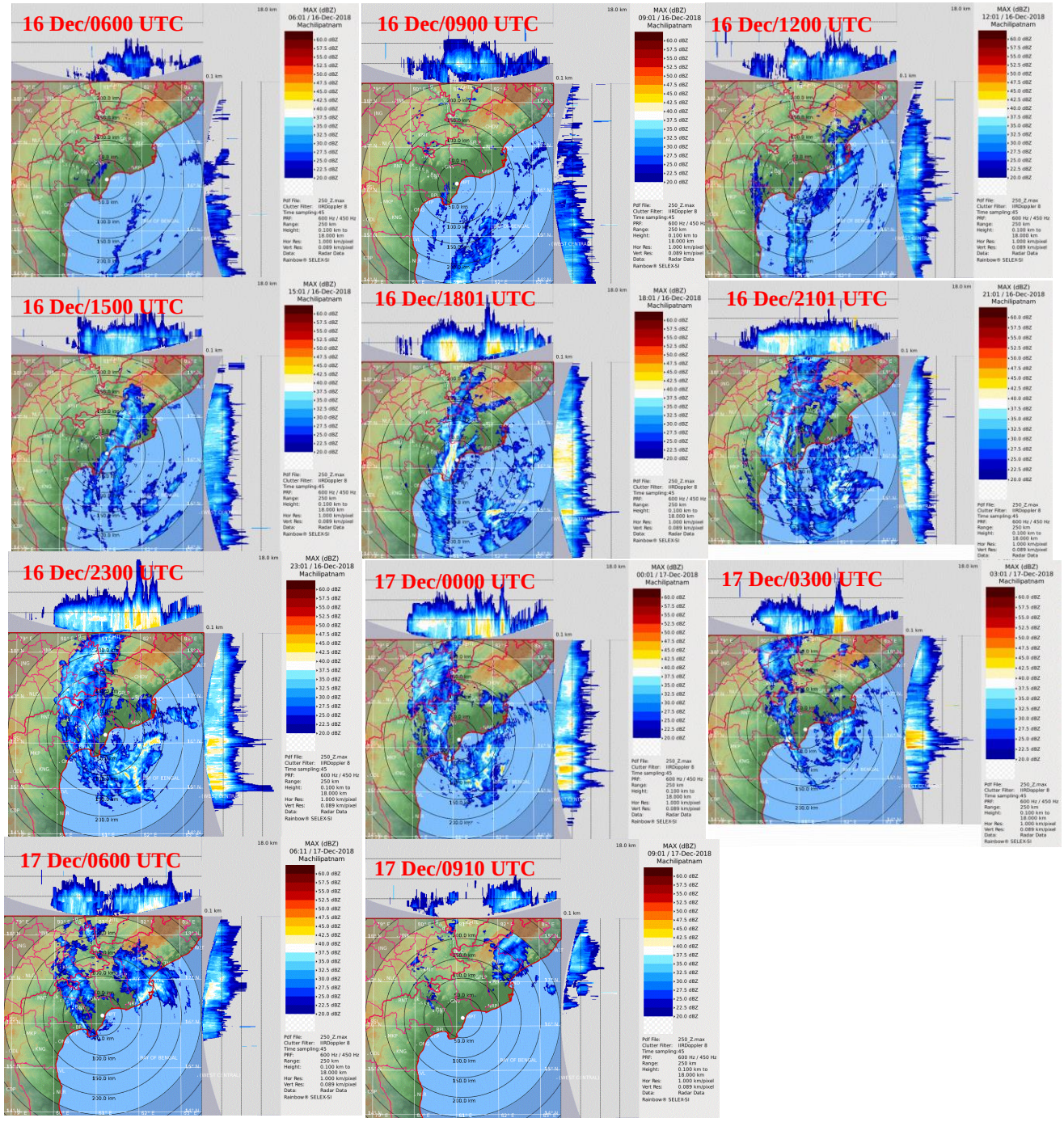


Fig.7(ii): Typical Radar imagery MAX-Z from DWR Machilipatnam From 13-18 Dec

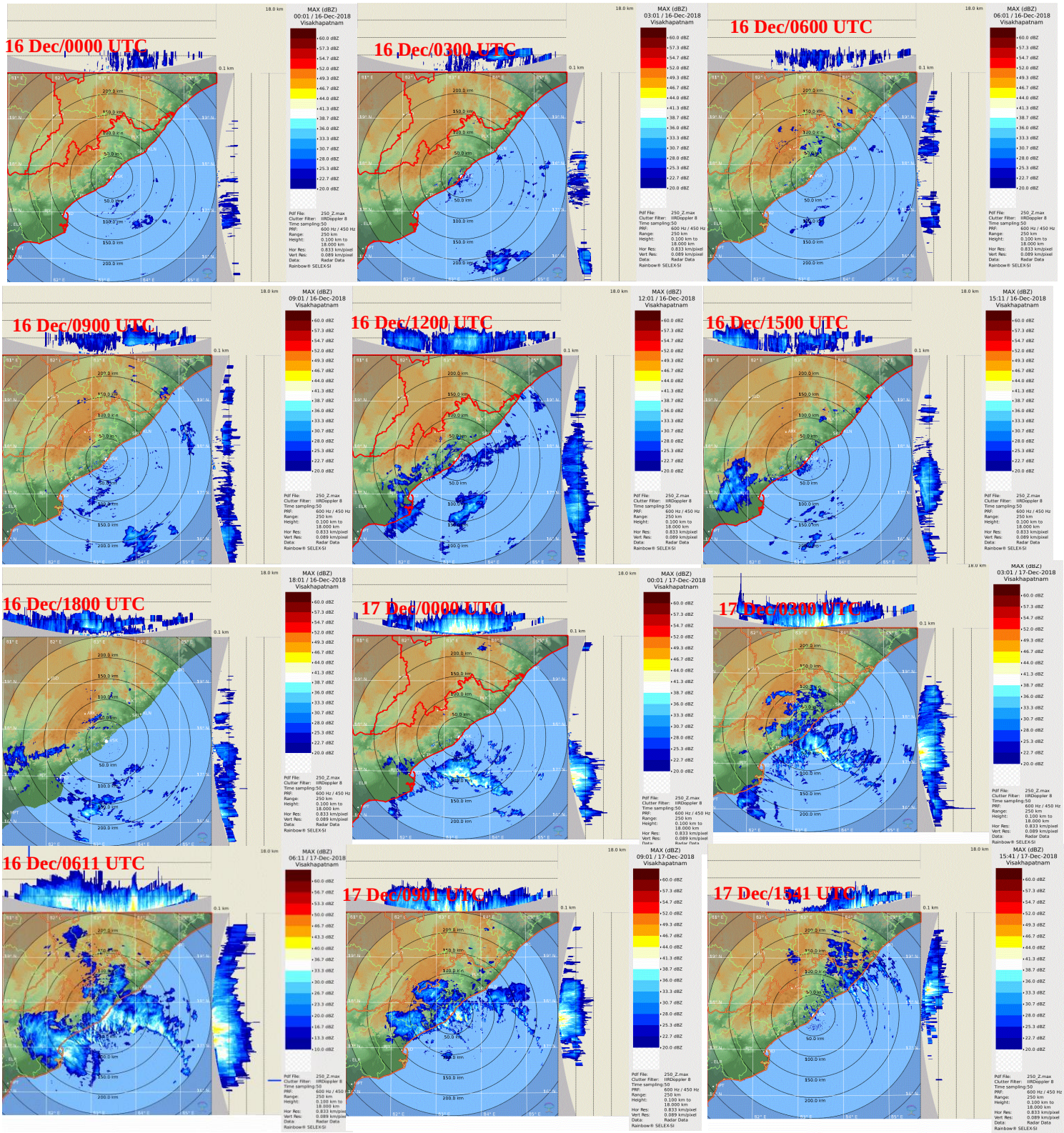


Fig.7(iii): Typical Radar imagery MAX-Z from DWR Vishakapatnam From 13-18 Dec

6. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 19th-18th December are presented in Fig.8. GFS (T1534). Analysis based on 0000 UTC of 13th to 18th December, indicates that the model could detect the genesis of the low pressure system and its track towards north Andhra Pradesh Coast. It could also detect the gradual intensification upto SCS and its weakening after the landfall.

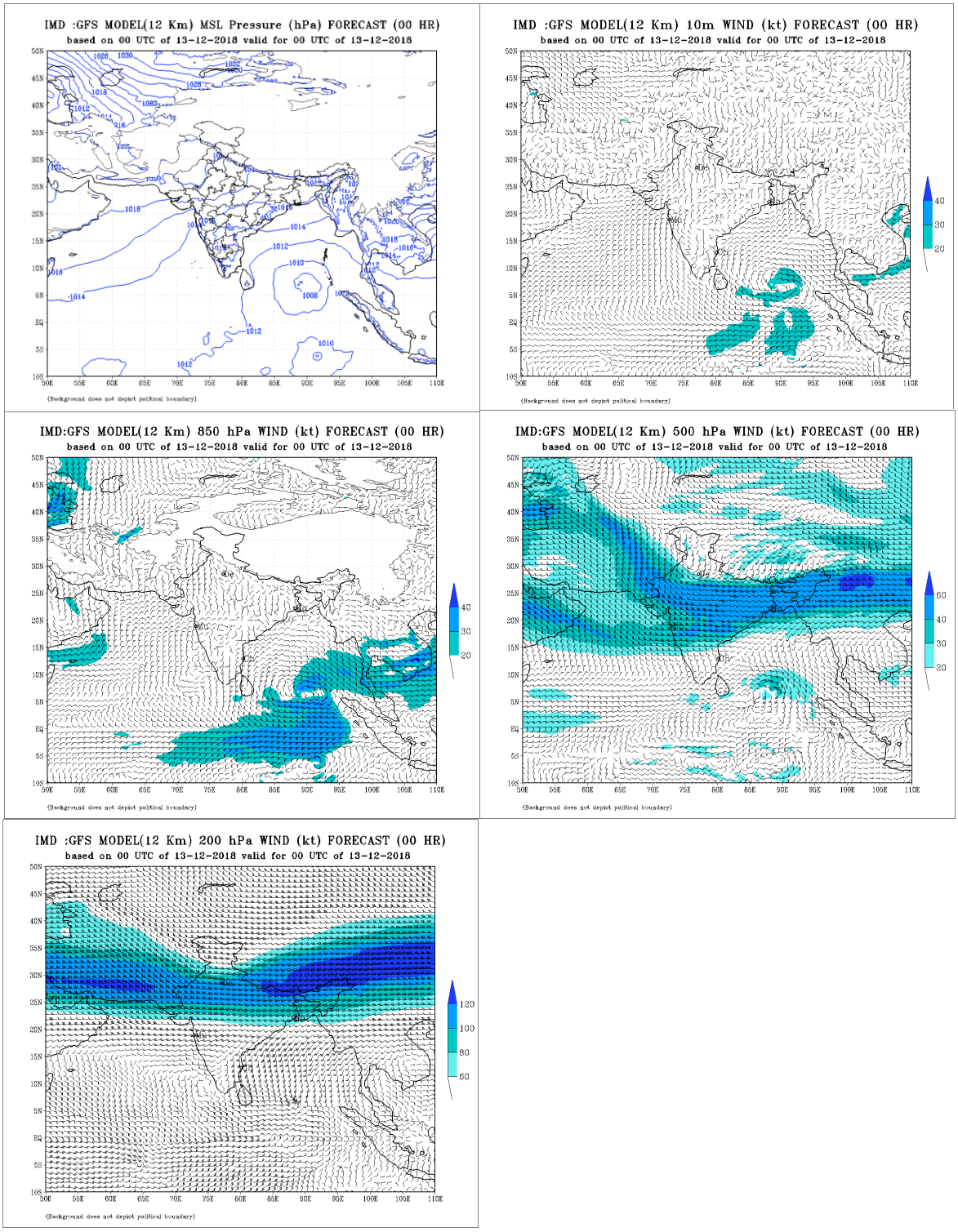


Fig. 8(a): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 13th December 2018

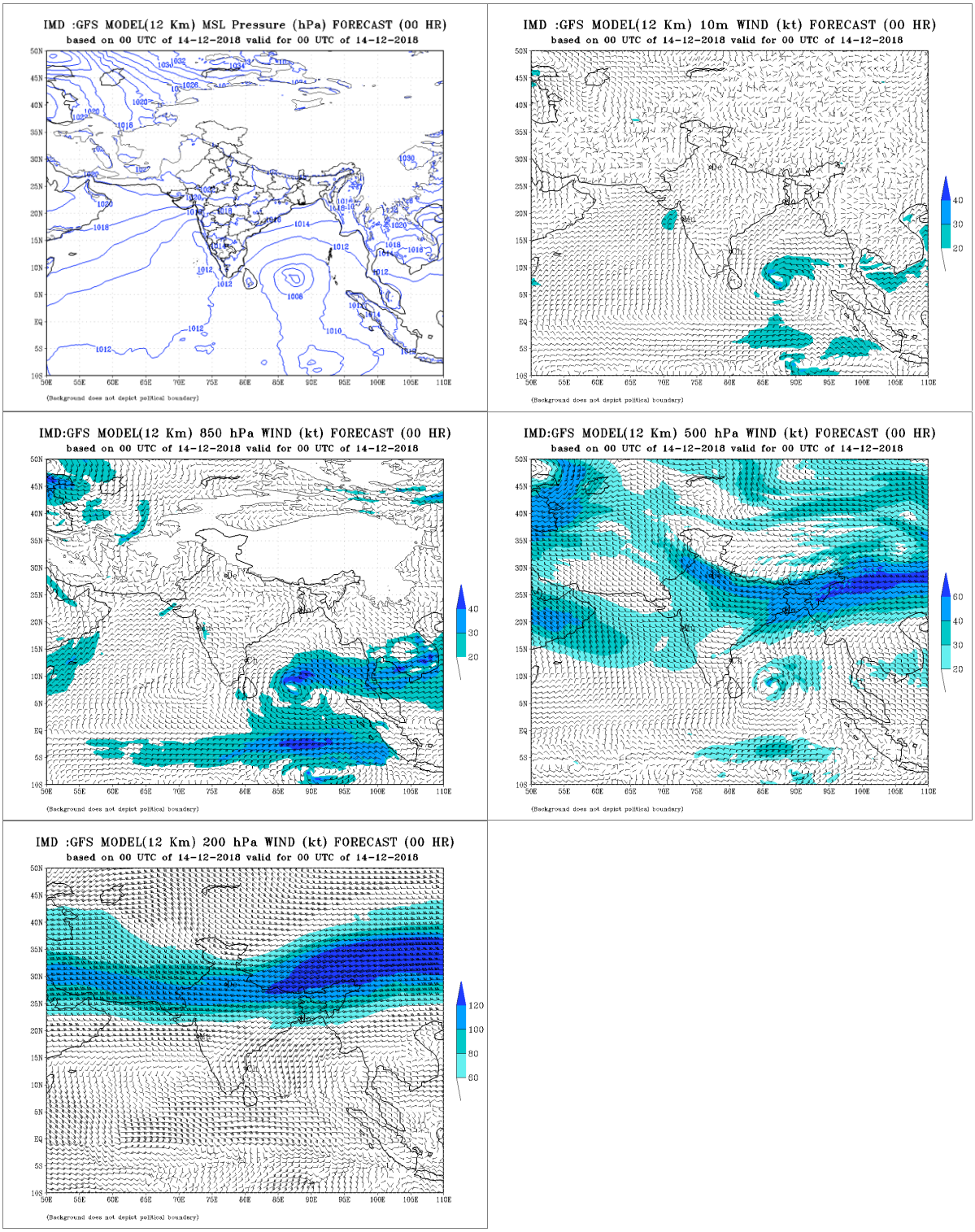


Fig. 8(b): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 14th December 2018

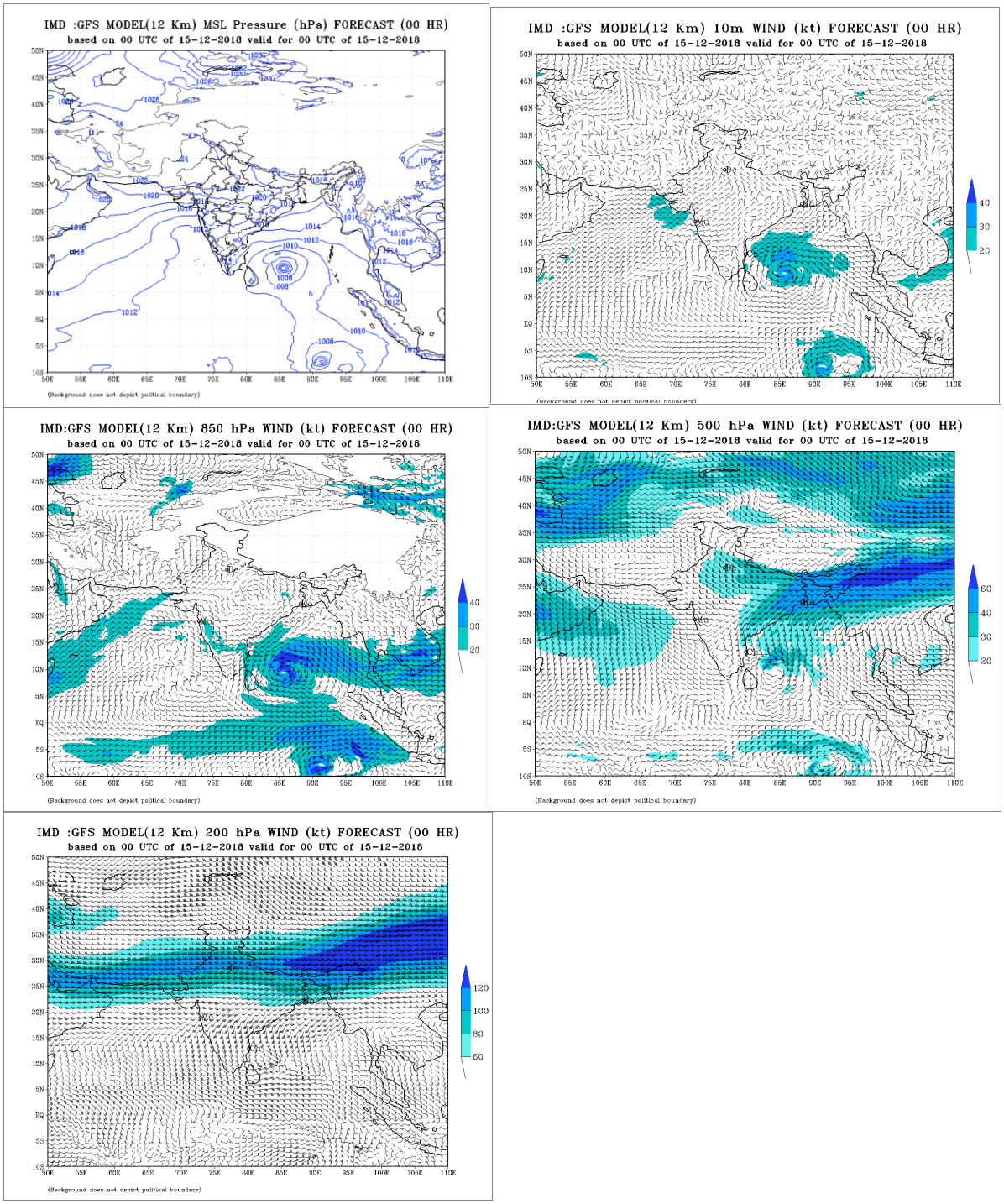


Fig. 8(c): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 15th December 2018

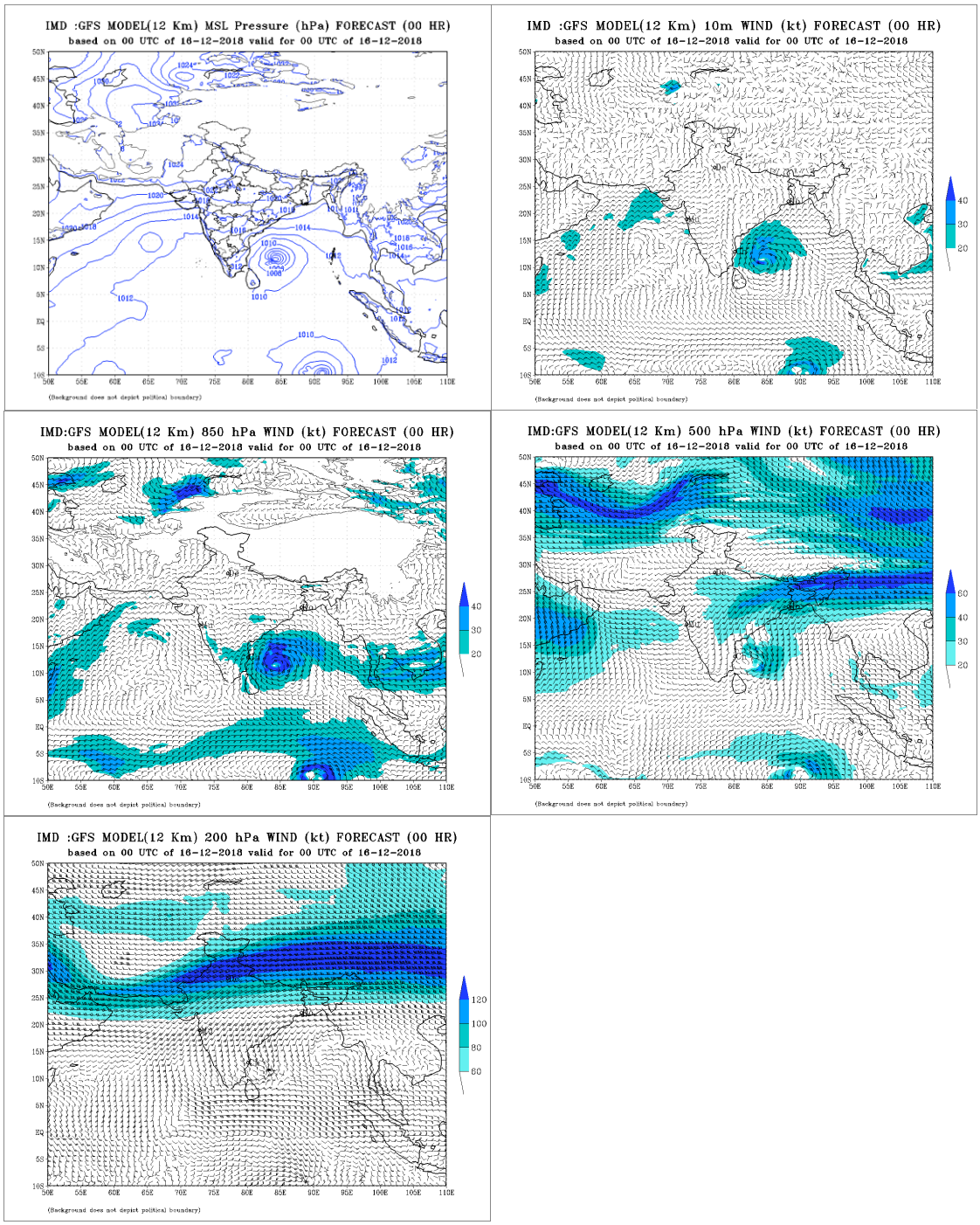


Fig. 8(d): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 16th December 2018

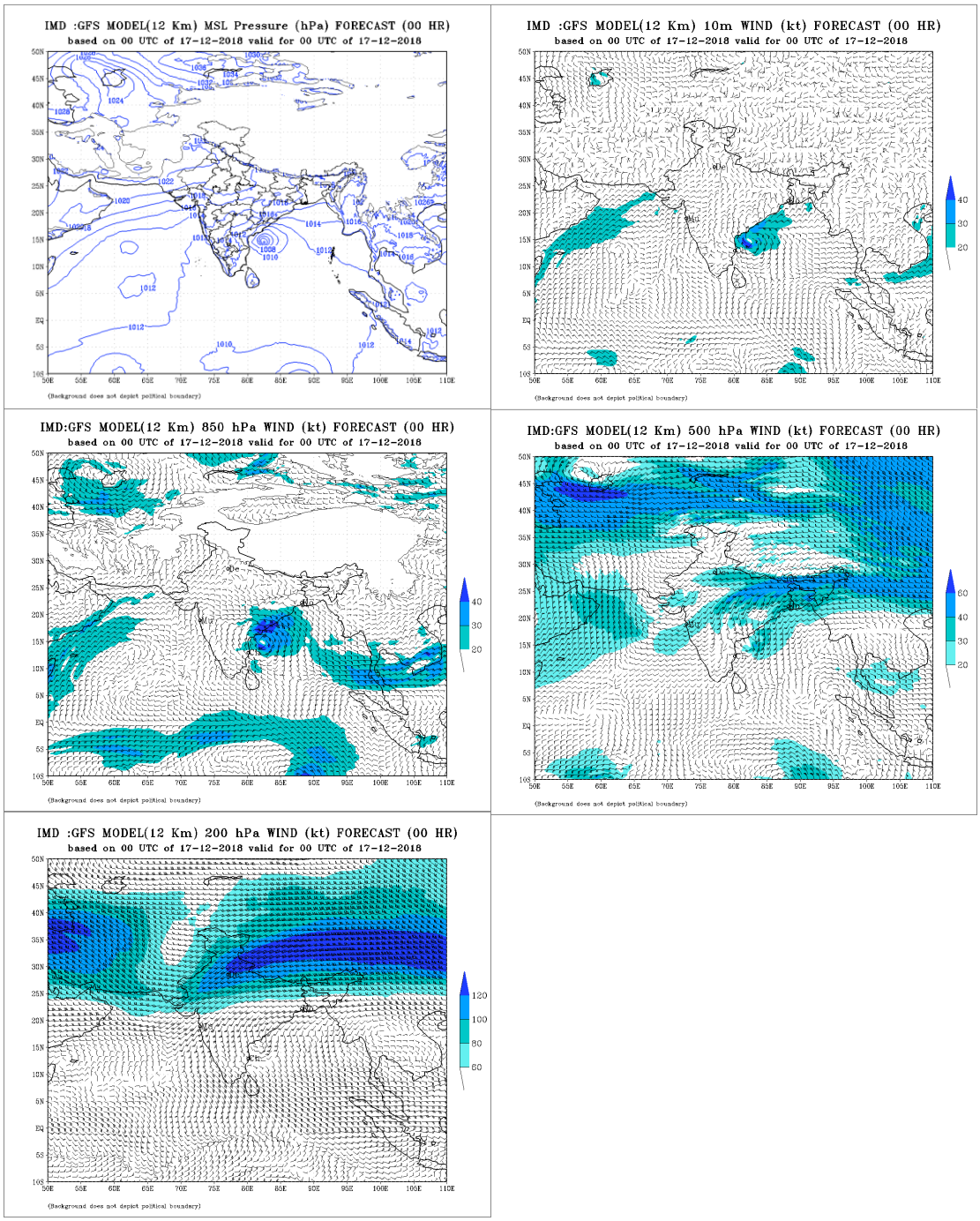


Fig. 8(e): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 17th December 2018

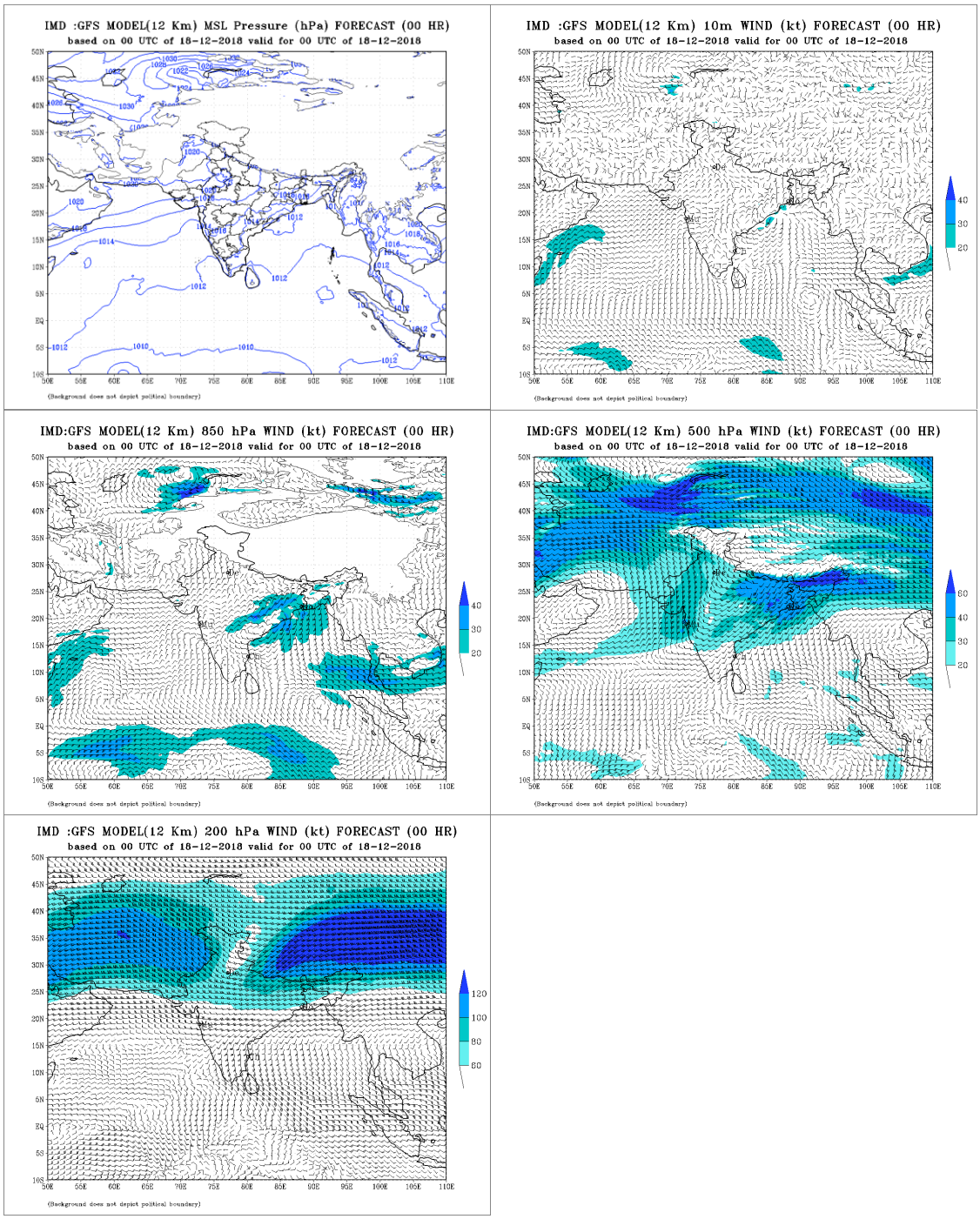


Fig. 8(f): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 18th December 2018

7. Realized Weather:

Rainfall associated with SCS Phethai based on IMD-NCMRWF GPM merged gauge rainfall data is depicted in **Fig 9**.

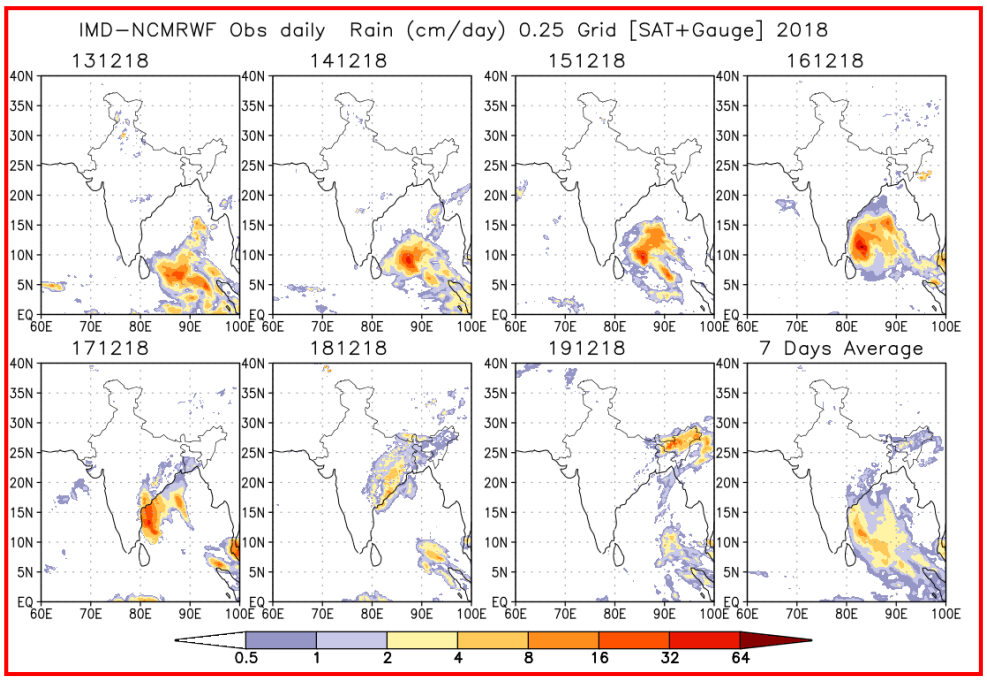


Fig.9: IMD-NCMRWF merged satellite and rain gauge observed rainfall (cm/day) during 13-18 December in association with SCS PHETHAI.

It indicates that the system caused rainfall at most places with heavy to very rainfall at isolated places over central parts of south BoB during 13th-15th, over southwest BoB on 16th and over coastal Andhra Pradesh on 17th. On 18th, low to moderate rainfall activity was observed over coastal Andhra Pradesh and adjoining Odisha.

Heavy to very heavy rainfall occurred at isolated places over north coastal Andhra Pradesh and heavy rainfall at isolated places over Telangana in past 24 hours ending at 0830 hours IST of 17th December. Heavy to very heavy rainfall occurred at a few places over north coastal Andhra Pradesh and heavy rainfall at a few places over Odisha & isolated places over Jharkhand in past 24 hours ending at 0830 hours IST of 18th December.

Realized 24 hrs accumulated rainfall (≥7cm) ending at 0830 hrs IST of date during the life cycle of the system is presented below:

17 December 2018

Coastal Andhra Pradesh: Vijayawada-13, Gudivada-10, Nuzvid, Avanigada & Vijayawada-9 each, Eluru-8 and Kaikalur, Chintalapudi, Repalle, Amalapuram & Tenali-7 each

Telangana: Aswaraopeta, Sathupalle & Aswaraopet-9 each, Mulakalapalle, Chandrugonda & Enkuru-8 each and Kothagudem, Julurpad, Manuguru, Palawancha & Burgampadu-7 each

18 December 2018

Coastal Andhra Pradesh: Ninnimamidivalasa-19, Ananthagiri-14, Pachipenta-18, Pachipenta-15, Kantakapalle-14, Araku Valley-13, Salur-13, Amalapuram-12, Bheemunipatnam-12, Visakhapatnam-11, Mentada-11, Bondapalle-11, Ranastalam-11, Gajapathinagaram, Kalingapatnam-10, Cheepurupalle, Merakamudidam, Therlam, Nellimarla, Garividi, Bobbili-9, Vizianagaram, Chodavaram-8, Pusapatirega, Seethanagaram, Kakinada, Gantyada, Chintapalle, Parvathipuram, Balajipeta, Paderu, Tuni, Garugubilli, Srungavarapukota-7 each

Odisha: Gurundia, Padampur, Kirmira -10, Bolangir, Lahunipara, Tensa, Nuagada, Banaigarh, Bamra, Rajgangpur & Jamankira-9 each, Deogaon, Kuchinda, Burla, Hirakud,

Jhumpura, Joda, G Udayagiri, Reamal, Ambabhona, Pottangi, Lakhanpur, Binika, Bargarh, Panposh, Barpalli, Jharsuguda, Paikmal, Batli & Champua-8 each and Laikera, Sambalpur, Gaisilet, Ullunda, Paralakhemundi, Dunguripalli, Deogarh, Keonjhargarh, Rairakhol, Sonepur, Hemgiri, Bijepur, Atabira & Lanjigarh-7 each
Jharkhand: Jamshedpur-9 and Chakradharpur & Chaibasa-7 each

7.2. Wind

Maximum sustained wind of 70-80 kmph gusting to 90 kmph were reported at the time of landfall.

8. Damage due to SCS, Phethai

Damage over Andhra Pradesh

As per media reports, over 10.3 lakh hectares of agricultural crop, 10,000 hectares of horticulture crops and 12,000 mobile towers were damaged in Andhra Pradesh (The News Minute, 19th Dec). East and West Godavari were worst hit. One farmer reportedly died of shock seeing damaged crops. 8 persons reportedly died Some damage photographs are presented below:

Fig.10(i):Exposed roots of uprooted trees in coastal Andhra Pradesh

Fig.10(ii):Uprooted mobile towers in coastal AP (India

Fig.10(iii): Flooded farm lands in coastal AP (The News Minute)

Fig.10(iv):Farmer died of shock seeing damaged crops

Fig.10(v) : NDRF Team on rescue and road clearing operation (Kanak News)

9. Performance of operational NWP models

IMD operationally runs a regional models, WRF for short-range prediction and one Global model T1534 for medium range prediction (10 days). The WRF-VAR model is run at the horizontal resolution of 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. 25^0S to 45^0 N long 40^0 E to 120^0 E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 12 km. The boundary conditions are updated at every six hours interval.

Global models are also run at NCMRWF. These include GFS and unified model adapted from UK Meteorological Office. In addition to the above NWP models, IMD also run operationally dynamical statistical models. The dynamical statistical models have been developed for (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decay in intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis (T3.0) and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, GFS (NCEP), ECMWF and JMA. The SCIP model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). Decay model is used for prediction of intensity after landfall. The performance of the individual models, MME forecasts, SCIP, GPP, RII for SCS Phethai are presented and discussed in following sections.

9.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for PHETHAI

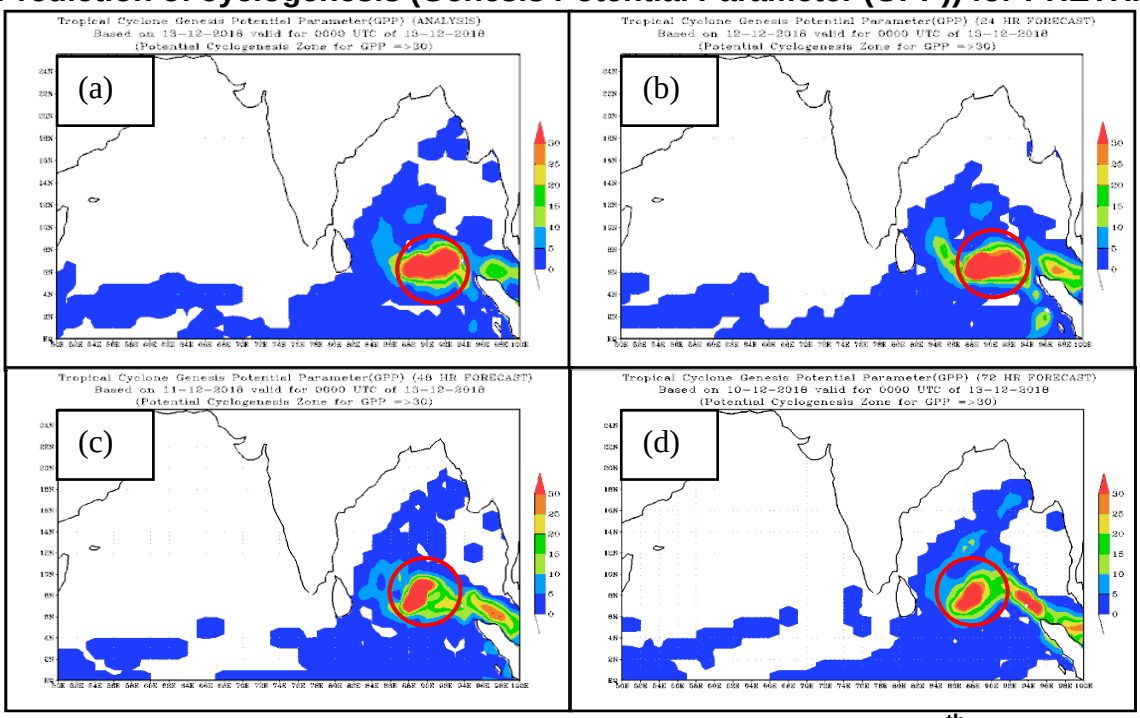


Fig.11 (a-d): Predicted zone of cyclogenesis for 0000 UTC of 13th based on 0000 UTC of 10–13th December 2018

Fig. 11 (a-d) indicates that the GPP could predict the potential zone for cyclogenesis on 13th over central parts of south BoB and adjoining EIO correctly about 96 hours in advance.

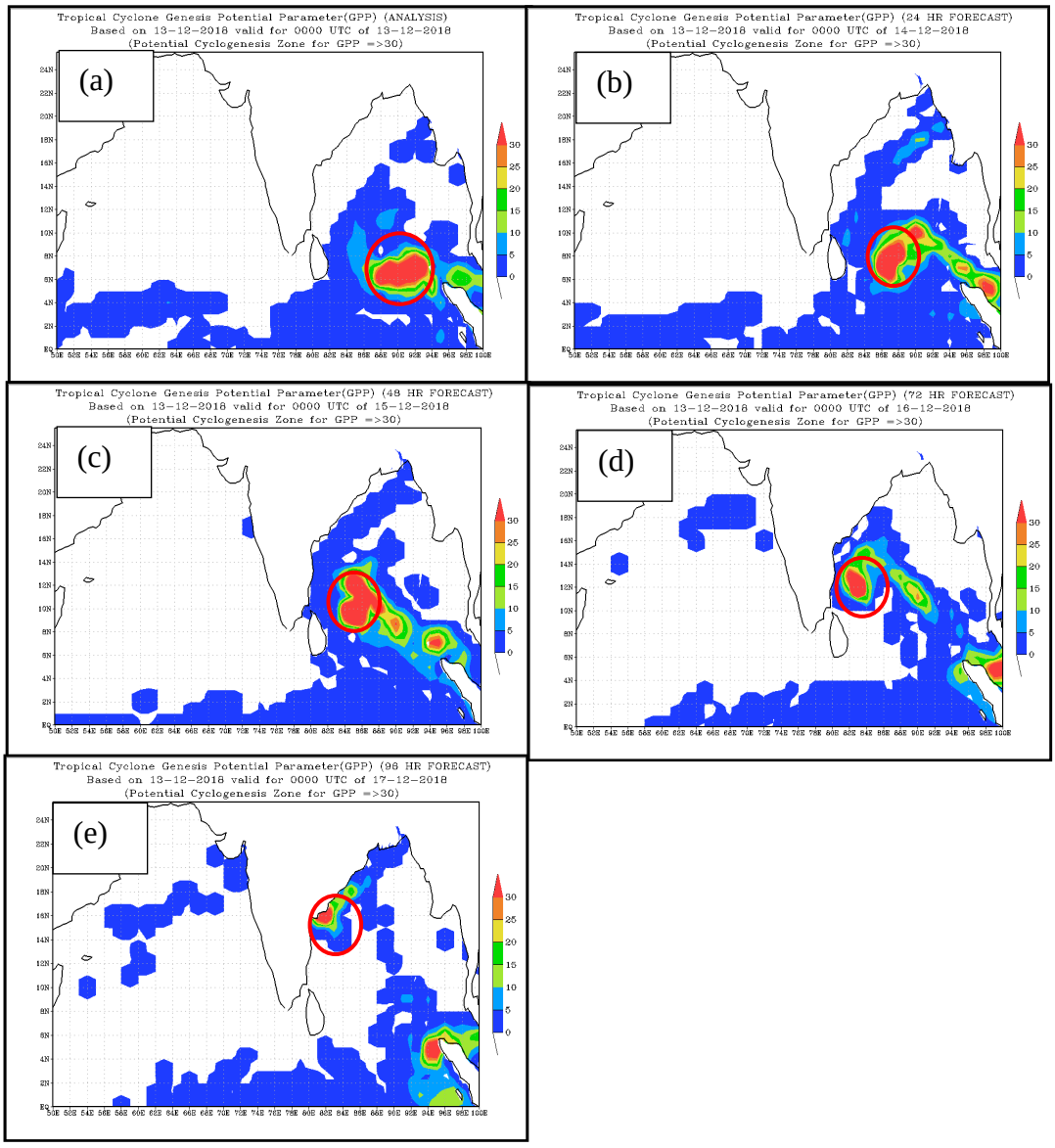


Fig.12 (a-e): Predicted zone of cyclogenesis based on 0000 UTC of 13 December 2018 (at stage Depression) for 0000 UTC of 13th-17th December

The model could predict cyclogenesis zone correctly about 72 hrs in advance. Since all low pressure systems do not intensify into cyclones, it is important to identify the potential of intensification (into cyclone) of a low pressure system at the early stages (T No. 1.0, 1.5, 2.0) of development. Conditions for (i) Developed system: Threshold value of average GPP ≥ 8.0 and (ii) Non-developed system: Threshold value of GPP < 8.0.It also indicated potential for intensification of the system into a Cyclonic storm based on initial condition of 00 UTC of 11th Dec onwards. Fig. 13 shows area average analysis of GPP.

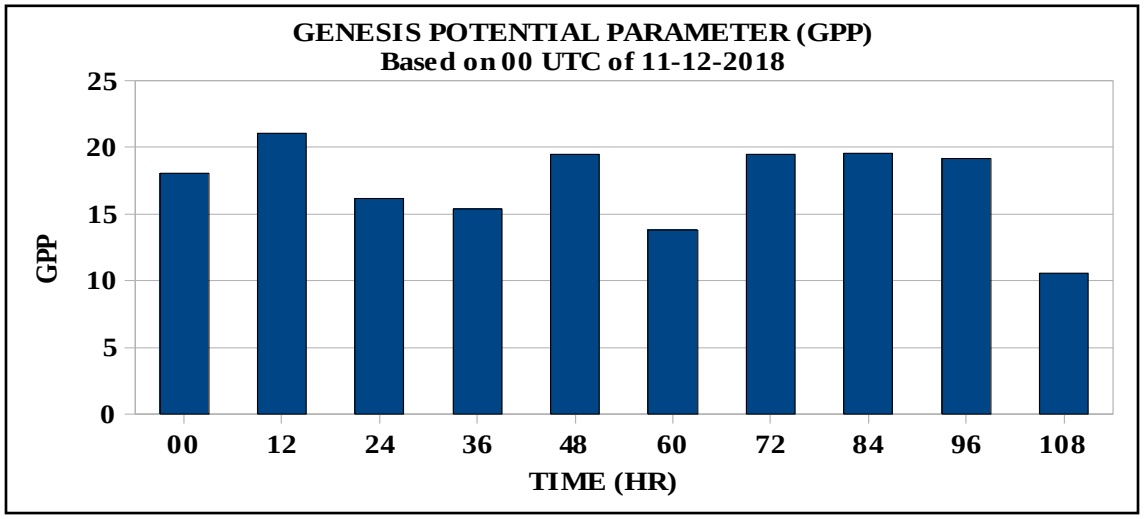


Fig.13(i) Area average analysis and forecasts of GPP based on 0000 UTC of 11.12.2018

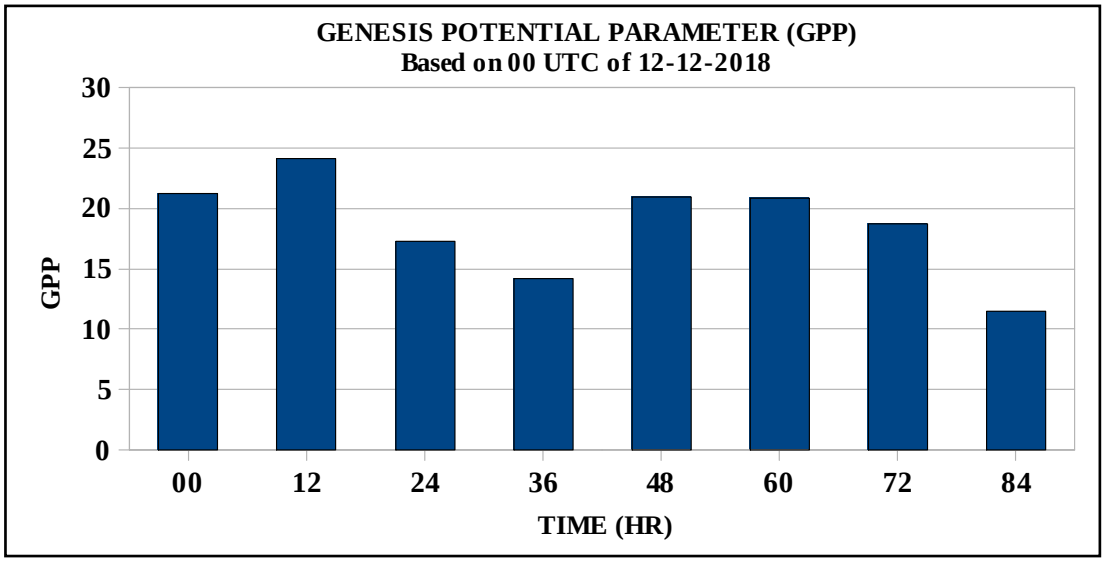


Fig.13(ii) Area average analysis and forecasts of GPP based on 0000 UTC of 12.12.2018

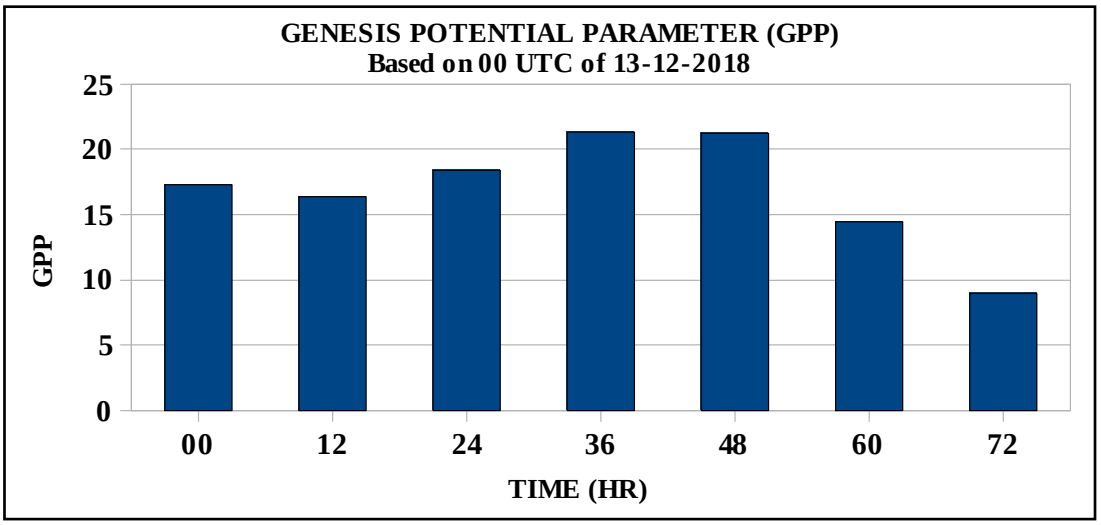


Fig13(iii) Area average analysis and forecasts of GPP based on 0000 UTC of 13.12.2018

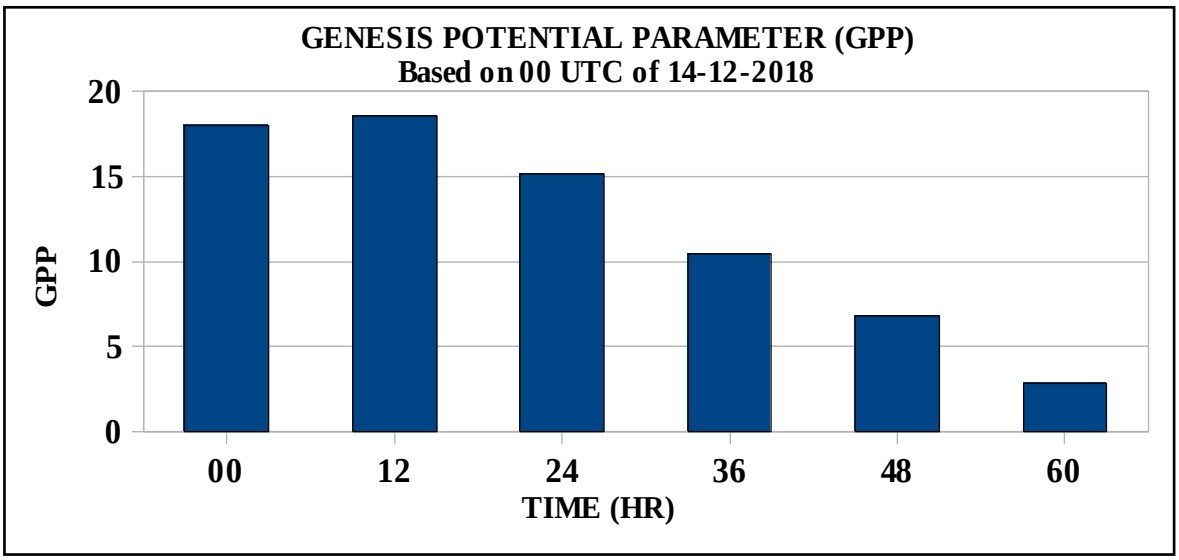


Fig.13(iv) Area average analysis and forecasts of GPP based on 0000 UTC of 14.12.2018

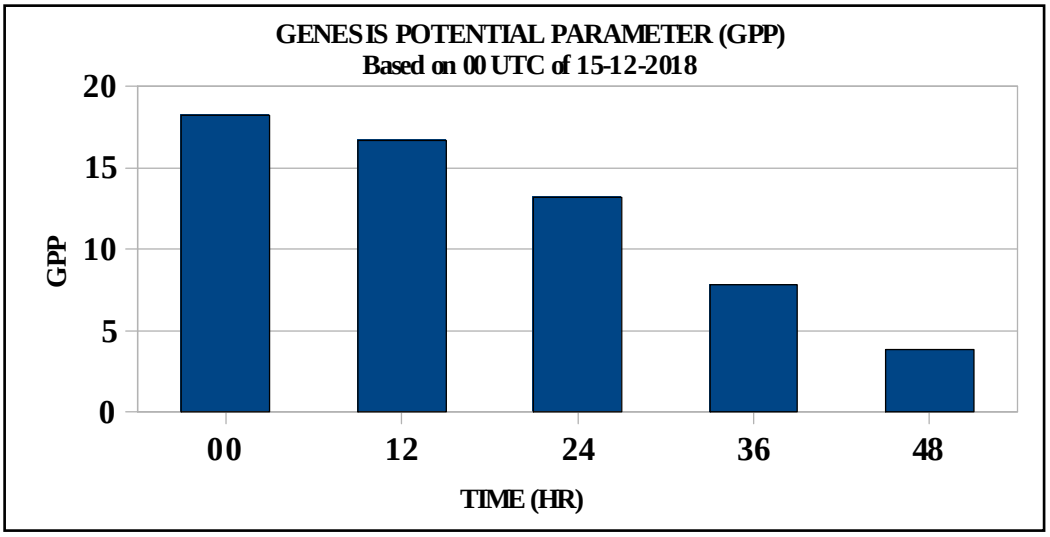


Fig.13(v) Area average analysis and forecasts of GPP based on 0000 UTC of 15.12.2018

9.2 Track prediction by NWP models

Track prediction by various NWP models is presented in **Fig.14**. Based on initial conditions of 0000 UTC of 13th December, most of the models indicated initial northwestward movement towards north Andhra Pradesh coast however only NCEP GFS and IMD GFS models indicated landfall over north Andhra Pradesh coast around Kakinada around 00UTC of 17th Dec.

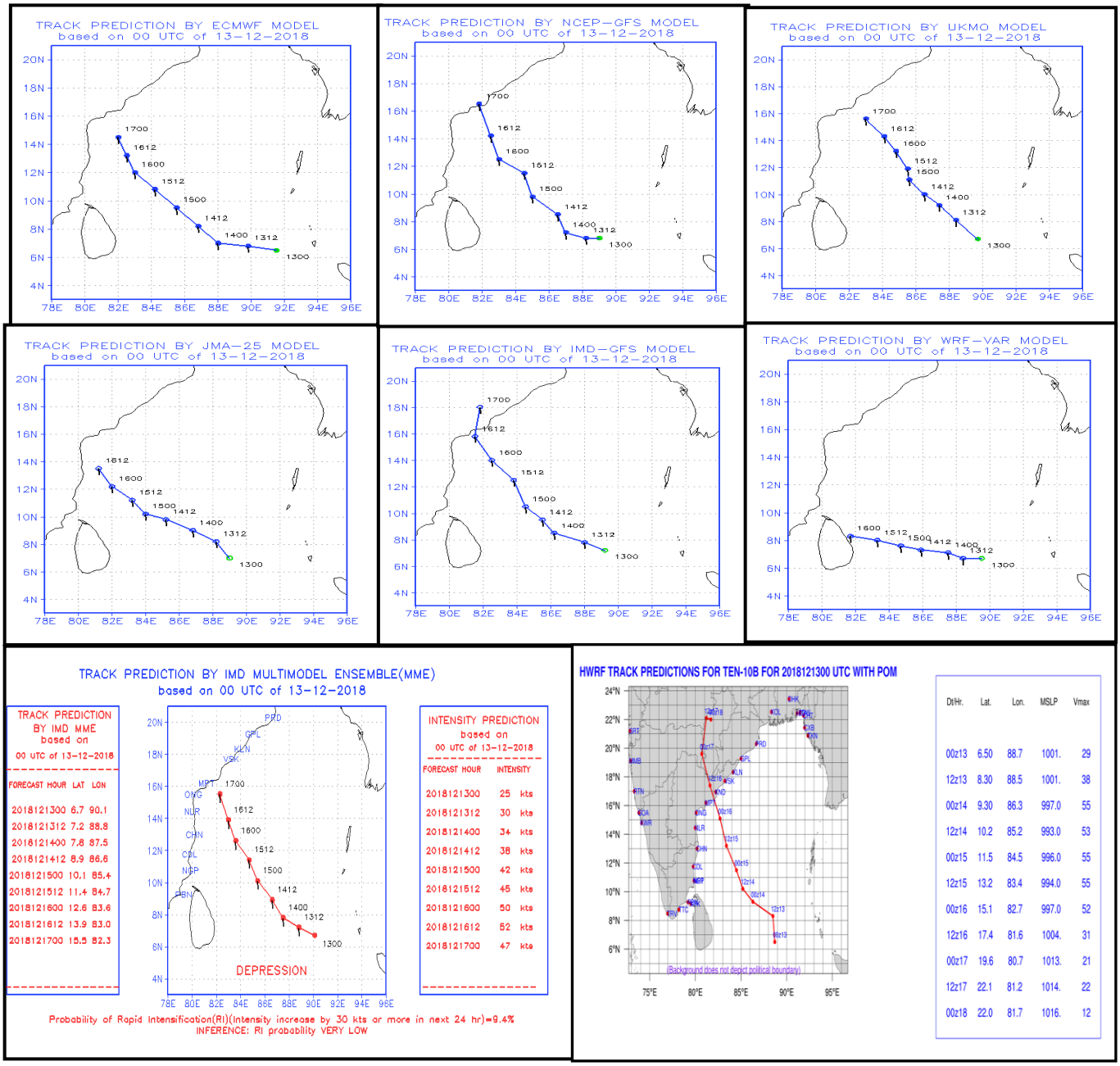


Fig. 14 (a): NWP model track forecast based on 0000 UTC of 13.12.2018

Based on initial conditions of 0000 UTC of 14th December, models including ECMWF, NCEP GFS and IMD MME indicated initial northwestward movement towards north Andhra Pradesh coast with increase in northward component of movement thereafter without landfall. Models like UKMO, JMA and IMD GFS predicted landfall over Andhra Pradesh. However, they varied w.r.t. landfall point and time. The forecast landfall point by IMD GFS and UKMO was closer to actual landfall point.

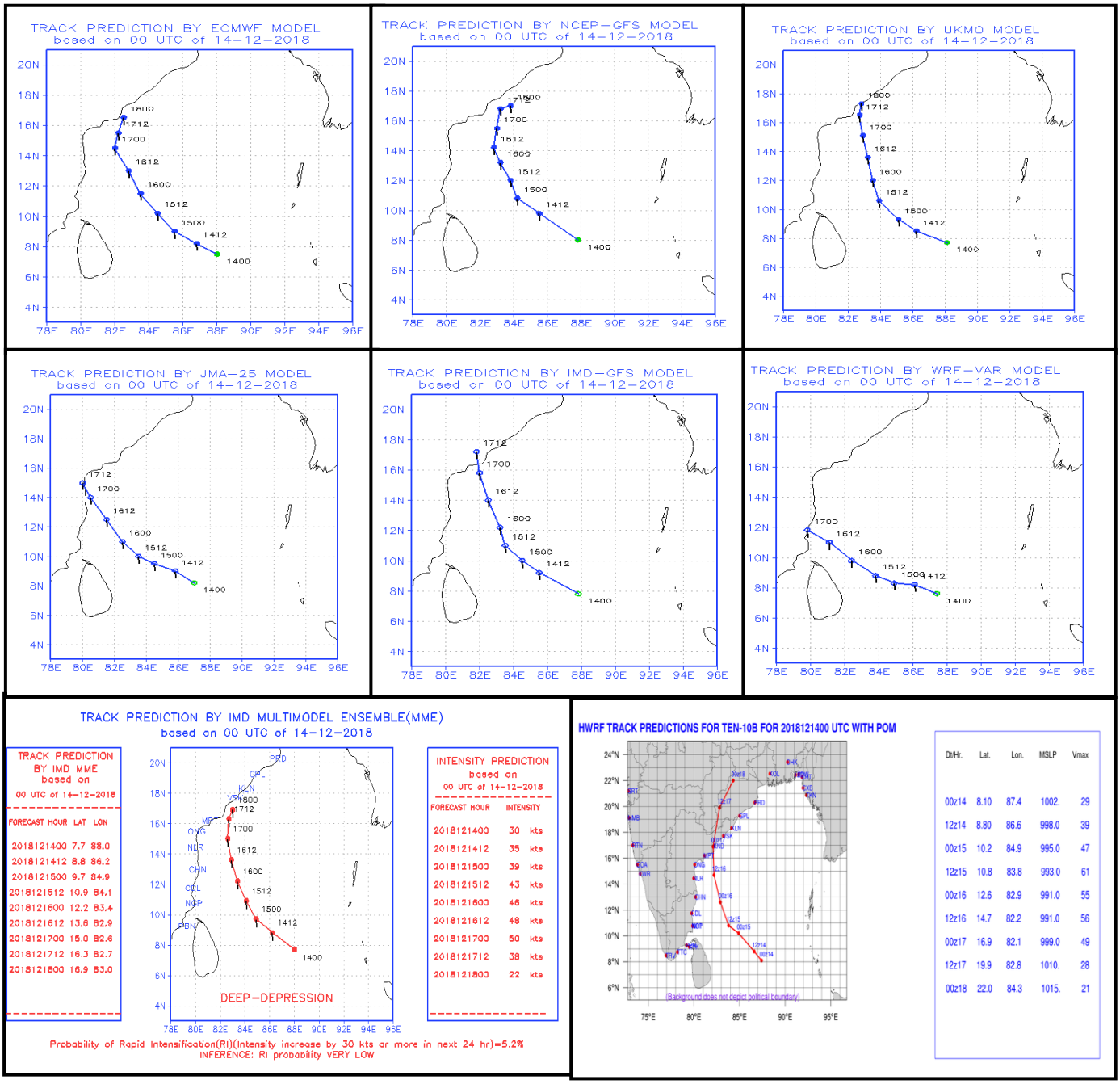


Fig. 14 (b): NWP model track forecast based on 0000 UTC of 14.12.2018

Based on initial conditions of 0000 UTC of 15th December, models including ECMWF, NCEP GFS, UKMO, IMD GFS and IMD MME indicated initial northeastwards recurvature from 0000 UTC of 17th onwards. Models like IMD GFS, NCEP GFS and WRF predicted landfall over north Andhra Pradesh. However, they varied w.r.t. landfall point and time.

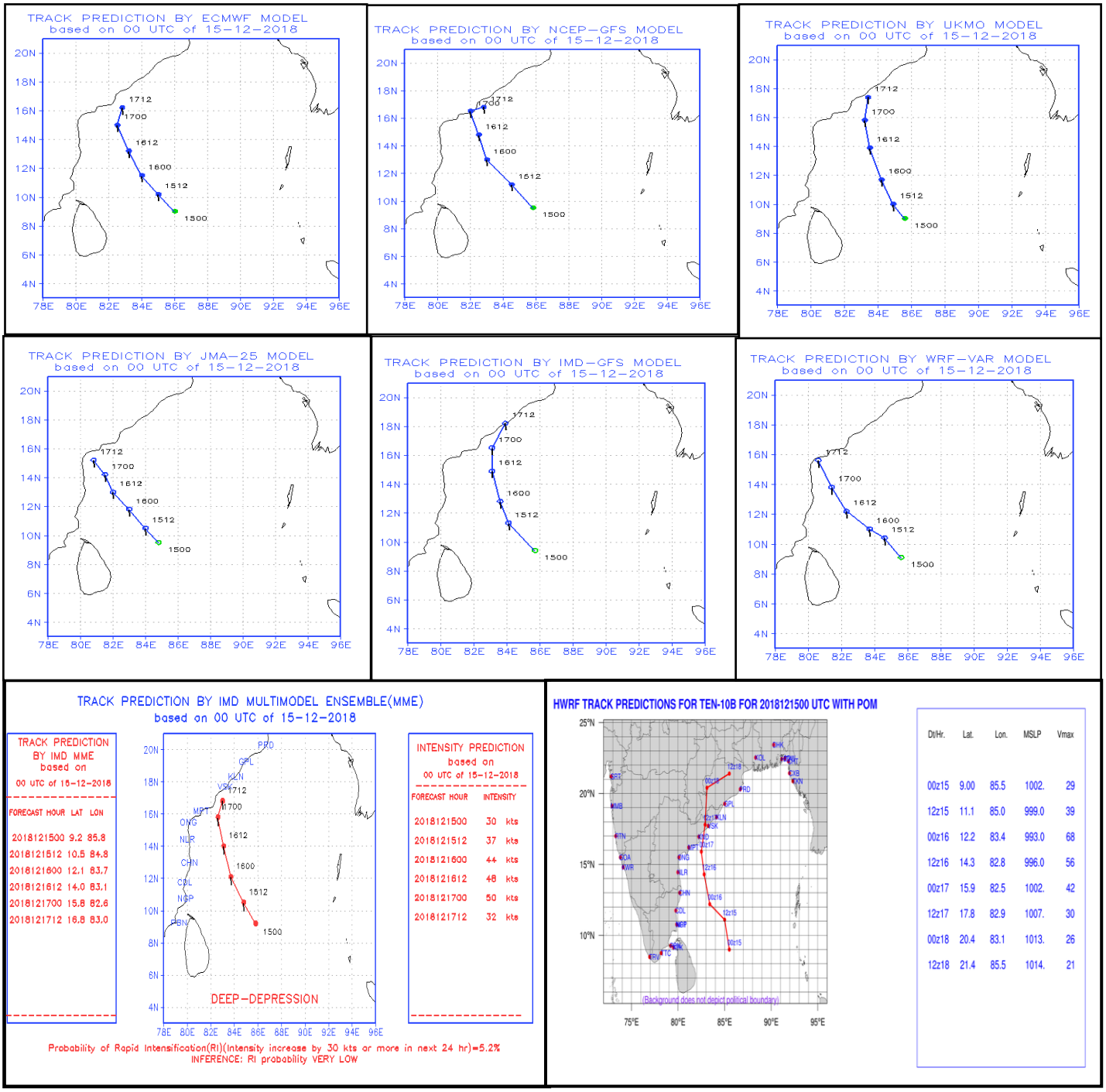


Fig. 14 (c): NWP model track forecast based on 0000 UTC of 15.12.2018

Based on initial conditions of 0000 UTC of 16th December, models including ECMWF, JMA, IMD GFS and WRF VAR indicated landfall over north Andhra Pradesh. IMD GFS and WRF VAR predicted landfall time closer to actual landfall time. NCEP GFS, UKMO and MME predicted weakening of system over sea.

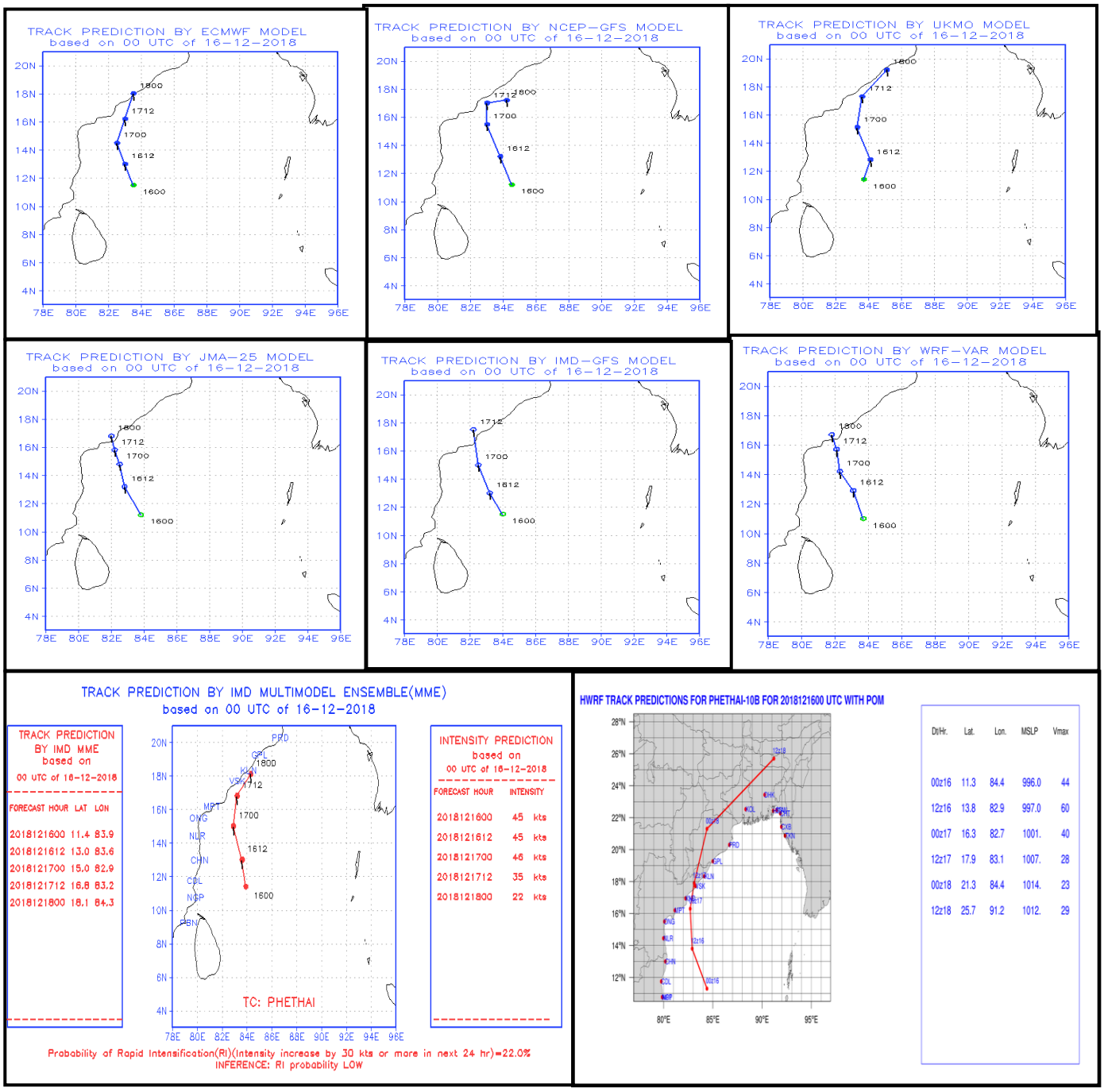


Fig. 14 (d): NWP model track forecast based on 0000 UTC of 16.12.2018

Based on initial conditions of 0000 UTC of 17th December, models including NCEP GFS, UKMO, IMD GFS and IMD MME indicated landfall over north Andhra Pradesh around 1200 UTC of 17th. ECMWF, JMA and WRF VAR predicted weakening of system over sea.

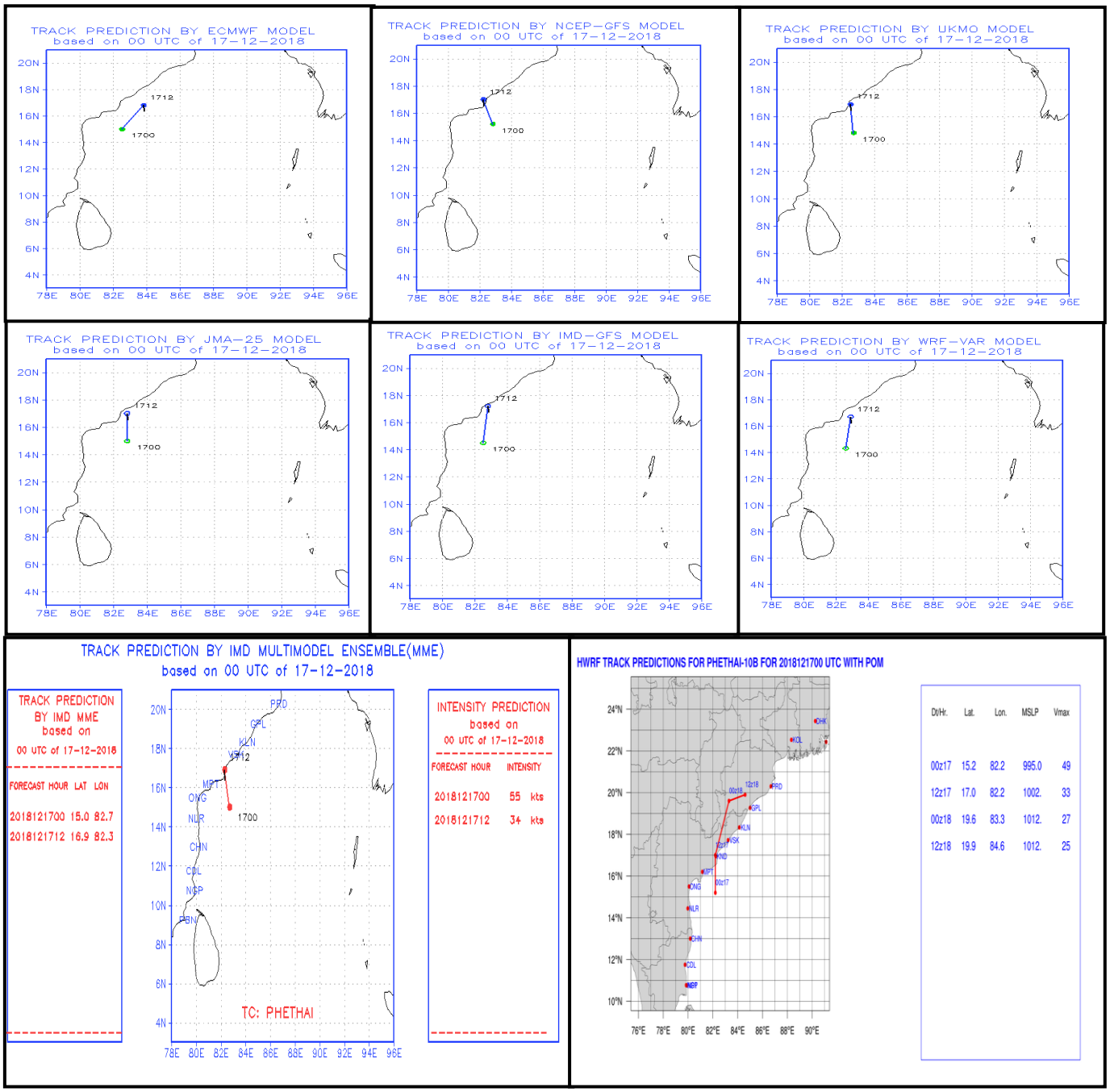


Fig. 14 (e): NWP model track forecast based on 0000 UTC of 17.12.2018

Comparing different models IMD GFS was consistent in predicting landfall near Kakinada while other models were mostly indicating recurvature over the sea before landfall and weakening based on initial condition of 14th to 17th Dec.

9.2. Track forecast errors:

Average track forecast errors by various NWP models is presented in Table 2 (a). For 24, 48 and 72 hours lead period, the error in track forecast was the least by ECMWF followed by IMD MME. For 96 hours lead period, the error in track forecast was the least by IMD MME followed by UKMO.

Table-2 (a). Average track forecast errors (Direct Position Error (DPE)) in km (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H
IMD-GFS	83(9)	120(8)	137(7)	147(6)	180(5)	164(4)	177(3)	314(2)	-
IMD-WRF	63(9)	114(8)	175(7)	242(6)	326(5)	425(4)	-	-	-
JMA	80(9)	115(8)	155(7)	187(6)	215(5)	243(4)	252(3)	-	-
NCEP-GFS	97(9)	145(8)	144(7)	158(6)	140(5)	113(4)	115(3)	111(2)	-
UKMO	74(9)	90(8)	135(7)	162(6)	151(5)	166(4)	117(3)	88(2)	-
ECMWF	85(9)	70(8)	66(7)	61(6)	84(5)	93(4)	110(3)	132(2)	-
IMD-HWRF	95(18)	142(16)	175(14)	208(12)	212(10)	287(8)	342(6)	387(4)	412(2)
IMD-MME	62(9)	74(8)	91(7)	114(6)	108(5)	108(4)	55(3)	73(2)	-

Along track errors (ATE)and cross track errors (CTE) by HWRF model are presented in Tables 2 (b) and 2 (c). These tables show that DPE was largely contributed by CTE i.e. the forecast tracks were not close to observed track. ATE that is the errors in speed of movement of the storm.

Table-2 (b). Along the Track (AT) Forecast Error in km of IMD-HWRF Model (Number of forecasts verified is given in the parentheses) ::

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr
HWRF	61(18)	65(16)	82(14)	99(12)	67(10)	93(8)	58(6)	123(4)	280(2)

Table-2 (c): Cross the Track (CT) Forecast Error in km of IMD-HWRF Model (Number of forecasts verified is given in the parentheses) ::

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr
HWRF	132(18)	205(16)	237(14)	264(12)	292(10)	296(8)	325(6)	389(4)	403(2)

9.3. Landfall forecast errors:

Average errors in landfall point and time are presented in Table 3 and 4. The tables indicate that most of the models didn't predict landfall at different lead times . The landfall point errors of IMD GFS and NCEP GFS were significantly less as compared to other models. The landfall time errors were the least by IMD HWRF upto 72 hours lead period.

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H
Based on	**17 December 00z**	**16 December 12z**	**16 December 00z**	**15 December 12z**	**15 December 00z**	**14 December 12z**	**14 December 00z**	**13 December 12z**	**13 December 00z**
IMD-GFS	93	77	8	27	246	-	47	85	85
IMD-WRF	-	-	47	-	-	-	673	-	-
JMA	-	87	27	-	-	-	316	324	-
NCEP-GFS	8	-	-	52	27	8	-	18	51
UKMO	57	230	-	-	-	-	87	-	-
ECMWF	-	-	190	27	-	52	-	-	-
IMD-MME	39	-	-	-	-	-	-	82	-
IMD-HWRF	15	23	124	273	110	88	25	74	39

Table4: Landfall time forecast errors (hour) at different lead time (hr)
('+' indicates delay landfall, '-' indicates early landfall)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H
Based on	**17 December 00z**	**16 December 12z**	**16 December 00z**	**15 December 12z**	**15 December 00z**	**14 December 12z**	**14 December 00z**	**13 December 12z**	**13 December 00z**
IMD-GFS	+4	+3	0	-4	+4	-	-3	-8	-6
IMD-WRF	-	-	+1	-	-	-	-8	-	-
JMA	-	+6	+12	-	-	-	+4	-8	-
NCEP-GFS	+2	-	-	+4	-8	-8	-	-8	-8
UKMO	+4	+4	-	-	-	-	+16	-	-
ECMWF	-	-	+16	+4	-	+4	-	-	-
IMD-MME	+4	-	-	-	-	-	-	+4	-
IMD-HWRF	0	0	3	0	3	0	-9	-12	-18

9.4. Intensity forecast errors by various NWP Models

9.4.1. The intensity forecasts of IMD-SCIP model and HWRF model are shown in Table 5. The intensity error was very high with HWRF model. The intensity forecast by IMD SCIP for different lead periods based on 00 & 12 UTC during 13th – 16th December is presented in Fig. 16. It indicates that intensity prediction based on 12 UTC of 13th and 00 UTC of 15th December was closer to actual intensity.

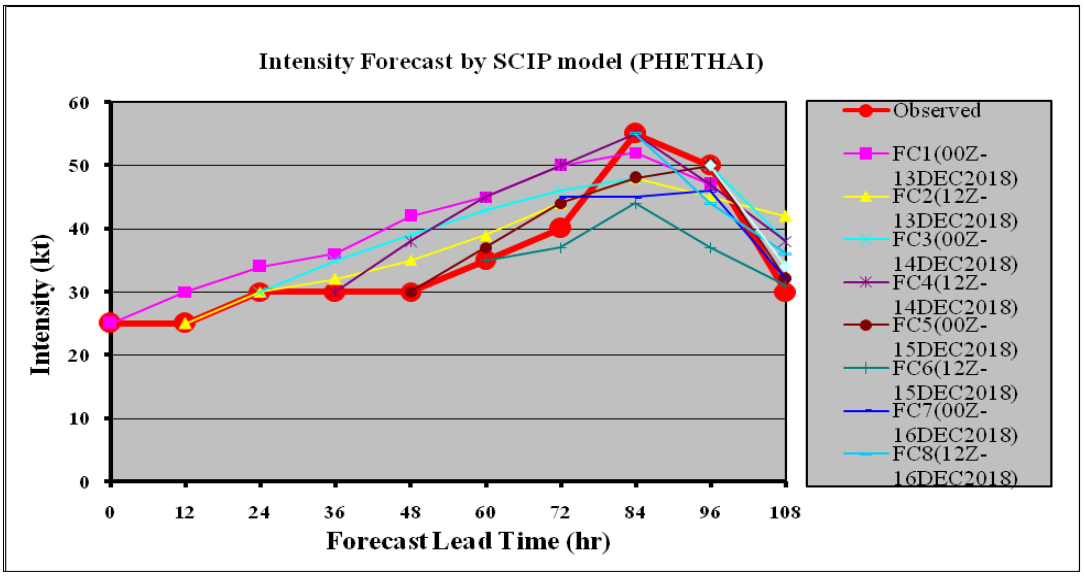


Fig. 15: Intensity forecast by IMD SCIP for different lead periods based on 00 & 12 UTC during 13th – 16th December

Table 5: Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of SCIP and HWRF models (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H
IMD-SCIP (AAE)	4.8(9)	6.3(8)	7.3(7)	3.8(6)	5.2(5)	6.3(4)	5.3(3)	7.5(2)	
HWRF (AAE)	9.7(18)	13.6(16)	14.6(14)	13.2(12)	10.4(10)	7.9(8)	12.7(6)	14.5(4)	8.5(2)
IMD-SCIP (RMSE)	5.6	7.0	8.0	5.7	6.0	7.3	5.7	8.7	
HWRF (RMSE)	11.6	16.2	17.7	15.4	13.4	10.3	15.1	17.9	8.5

9.4.2 Landfall intensity predicted by SCIP Model

The landfall intensity predicted by IMD SCIP model for first and second landfall is presented in Fig.17 (a-b).

(i) First landfall: The forecast intensity was closer to observed intensity at the time of landfall most of the times except based on initial conditions of 00 UTC of 14th and & 00 & 12 UTC of 15th December**.**

(ii) Second landfall: IMD SCIP model overestimated the intensity during second landfall for all initial conditions during 12th to 17th.

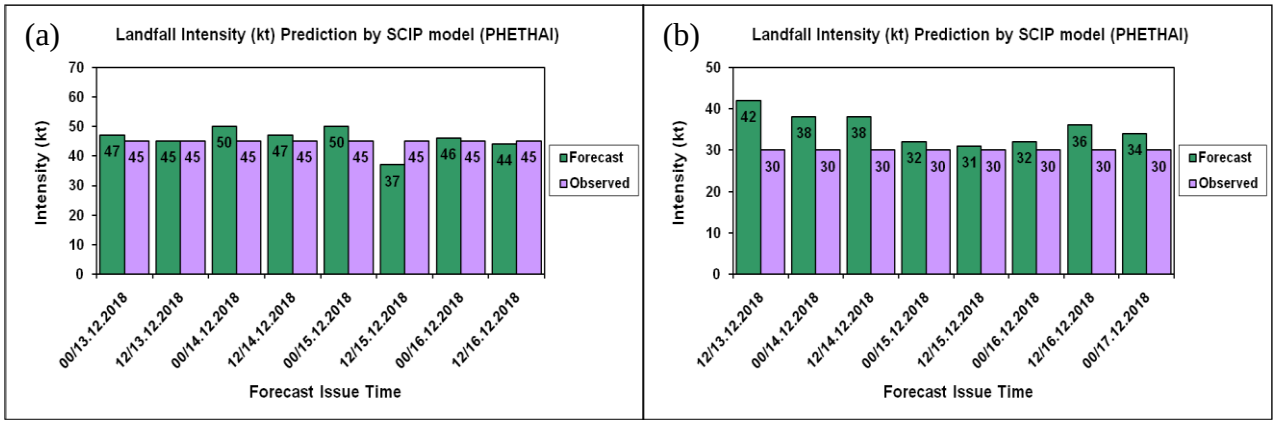


Fig. 16 (a-b): The landfall intensity predicted by IMD SCIP model for first and second landfall

10. Operational Forecast Performance

10.1. Genesis Forecast

- First information about formation of low pressure area (LPA) over southeast BoB and neighbourhood around 9th December was issued in the Tropical Weather Outlook (TWO) dated the 5th December at 1230 IST (more than 4 days in advance of formation of LPA). LPA formed at 1730 IST of 9th.
- In the TWO issued at 1300 IST of 7th, it was mentioned that, the LPA will form around 9th and will become more marked thereafter. WML formed at 0830 IST of 11th.
- In the TWO issued at 1300 IST of 10th, it was mentioned that the LPA would become WML during next 48 hours and intensify into a depression around 13th (around 48 hours in advance). WML formed at 0830 IST of 11th. Depression formed at 0530 IST of 13th.

10.2. Landfall Forecast

- In the bulletin issued at 0830 IST of 14th December when it was a D, it was predicted that the system would cross Andhra Pradesh coast between Ongole and Kakinada during 17h December afternoon as a cyclonic storm.
- The landfall point was further specified to be between Machilipatnam and Kakinada during 17th December afternoon in the bulletin issued at 1430 IST of 16th.
- The CS Phethai crossed Andhra Pradesh coast close to south of Yanam, about 40 km south of Kakinada during 1330-1430 IST (afternoon) of 17th December with a wind speed of 70-80 kmph gusting to 90 kmph as a cyclonic storm. Typical observed and forecast track is presented in **Fig. 17**.

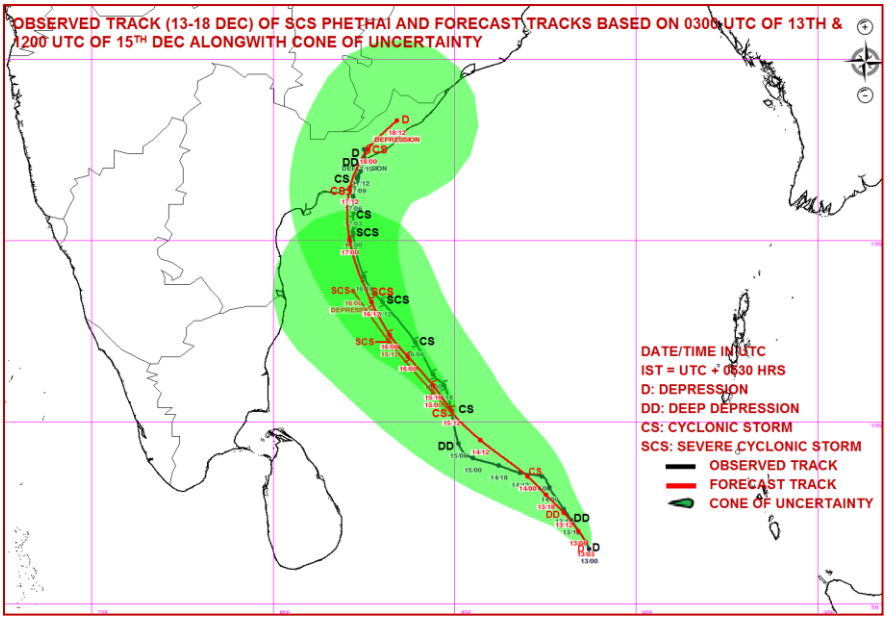


Fig.17: Observed track of SCS Phethai and forecast based on 0300 UTC of 13th and 1200 UTC of 15th December demonstrating the forecast of movement towards Andhra Pradesh coast since beginning and accurate landfall point forecast.

- The landfall point forecast errors (first landfall) were about 15.6, 15.6 and 46.7 km for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 115.4 km respectively. The landfall time forecast errors were about 2.0, 4.5 and 2.5 hours for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 3.6, 5.4 and 4.6 hours respectively. The landfall point and time errors were less than long period average (LPA) of past five years for all lead periods (**Fig.18 and Table 6**)

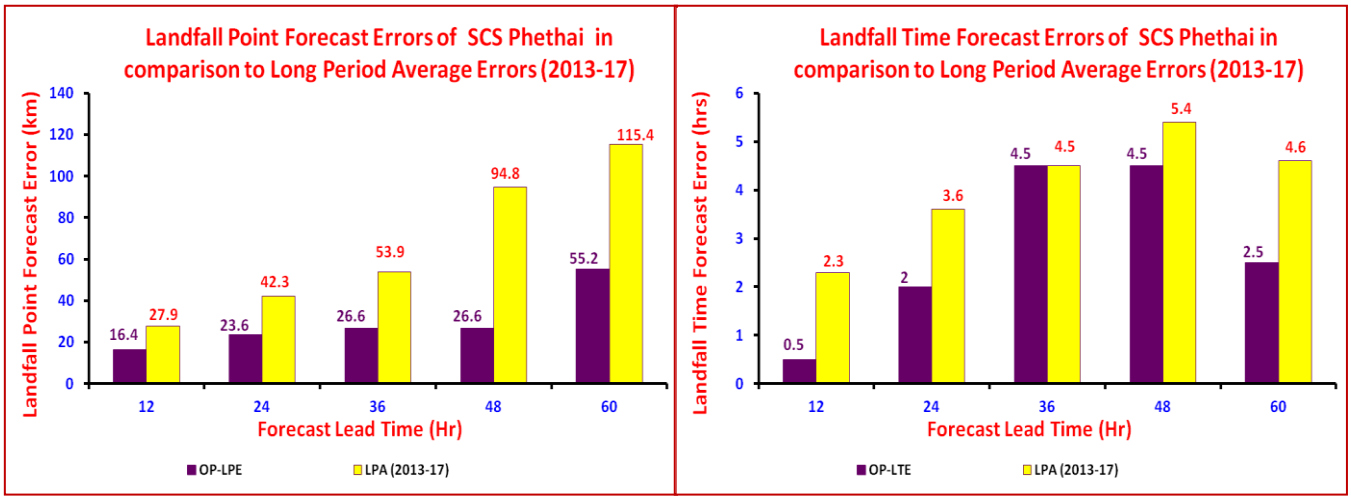


Fig.18: Landfall Point (km) and Time (hrs) Errors for SCS Phethai for first landfall

Table 6 (a): Operational and long period average landfall point (km) and time (hrs) errors in association with SCS Phethai (first landfall)

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2013-17)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hours)	LPE (km)	LTE (hours)
12	16/18	16.50/82.11	16.55/82.25	17/0900	17/0830	16.4	0.5	27.9	2.3
24	16/06	16.74/82.35	16.55/82.25	17/1030	17/0830	23.6	2.0	42.3	3.6
36	15/18	16.45/82.03	16.55/82.25	17/1300	17/0830	26.6	4.5	53.9	4.5
48	15/06	16.45/82.03	16.55/82.25	17/1300	17/0830	26.6	4.5	94.8	5.4
60	14/18	16.35/81.79	16.55/82.25	17/1100	17/0830	55.2	2.5	115.4	4.6

Table 6 (b): Operational and long period average landfall point (km) and time (hrs) errors in association with SCS Phethai (second landfall)

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2013-17)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hrs)	LPE (km)	LTE (hrs)
12	17/00	17.30/82.65	17.20/82.47	17/1430	17/1430	22.7	0.0	27.9	2.3
24	16/12	17.15/82.42	17.20/82.47	17/1400	17/1430	07.8	0.5	42.3	3.6
36	16/06	17.20/82.45	17.20/82.47	17/1330	17/1430	02.2	1.0	53.9	4.5

LPE: Landfall Point Error, LTE: Landfall Time Error, LPA: Long Period Average,
LPE= Forecast Landfall Point-Actual Landfall Point,
LTE= Forecast Landfall Time-Actual Landfall Time

10.3. Track Forecast

- In the first Bulletin issued at 0930 IST of 13th, it was mentioned that the system would move northwestwards towards Andhra Pradesh coast during next 72 hours.
- First information about the northeastwards recurvature of system was given in the bulletin issued at 1430 IST of 14th December.

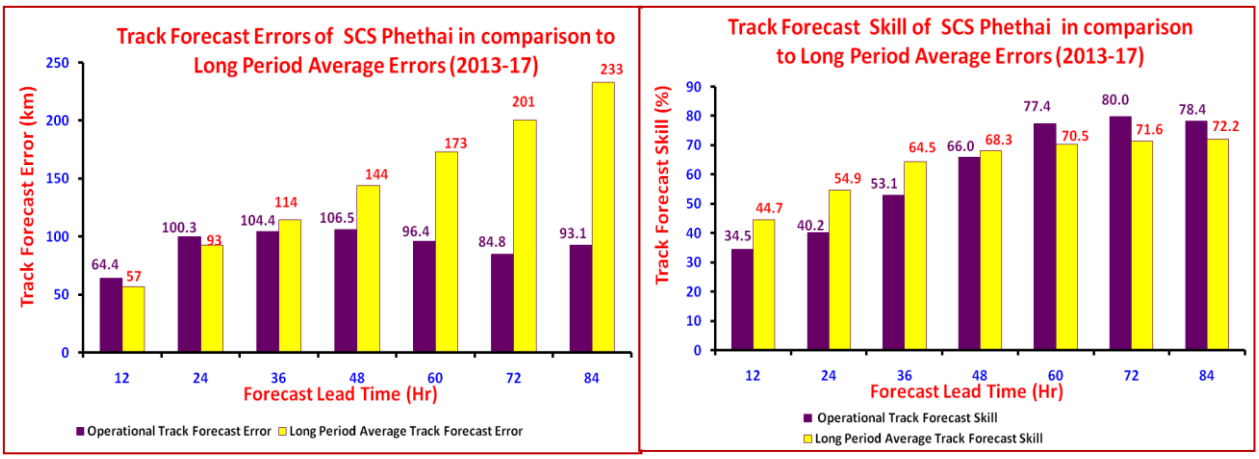


Fig.19: Track Forecast Errors and Skill for SCS Phethai

- The track forecast errors were about 100.3, 106.5 and 84.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 93, 144 and 201 km respectively. For all the lead periods beyond 24 hours, the track forecast errors were significantly less than the past five years average. For 12 & 24 hours lead period, it was comparable to past five years average (**Fig.19 and Table 7**).

Table 7: Operational and long period average track forecast errors (km) & Skill (%)

Lead Period (hrs)	No. of obs. verified	Operational Track Forecast		Long Period Average (2013-17) Track Forecast	
		Error (km)	Skill (%)	Error (km)	Skill (%)
12	15	64.4	34.5	57	44.7
24	13	100.3	40.2	93	54.9
36	11	104.4	53.1	114	64.5
48	9	106.5	66.0	144	68.3
60	7	96.4	77.4	173	70.5
72	5	84.8	80.0	201	71.6
84	2	93.1	78.4	233	72.2

4.4. Intensity Forecast

- In the first bulletin issued by IMD at 0930 hrs IST of 13th with the formation of depression, it was indicated that the system would intensify into a deep depression during next 12 hours and into a cyclonic storm during subsequent 24 hours. The depression intensified into a deep depression at midnight (2330 IST) of 13th and into a CS in the evening (1730 IST) of 15th.
- In the bulletin issued at 0030 IST of 14th with the intensification of system into a DD, it was further predicted that it would intensify into a CS during next 24 hrs and into an SCS during subsequent 24 hrs.
- The weakening of the system from SCS to CS category at the time of landfall was first predicted in the bulletin issued at 1430 IST of 14th Dec.
- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 6.7, 7.1 and 4.8 knots against the LPA of 10.4, 15.5 and 15.7 knots respectively. The skill in intensity (wind) forecast based on AE for 24, 48 and 72 hrs lead period was 56.2, 64.4 and 31.7% against the LPA of 37.1, 56.8 and 69.3% respectively (**Fig.20 and Table 8**). For all lead periods, the errors in intensity forecast were significantly less.
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 7.3, 9.3 and 6.0 knots against the LPA of 14.0, 20.6 and 20.6 knots respectively. The skill in intensity (wind) forecast based on RMSE for 24, 48 and 72 hrs lead period was 67.7, 55.3 and 31.2% against the LPA of 40.1, 60.0 and 73.0% respectively (**Fig.21 and Table 8**). For all lead periods, the errors in intensity forecast were significantly less.

Table 8: Average Intensity forecast errors (kt) and Skill (%) in association with SCS Phethai

Lead Period (hrs)	N	Average Intensity Error (kts)		LPA (2013-17) Intensity forecast Error (kts)		Skill (%) in intensity forecast		LPA (2013-17) Intensity forecast Skill (%)	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	15	3.8	4.6	6.3	8.7	43.0	51.9	22.3	28.0
24	13	6.7	7.3	10.4	14.0	56.2	67.7	37.1	40.1
36	11	6.1	7.3	13.8	18.4	64.0	65.9	48.2	51.0
48	9	7.1	9.3	15.5	20.6	64.4	55.3	56.8	60.0
60	7	6.8	8.3	15.8	20.9	36.7	40.8	64.4	67.9
72	5	4.8	6.0	15.7	20.6	31.7	31.2	69.3	73.0
84	2	9.0	9.0	24.6	22.1	55.3	63.9	62.0	76.5

N: No. of observations verified; AE: Absolute Error; RMSE: Root Mean Square Error, LPA: Long Period Average (2013-17).

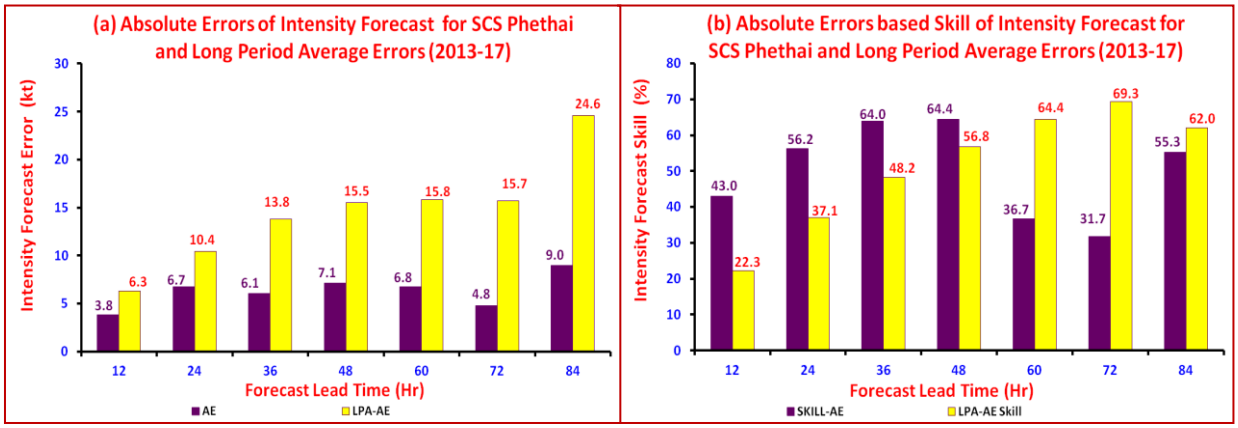


Fig.20: Absolute errors (AE) of intensity forecast and skill for SCS Phethai

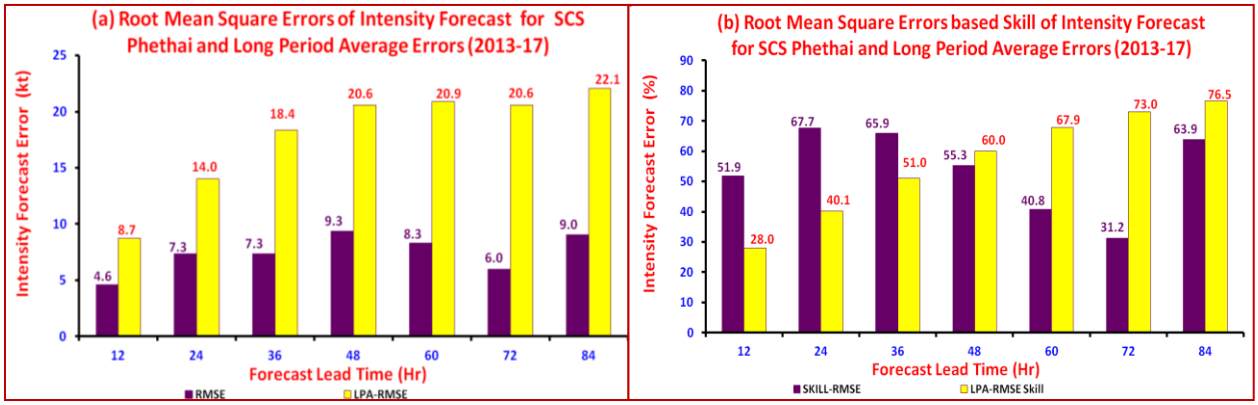


Fig.21: Root Mean Square Errors (RMSE) of intensity forecast and skill for SCS Phethai

6. Warning Services

Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity, and landfall forecast for +06, +12, +18, +24, +36 and +48… +84 hrs lead period till the system weakened into a low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day and every three hours during the cyclone period. The hourly update was also provided prior to and during the landfall of the cyclone.
- **Cyclone structure forecast for shipping and coastal hazard management** The radius of maximum wind and radii of MSW ≥28 knots and ≥34 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36 ….. +84 hrs lead period.
- **Four stage Warning:** The pre-cyclone watch for Andhra Pradesh coast was issued with the formation of depression in the first bulletin issued by IMD at 0930 hrs IST of 13th Dec. It was upgraded to cyclone alert in the bulletin issued at 0815 hrs IST of 15th Dec when system was having the intensity of deep depression. It was further upgraded to cyclone warning in the bulletin issued at 2030 hrs IST of 15th Dec (about 45 hours prior to landfall).
- **Adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update during cyclone period to the central, state and district level disaster management agencies including MHA NDRF, NDMA for all concerned states along the east coast of India including Tamil Nadu, Andhra Pradesh, Puducherry, Odisha, West Bengal and Andaman & Nicobar Islands. The bulletin also contained the suggested action for disaster managers and general public in particular for fishermen. These bulletins were also issued to Defence including Indian Navy & Indian Air Force.
- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The adverse weather warnings related to heavy rain, gale/squally wind & storm surge were also presented in graphics alongwith colour codes in the website.
- **Warning and advisory through social media:** Daily updates were uploaded on face book and tweeter regularly during the life period of the system.
- **Press release and press briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at Chennai, Kolkata and Cyclone

warning centres at Bhubaneswar and Visakhapatnam to ports, fishermen, coastal and high sea shipping community.

- **Fishermen Warning:** First warning for fishermen of the states of West Bengal, Odisha, Andhra Pradesh, Tamil Nadu and Andaman & Nicobar Islands was issued at 0930 hrs IST of 13th December.
- **Advisory for international Civil Aviation :** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all meteorological watch offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognostics and diagnostics of the systems were described in the RSMC bulletins and tropical cyclone advisory bulletins.

Statistics of bulletins issued by RSMC New Delhi in association with the SCS Phethai are given in **Table 9.**

Table 9 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	33	1. IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Chief Secretary- Tamil Nadu, Andhra Pradesh, Puducherry, Odisha, West Bengal, and Andaman & Nicobar Islands.
2	Hourly Bulletins	7	• Email to Cabinet Secretary, Principal Secretary to Prime Minister, Secretary Ministry of Home Affairs, Defence, Agriculture, Information & Broadcasting, Department of Sc. & Technology, NDMA, and Shipping & Surface Transport, Control Room Home Affairs, Director Indian Railways, Director General Doordarshan & All India Radio, Director General National Disaster Response Force and Chief Secretary- Tamil Nadu, Andhra Pradesh, Puducherry, Odisha, West Bengal, and Andaman & Nicobar Islands. • Put up on RSMC New Delhi website
3	Bulletin from DGM	6	FAX and email to Cabinet Secretary, Principal Secretary to Prime Minister, Secretary Ministry of Home Affairs, Defence, Agriculture, Information & Broadcasting, Department of Sc. & Technology, NDMA, and Shipping & Surface Transport, Control Room Home Affairs, Director Indian Railways, Director General Doordarshan & All India Radio, Director General National Disaster Response Force and Chief Secretary- Tamil Nadu, Andhra Pradesh, Puducherry, Odisha, West Bengal, and Andaman & Nicobar Islands.
4	RSMC Bulletin	32	1. IMD's website 2. WMO/ESCAP member countries and WMO through GTS and E-mail.
5	GMDSS	24	1. IMD website, RSMC New Delhi website

	Bulletins		2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
6	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	16	1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
7	Warnings through SMS	Daily	SMS to disaster managers at national level and concerned states (every time when there was change in intensity) To general public to users registered with RSMC website from the states of Odisha, Andhra Pradesh, West Bengal, Tamil Nadu, Andaman & Nicobar Islands and National level disaster managers.
8	Warnings through Social Media	Daily (4 times)	Cyclone Warnings were uploaded on Social networking sites (Face book and Tweeter) since inception to weakening of system (every time when there was change in intensity).
9	Message through Whatsapp	Daily	Everyday based on observation of 00, 03, 06, 12, 18 UTC observations to central level disaster managers and hourly on the day of landfall
10	Press Release	6	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefings	Daily	Regular briefing daily

Table 9 (b): Bulletins issued by CWC Vishakhapatnam in association with SCS Phethai

S.No.	Type of Bulletin	No. of Bulletins issued
		CWC Vishakhapatnam
1.	Cyclone Alert Bulletins	1
2.	Coastal Weather Bulletins	20
3.	Fishermen Warnings issued	26
4.	Cyclone Warning Bulletins	17
5.	Press Bulletins	2
6.	Port Warnings	12
7.	Special Weather Bulletins	3
8	Gale Wind Warning	5
9.	Air Bulletins	17
10	SMS	400

7. Summary

An LPA formed over Equatorial Indian Ocean and adjoining central parts of south Bay of Bengal (BoB) on 9th December. It lay as a WML over central parts of south BoB and adjoining EIO on 11th. It concentrated into a D over southeast BoB in the early morning of 13th and into a DD over southeast BoB in the same mid-night. It intensified into CS **"Phethai**" in the evening of 15th and into a severe cyclonic storm (SCS) in the afternoon of 16th December. It weakened into a CS in the morning of 17th. Moving north-northwestwards and then northwards it crossed Andhra Pradesh coast near 16.55^0N and

82.25^{0}E (close to south of Yanam and 40 km south of Kakinada) during 17th afternoon (1330-1430 IST) as a cyclonic storm with maximum sustained wind speed of 70-80 kmph gusting to 90 kmph. Thereafter, it weakened rapidly into a DD over westcentral BoB off Kakinada coast in the same evening. Moving north-northeastwards, it crossed again Andhra Pradesh coast close to Tuni during 1930-2030 IST and weakened into a depression over coastal Andhra Pradesh during same midnight. It further weakened into a WML over northwest and adjoining westcentral BoB & coastal Odisha in the early morning and into an LPA over northwest BoB and adjoining Odisha in the morning (0830 IST) of 18th December.

The system was monitored & predicted continuously by IMD prior to it's genesis as low pressure area over BoB from 5th December onwards till it's dissipation on 18th. It's genesis, movement, landfall, recurvature, intensity and associated adverse weather were well predicted by IMD. The landfall point forecast errors were about 15.6, 15.6 and 46.7 km for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 115.4 km respectively. The landfall time forecast errors were about 2.0, 4.5 and 2.5 hours for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 3.6, 5.4 and 4.6 hours respectively. The track forecast errors were about 100.3, 106.5 and 84.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 93, 144 and 201 km respectively. The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 6.7, 7.1 and 4.8 knots against the LPA of 10.4, 15.5 and 15.7 knots respectively.

8. Acknowledgement:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledges the contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of SCS Phethai. We acknowledge the contribution of all sister organizations of Ministry of Earth Sciences including National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), research institutes including IIT Bhubaneswar, IIT Delhi and Space Application Centre, Indian Space Research Organisation (SAC-ISRO) for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai, Kolkata, Cyclone Warning Centre (CWC) Bhubaneswar, Visakhapatnam, Doppler Weather Radar Stations at Visakhapatnam and Machilipatnam, Numerical Weather Prediction Division, Satellite and Radar Division, Surface & Upper air instruments Divisions, New Delhi and Information System and Services Division at IMD is also duly acknowledged.
