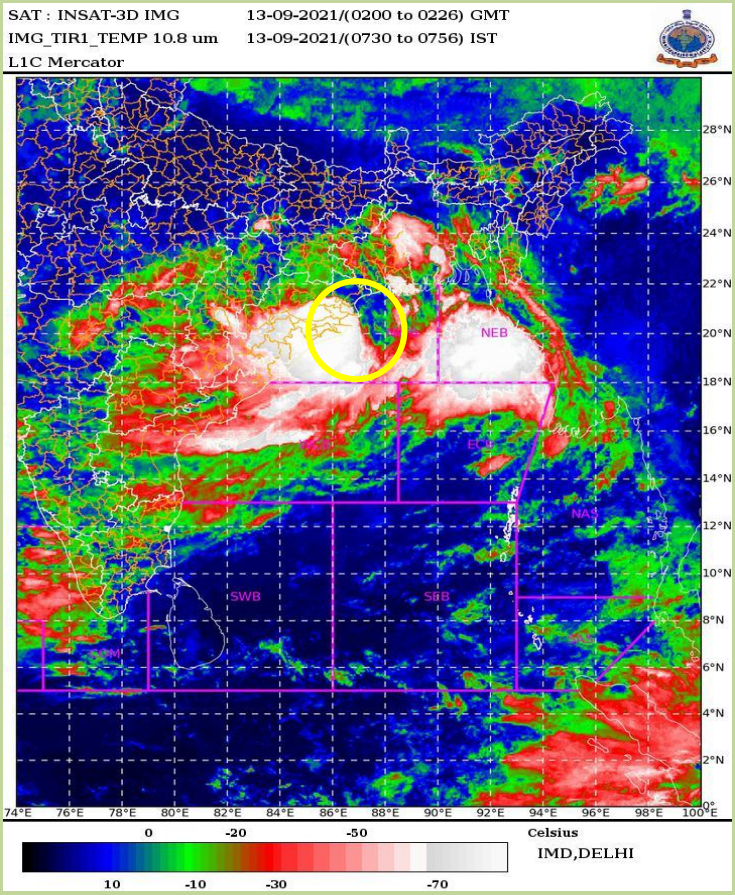
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Deep Depression over northwest Bay of Bengal (12-15 September, 2021): A Report



INSAT-3D enhanced Colored IR imagery based on 0200 UTC of 13th September

Cyclone Warning Division

India Meteorological Department

New Delhi

September 2021

Deep depression over northwest Bay of Bengal during 12th -15th September, 2021

1. Introduction

- A low pressure area (LPA) formed over eastcentral and adjoining northeast Bay of Bengal (BoB) in the early morning (0000 UTC/0530 hrs IST) of 11th September, 2021.
- It lay as a well marked low pressure area (WML) over northwest and adjoining westcentral BoB in the early morning (0000 UTC/0530 hours IST) of 12th.
- Under favourable environmental and oceanic conditions, it concentrated into a depression over northwest BoB and adjoining Odisha coast in the evening (1200 UTC/1730 hrs IST) of 12th.
- Moving west-northwestwards, it intensified into a deep depression over northwest BoB very close to Odisha coast in the early morning (0000 UTC/0530 hrs IST) of 13th and crossed the north Odisha coast, close to south of Chandbali between 0530 & 0630 hrs IST (0000 & 0100 UTC) as a deep depression with maximum sustained wind speed of 30 knots (50-60 kmph).
- Continuing to move further west-northwestwards, it weakened into a depression over north Chhattisgarh & adjoining north interior Odisha in the morning (0300 UTC/0830 hrs IST) of 14th and into a WML over northeast Madhya Pradesh & neighbourhood in the early morning (0000 UTC/0530 hrs IST) of 15th.
- The observed track and best track parameters of the system are presented in Fig. 1 and table 1.

2. The salient features of the system were as follows:

- Deep depression over BoB was the first depression over the north Indian Ocean during the monsoon season, 2021.
- It caused active to vigorous monsoon conditions leading to extremely heavy rainfall at a few places over Odisha on 12th & 13th , at isolated places over Chhattisgarh on 13th and over East Madhya Pradesh on 14th. In conjunction with another low pressure area over Gujarat, extremely heavy rainfall at a few places also occurred over Saurashtra and north Konkan on 13th September. Low level convergence of wind & enhanced moisture incursion from the Bay of Bengal in association with a trough extending eastwards across the system also caused extremely heavy rains at isolated places over West Bengal on 14th September.
- A few of the rainfall amounts such as Astaranga & Kakatpur-53 cm-each, Balikuda-44cm, Kantapada-38cm, Niali-37cm, Puri-34 cm, Gop & Satyabadi-33cm-each, Ragunathpur-32 cm were recorded over Odisha on 12th, Talcher – 39 cm, Birmaharajpur – 37cm, Tikarapara – 35cm in Odisha on 13th and Lodhika – 52cm, Visavadar – 47cm, Kalavad – 41cm in Saurashtra had been exceptionally heavy. These extreme rainfall events caused Flash floods & Urban flood situation in major Districts including Puri, Khorda, Jagatsinghpur, Kendrapara, Subarnapur & Angul in Odisha and Rajkot & Jamnagar in Saurashtra. As per the report from Central Water Commission Mahanadi river was in spate over some parts of Odisha due to this rainfall.

- It had a total life period of 60 hours against the average life period (1990-2013) of 75 hours of deep depression category in monsoon season over the BoB. The system had track length of about 545 km

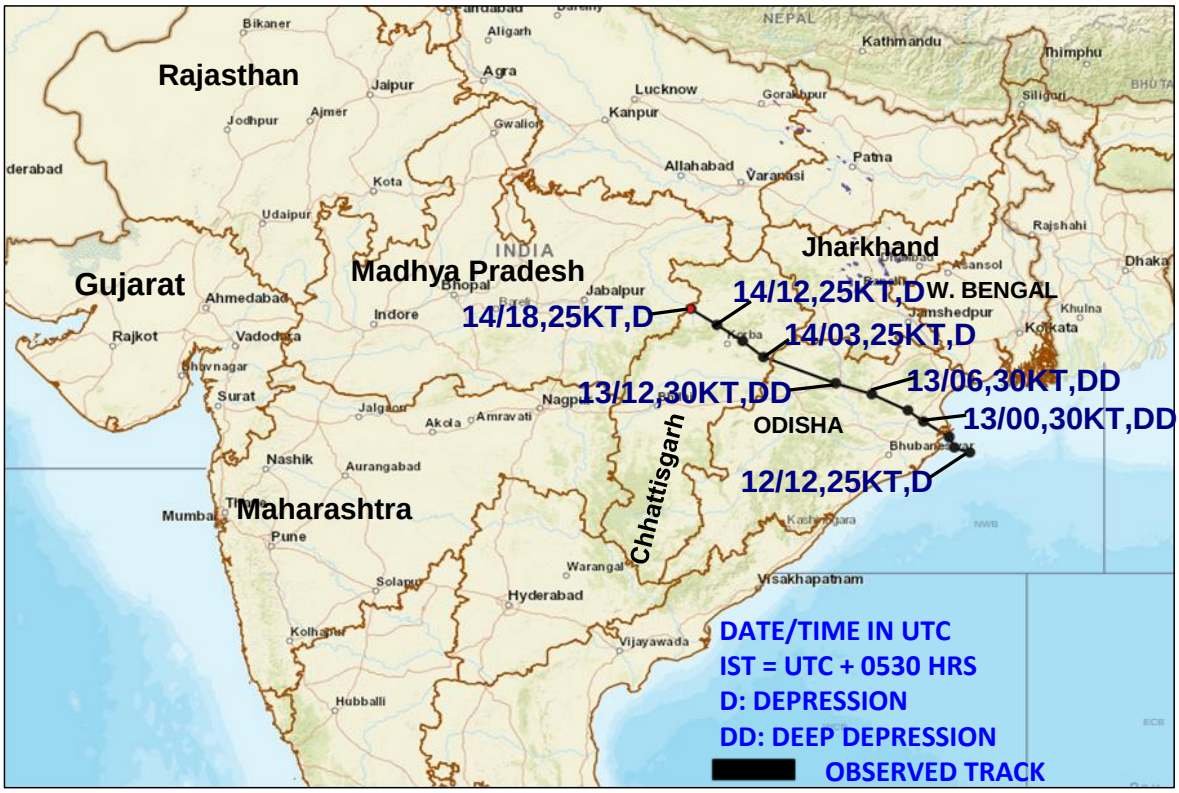


Fig.1: Observed track of deep depression over northwest BoB during 12th-15th Sep, 2021

3. Brief life history

3.1. Genesis

Under the influence of a cyclonic circulation over eastcentral BoB & neighbourhood, a low pressure area formed over eastcentral & adjoining northeast BoB at 0000 UTC of 11th September. At that time, Sea Surface temperature (SST) was around 29-30°C over central & north BoB. The tropical cyclone heat potential (TCHP) was about 80-100 KJ/cm2 over central & north BoB and >100 KJ/cm2 over northwest BoB. Madden Julian oscillation (MJO) index was in phase 3 with amplitude more than 1. It was forecast to continue in same phase with amplitude remaining more than 1 till 16th September. The environmental conditions indicated, increase in positive vorticity at lower level (150x10-6S-1) to the southeast of system centre over central BoB during past 24 hours. The positive vorticity zone extended upto 500 hpa level. A zone of positive upper level divergence (30x10-5S-1) lay over westcentral BoB to the southwest of system centre. Another zone of positive upper level divergence (20 x 10-5 S-1) lay over northeast BoB off Myanmar coast. A zone of positive lower level convergence 30x10-5S-1 lay over westcentral BoB and another zone (30x10-5S-1) lay over eastcentral BoB off Myanmar coast. The vertical wind shear (VWS) was low to moderate (05-15 kts) over the north and adjoining central BoB. Thus, favourable sea and

environmental conditions (SST 29-300C, TCHP 80-100 KJ/cm2, low to moderate VWS, positive low level vorticity low level convergence and increasing equatorward outflow) prevailed and supported further intensification of system into a depression over BoB.

It became well-marked low pressure (WML) area over northwest and adjoining westcentral Bay of Bengal at 0000 UTC of 12th September. Similar sea conditions prevailed. A zone of positive vorticity (100x10-6S-1) at lower level lay to the southeast of system centre over northwest BoB. The positive vorticity zone extended upto 500 hPa level. A zone of positive lower level convergence 10x10-5s-1 lay over westcentral BoB and another zone (10x10-5S-1) lay over eastcentral BoB off Myanmar coast. A zone of positive upper-level divergence (30x10-5S-1) lay over westcentral BoB to the southwest of the system centre and another zone (30x10-5S-1) is seen over east-central BoB off Myanmar coast. Strong equatorward outflow prevailed over the region. The VWS was moderate (15-20 kts) over the northwest BoB. The favourable sea surface temperature (SST) of about 29-30°c over northwest Bay of Bengal (BoB), the tropical cyclone heat potential (TCHP) of about 80-100 KJ/cm2 over the same area and favourable. MJO conditions and favourable upper level divergence supported further intensification of system.

Similar sea and environmental conditions continued and the system intensified into a depression over northwest BoB and adjoining Odisha coast at 1200 UTC of 12th September.

3.2. Intensification and movement:

At 0000 UTC of 13th September, the depression over northwest BoB & adjoining Odisha coast moved west-northwestwards, intensified into a deep depression and lay centered over the northwest BoB, very close to north Odisha coast, near latitude 20.5°N and longitude 86.9°E, close to the southeast of Chandbali (42973). At 0000 UTC of 13th September, favourable sea conditions & MJO phase prevailed over northwest BoB. Positive low level vorticity (150x10-6s-1), moderate VWS (15-20 Kts), and favourable upper-level divergence helped in maintenance of active convection over the region. Under these conditions, the system intensified into a deep depression, moved west-northwestwards and crossed the north Odisha coast, close to the south of Chandbali between 0530 & 0630 hrs IST (0000 – 0100 UTC) of 14th September as a deep depression with maximum sustained wind speed of 30 knots.

At 0300 UTC of 14th September, the system was over land. The upper tropospheric ridge lay near 220 N, to the north of the system center. The system was steered by the mean winds in the middle and upper troposphere (500-850 hPa levels) towards the west-northwest. Due to land interactions, marginal weakening was expected during its movement across central India. Under this scenario, the deep depression over north interior Odisha moved further west-northwestwards, weakened into a depression and lay centred at 0300 UTC of 14th September, over north Chhattisgarh & adjoining north interior Odisha, about 80 km west-northwest of Jharsiguda (Odisha) and about 120 km southsoutheast of Ambikapur (Chhattisgarh).

Under the influence of active monsoon conditions and favourable environmental the depression maintained it's intensity for next 15 hours, moved west-northwestwards across north Chattisgarh and Madhya Pradesh and weakened into a well-marked low-pressure area over northeast Madhya Pradesh & neighbourhood at 0000 UTC of 15th September 2021.

The typical satellite imageries during life cycle of the system are presented in Fig. 2.

Table 1: Best track positions and other parameters of the Deep Depression over the Northwest Bay of Bengal and adjoining Odisha coast during 12 Sept- 15 Sept, 2021

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
12.09.2021	1200	20.3	87.4	1.5	992	25	4	D
	1800	20.4	87.1	1.5	992	25	4	D
13.09.2021	0000	20.6	87.0	2.0	990	30	4	DD
	0300	20.9	86.5	2.0	990	30	6	DD
	Crossed north Odisha coast, close to south of Chandbali between 0530 & 0630 hrs IST as a Deep Depression with maximum sustained wind speed of 30 knots							
	0600	21.1	86.2	-	990	30	6	DD
	1200	21.4	85.5	-	990	30	6	DD
	1800	21.6	84.8	-	990	30	6	DD
14.09.2021	0000	22.0	83.6	-	990	30	6	DD
	0300	22.1	83.4	-	990	25	5	D
	0600	22.4	83	-	990	25	5	D
	1200	22.7	82.5	-	996	25	4	D
	1800	23.0	82.0		996	25	4	D
	0000	Weakened into a well marked low pressure area over northeast Madhya Pradesh & neighbourhood						

Knots: kt, 1 kt = 1.85 kmph, Time in IST= Time in UTC + 0530 hrs

4. Monitoring through satellite and radar:

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the system was monitored since 2nd September, about 9 days prior to the formation of LPA over eastcentral & adjoining northeast BoB on 11th and 10 days prior to formation of depression on 12th. The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites and available ships & buoy observations in the region. The system was also monitored by Doppler Weather RADAR (DWR) Paradip (Odisha). Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions, global models and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the system. A digitized forecasting system of IMD was utilized for analysis and comparison of various models' guidance, decision making process and warning products generation. Typical satellite and radar imageries at the time of crossing Odisha coast are presented in Fig.2.

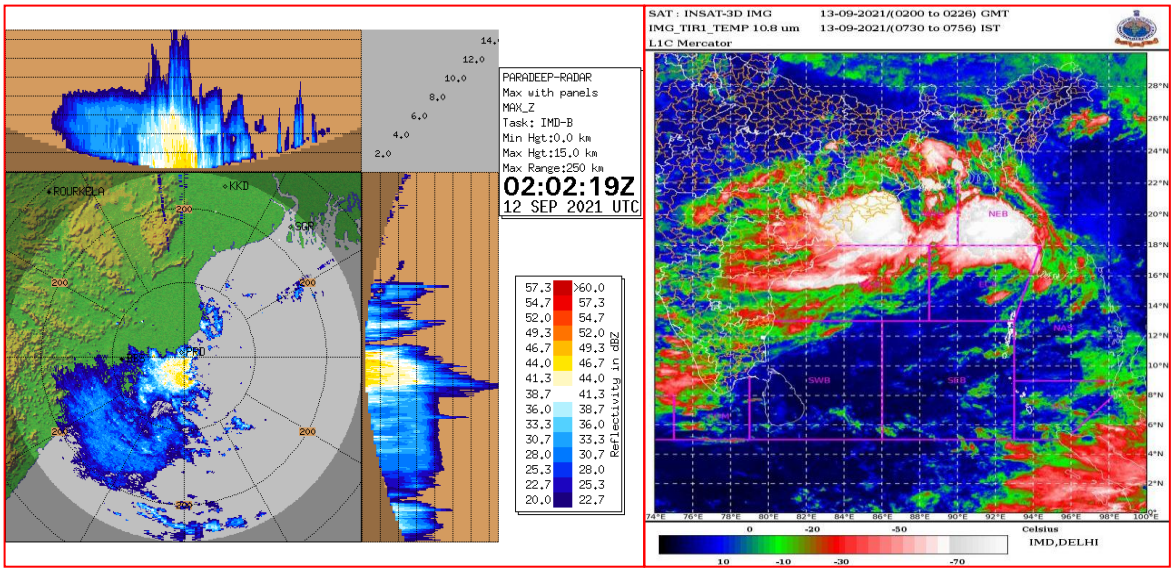


Fig.2: Typical imagery from Doppler weather Radar Paradip and INSAT 3D satellite at the time of crossing the coast on 13th early morning

4.1 Detailed feature observed through Satellites and Radar:

The system was monitored by DWR Paradip. Typical Radar imageries during life cycle of the system are presented in Fig. 3.

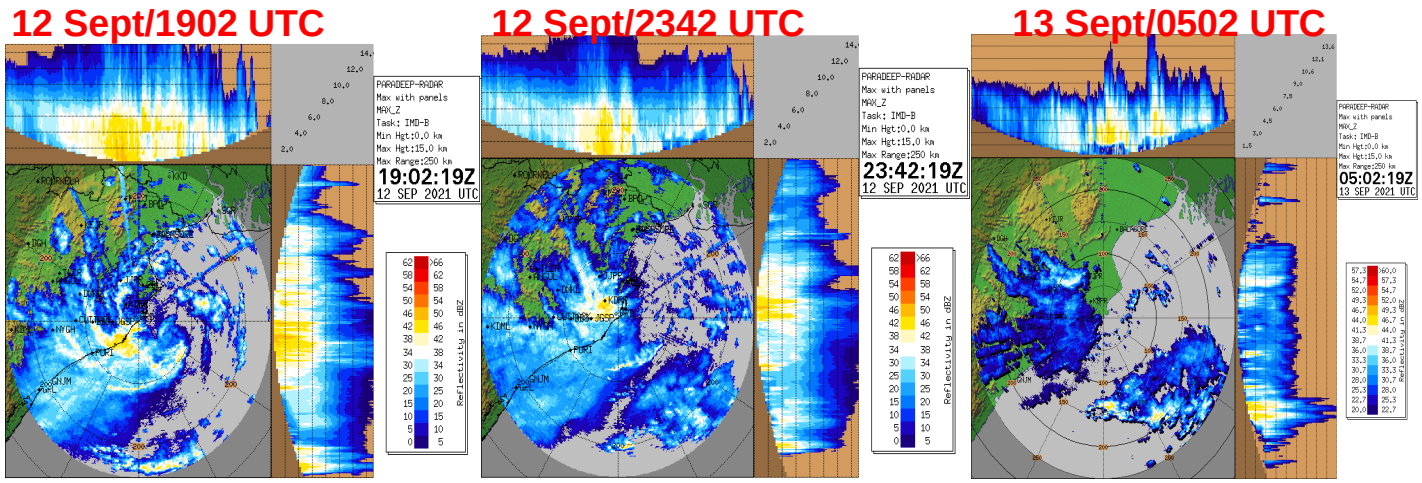


Fig.3: Typical imagery from Doppler weather Radar Paradip during 12- 13 Sept, 2021

Typical INSAT-3D IR, visible, enhanced colored and cloud top brightness temperature imageries during life cycle of the system are presented in Fig. 4.

As per INSAT 3D imagery at 0300 UTC of 12th Sept, the WML over northwest Bay of Bengal& neighbourhood was centered near 19.5^{0}N / 88.0^{0}E. Intensity of the system was T1.0. Associated broken low and medium clouds with embedded intense to very intense convection lay over north & adjoining central Bay of Bengal and east Odisha. Minimum cloud top temperature was -93^{0}C.

As per INSAT 3D imagery at 0300 UTC of 13th Sept, the system lay over land. Associated broken low and medium clouds with embedded intense to very intense convection lay over northwest & adjoining westcentral Bay of Bengal, Odisha and adjoining

north coastal Andhra Pradesh and gangetic West Bengal. Minimum cloud top temperature is -93^{0}C.

As per INSAT 3D imagery at 0300 UTC of 14th Sept, the system lay over land. Associated broken low and medium clouds with embedded intense to very intense convection lay over Chhattisgarh, south Jharkhand, Gangetic West Bengal, Odisha, and adjoining northwest Bay of Bengal & neighbourhood. Minimum cloud top temperature was -90 ^{0}C.

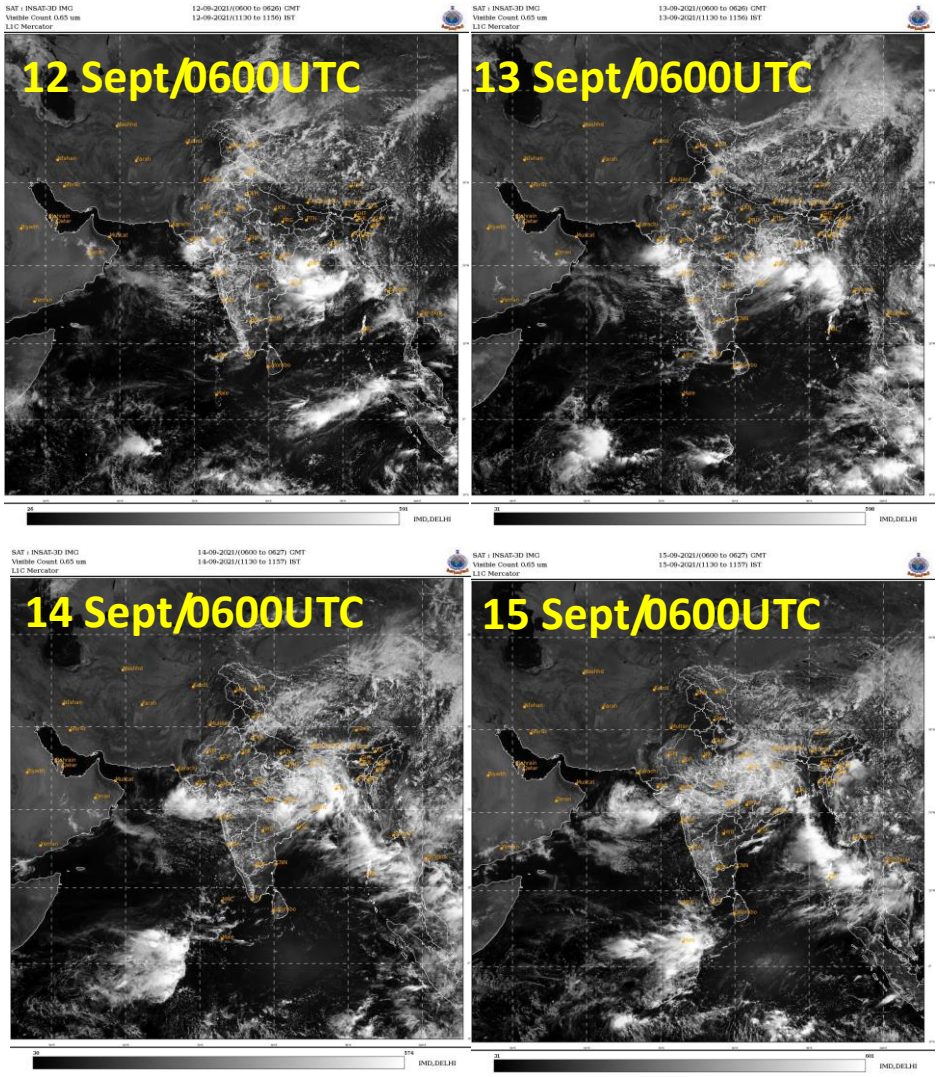


Fig. 4(i): INSAT-3D Visible imageries during 12-15 Sept, 2021

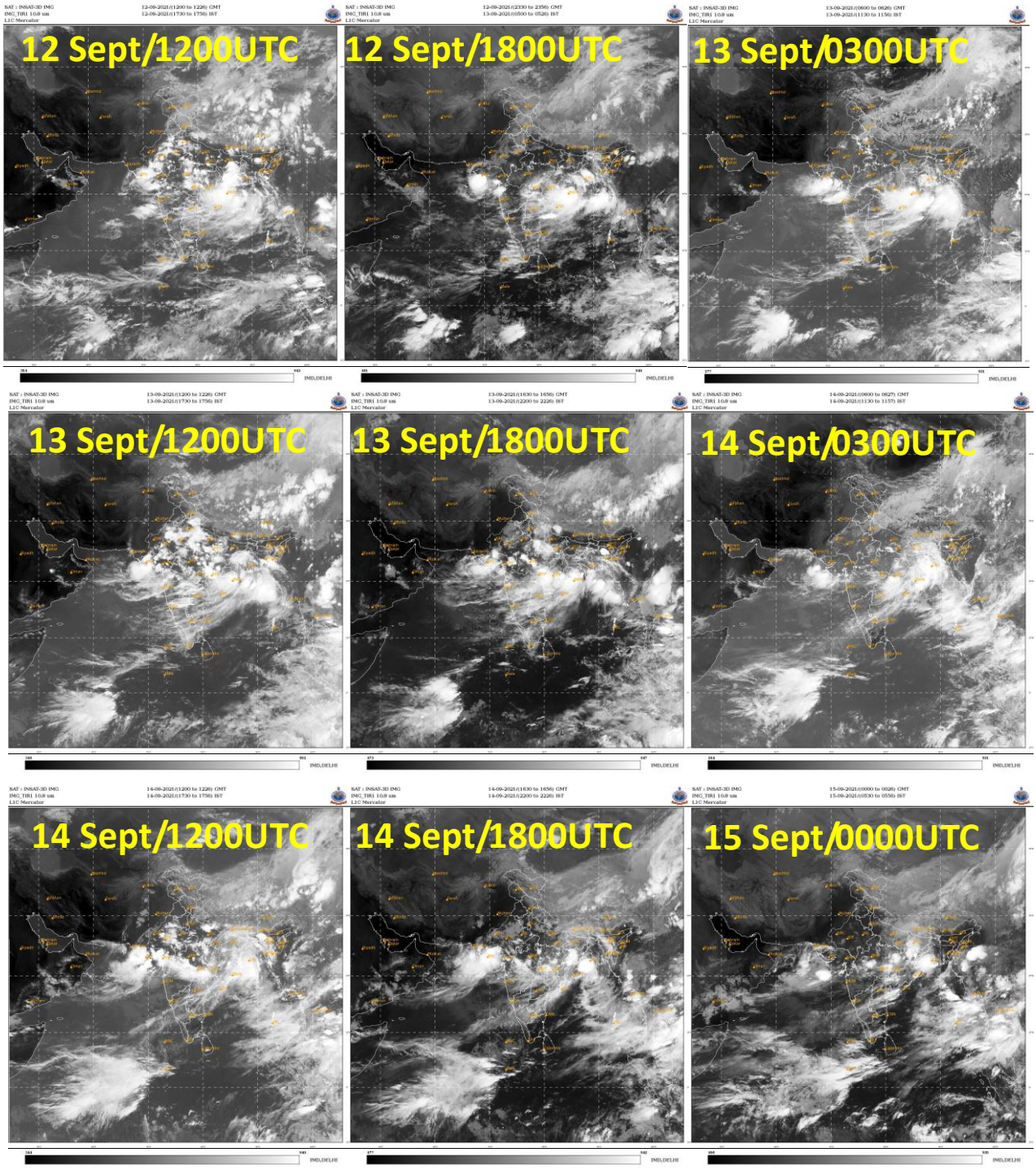


Fig. 4(ii): INSAT-3D IR imageries during 12-15 Sept, 2021

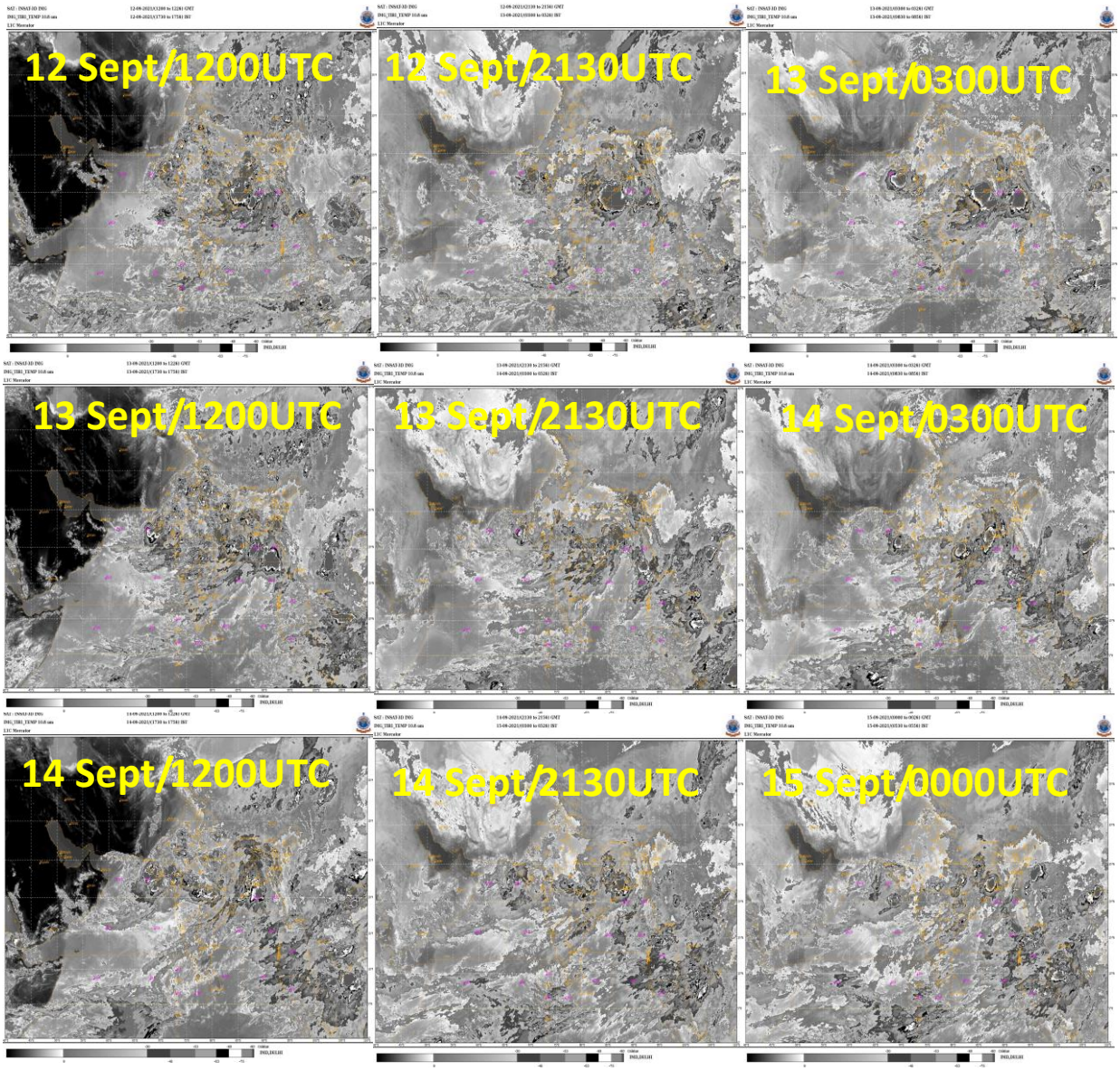


Fig. 4(iii): INSAT-3D BD imageries during 12-15 Sept, 2021

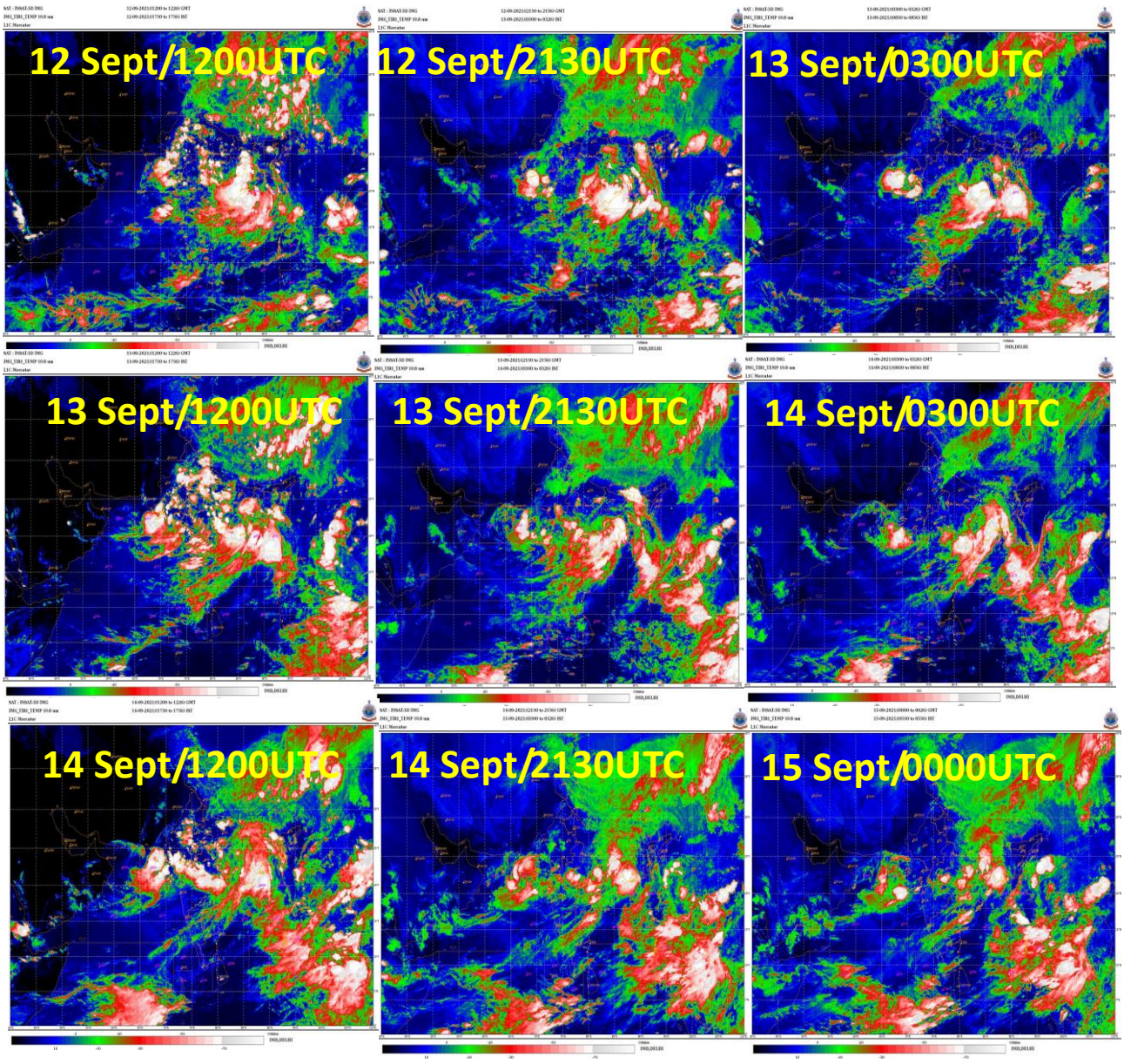


Fig. 4(iv): INSAT-3D enhanced color imaginaries imageries during 12-15 Sept, 2021

5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10 m, 850, 500 and 200 hPa levels are presented in Fig.5. The analysis field of IMD GFS at 0000 UTC of 12th September indicated a deep depression over northwest BoB off Odisha coast with vertical extension upto 500 hPa level. East-southeasterly winds prevailed in the upper level indicating west-northwestwards movement. GFS slightly over-estimated the intensity at 0000 UTC of 12th, as system lay as a WML over northwest BoB at that time.

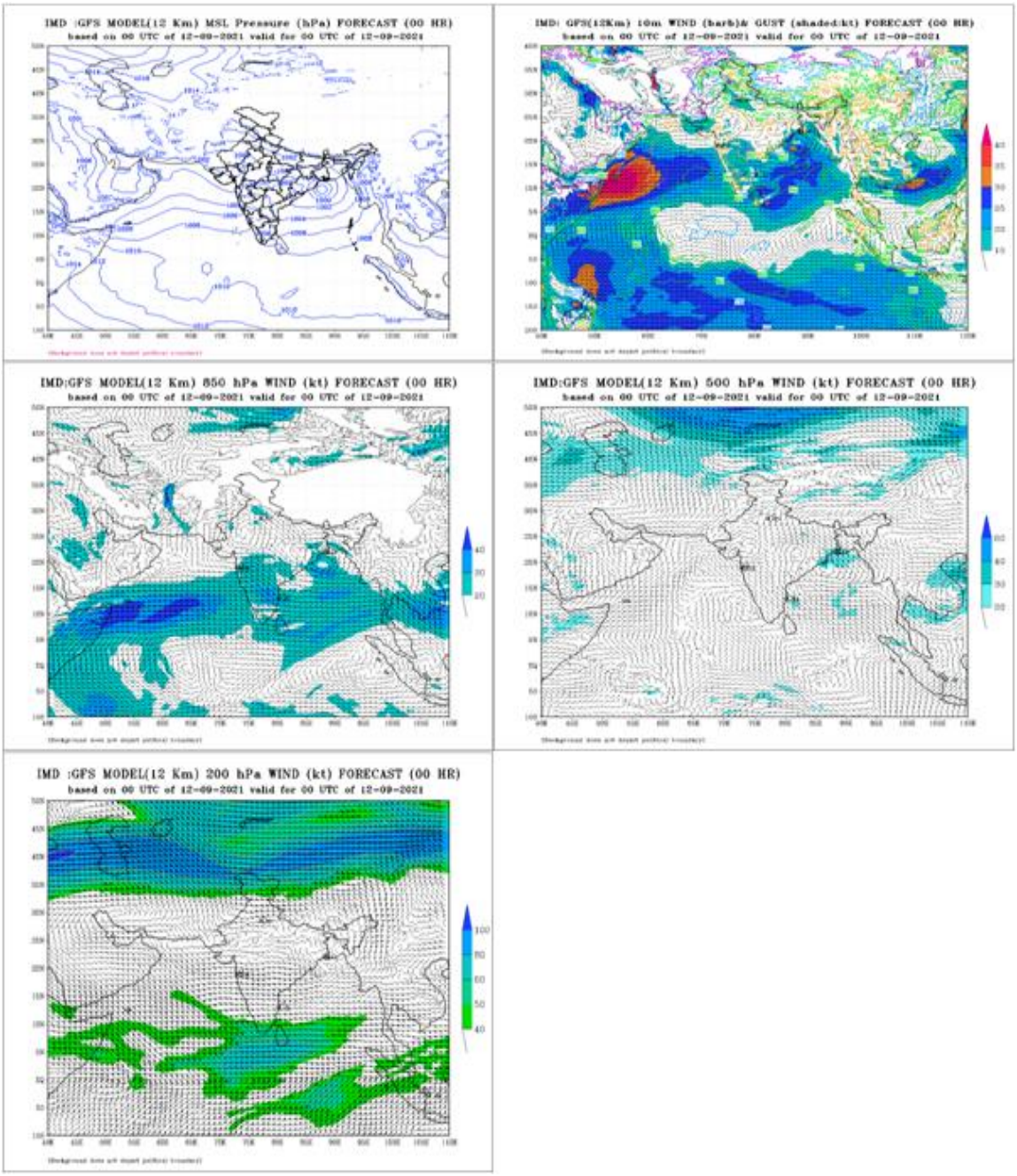


Fig5 (i): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 12 September, 2021

The analysis field of IMD GFS at 0000 UTC of 13th September indicated further intensification of system north Odisha coast with vertical extension upto 500 hPa level. However, GFS slightly over-estimated the intensity at 0000 UTC of 13th, as system lay as a deep depression over north coastal Odisha at that time. However, movement and landfall time was correctly picked up.

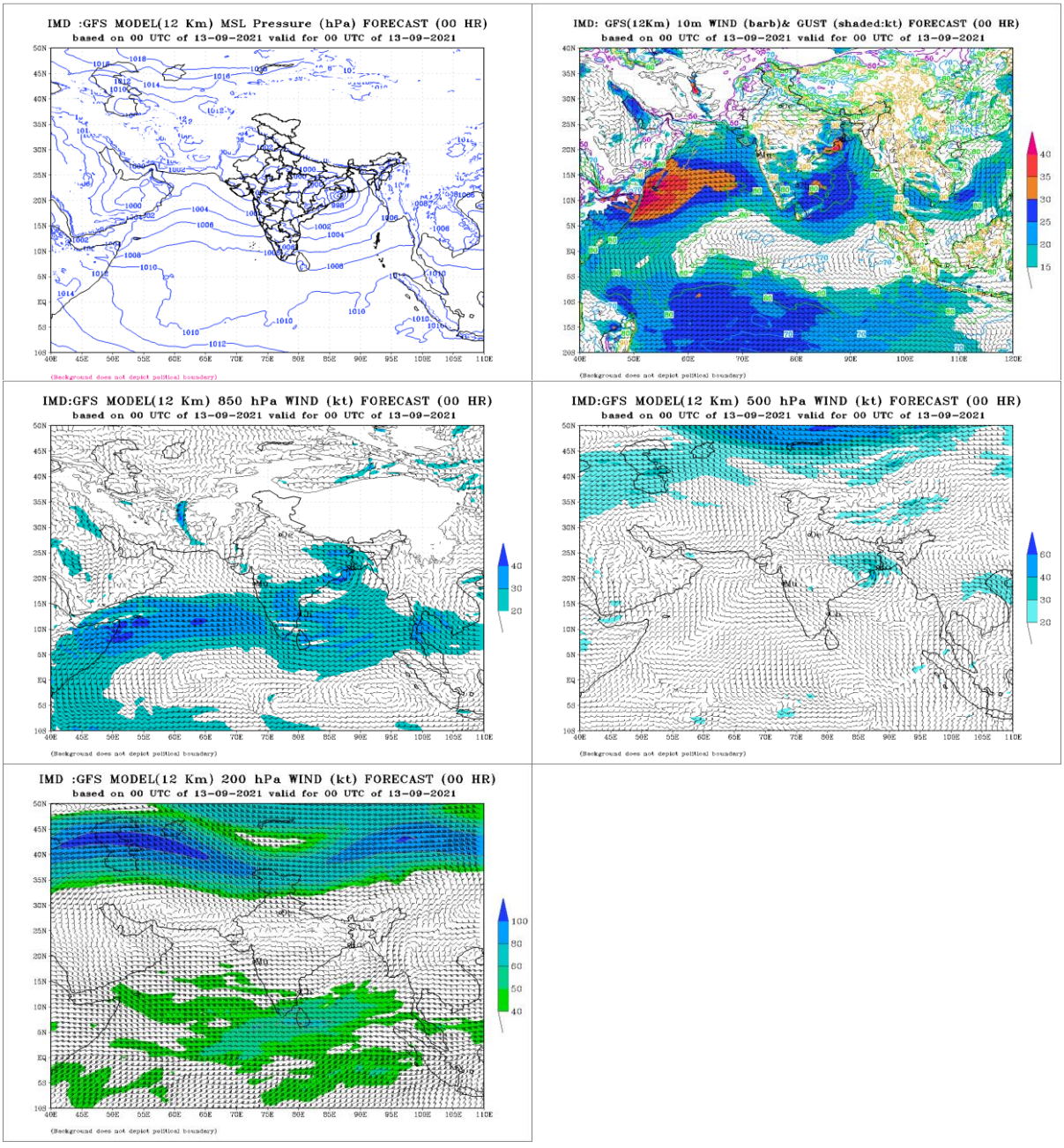


Fig5 (ii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 13 September 2021

The analysis field of IMD GFS at 0000 UTC of 14th September indicated weakening of system over interior Odisha.

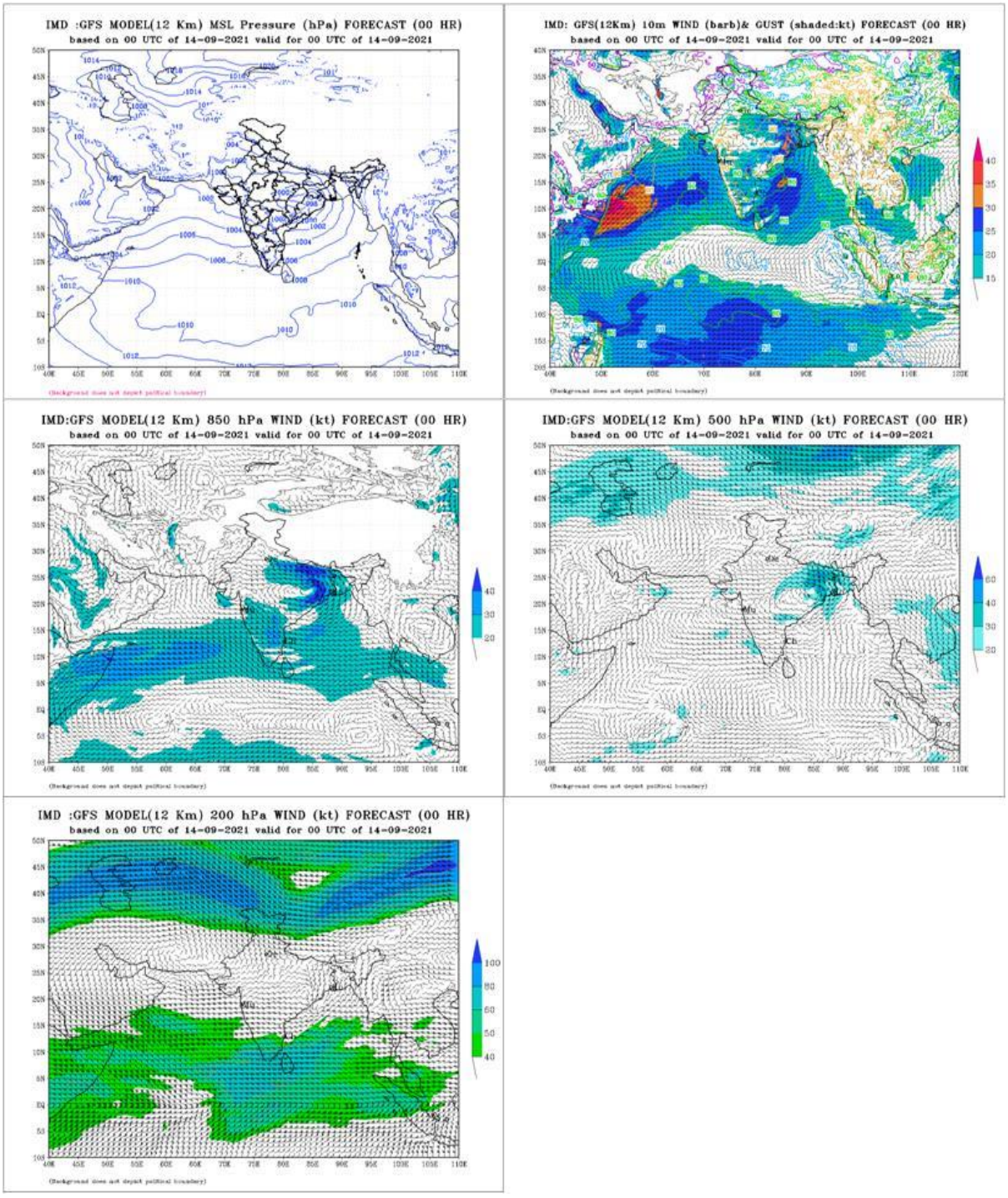


Fig5 (iii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 14th September 2021

Thus, IMD GFS could capture the genesis and movement correctly. However, it slightly over estimated the intensity of the system.

6. Realized Weather:

6.1 Rainfall:

Under the influence of deep depression, active to vigorous monsoon conditions prevailed leading to extremely heavy rainfall at a few places over Odisha on 12th & 13th, at isolated places over Chhattisgarh on 13th and over East Madhya Pradesh on 14th. In conjunction with another low pressure area over Gujarat, extremely heavy rainfall at a few places also occurred over Saurashtra and north Konkan on 13th September. Low level convergence of wind & enhanced moisture incursion from the Bay of Bengal in association with a trough extending eastwards across the system also caused extremely heavy rains at isolated places over West Bengal on 14th September.

The daily rainfall distribution ending at 0300 UTC of each date during 9-15 Sept, 2021 based on merged gridded rainfall data of IMD/NCMRWF is shown in Fig.6.

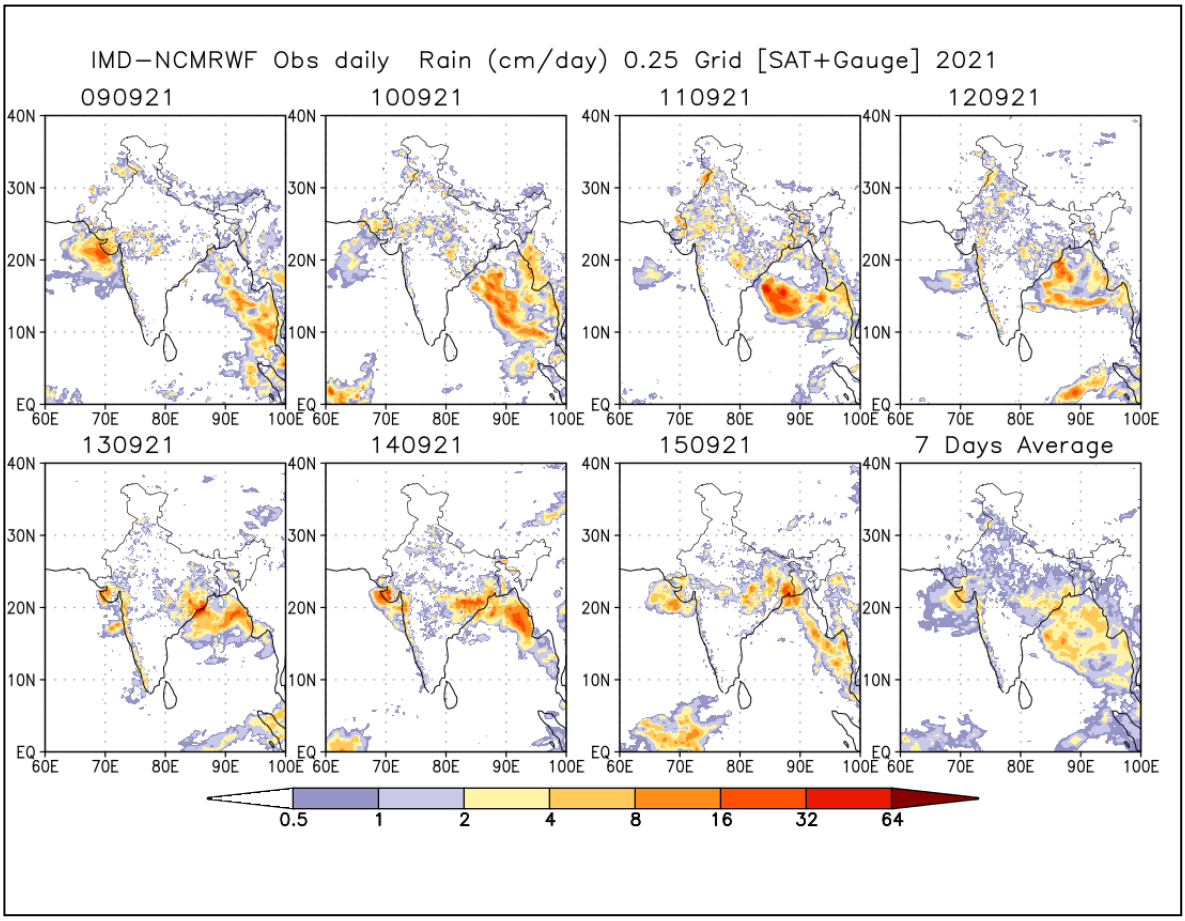


Fig.6: Daily rainfall distribution based on merged grided rainfall data of IMD/NCMRWF during 9-15 Sept 2021

(Heavy rainfall distribution: Isolated places: upto 25%, A few places: 26-50%, Many places : 51-75%, Most places: 76-100% of total stations in the region;
Heavy rainfall: 64.5 – 115.5 mm, Very heavy rainfall: 115.6 – 204.4 mm, Extremely heavy rainfall: 204.5 mm or more).
The 24 hour cumulative rainfall (≥ 7 cm) ending at 0830 hours IST of date during 13th -15th August is presented below:

Datewise 24 hours accumulated rainfall (≥ 7cm) ending at 0830 hours IST of date in association with the system:

12th September

Odisha

Paradeep -13, Jagatsinghpur, Tentulikhunti & Balikuda-10 each, Kujanga & Tihidi-9 each, Bari, Rajkishorenagar & Derabis – 8 each and Bissem-Cuttack, Rajgangpur, Kalampur, Lahunipara, Alipingal, Rajkanika & Marsaghai-7 each

13th September

Odisha

Astaranga & Kakatpur-53-each, Balikuda-44, Kantapada-38, Niali-37, Puri-34, Gop & Satyabadi-33-each, Ragunathpur-32, Balipatna & Kendrapada-28-each, Marshaghai & Kujanga-27, Jagatsinghpur & Pipili-26-each, Tirtol-25, Brahmagiri-24, Paradeep & Chandikhol-22-each, Derabis-21, Tangi, Birmaharajpur & Bhubaneswar-20-each, Boudhgarh & Krishnaprasad-18-each, Garadpur-17, Nayagarh, Ullunda, Harabhanga, Phulbani, Binjharpur, Bolagarah, Mahanga & Sonepur-15-each, Salipur & Banpur-14, Odagaon, Bari & Ranpur-13-each, Jajpur, Banki & Cuttack-12, Dashpalla & Rairakhol-11-each, Lakhanpur-10,

14th September

Odisha

Talcher - 39, Birmaharajpur - 37, Tikarpara - 35, Sonepur - 28, Boudhgarh - 26, Patnagarh & Banarpal - 25 each, Bolangir, Hindol & Paikmal - 24 each, Kantamal & Parjang - 23 each, Barmul & Belpada - 22 each, Bari, Jenapur, Phiringia, Gaisilet & Mahanga – 21 each, Angul, Nawapara, Kamakhyanagar, Tarva & Athmalik – 20 each, Altuma, Harabhanga, Banki, Gania & Narsinghpur – 19 each, Rajkishorenagar, Phulbani, Kankadahad & Agalpur-18 each, Jharbandh, Binjharpur, Bhuban & Dhenkanal -17 each, Daitari, Athgarh, Khairamal, Rajghat, Chandikhol, Khaprakhol, Padampur – 16 each, Ullunda & Salebhatta – 15 each, Sukinda, Danagadi & Tikabali 14 each, Balasore, Telkoi, Komna, Tigiria, Salepur & Naraj – 13 each, Dunguripalli, Daspalla & Cuttack-12 each, Jaleswar, Korei, Loisingha, Jajpur & Rairakhol -11 each, Rengali, Turekela & Saintala - 10 each, Barpalli, Madanpur Rampur, Jagannath Prasad, Karlamunda, Harichandanpur, Burla, Baliguda, Chendipada, Kaniha, Atabira , K Nuagaon & Kotagarh - 9 each, Chandbali, Bhadrak, Akhuapada, Nh5 Gobindpur, Kalinga, Pallahara, Kujanga, Rajkanika, Raikia, G Udayagiri, Bargarh, Similiguda , Daringibadi, Bonth, Batli, Mundali, Dhamnagar & Jujumura - 8 each and Bhograi, Nawana, Anandpur, Belaguntha, Khandapara, Bijepur, Niali, Kaptipada, Narla, Bhanjnagar, Nischintakoili, Belgaon & Betanati – 7 each.

Gujarat Region:

Kaprada -19, Dharampur - 17, Waghai - 14, Valsad - 13, Valsadkvkaws - 12, Dholera , Umergam & Dangs – 11 each, Vansda - 10, Quant, Uchchhal & Khergam – 9 each, Surat City, Subir, Daman & Chhota Udepur – 8 and Mangrol, Pardi & Surat – 7 each.

Saurashtra & Kutch:
Lodhika - 52, Visavadar - 47, Kalavad - 41, Dhoraji -25, Targhadia - 24, Junagadh & Kotdasangani - 21 each, Rajkot , Junagarh & Keshod - 20, Gondal & Jamkandorna – 19 each, Paddhari - 18, Ranavav -16, Talala & Mendarda – 15 each, Porbandar - 14, Malia - 13, Vanthali, Jamnagar, Jamjodhpur & Upleta – 12 each, Dhrol, Manavadar, Vadia & Bhesan – 11 each, Lalpur, Kutiana, Bhanvad & Kalyanpur – 10 each, Jetpur, Tankara & Jamnagarkvkaws – 9 each, Una, Veraval & Diu (dist Diu) - 8 each and Gir Gadhada & Dwarka 7 each.

Chhattisgarh:
Gariabund-20, Basana-19, Magarlod, Bagbahara & Chhura-14 each, Kurud-13, Rajim, Mahasamund & Saraipali-11 each, Raipur & Labhandih-10 each, Patan-9, Arang & Mana-raipur, Kartala & Abhanpur 8 each and Sakti, Bilaigarh, Saja & Gandai-7 each

15th September

Gangetic West Bengal:
Kharagpur-28, Midnapore-28, Kalaikunda & Mohanpur-27 each, Midnapore-26, Uluberia AWS-20, Contai & Diamond Harbour-18 each, Durgachack-17, Dum Dum-16, MO Salt Lake-14, Barrackpur-13, Lalgarh & Burdwan -12 each, Jhargram -11, Alipore & AMFU Kakdwip-10 each, Harinkhola, Canning & Digha-9 each, Bagati-8 and Kalyani -7

Chhattisgarh:-Pendra Road-18, Dhamtari-15, Marwahi-13, Gurur-12, Dondilohara & Mainpat-11each, Pendra, Jashpurnagar & Mungeli-10, Balod, Dongargaon, Lakhanpur & Kota-9, Gariabund, Gundardehi, Mohla, Chhuikhadan, Surajpur, Katghora & Bemetara-8 each and Duldula, Batoli, Khairagarh, Ambagarh Chowki, Rajpur, Pusaur, Gandai, Baloda Bazar, Sarangarh & Manora-7each.

West Madhya Pradesh:-Khirkiya—11 and Budhni & Bhimpur-7 each,
East Madhya Pradesh:
Amarkantak-24, Lanji-13, Balaghat--10, Karanjia-9, Kotma-8 and Channodi & Lalburra-7 each.

Odisha: Chandanpur-15, Ghatagaon-13, Bhograi & Sundargarh-12, Kakatpur-11, Deogaon & Banaigarh-10, Lathikata & Bangiriposi-9, Jamsolaghat, Gurundia, Lahunipara & Jharsuguda-8, Gunupur & Jaleswar-7

Gujarat Region:-Mangrol-16 and Mahuva, Chhota Udepur-7 each.
Saurashtra & Kutch:
Mangrol(J)-16, Vanthali & Junagadh-10 each, Malia, Jamkandorna & Jamjodhpur-9 each and Rajula, Anjar & Bhanvad-7 each.

Vidarbha:-Gondia -7

6.2 Realised wind:

At 1200 UTC of 12th, a buoy located near 17.5^0 N/89.1^0 E reported mean sea level pressure (MSLP) of 1001.9 hPa and winds of 100^0/21.4 kt. Another Buoy near 16.3^0 N/ 87.9^0 E reported 1002.4 hPa and winds of 200^0/15.6 kt. Another Buoy near 13.9^0 N/86.9^0 E reported 1005.2 hPa and winds of 220^0/19.4 Kt.

At 0300 UTC of 13th a buoy located near 17.5^0 N/ 89.1^0 E MSLP of 1001.9 hPa and winds of 100^0/21.4 kt. Another buoy near 16.3^0 N/ 87.9^0 E reported 1002.4 hPa and winds Of 200^0/15.6 kt. Another buoy near 13.9^0 N/ 86.9^0 E reported 1005.2 hPa and winds of 220^0/19.4 kt.

7. Damage by Deep Depression

The record heavy rain over Odisha claimed the lives of at least 3 persons, hit over 19.53 lakh people and inundated extensive areas in 11 districts, prompting authorities to launch evacuation of people from low lying areas of coastal Odisha.

(a) Vehicles wade through a waterlogged road during rain in Puri, on September 12, 2021 (source: https://www.indiatoday.in/ dated 14/09/2021)
(b) Bhubaneswar railway station (source:https://www.downtoearth.org.in/ dated 13/09/2021)
(c) A tree uprooted on Nandankanan-KIIT Road in Bhubaneswar (source:https:// https://odishatv.in// dated 13/09/2021)
(d) Heavy rain in the wake of a deep depression in the Bay of Bengalis likely to have caused the accident on a bridge over river Nandira when the goods train was on its way from Firozpur to Khurda Road (source: https://economictimes.indiatimes.com/ dated 14/09/2021)

8. Bulletins issued by IMD

IMD issued regular bulletins to WMO/ESCAP Panel member countries including Bangladesh and Myanmar, National & State Disaster Management Agencies of Andhra Pradesh, Odisha, Chattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Telangana, Uttar Pradesh and Rajasthan, general public and media. Regular Bulletins every six hourly were issued since formation of depression over northwest BoB. In addition, RSMC New Delhi also issued Press Release and SMS to registered users.

IMD continuously monitored the BoB region and issued warnings to all concerned at central and state level since 2nd September, even before the formation of any cyclonic circulation over the region. A total of 13 national bulletins, 11 RSMC bulletins to WMO/ESCAP Panel member countries, regular Press Release, six hourly SMS to coastal population including fishermen and farmers were issued. Warnings and advisories for fishermen were issued since 11th September. Frequent updates on social networking sites were also issued since 12th September with the formation of low pressure area to trigger mass response and sensitise masses about the impending disaster in association with the system. Regular bulletins were issued at National level by Cyclone Warning Division and at State level by concerned Meteorological Centres of IMD for the states of Odisha, Chattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Telangana, Rajasthan, West Bengal, Gujarat and Telengana.

IMD issued regular warning bulletins to the concerned central and state disaster management authorities and press & media. The verification of heavy rainfall warnings issued by IMD for the depression during 12th-15th September is presented in Table 3. It can be found that the occurrence of heavy rainfall in association with the system could be predicted well in advance.

Bulletins issued by Cyclone Warning Division of IMD in association with the system are given in Table 2

Table 2(a): Bulletins issued by Cyclone Warning Division, IMD, New Delhi

S. No.	Bulletins	No. of Bulletins	Issued to
1	National Bulletin	13	1. IMD's website 2. FAX and e-mail to Control Room NDM, Ministry of Home affairs, Control Room NDMA, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Director Indian Railways, Indian Navy, IAF, Chief Secretary: Odisha, Chattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Telangana, Rajasthan, West Bengal, Gujarat and Telengana
2	RSMC Bulletin	11	1. IMD's website 2. All WMO/ESCAP member countries through GTS and E-mail. 3. Indian Navy, IAF by E-mail
3	Press Release	1	1. Disaster Managers, Media persons by email and uploaded on website

4	Facebook /Twitter	14 times	Highlights uploaded on facebook/twitter since formation of low pressure area.
5	SMS	54202 8,11,106	Sent to general public and fishermen Sent to farmers of Odisha, Chattisgarh and Madhya Pradesh through Kisan portal

Table-2(b): Bulletins issued by Cyclone Warning Centre (CWC) Visakhapatnam / ACWC Kolkota/CWC Bhubaneswar

S. N.	Type of Bulletin	Number of Bulletins		
		CWC Visakhapatnam	ACWC Kolkota	CWC Bhubaneswar
1.	Sea Area Bulletins	NIL	5	NA
2.	Coastal Weather Bulletins	7	5	12
3.	Fishermen Warnings issued	12	5	20
4.	Port Warnings	4	4	12
5.	Heavy Rainfall Warning	1	6	11
6.	Gale Wind Warning	NIL	4	07
7.	Storm surge warning	NIL	NIL	NIL
8.	Information & Warning issued to State Government and other Agencies	NIL	6	11
9.	SMS/ Whatsapp (message in group)	1789	5000	>20763

9. Operational Forecast Performance

9.1. Genesis, track, landfall and intensity forecast performance:

1. First information about the expected formation of an LPA over BoB was released in the extended range outlook issued by IMD on 2nd September (about 9 days ahead of formation of LPA on 11th)
2. The Tropical Weather Outlook issued at 1200 hours IST of 7th September indicated expected formation of an LPA over north BoB around 11th (about 90 hours prior to formation of LPA). Actually the LPA formed at 0530 hours IST of 11th .
3. The extended range outlook issued on 9th September indicated expected development of depression around 13th September (about 72 hours ahead of formation of depression). Actually, depression formed at 1730 hours IST of 12th September.
4. The Tropical Weather Outlook issued at 1200 hours IST of 10th September reiterated that the LPA would form over central and adjoining north BoB on 11th and would concentrate into a depression during subsequent 48 hours. It further indicated that the system would move west-northwestwards towards Odisha coast. The LPA actually formed on 11th, depression on 12th and the system moved west-northwestwards under the influence of a sub-tropical ridge lying to it's north and crossed north Odisha coast on 13th.
5. The first bulletin issued at 2100 hours IST of 12th with the formation of depression, indicated that the system would cross north Odisha coast near Chandbali by early morning of 13th. Actually the system crossed north Odisha coast, close to south of Chandbali between 0530 & 0630 hrs IST of 13th.

9.2. Realised Weather Verification

9.2.1.1. Rainfall

Table 3: Verification of heavy rainfall warning issued by IMD for deep depression over northwest Bay of Bengal and neighborhood (12-15 Sept, 2021)

Date/Base Time of observation (UTC)	24 hr Heavy rainfall warning ending at 0830 hrs IST of next day	Realised 24-hour heavy rainfall ending at 0300 UTC of date
13/09/2021 0300 UTC	Heavy to very heavy rainfall at a few places & extremely heavy falls at isolated places very likely over Odisha & Saurashtra and heavy to very heavy rainfall & extremely heavy falls at isolated places very likely over Chhattisgarh, South Gujarat region and north Konkan (Palghar District) on 13th September and over southwest Madhya Pradesh, south Gujarat region and Suarashtra on 15th September. Isolated heavy to very heavy falls very likely over north Madhya Maharashtra on 13th & 14th September, heavy rainfall at isolated places over Madhya Pradesh and Vidarbha on 13th, very heavy rainfall at isolated places over Madhya Pradesh on 14th and over adjoining areas of east Madhya Pradesh on 15th. Isolated heavy falls	**12th September** **Odisha** Paradeep -13, Jagatsinghpur, Tentulikhunti & Balikuda-10 each, Kujanga & Tihidi-9 each, Bari, Rajkishorenagar & Derabis – 8 each and Bissem-Cuttack, Rajgangpur, Kalampur, Lahunipara, Alipingal, Rajkanika & Marsaghai-7 each **13th September** **Odisha** Astaranga & Kakatpur-53-each, Balikuda-44, Kantapada-38, Niali-37, Puri-34, Gop & Satyabadi-33-each, Ragunathpur-32, Balipatna & Kendrapada-28-each, Marshaghai & Kujanga-27, Jagatsinghpur & Pipili-26-each, Tirtol-25, Brahmagiri-24, Paradeep & Chandikhol-22-each, Derabis-21, Tangi, Birmaharajpur & Bhubaneswar-20-each, Boudhgarh & Krishnaprasad-18-each, Garadpur-17, Nayagarh, Ullunda, Harabhanga, Phulbani, Binjharpur, Bolagarah, Mahanga & Sonepur-15-each, Salipur & Banpur-14, Odagaon, Bari & Ranpur-13-each, Jajpur, Banki & Cuttack-12, Dashpalla & Rairakhol-11-each, Lakhanpur-10, 14th September **Odisha** Talcher - 39, Birmaharajpur - 37, Tikarpara - 35, Sonepur - 28, Boudhgarh - 26, Patnagarh & Banarpal - 25 each, Bolangir, Hindol & Paikmal - 24 each, Kantamal & Parjang - 23 each, Barmul & Belpada - 22 each, Bari, Jenapur, Phiringia, Gaisilet & Mahanga – 21 each, Angul, Nawapara, Kamakhyanagar, Tarva & Athmalik – 20 each, Altuma, Harabhanga, Banki, Gania & Narsinghpur – 19 each, Rajkishorenagar, Phulbani, Kankadahad & Agalpur-18 each, Jharbandh, Binjharpur, Bhuban & Dhenkanal -17

	over north coastal Andhra Pradesh, Gangetic West Bengal, Jharkhand and Telangana on 13th.	each, Daitari, Athgarh, Khairamal, Rajghat, Chandikhol, Khaprakhol, Padampur – 16 each, Ullunda & Salebhatta – 15 each, Sukinda, Danagadi & Tikabali 14 each, Balasore, Telkoi, Komna, Tigiria, Salepur & Naraj – 13 each, Dunguripalli, Daspalla & Cuttack-12 each, Jaleswar, Korei, Loisingha, Jajpur & Rairakhol -11 each, Rengali, Turekela & Saintala - 10 each, Barpalli, Madanpur Rampur, Jagannath Prasad, Karlamunda, Harichandanpur, Burla, Baliguda, Chendipada, Kaniha, Atabira , K Nuagaon & Kotagarh - 9 each, Chandbali, Bhadrak, Akhuapada, Nh5 Gobindpur, Kalinga, Pallahara, Kujanga, Rajkanika, Raikia, G Udayagiri, Bargarh, Similiguda , Daringibadi, Bonth, Batli, Mundali, Dhamnagar & Jujumura - 8 each and Bhograi, Nawana, Anandpur, Belaguntha, Khandapara, Bijepur, Niali, Kaptipada, Narla, Bhanjnagar, Nischintakoili, Belgaon & Betanati – 7 each.
14/09/2021 0300 UTC	**14th September:** Heavy to very heavy rainfall & extremely heavy falls at isolated places likely over Chattisgarh & east Madhya Pradesh, heavy to very heavy rainfall at isolated places likely over interior Odisha, south Gujarat Region, Saurashtra, north Konkan, north Madhya Maharashtra and heavy rainfall at isolated places over Vidarbha, Jharkhand, Gangetic West Bengal, east Uttar Pradesh and East Rajasthan,. **15th September:** Heavy to very heavy & extremely heavy falls at isolated places very likely over Gujarat State & Madhya Pradesh; heavy to very heavy rainfall at isolated places over north Konkan and heavy rainfall at isolated places over Chhattisgarh, east Uttar Pradesh and	Gujarat Region: Kaprada -19, Dharampur - 17, Waghai - 14, Valsad - 13, Valsadkvkaws - 12, Dholera , Umergam & Dangs – 11 each, Vansda - 10, Quant, Uchchhal & Khergam – 9 each, Surat City, Subir, Daman & Chhota Udepur – 8 and Mangrol, Pardi & Surat – 7 each. Saurashtra & Kutch: Lodhika - 52, Visavadar - 47, Kalavad - 41, Dhoraji - 25, Targhadia - 24, Junagadh & Kotdasangani - 21 each, Rajkot , Junagarh & Keshod - 20, Gondal & Jamkandorna – 19 each, Paddhari - 18, Ranavav -16, Talala & Mendarda – 15 each, Porbandar - 14, Malia - 13, Vanthali, Jamnagar, Jamjodhpur & Upleta – 12 each, Dhrol, Manavadar, Vadia & Bhesan – 11 each, Lalpur, Kutiana, Bhanvad & Kalyanpur – 10 each, Jetpur, Tankara & Jamnagarkvkaws – 9 each, Una, Veraval & Diu (dist Diu) - 8 each and Gir Gadhada & Dwarka 7 each. **Chhattisgarh:** Gariabund-20, Basana-19, Magarlod, Bagbahara & Chhura-14 each, Kurud-13, Rajim, Mahasamund & Saraipali-11 each, Raipur & Labhandih-10 each, Patan-9, Arang & Mana-raipur, Kartala & Abhanpur 8 each and Sakti, Bilaigarh, Saja & Gandai-7 each **15th September** Gangetic West Bengal: Kharagpur-28, Midnapore-28, Kalaikunda & Mohanpur-27 each, Midnapore-26, Uluberia AWS-20, Contai & Diamond Harbour-18 each, Durgachack-17, Dum Dum-16, MO Salt Lake-14, Barrackpur-13, Lalgarh & Burdwan -12 each, Jhargram -11, Alipore & AMFU Kakdwip-10 each, Harinkhola, Canning & Digha-9 each, Bagati-8 and Kalyani -7 Chhattisgarh:-Pendra Road-18, Dhamtari-15, Marwahi-13, Gurur-12, Dondilohara & Mainpat-11each, Pendra, Jashpurnagar & Mungeli-10, Balod, Dongargaon, Lakhanpur & Kota-9, Gariabund, Gundardehi, Mohla, Chhuikhadan, Surajpur, Katghora

	East Rajasthan. **16th September:** Heavy to very heavy rainfall at isolated places very likely over Gujarat State, east Rajasthan and west Madhya Pradesh, and heavy rainfall at isolated places very likely over east Uttar Pradesh, Haryana, Chandigarh & Delhi, west Madhya Pradesh, east Rajasthan and north Konkan**.**	& Bemetara-8 each and Duldula, Batoli, Khairagarh, Ambagarh Chowki, Rajpur, Pusaur, Gandai, Baloda Bazar, Sarangarh & Manora-7each. West Madhya Pradesh:-Khirkiya—11 and Budhni & Bhimpur-7 each, East Madhya Pradesh: Amarkantak-24, Lanji-13, Balaghat--10, Karanjia-9, Kotma-8 and Channodi & Lalburra-7 each. Odisha: Chandanpur-15, Ghatagaon-13, Bhograi & Sundargarh-12, Kakatpur-11, Deogaon & Banaigarh-10, Lathikata & Bangiriposi-9, Jamsolaghat, Gurundia, Lahunipara & Jharsuguda-8, Gunupur & Jaleswar-7 Gujarat Region:-Mangrol-16 and Mahuva, Chhota Udepur-7 each. Saurashtra & Kutch: Mangrol(J)-16, Vanthali & Junagadh-10 each, Malia, Jamkandorna & Jamjodhpur-9 each and Rajula, Anjar & Bhanvad-7 each. Vidarbha:-Gondia -7

9.2.2.2. Realised Wind

Date/ Base Time of Observation	**Gale/ Squally wind Forecast at 0300 UTC of date**	**Realised 24- hour Gale/ Squally wind Forecast at 0300 UTC of date**
12.09.2021 /1200UTC	Squally wind speed reaching 45-55 kmph to gusting 65 kmph very likely over north & adjoining westcentral Bay of Bengaland along & off Odisha, West Bengal and North Andhra Pradesh coasts on 12th tonight and 13th Sept.	At 1200 UTC of 12th, a buoy located near 17.50 N/89.10 E reported mean sea level pressure (MSLP) of 1001.9 hPa and winds of 1000/21.4 kt. Another Buoy near 16.30 N/ 87.90 E reported 1002.4 hPa and winds of 2000/15.6 kt. Another Buoy near 13.90 N/86.90 E reported 1005.2 hPa and winds of 2200/19.4 Kt. At 0300 UTC of 13th a buoy located near 17.50 N/ 89.10 E MSLP of 1001.9 hPa and winds of 1000/21.4 kt. Another buoy near 16.30 N/ 87.90 E reported 1002.4 hPa and winds Of 2000/15.6 kt. Another buoy near 13.90 N/ 86.90 E reported 1005.2 hPa and winds of 2200/19.4 kt.
13.09.2021 /0300UTC	Squally wind speed reaching 50-60 kmph to gusting 70 kmph very likely over north & adjoining westcentral Bay of Bengaland along & off Odisha, West Bengal and North Andhra Pradesh coasts during next 12 hours and decrease gradually becoming 40 -50 kmph gusting to 60 kmph during subsequent 12 hours.	

10. Summary and Conclusions:

A low pressure area (LPA) formed over eastcentral and adjoining northeast Bay of Bengal(BoB) in the early morning (0530 hrs IST) of 11th September, 2021. It lay as a well marked low pressure area (WML) over northwest and adjoining westcentral BoB in the early morning (0530 hours IST) of 12th. It concentrated into a depression over northwest BoB and adjoining Odisha coast in the evening (1730 hrs IST) of 12th. Moving west-northwestwards, it intensified into a deep depression over northwest BoB very close to Odisha coast in the early morning (0530 hrs IST) of 13th and crossed north Odisha coast, close to south of Chandbali between 0530 & 0630 hrs IST as a deep depression with maximum sustained wind speed of 30 knots (50-60 kmph). Continuing to move further west-northwestwards, it weakened into a depression over north Chhattisgarh & adjoining north interior Odisha in the morning (0830 hrs IST) of 14th and into a WML over northeast Madhya Pradesh & neighbourhood in the early morning (0530 hrs IST) of 15th.

It caused active to vigorous monsoon conditions leading to extremely heavy rainfall at a few places over Odisha on 12th & 13th, at isolated places over Chhattisgarh on 13th and over East Madhya Pradesh on 14th. In conjunction with another low pressure area over Gujarat, extremely heavy rainfall at a few places also occurred over Saurashtra and north Konkan on 13th September. It also caused extremely heavy rains at isolated places over West Bengal on 14th September.

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