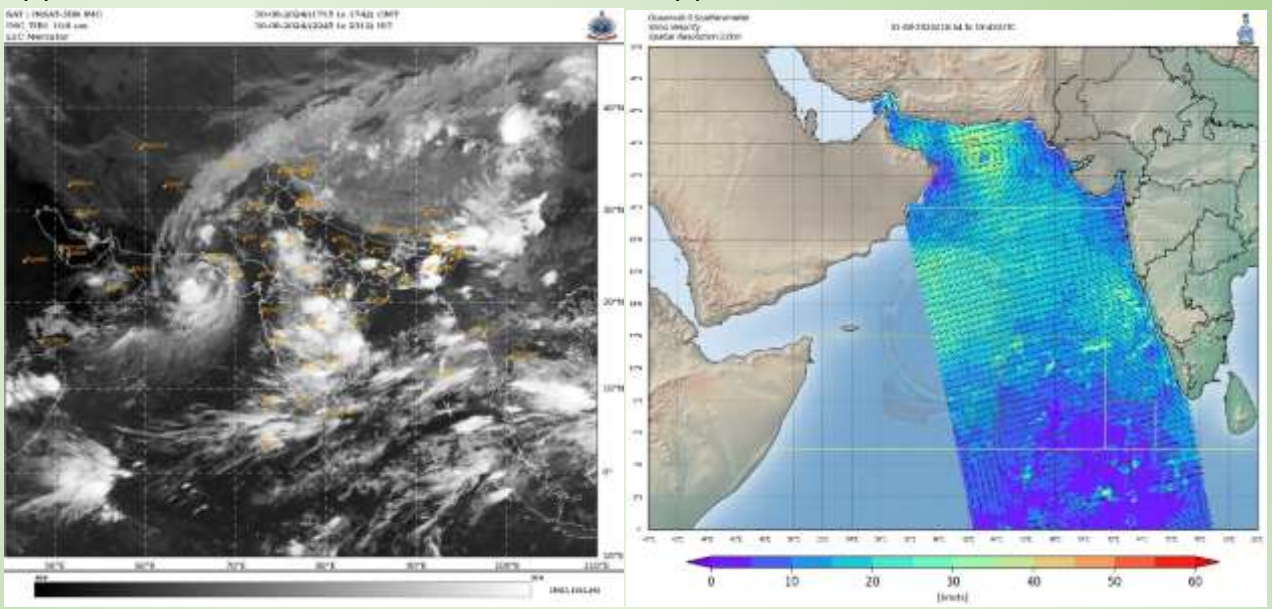
Cyclonic Storm "ASNA" over the Arabian Sea
(25th August-2nd September, 2024) A Report

(a) (b)



Typical (a) INSAT 3D(R) at 2245 hrs IST/ 1715 UTC of 30th August and
(b) Oceansat- 3 Imagery at 2345 hrs IST/1815 UTC of 31st August, 2024 in connection with cyclonic storm "ASNA"

Cyclone Warning Division
India Meteorological Department

New Delhi
September 2024

1. Life History of "ASNA":

- A **Low-pressure area** formed over northwest Bay of Bengal (BoB) and adjoining areas of West Bengal and Bangladesh in the morning (0530 hrs IST/0000 UTC) of 16th August 2024. It lay over South Bangladesh during 17th to 19th August, over Central Bangladesh on 20th and over North Bangladesh on 21st and 22nd August. Thereafter it moved westwards and lay over West Bengal & adjoining Northeast Jharkhand on 23rd August.
- While moving westwards, it concentrated into a well-marked low-pressure area over Southeast Uttar Pradesh (UP) & adjoining areas of northeast Madhya Pradesh (MP) in the morning of 24th August.
- Continuing to move further westwards, it intensified into a **Depression** over Northwest MP in the morning (0530 hours IST/0000 UTC) of 25th August.
- It then moved west-south-westwards and intensified into a **Deep Depression** over East Rajasthan & adjoining West MP in the same midnight (2330 hours IST/1800 UTC) of 25th August. The deep depression continued to move west-south-westwards and lay centred over North Gujarat region by evening (1730 hours IST/1200 UTC) of 26th August.
- It then moved westwards across Gujarat state during 27th -29th August. It emerged into the Northeast Arabian Sea off Kachchh and the adjoining Pakistan coast on 30th August morning (0830 hrs IST/0300 UTC).
- It intensified into a **cyclonic storm (CS) "ASNA"** over northeast Arabian Sea off Kachchh and adjoining Pakistan coast around noon (1130 hours IST/0600 UTC) of 30th August. It then moved nearly westwards, intensified slightly and lay cantered over Northeast Arabian Sea in the morning (0530 hours IST/0000 UTC) of 31st August.
- It then gradually moved south-south-westwards and weakened into a **Deep Depression** in the evening (1730 hours IST/1200 UTC) of the 1st September, 2024 over northwest Arabian Sea.
- Continuing to move further south-south-westwards, it weakened into a **Depression** in the morning (0530 hours IST/0000 UTC) of the 2nd September, 2024 over the northwest Arabian Sea and into a **well-marked low-pressure area** over the same region in the afternoon (1130 hours IST/0600 UTC) of 2nd September, 2024.
- It further weakened into a **low-pressure area** over westcentral & adjoining northwest Arabian Sea in the morning (0830 hours IST/0300 UTC) of 3rd September, 2024.
- The observed track of the cyclonic storm "ASNA" since its inception from a low-pressure area over Northwest Bay of Bengal on 16th August is presented in Fig. 1a and from the stage of depression on 25th August to weakening into a depression on 2nd September is presented in Fig. 1b.

(1a)

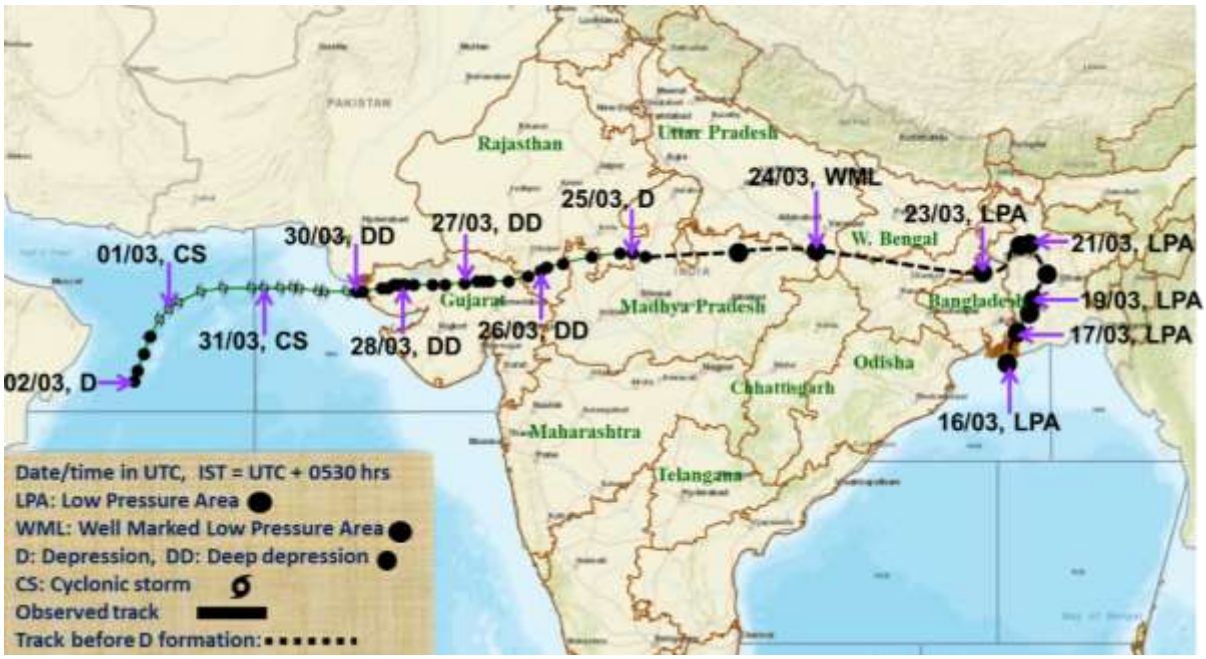


Fig. 1a: Track of Cyclonic Storm "ASNA" during 16th August-02nd September from the stage of low-pressure area

(1b)

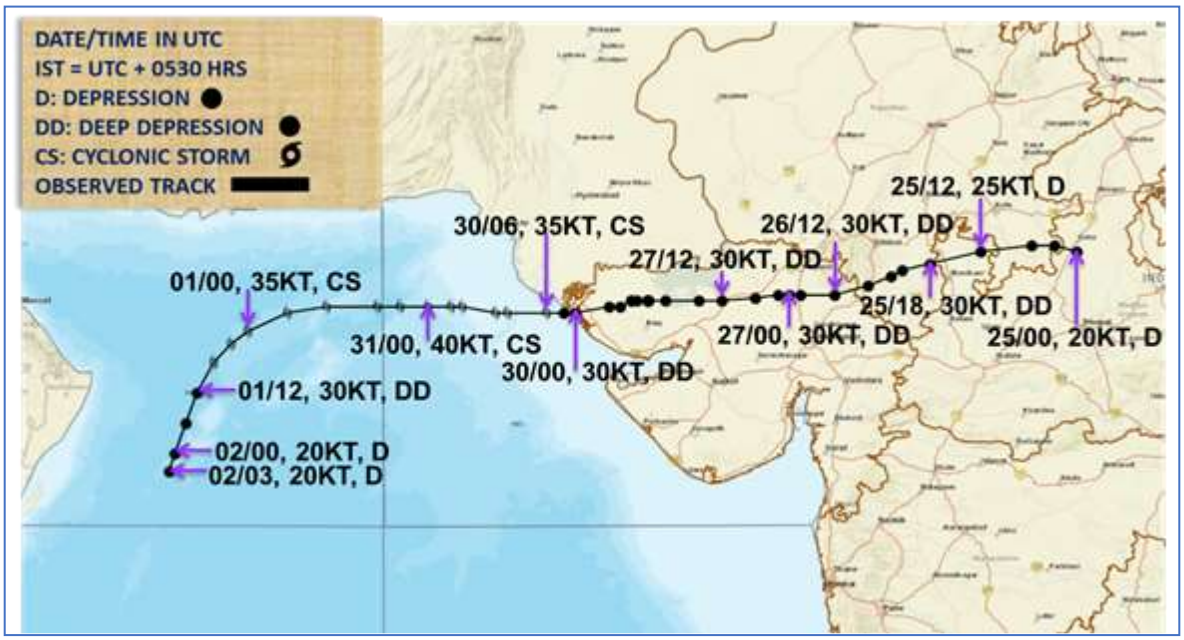


Fig. 1b: Observed track of cyclonic storm "ASNA" over the land/Arabian Sea during 25th August– 2nd September, 2024

2. Salient Features

(i) Salient features compared to climatology:

The development of cyclonic storms in August over the Arabian Sea is a rare activity. However, during 1891-2023, 3 cyclonic storms developed over the Arabian Sea in the years 1944, 1964 and 1976. Out of these 3, 2 developed from low pressure area over North Bay of Bengal and neighbourhood and 1 developed over the Arabian Sea. All three dissipated over the sea **(Fig. 2).** Details of these cyclonic storms are given below:

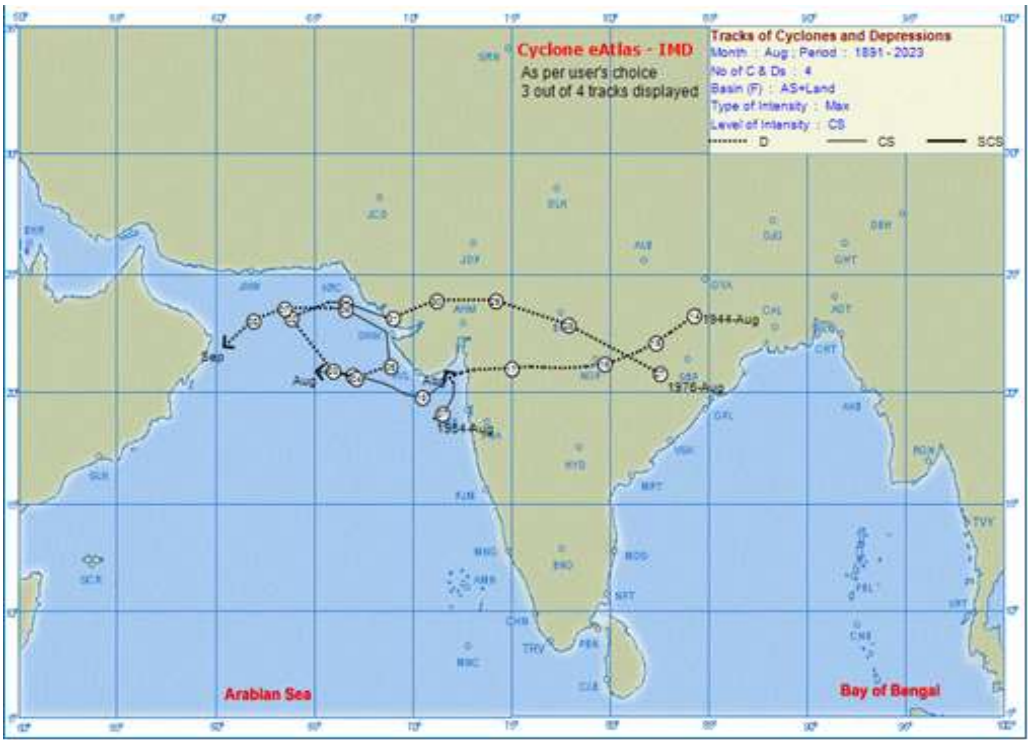


Fig. 2: Tracks of cyclonic storms (≥ 34 knots or 63 kmph) in the month of August during 1891-2023 over the Arabian Sea

➢ **1944**: A depression formed over Jharkhand on 14th August. It moved west-south westwards across central parts of the country and emerged into the Northeast Arabian Sea off the South Gujarat coast. Thereafter, it moved southwestwards and intensified into a cyclonic storm over eastcentral & adjoining northeast Arabian Sea near South Gujarat coast around 18th August. Thereafter, it moved west-northwestwards as a cyclonic storm, away from the Indian coast and weakened over Northeast Arabian on 19th August.

➢ **1964**: A depression formed over Eastcentral Arabian Sea off North Maharashtra coast on 7th August. It moved initially north-northeastwards, intensified into a cyclonic storm for a brief period and gradually recurved north-northwestwards and weakened into a low-pressure area near the South Gujarat coast in the same evening.

➢ **1976**: A depression formed over Odisha on 27th August. It moved across northern parts of the country across Chhattisgarh, East Rajasthan, North Gujarat region and intensified into a cyclonic storm near Saurashtra and Kutch coast on 31st August. Thereafter, it made a loop over the northeast Arabian Sea and weakened near Oman coast on 8th September.

(ii) Movement:

The six hourly average translational speed of "ASNA" was 12.3 kmph against the normal speed of 14.7 kmph for the CS category **(Fig. 3a)** over the Arabian Sea during the monsoon season (June-September). The translational speed initially decreased till 29th midnight (1800 UTC/2330 hrs IST) and increased thereafter becoming maximum around the early morning of 1st September (during the cyclone intensity period). The translational speed decreased thereafter with almost southwards movement and a decrease in the intensity of the system. The decrease in translational speed of the system during the period from 24th to 29th September can be attributed to the presence of a trough in westerly winds in middle tropospheric levels that restricted the westward movement of the system. The increased translational speed on 30th and 31st is attributed to the steering anticyclone over the Arabian Peninsula and adjoining northwest Arabian Sea. It initially moved west-southwestwards till early morning (0000 UTC) of 30th August and then nearly westwards till evening (1200 UTC) of 31st August. Thereafter, it gradually recurved south-southwestwards and weakened into a well-marked low-pressure area over the Northwest Arabian Sea at noon (0600 UTC) on 2nd September.

(ii) Maximum sustained wind speed (MSW) and estimated central pressure (ECP):

No rapid intensification was observed during the life cycle of ASNA. The system reached its peak intensity of maximum sustained wind speed of 40 knots gusting to 50 knots (70-80 kmph gusting to 90 kmph) at 0000 UTC (0530 IST) 31st August with estimated central pressure (ECP) of 990 hPa and pressure drop of about 8 hPa over Northeast Arabian Sea. It was moving in a favourable environment with high sea surface temperature (SST), high positive vorticity at lower levels, low to moderate anticyclonic vertical wind shear (5-15 knots), enhanced warm moist air incursion into the core region of the system from southeast Arabian Sea, favourable Madden Julian Oscillation and convectively coupled equatorial waves (**Fig. 3b**). After, entering northwest Arabian Sea, it encountered colder sea conditions and started weakening gradually from 1st September Morning (0300 UTC).

(iii) Landfall characteristics:

Cyclonic Storm ASNA didn't make any landfall. It rather emerged into sea after moving slowly across Northwest Madhya Pradesh, South Rajasthan and North Gujarat State as a depression/deep depression for 5 days during 25th morning (0530 hours IST/0000 UTC) to 30th morning (0530 hours IST/0000 UTC). Cyclone/Deep depressions/low pressure systems generally weaken during their movement over land. However, this system intensified during its movement over land during west-south-westward movement of the depression. Due to west-south-westward movement over Rajasthan and Gujarat, it got continuous moisture supply from the Arabian Sea and hence intensified into a deep depression and maintained its intensity over land. Further moisture supply and other environmental conditions became favourable over north Arabian Sea for its intensification into cyclonic storm around 30th August noon (1130 hrs IST/0600 UTC)

(iv) Track length:

The total track length of cyclonic storm "ASNA" was 1780 km against average track length of 1032 km.

(v) Life Period:

The total life period (depression to depression) of "ASNA" was 8 days & 6 hours against the normal of 3 days & 18 hours for cyclonic storm category over the NIO in monsoon season based on the data of 1990-2013.

(vi) Accumulated Cyclone Energy and Power Dissipation Index:
The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were $5.1x10^2$ knots, $1.78x10^4$ knots^2 and $0.63x10^6$ knots^3 respectively.

(vii) Dissipation over the sea: "ASNA" dissipated over the sea like the earlier CS in August during the period 1891-2023 indicating the climatological pattern. All models and the observational diagnostics also suggested the weakening of the system over the sea well in advance.

(viii) Adverse weather:
During its different stages of development, i.e. during low pressure area to deep depression stage, while moving over land it affected almost all the states over the eastern and western parts of the country from Tripura, Meghalaya, Gangetic West Bengal, Odisha, Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan & Gujarat State and also Bangladesh leading to extensive flooding and massive damage to life and property. Some of the highest amount of 24 hourly accumulated rainfall during the life period of this system are:

At the stage of low pressure area over northwest Bay of Bengal during 16-22 August, it caused extremely heavy rainfall over Tripura, Meghalaya and Bangladesh leading to massive flooding over these regions. Cherrapunji (Meghalaya) reported 34 cm, Mawsynram (Meghalaya) 25 cm, Bagafa (Tripura) 38 cm & Belonia (Tripura) 32 cm on 19th August; Mawsynram (Meghalaya) reported 34 cm & Agartala (Meghalaya) reported 20 cm on 20th August and Bagafa (Tripura) reported 49 cm on 21st August. Bangladesh also reported heavy to very heavy rainfall over southeast Bangladesh during 17th – 20th August.

Vapi (Gujarat) reported 36 cm & Kathiawada (Madhya Pradesh) 21 cm on 24th August, Khergam (Gujarat) reported 35 cm, Pipalkhunt (East Rajasthan) 26 cm, Rajkot (Saurashtra & Kachchh) 23 cm on 25th August, Tankara (Saurashtra & Kachchh) 36 cm, Morva Hadaf 34 cm (Gujarat region) & Bagidora (East Rajasthan) 20 cm on 26th August; Khambhalia (Saurashtra & Kachchh) reported 43 cm on 27th August, Naliya Saurashtra & Kachchh) 30 cm on 28th August and Mandvi 39 cm on 29th August. Details are discussed in Realised Weather Section. No adverse situations due to strong winds and storm surges were experienced in association with this system.

(ix) Forecast performance:
The genesis, track and intensity, emergence into Arabian Sea, its further intensification into Cyclonic storm and then weakening over Sea was well predicted 3-4 days in advance. The track (intensity) forecast errors were 56 kms (3.2 kts), 110 kms (5.0 kts), 174 kms (1.7 kts) for 24, 48 and 72 hours lead periods respectively. Similarly, the occurrence of heavy to extremely heavy rainfall along its path from Tripura to Gujarat was also predicted well in advance (3-4 days) along with expected damage and suggested actions. Details are given in section 4.

Table1: Best track positions and other parameters of the Cyclonic Storm ASNA over Land/Arabian Sea from 25th August – 02nd September, 2024

Date	Time (UTC)	Lat.	Long.	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (KT)	Estimated Pressure drop at the Centre (hPa)	Grade
25.08.24	0000	24.5	77.3	-	997	20	3	D
	0300	24.6	76.9	-	997	20	3	D
	0600	24.6	76.5	-	996	20	4	D
	1200	24.4	75.6	-	996	25	4	D
	1800	24.3	74.7	-	995	30	5	DD
26.08.24	0000	24.2	74.2	-	995	30	5	DD
	0300	24.1	74.0	-	995	30	5	DD
	0600	23.8	73.6	-	995	30	5	DD
	1200	23.8	73.0	-	995	30	5	DD
	1800	23.8	72.4	-	995	30	5	DD
27.08.24	0000	23.8	72.2	-	995	30	5	DD
	0300	23.8	72.0	-	995	30	5	DD
	0600	23.7	71.7	-	995	30	5	DD
	1200	23.7	71.0	-	995	30	5	DD
	1800	23.7	70.6	-	995	30	5	DD
28.08.24	0000	23.7	70.0	-	995	30	5	DD
	0300	23.7	69.7	-	995	30	5	DD
	0600	23.7	69.7	-	994	30	5	DD
	1200	23.7	69.7	-	994	30	5	DD
	1800	23.7	69.7	-	994	30	5	DD
29.08.24	0000	23.7	69.5	-	994	30	5	DD
	0300	23.7	69.4	-	994	30	5	DD
	0600	23.7	69.4	-	994	30	5	DD
	1200	23.6	69.2	-	994	30	5	DD
	1800	23.6	69.0	-	994	30	5	DD
30.08.24	0000	23.5	68.4	-	994	30	5	DD
	0300	23.5	68.2	2.0	994	30	5	DD
	0600	23.5	67.9	2.5	992	35	6	CS
	0900	23.5	67.5	2.5	992	35	6	CS
	1200	23.5	67.2	2.5	992	35	6	CS
	1500	23.5	67.0	2.5	991	35	7	CS
	1800	23.6	66.4	2.5	991	35	7	CS
	2100	23.6	66.2	25	991	35	7	CS
31.08.24	0000	23.6	65.8	2.5	990	40	8	CS
	0300	23.6	65.3	2.5	990	40	8	CS
	0600	23.6	64.9	2.5	990	40	8	CS
	0900	23.6	64.4	2.5	990	40	8	CS
	1200	23.6	64.4	2.5	990	40	8	CS

	1500	23.6	63.7	2.5	990	40	8	CS
	1800	23.5	63.7	2.5	990	40	8	CS
	2100	23.4	63.0	2.5	990	40	8	CS
01.09.24	0000	23.2	62.6	2.5	990	40	8	CS
	0300	23.0	62.3	2.5	992	35	7	CS
	0600	22.7	62.0	2.5	994	35	6	CS
	0900	22.5	61.8	2.5	994	35	6	CS
	1200	22.2	61.7	2.0	996	30	5	DD
	1800	21.7	61.5	2.0	997	30	5	DD
02.09.24	0000	21.2	61.3	1.5	998	20	4	D
	0300	20.9	61.2	1.5	999	20	3	D
	0600	Weakened into a well-marked low-pressure area over Northwest Arabian Sea.						

Maximum sustained surface wind speed (MSW) in knots (kt), 1 kt = 1.86 kmph, D: Depression, DD: Deep depression, CS: Cyclonic storm, SCS: Severe Cyclonic Storm, ECP: Estimated Central Pressure, C.I. No.: Current Intensity No., ∆P: Pressure drop at centre.

3. Genesis, intensification and movement

3.1 Genesis

At 0000 UTC on 15th August 2024, a cyclonic circulation had formed over South Bangladesh and adjoining Gangetic West Bengal. Under its influence, a Low-Pressure Area was established over the northwest Bay of Bengal and adjoining areas of West Bengal and Bangladesh at 0000 UTC on 16th August 2024 (Fig. 1a). It lay as a Well-Marked Low-Pressure Area over southeast Uttar Pradesh and adjoining northeast Madhya Pradesh at 0300 UTC on 24th August 2024. Moving nearly westward under favourable conditions, it concentrated into a Depression over northeast Madhya Pradesh and its neighbourhood at 0000 UTC on 25th August 2024. Most numerical weather prediction models (IMD GFS, NCEP GFS, GEFS, ECMWF, and NCUM) had shown consensus, indicating that the existing Depression over Madhya Pradesh would move nearly west-south-westwards and intensify into a Deep Depression over South Rajasthan and adjoining North Gujarat around 27th August. The Madden-Julian Oscillation (MJO) index was in phase 3 with amplitude greater than 1. It moved eastwards across phases 3 and 4, with its amplitude remaining close to 1 during the last week of August and the initial 2 to 3 days of September. Consequently, the MJO index enhanced the convective activity over the eastern parts of the Arabian Sea (AS) during this period. Weak westerly winds (1–3 mps) prevailed over southern and adjoining central parts of AS and BoB during both weeks. Also, the Eastward-moving Kelvin waves (KW) were observed over the northern parts of AS and the southern BoB during this period. Zonal winds and equatorial waves supported the convective activities associated with the Depression over Central India and the expected Low-Pressure Area over Bangladesh and its neighbourhood. East-north-easterly winds in the middle levels steered the Depression west-south-westwards over central and west India. The approaching trough in the westerlies favoured the system's intensification and slowed its westerly movement.

3.2 Intensification

Depression over northeast Madhya Pradesh and Neighborhood at 0000 UTC of 25th August 2024, moved west-south-westwards and intensified into a **Deep Depression** over East Rajasthan & adjoining West MP at midnight of 25th August

(2330 hours IST/1800 UTC) of 25th August. The Deep Depression continued to move west-south-westwards and lay centred over North Gujarat region by evening (1730 hours IST/1200 UTC) of 26th August. It then moved westwards across Gujarat state during 27th -29th August. It emerged into the Northeast Arabian Sea off Kachchh and the adjoining Pakistan coast on 30th August morning (0830 hrs IST/0300 UTC). It intensified into a **cyclonic storm (CS) "ASNA" over** northeast Arabian Sea off Kachchh and adjoining Pakistan coast around noon (1130 hours IST/0600 UTC) of 30th August. It then moved nearly westwards, intensified slightly and lay cantered over Northeast Arabian Sea in the morning (0530 hours IST/0000 UTC) of 31st August with a maximum sustained wind speed of 40 KTS.

At 0000 UTC of 26th August 2024, the Madden-Julian Oscillation (MJO) index was in phase 3 with amplitude greater than 1. It moved eastwards across phases 3 and 4, with the amplitude remaining close to 1 during the subsequent five days. The presence of convectively coupled equatorial Rossby waves (ERW) propagating westwards, starting from the South China Sea and Bay of Bengal (BoB) to the southeast and east-central regions during this period. Weak westerly winds (1–3 mps) prevailed over southern and adjoining central parts of the Arabian Sea and Bay of Bengal. Eastward-moving Kelvin waves (KW) were observed over the northern parts of the Arabian Sea and the southern Bay of Bengal. Low-level convergence had increased to around 20×10^{-6} s^{-1} southwest of the system centre. Upper-level divergence was approximately 30×10^{-6} s^{-1} to the southwest of the system centre, extending up to the east-central Arabian Sea. The wind shear was moderate over the system area. Vorticity at the 850 hPa level was around 100×10^{-6} s^{-1} near the system area, extending up to 200 hPa. Thus, a favourable MJO, the presence of equatorial waves, moisture feedback from the Arabian Sea, and moderate wind shear contributed to the conditions.

At 0000 UTC of 27th August 2024, the Madden-Julian Oscillation (MJO) index was in phase 4 with an amplitude greater than 1. It moved across phases 4 and 5, with the amplitude remaining above 1 during the subsequent five days. There was also a significant presence of convectively coupled equatorial Rossby waves (ERW) propagating westwards from the Bay of Bengal (BoB), central India, and the central Arabian Sea during that period. Westerly winds (5–7 mps) were observed over the same region, while strong easterlies (5–7 mps) prevailed over the northwestern parts of India and the northeast Arabian Sea during the same time frame. Eastward-moving Kelvin waves (KW) were also present over the southeast Arabian Sea. These features supported the enhancement of convective activity over the Arabian Sea and the Bay of Bengal. Vorticity at the 850 hPa level was around 250×10^{-6} s^{-1} near the system area, extending up to 200 hPa. Shear tendency was increasing over the system area and decreasing toward southern Pakistan. Low-level convergence was approximately 20×10^{-6} s^{-1} around the system area, while upper-level divergence was also about 20×10^{-6} s^{-1}, extending into the east-central Arabian Sea. The wind shear was moderate (15–25 knots) over the system area.

At 0000 UTC of 28th August 2024, the Madden-Julian Oscillation (MJO) index lay in phase 4 with amplitude greater than 1. It moved across phases 4 and 5, with the amplitude remaining above 1 during the subsequent five days. A significant presence of convectively coupled equatorial Rossby waves (ERW) propagating westwards from the Bay of Bengal, central India, and the central Arabian Sea during the period was also noticed. Westerly winds (5–7 mps) prevailed over the same region, while strong easterlies (5–7 mps) were observed over the north-western parts of India and the northeast Arabian Sea during the same period. Eastward-moving Kelvin waves (KW) were also present over the southeast Arabian Sea. These features favoured the enhancement of convective activity over the Arabian Sea and the Bay of Bengal. Vorticity at the 850 hPa level was around 250×10^{-6} s^{-1} near the system area, extending up to 200 hPa. Shear tendency had increased over the system area and decreased toward southern Pakistan. Low-level convergence was approximately 20×10^{-6} s^{-1} southwest of the system area. Upper-level divergence was about 20×10^{-6} s^{-1} southwest of the system area, extending into the northeast Arabian Sea. The wind shear was moderate (15–20 knots) over the system area.

At 0000 UTC of 29th August 2024, The Madden-Julian Oscillation (MJO) index lay in phase 4 with amplitude greater than 1. It moved across phases 4 and 5, with the amplitude remaining above 1 during the subsequent five days. It also indicated a significant presence of convectively coupled equatorial Rossby waves (ERW) propagating westwards from the Bay of Bengal, central India, and the central Arabian Sea during that period. Westerly winds (5–7 mps) prevailed over the same region, while strong easterlies (5–7 mps) were observed over the northwestern parts of India and the northeast Arabian Sea. Eastward-moving Kelvin waves (KW) were also present over the southeast Arabian Sea. These features enhanced convective activity over the Arabian Sea and the Bay of Bengal. Vorticity at the 850 hPa level was around 150×10^{-6} s^{-1} near the system area, extending up to 200 hPa. Shear tendency increased over the system area and decreased toward southern Pakistan. Low-level convergence was approximately 20×10^{-6} s^{-1} to the west of the system area, while upper-level divergence was about 30×10^{-6} s^{-1}, extending into the northeast Arabian Sea. The wind shear remained moderate (15–20 knots) over the system area.

At 0000 UTC of 30th August 2024, The Madden-Julian Oscillation (MJO) index was in phase 4 and moved to phase 5 from 30th August with an amplitude greater than 1. Sea surface temperatures (SST) over the Bay of Bengal (BoB) ranged between 28–30°C, while those over the Arabian Sea (AS) were around 27–28°C. Cooler temperatures (<26°C) prevailed over the west-central AS, with very warm conditions (>32°C) over the Gulf of Aden. The Tropical Cyclone Heat Potential (TCHP) was high (>100 kJ/cm²) over the central BoB but lower (<50 kJ/cm²) over the north and adjoining central AS. Sea conditions indicated that the deep depression over the Kachchh coast, adjoining areas of Pakistan, and the northeast Arabian Sea encountered colder sea conditions in the AS, limiting significant intensification. Low-level vorticity was around 250×10^{-6} s^{-1} near the system area over the Saurashtra

and Kachchh region. Low-level convergence was approximately 10×10^{-6} s^{-1} near the system centre, while upper-level divergence was about 20×10^{-6} s^{-1}, extending into the west-central AS. Wind shear was low to moderate over Saurashtra, Kachchh, and adjoining northeast AS. These conditions supported a favourable environment for intensification, making the strengthening of the deep depression over the Kachchh coast and adjoining regions of Pakistan and northeast AS highly likely. An upper tropospheric ridge lay near 27°N, associated with an anticyclonic circulation over coastal Iran.

At 0000 UTC of 31st August 2024, the Madden-Julian Oscillation (MJO) index was currently in phase 4 and moved to phase 5 from 31st August with an amplitude greater than 1. The sea surface temperature (SST) over the Bay of Bengal (BoB) and Arabian Sea ranged between 28–29°C. It was cooler (<26°C) over the west-central Arabian Sea (AS) and very warm (>32°C) over the Gulf of Aden. The Tropical Cyclone Heat Potential (TCHP) was high (>100 kJ/cm²) over the central BoB and lower (<50 kJ/cm²) over the northern and adjoining central AS. The cyclone Asna over the northeast Arabian Sea and adjoining areas of the Pakistan coast encountered colder sea conditions in the AS, potentially hindering significant intensification. The low-level vorticity near the system area over the northeast Arabian Sea was around 200×10^{-6} s^{-1}. Low-level convergence was approximately 10×10^{-6} s^{-1} to the south of the system centre, while upper-level divergence was also about 10×10^{-6} s^{-1} southwest of the system centre, extending up to the west-central Arabian Sea. Wind shear was low to moderate over the northeast AS, indicating a favourable environment for maintaining its intensification. An upper tropospheric ridge was situated near 30°N. A westerly trough was approaching the Indian region, extending up to 28°N along 620E. The system was tracking westwards under the influence of easterlies prevailing to the ridge's south.

At 0000 UTC of 01st September, the Madden-Julian Oscillation (MJO) index was in phase 5 with an amplitude greater than 1. The sea surface temperature (SST) over the Bay of Bengal (BoB) and Arabian Sea (AS) ranged between 28–29°C. It was cooler (<26°C) over the west-central AS and very warm (>32°C) over the Gulf of Aden. The Tropical Cyclone Heat Potential (TCHP) was high (>100 kJ/cm²) over the central BoB and lower (<50 kJ/cm²) over the northern and adjoining central AS. Sea conditions indicated that Cyclone Asna over the northeast and adjoining northwest Arabian Sea had entered an area with TCHP less than 50 kJ/cm², reducing the likelihood of significant intensification. The low-level vorticity was approximately 150×10^{-6} s^{-1} to the south of the system area. Low-level convergence was about 15×10^{-6} s^{-1} to the south of the system center, and upper-level divergence was approximately 20×10^{-6} s^{-1} to the southwest of the system center. Wind shear was low to moderate (15–20 knots) over the central part of the north AS. These features suggested that Cyclonic Storm Asna over the northeast Arabian Sea and adjoining areas of the Pakistan coast had likely maintained its intensity as a cyclonic storm for the next 24 hours. The system tracked westwards under the influence of easterlies prevailing to the south of the ridge.

2.5.3.2 Weakening:

The **cyclonic storm (CS) "ASNA" over** northeast Arabian Sea off Kachchh and adjoining Pakistan coast gradually moved south-south-westwards and weakened into a **Deep Depression** in the evening (1730 hours IST/1200 UTC) of the 1st September, 2024 over northwest Arabian Sea. Continuing to move further south-south-westwards, it weakened into a **Depression** in the morning (0530 hours IST/0000 UTC) of the 2nd September, 2024 over the northwest Arabian Sea and into a **well-marked low-pressure area** over the same region in the afternoon (1130 hours IST/0600 UTC) of 2nd September, 2024. It further weakened into a **low-pressure area** over west central & adjoining northwest Arabian Sea in the morning (0830 hours IST/0300 UTC) of 3rd September, 2024.

At 0000 UTC of 2nd September, the sea surface temperature (SST) over the west-central Arabian Sea ranged between 28–29°C and was expected to decrease along the forecast path of the system. The Tropical Cyclone Heat Potential (TCHP) was less than 50 KJ/cm² over the northwest Arabian Sea. The low-level vorticity was around 100×10^{-6} s^{-1} to the south of the system area. Low-level convergence was approximately 5×10^{-6} s^{-1} to the south of the system centre, while upper-level divergence was also around 5×10^{-6} s^{-1} to the northwest of the system centre. Wind shear was very high (40–50 knots) over the system area. North-easterly winds in the upper levels over the system area steered the system south-westward.

3.3 Characteristics features w.r.t. Maximum Sustained Surface Wind speed and estimated central pressure and translational speed:

(a) Maximum Sustained Surface Wind speed and estimated central pressure:

No rapid intensification was observed during the life cycle of ASNA. The system reached its peak intensity of maximum sustained wind speed of 40 knots gusting to 50 knots (70-80 kmph gusting to 90 kmph) at 0000 UTC (0530 IST) of 31st August **(Fig. 1b)** with estimated central pressure (ECP) of 990 hPa and pressure drop of about 8 hPa over Northeast Arabian Sea **(Fig. 3b)**. It was moving in a favourable environment with high SST, high positive vorticity at lower levels, low to moderate anticyclonic vertical wind shear (5-15 knots), enhanced warm moist air incursion into the core region of the system from southeast Arabian Sea, favourable Madden Julian Oscillation and convectively coupled equatorial waves. After, entering northwest Arabian Sea, it encountered colder sea conditions and started weakening gradually from 1st September Morning (0300 UTC).

b. Translational speed & direction of movement:

"**ASNA"** exhibited six hourly average translational speeds of 12.3 kmph against normal of 14.7 kmph for cyclonic storms over the AS in the monsoon season during 1990-2013 (**Fig.3a**).

(a)

(b)

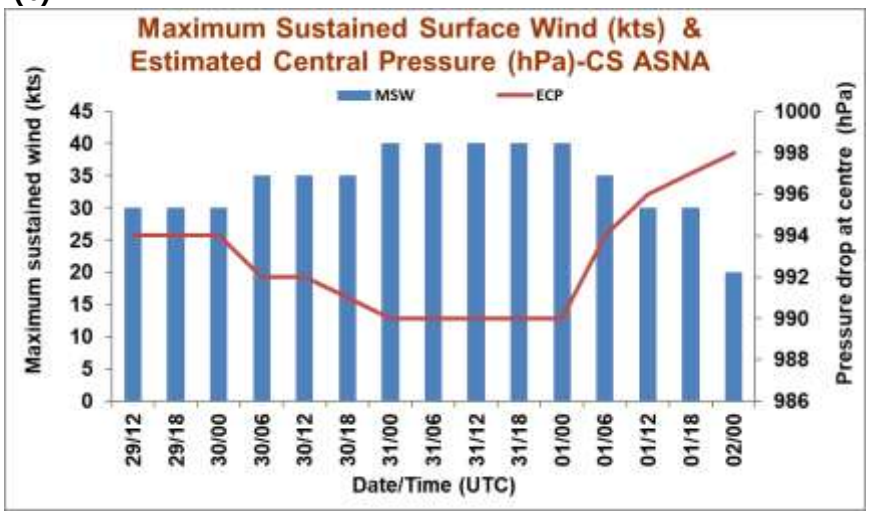


Fig. 3: (a) 6 hourly average translational speed and (b) maximum sustained wind speed & estimated central pressure during life cycle of ASNA

4. Monitoring of CS, "ASNA"

India Meteorological Department (IMD) maintained round-the-clock watch over the north Indian Ocean and the cyclone was monitored since 15th August, about 10 days before the formation of the depression on 25th August. The information about the system was first released in the weekly extended range outlook issued by IMD on 15th August, indicating the formation of low-pressure areas with moderate confidence (34-67%) to intensify further into Depression **(Fig. 4a)**. Further, the updated extended range outlook issued on 24th August, indicated the formation of a depression over Northwest Madhya Pradesh during the beginning of the week (24-29 August) with high confidence (68-100%). Actually, a depression formed over Northwest Madhya Pradesh on 25th August **(Fig. 4b)**. In the subsequent week the extended range outlook issued on 29 August indicated high probability of cyclogenesis (68-100%) over the Arabian Sea in week 1 (30 August to 5th September) coinciding with the period of cyclone "ASNA" over the Arabian Sea **(Fig. 4c)**.

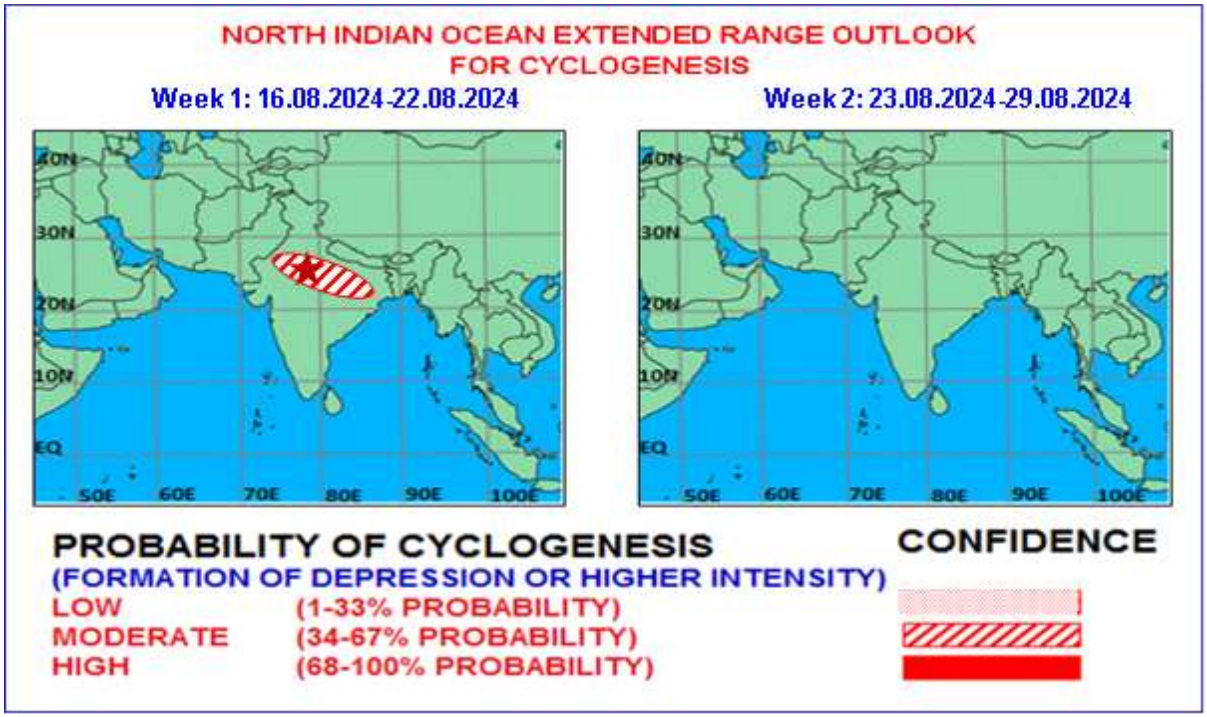


Fig. 4 (a): Weekly extended range outlook issued by IMD on 15th August, 2024 indicating area of cyclogenesis over Northwest MP during the week 1 (Actually genesis occurred on 25th August over Northwest MP)

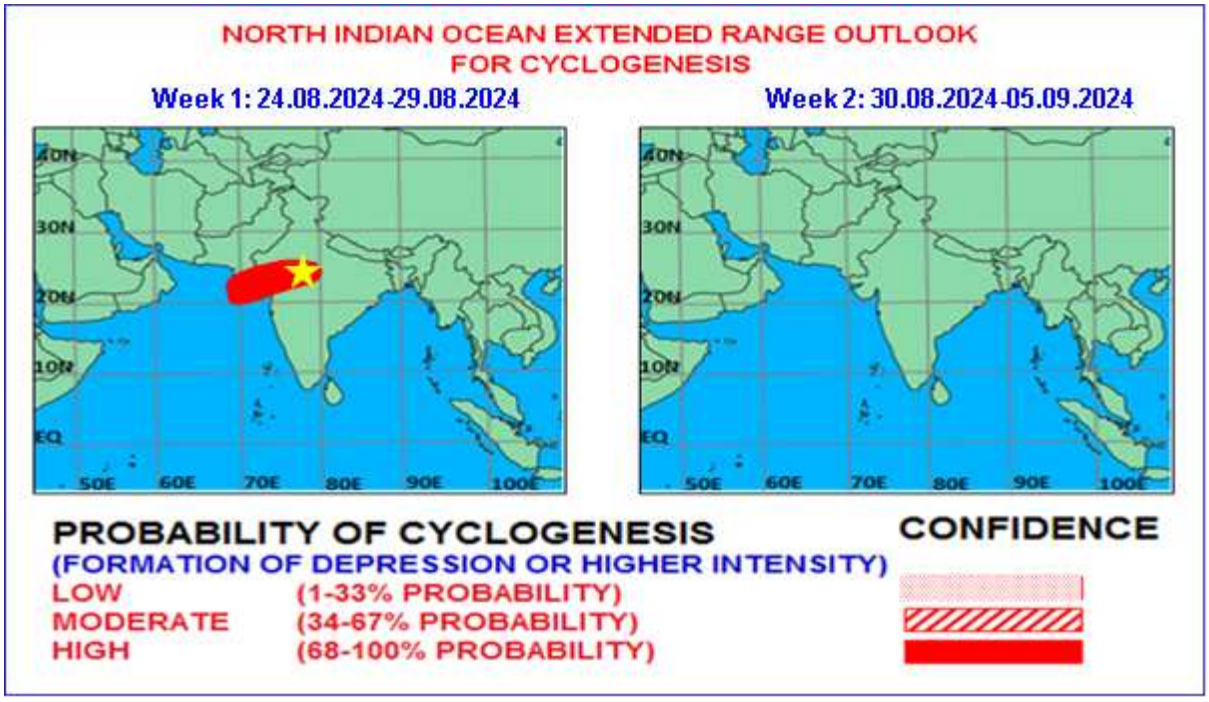


Fig. 4 (b): Weekly updated extended range outlook issued by IMD on 23rd August, 2024 indicating likely emergence of the system into Arabian Sea during week 1 with High Confidence about 6 days prior to its emergence into Northeast Arabian Sea (actually it emerged into Arabian Sea on 30th August)

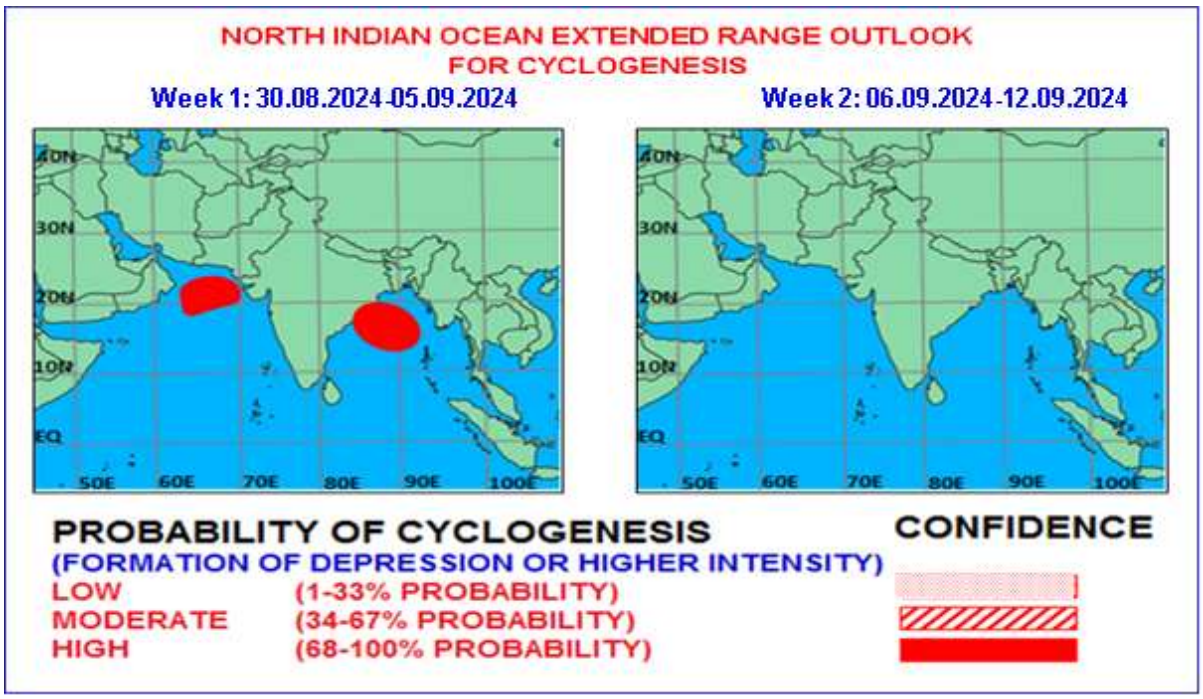


Fig. 4 (c): Weekly extended range outlook issued by IMD on 29th August, 2024 indicating likely westwards movement of ASNA over Northeast Arabian Sea and gradual south-westwards curvature (Actually it moved nearly westwards over Northeast Arabian Sea and gradually recurved south-south-westwards from 1st September/0000 UTC onwards).

4.1 Features observed through satellite:

The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, SCAT SAT, ASCAT, microwave imageries and available ships, buoy observations and coastal observations in the region. Various global models and dynamical-statistical models run by Ministry of Earth Sciences (MoES) institutions including IMD, NCMRWF, IITM & INCOIS and guidance from models from various international agencies under bilateral arrangement were utilized to predict the genesis, track and intensity of the cyclone as well as associated severe weather. The forecasts were mainly based on multi-model ensemble technique developed by IMD further modulated by observations and forecasters intervention at IMD. An indigenously developed digitized forecasting system of IMD was utilized for analysis and comparison of various observations and numerical weather prediction model's guidance, decision making process and warning products generation. Typical satellite-based products utilised for monitoring the system are presented in **Fig. 5**. The satellite imagery during the stage of cyclone suggested organisation of clouds in curved band pattern during intensification phase (30th to 31st August) and shear pattern during weakening phase (1st-2nd September) are presented in Fig. 5.

On day to day basis during the life cycle of the system "ASNA" (24 August-02 September) the convective activity that prevailed based on INSAT 3DR Visible images, IR images, Brightness temperature and enhanced coloured images are shown in **Fig6a-d** respectively.

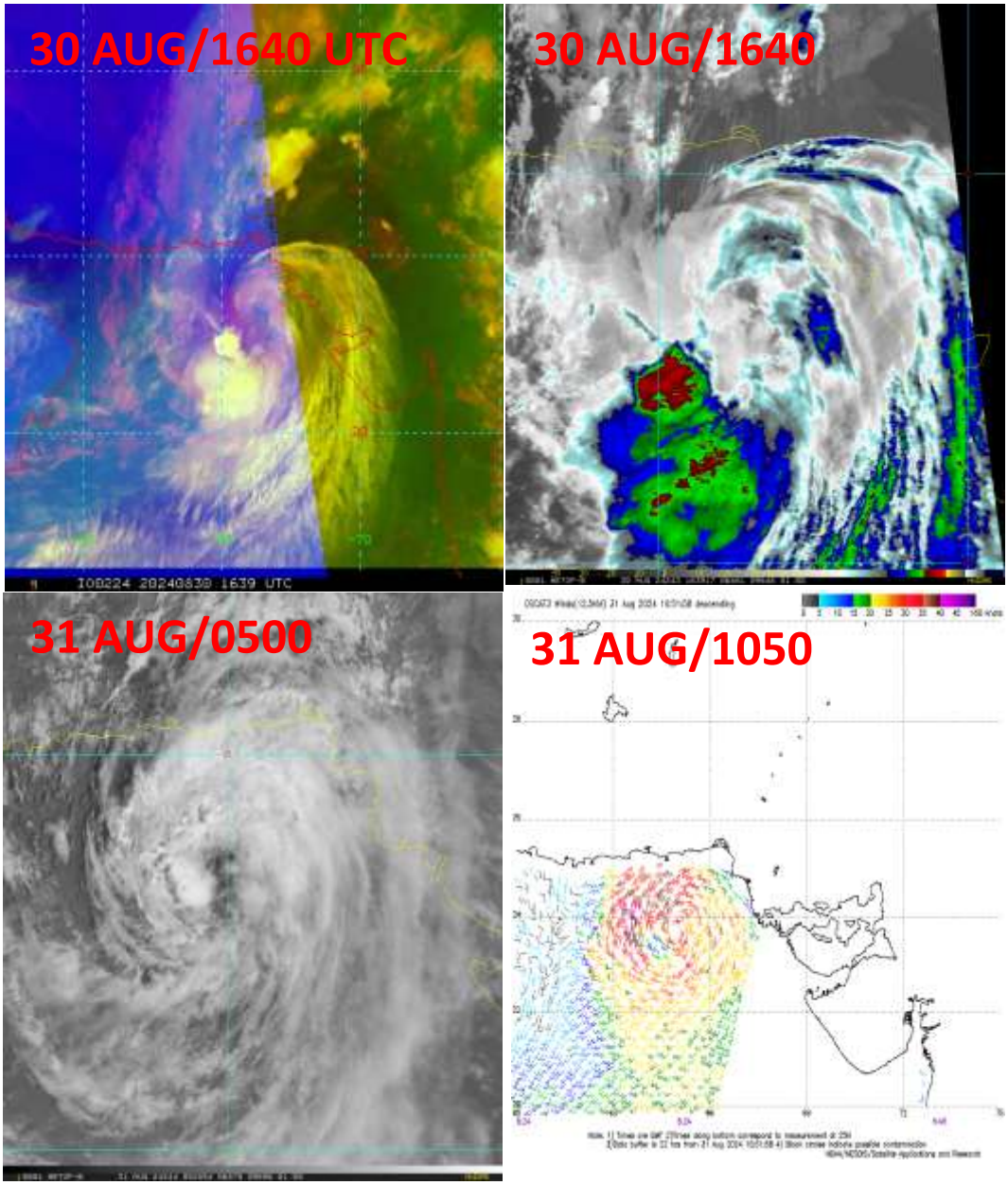


Fig. 5: Typical (a) INSAT 3D(R) at 2245 hrs IST/ 1715 UTC of 30th August and (b) Oceansat Imagery at 2345 hrs IST/1815 UTC of 31st August, 2024 in connection with cyclonic storm "ASNA"

At 0000 UTC of 24th August 2024, scattered to broken low and medium clouds, with embedded intense to very intense convection, were observed over east Madhya Pradesh,

where the minimum cloud top temperature (CTT) reached minus 80°C. Moderate to intense convection was noted over north Chhattisgarh, adjoining southeast Uttar Pradesh, and northwest Jharkhand, with a minimum CTT of minus 50 to 60°C.

At 0000 UTC of 25th August 2024, clouds associated with the depression over northwest Madhya Pradesh and its neighbourhood included scattered to broken low and medium clouds. Embedded intense to very intense convection was observed over Madhya Pradesh, adjoining southwest Uttar Pradesh, east Rajasthan, Gujarat, and Maharashtra, with a minimum cloud top temperature (CTT) of minus 93°C. Moderate to intense convection was noted over Chhattisgarh, where the minimum CTT ranged between minus 50°C and minus 60°C.

At 0000 UTC of 26th August 2024, scattered to broken low and medium clouds with embedded intense to very intense convection was observed over south Rajasthan, southwest Madhya Pradesh, north Madhya Maharashtra, and adjoining north Konkan, with a minimum cloud top temperature (CTT) of minus 93°C. Moderate to intense convection was noted over northeast Rajasthan, northwest Madhya Pradesh, south Madhya Maharashtra, and Konkan & Goa, where the minimum CTT ranged between minus 50°C and minus 60°C.

At 0000 UTC of 27th August 2024, scattered to broken low and medium clouds with embedded intense to very intense convection was observed over Gujarat, adjoining south Rajasthan, southwest Madhya Pradesh, north Madhya Maharashtra, the Gulf of Kutch, the Gulf of Cambay, northeast Arabian Sea, and adjoining south Pakistan, with a minimum cloud top temperature (CTT) of minus 93°C. Moderate to intense convection was noted over south Rajasthan and north Konkan.

At 0000 UTC of 28th August 2024, scattered to broken low and medium clouds with embedded intense to very intense convection was observed over Kutch, Saurashtra, northeast Arabian Sea, and the Gulf of Kutch, with a minimum cloud top temperature (CTT) of minus 93°C. Moderate to intense convection was noted over south Pakistan, southwest Rajasthan, the east Gujarat region, and the Gulf of Cambay.

At 0000 UTC of 29th August 2024, scattered to broken low and medium clouds with embedded intense to very intense convection was observed over Kachchh, Saurashtra, south Pakistan, northeast Arabian Sea, and the Gulf of Kachchh, with a minimum cloud top temperature (CTT) of minus 93°C. Moderate to intense convection was noted over west Rajasthan.

At 0000 UTC of 30th August 2024, scattered to broken low and medium clouds with embedded intense to very intense convection was observed over south Pakistan, the northeast Arabian Sea, and the Gulf of Kachchh, with a minimum cloud top temperature (CTT) of minus 93°C.

At 0600 UTC of 30th August 2024, the Intensity of the system was characterized as **T 2.5**. Scattered to broken low and medium clouds with embedded intense to very intense convection was observed over the northeast Arabian Sea, Kutch, and Gulf of Kutch, with a minimum cloud top temperature of minus 90°C. Moderate to intense convection was also present over south Pakistan and Saurashtra.

At 0000 UTC of 31st August 2024, the intensity of the system was characterized as **T 2.5.** Scattered to broken low and medium clouds with embedded intense to very intense

convection were observed over the north and adjoining central Arabian Sea, with a minimum cloud top temperature of minus 90°C. Moderate to intense convection was noted over the western part of Kachchh and adjoining south Pakistan.

At 2100 UTC on 31st August 2024, the intensity of the system was characterized as **T 2.5**. Scattered to broken low and medium clouds with embedded intense to very intense convection were observed over the northwest Arabian Sea, with a minimum cloud top temperature of minus 90°C. Moderate to intense convection was noted over Oman, the northeast Arabian Sea, south Pakistan, and adjoining Iran.

At 0000 UTC on 1st September 2024, the intensity of the system was characterized as **T 2.5.** Scattered to broken low and medium clouds with embedded intense to very intense convection was observed over the northwest Arabian Sea, with a minimum cloud top temperature of minus 90°C. Moderate to intense convection was noted over Oman, southeast Iran, and adjoining Pakistan.

At 1200 UTC on 1st September 2024, Intensity of the system was characterized as **T 2.0/C.I. 2.5.** The cloud mass showed further disorganisation. Scattered to broken low and medium clouds with embedded intense convection were observed over northwest and southeast Arabian Sea, with a minimum cloud top temperature of minus 70°C. Moderate to intense convection was present over southeast Iran, adjoining south Pakistan, the Gulf of Oman, and northern Oman.

At 0000 UTC on 2nd September 2024, the intensity of the system was characterized as **T 1.5.** Weak convection was observed over the northwest and adjoining west-central Arabian Sea, the Gulf of Oman, and northern Oman, with a minimum cloud top temperature of minus 20°C.

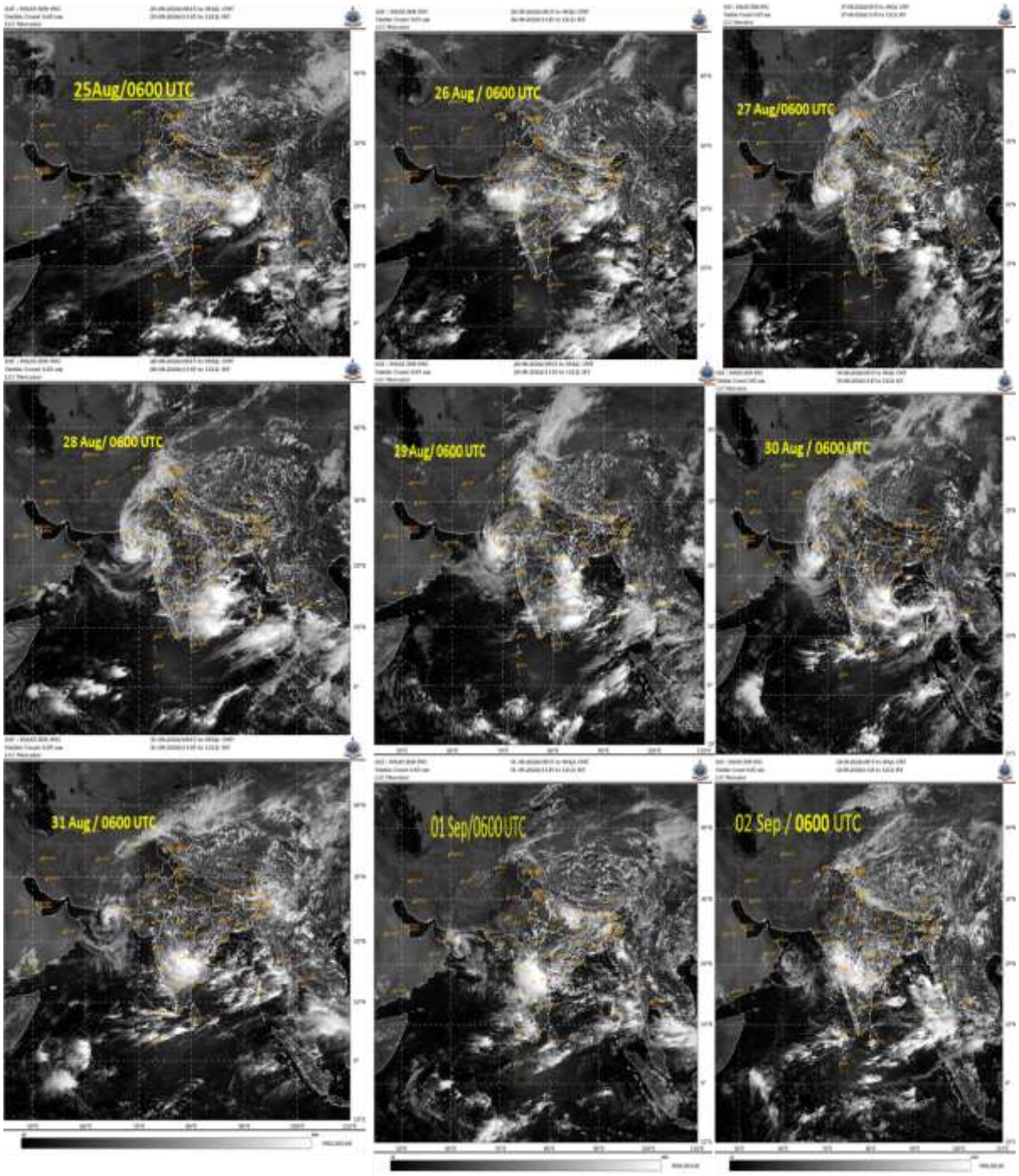


Fig.6(a): INSAT 3D(R) Visible imageries in connection with cyclonic storm "ASNA" during 24 Aug - 02 Sep, 2024.

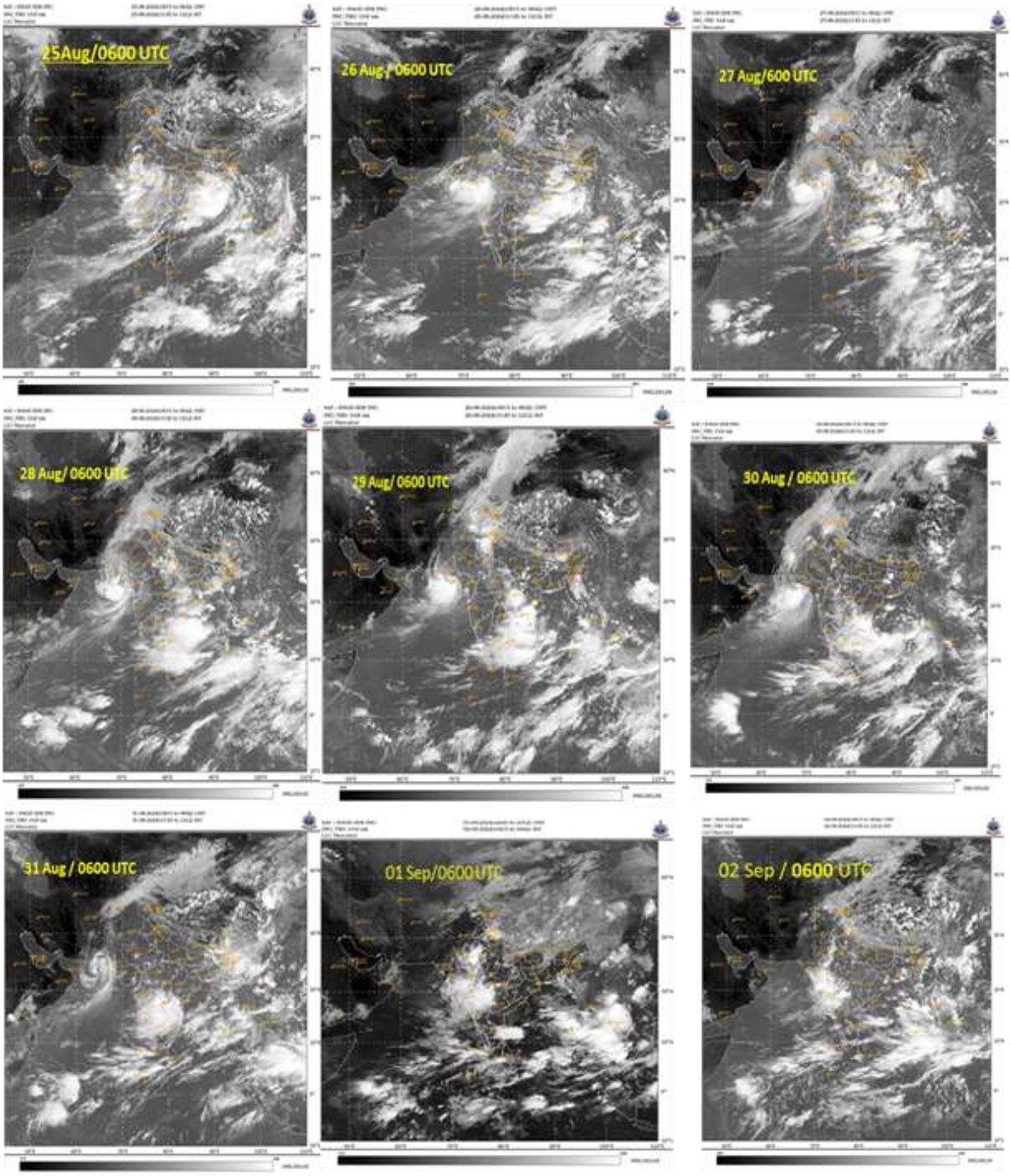


Fig.6b: INSAT 3D(R) IR imageries in connection with cyclonic storm "ASNA" during 24 Aug - 02 Sep, 2024.

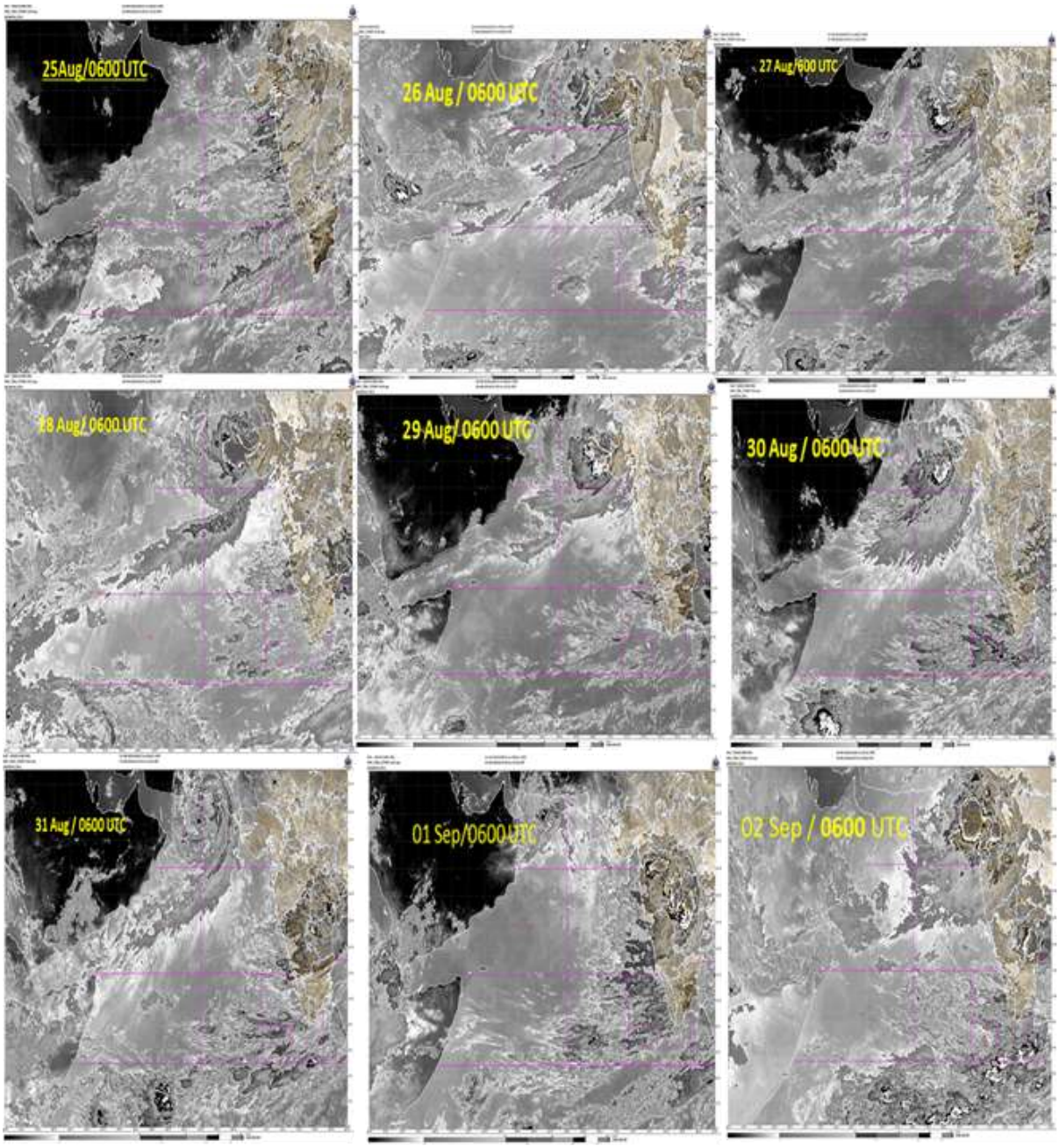


Fig.6c: INSAT 3D(R) IR enhanced imageries in connection with cyclonic storm "ASNA" during 24 Aug - 02 Sep, 2024.

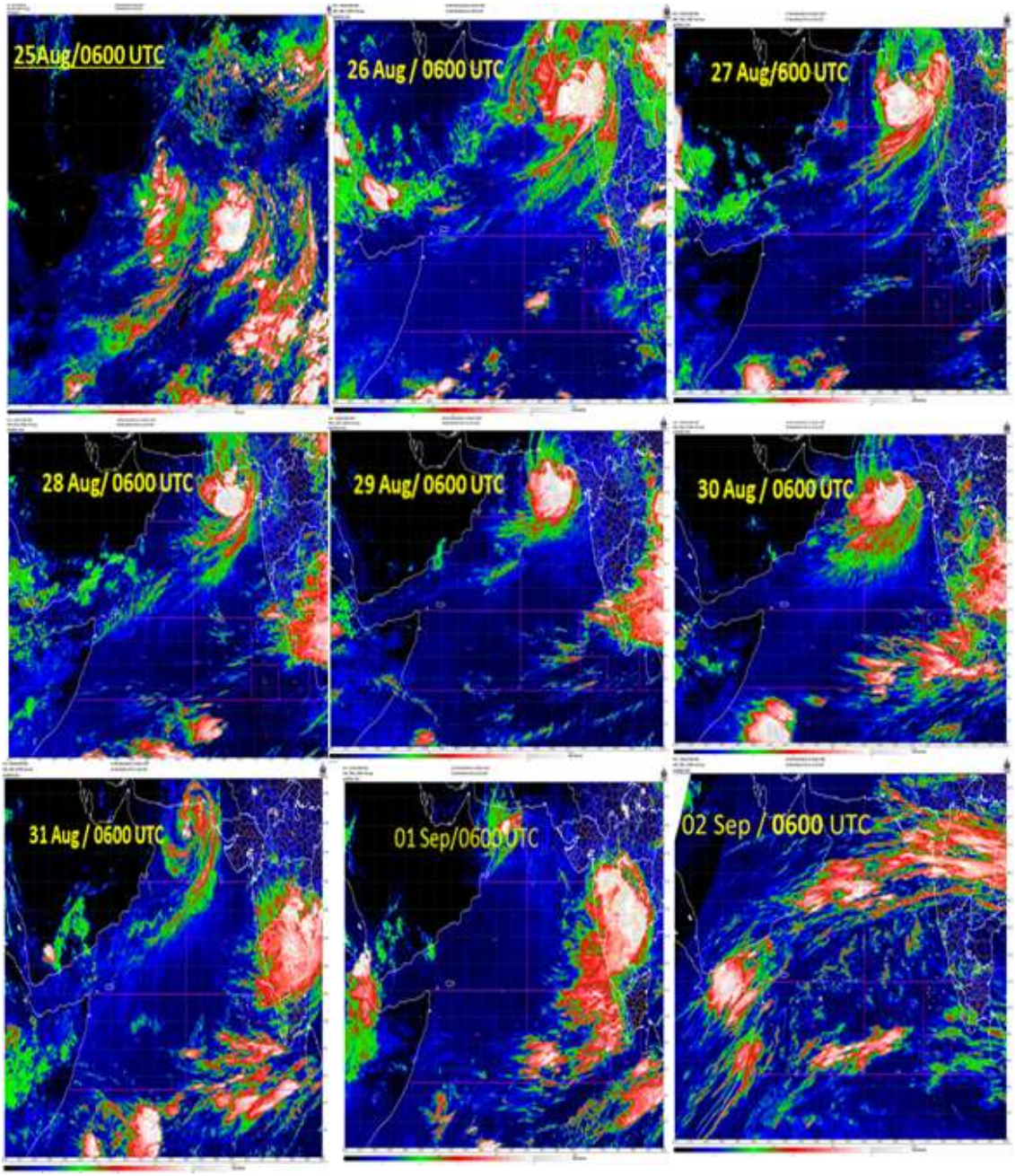


Fig.6d: INSAT 3D(R) enhanced coloured imageries in connection with cyclonic storm "ASNA" during 24 Aug - 02 Sep, 2024.

5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 25th August- 2nd September, 2024 are presented in **Fig. 7.1 – 7.9.**

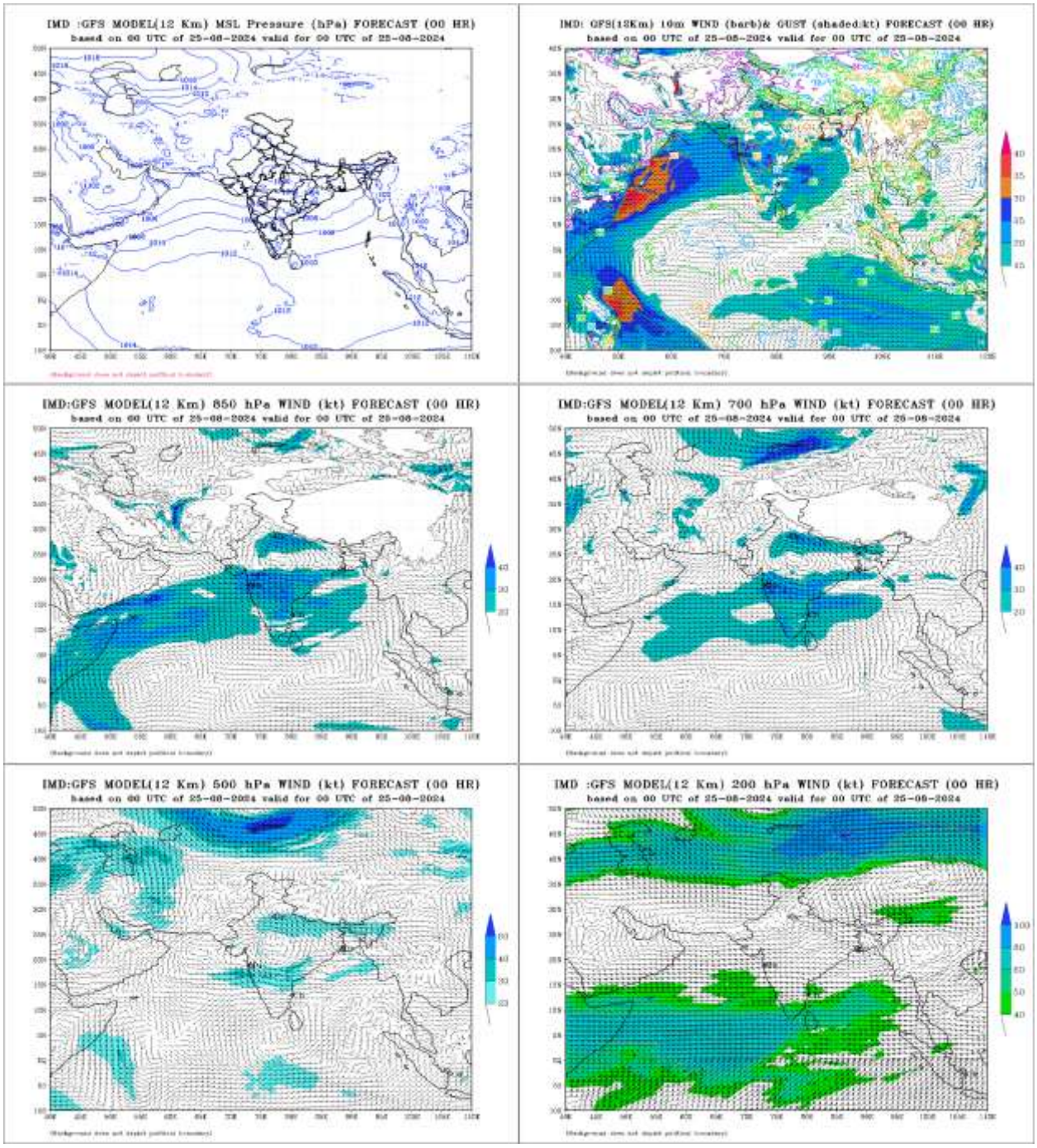


Fig.7. 1: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 25th August, 2024

The large-scale analysis from GFS on 25th August 0000 UTC **(Fig. 7.1)** indicated two close isobars (with one slightly extended one) in the MSLP analysis over Northwest Madhya Pradesh with associated cyclonic circulation extending upto 500 hPa level. The upper level ridge line was to the north of the system centre associated with easterly/northeasterly wind over the region. It is further observed that the low-level southwest monsoon current was favourable for the moisture incursion from the Arabian Sea at lower level and likely further intensification of the system from the current stage of Depression.

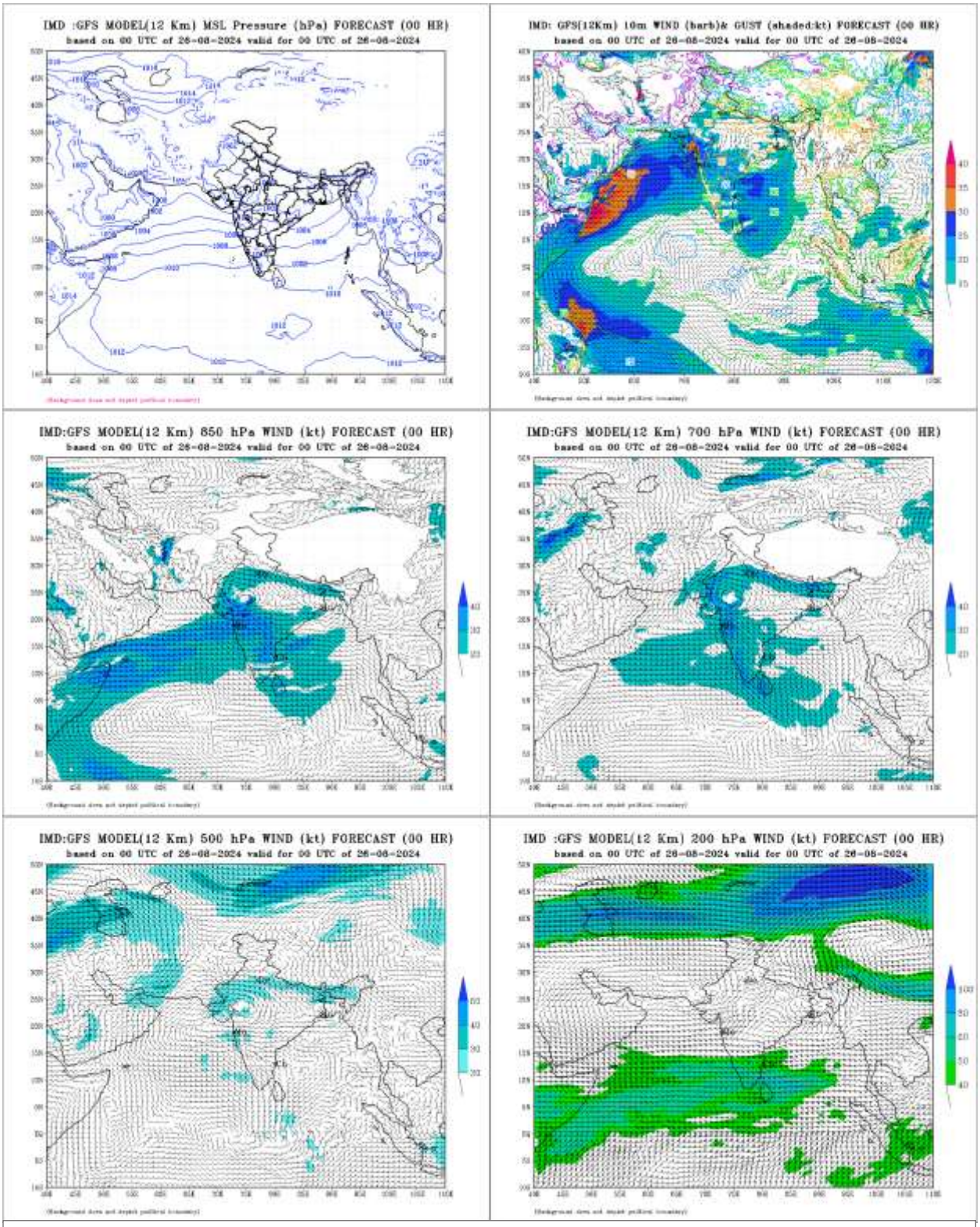


Fig.7.2: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 26th August, 2024

The analysis from GFS model (**Fig.7.2**) indicated two closed isobars with centre over NW Madhya Pradesh and adjoining east Rajasthan with a movement of west-southwest direction in past one day with associated cyclonic circulation extending up to 500 hPa level. The upper level ridge line was slightly to the north of the system centre and it is associated with easterly/northeasterly wind over the region.

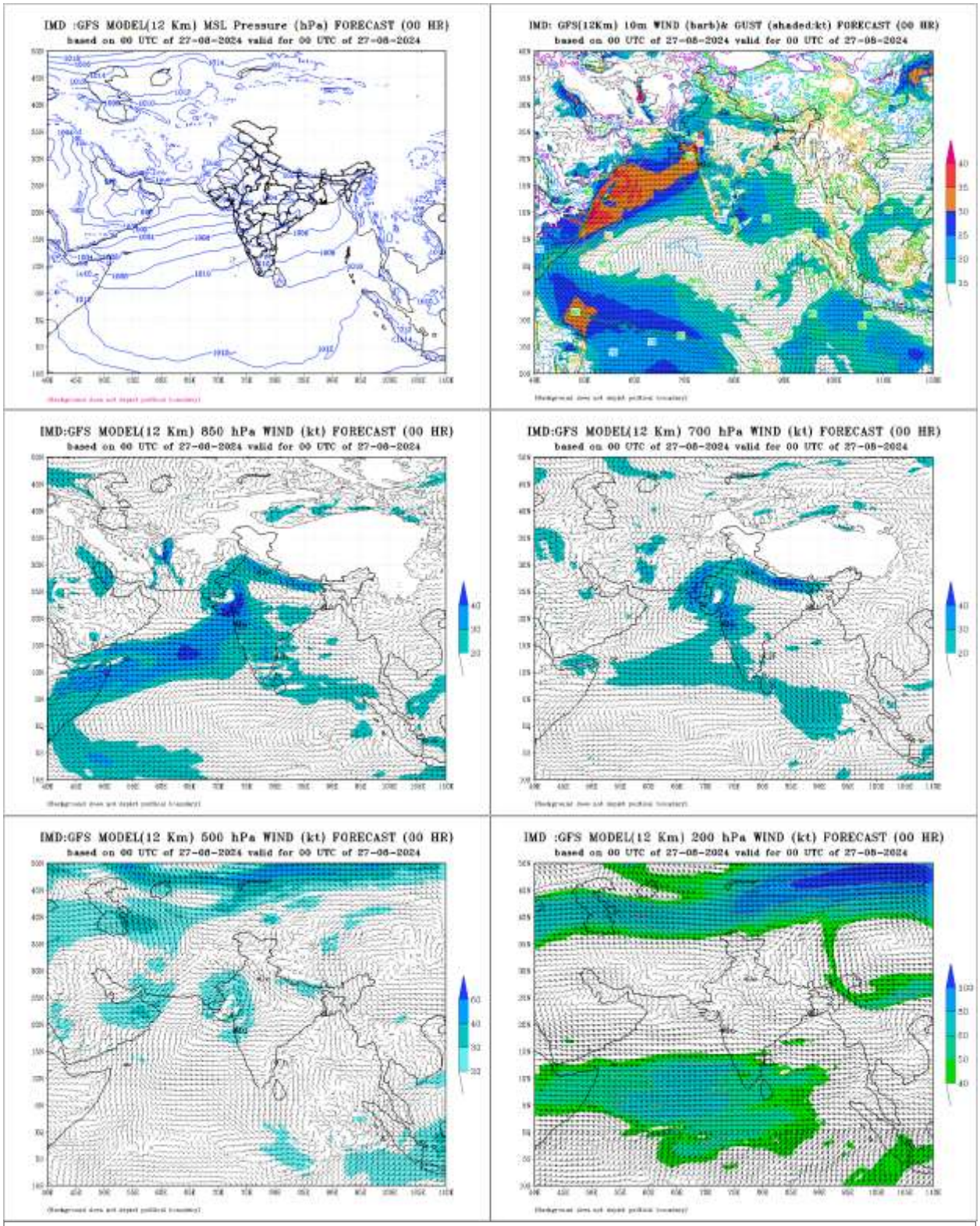


Fig.7.3: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 27th August, 2024

The analyses from GFS model during the period from 27-29 August (**Figs. 7.3 to 7.5**) indicated westward/west-southwestward movement of the system across Gujarat state with 3 clear closed isobars in the MSLP analysis and associated cyclonic circulation extending upto 500 hPa level. The upper level ridge line was slightly to the north of the system centre and it is associated with easterly/northeasterly wind over the region.

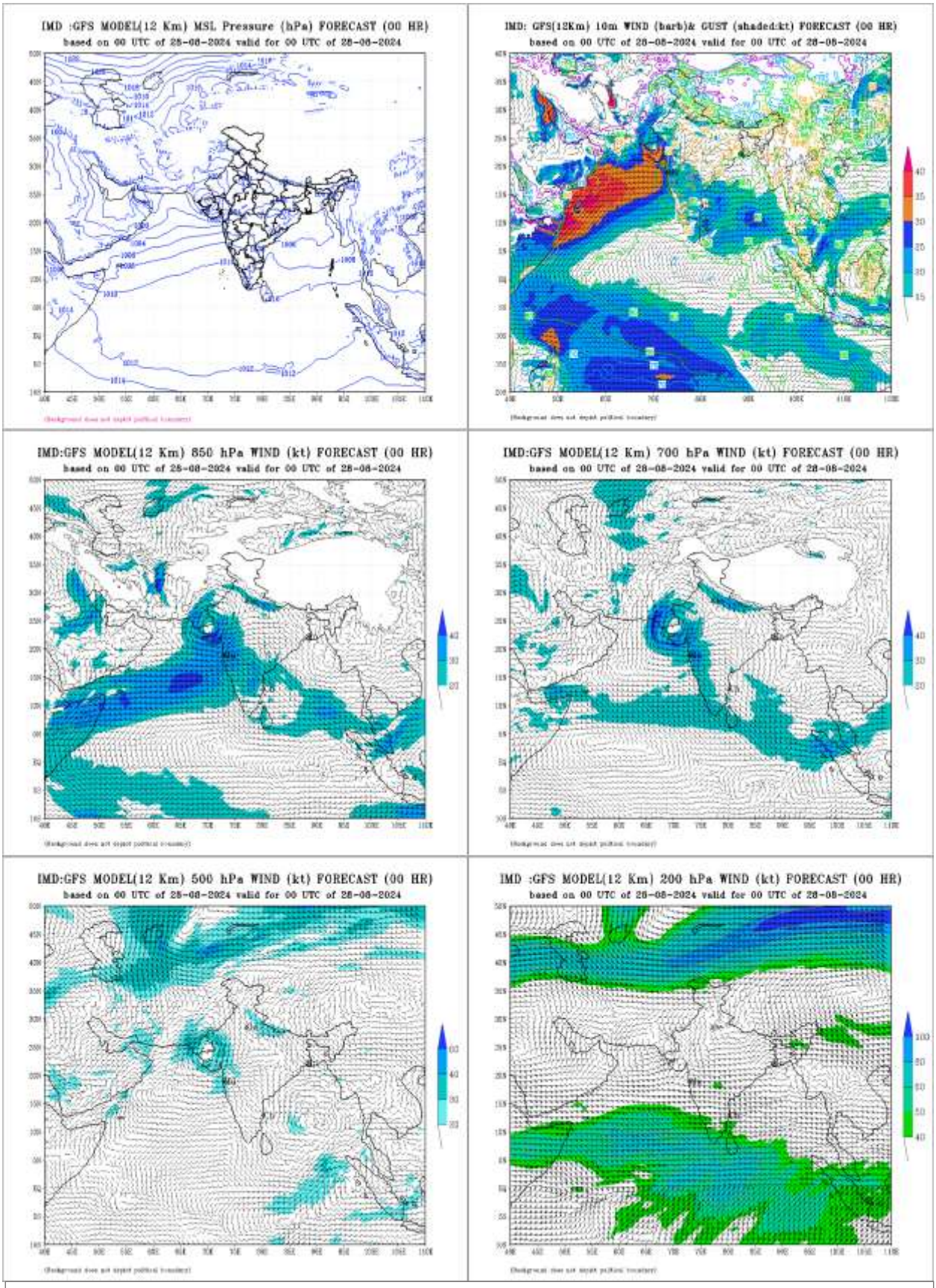


Fig.7.4: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 28th August, 2024

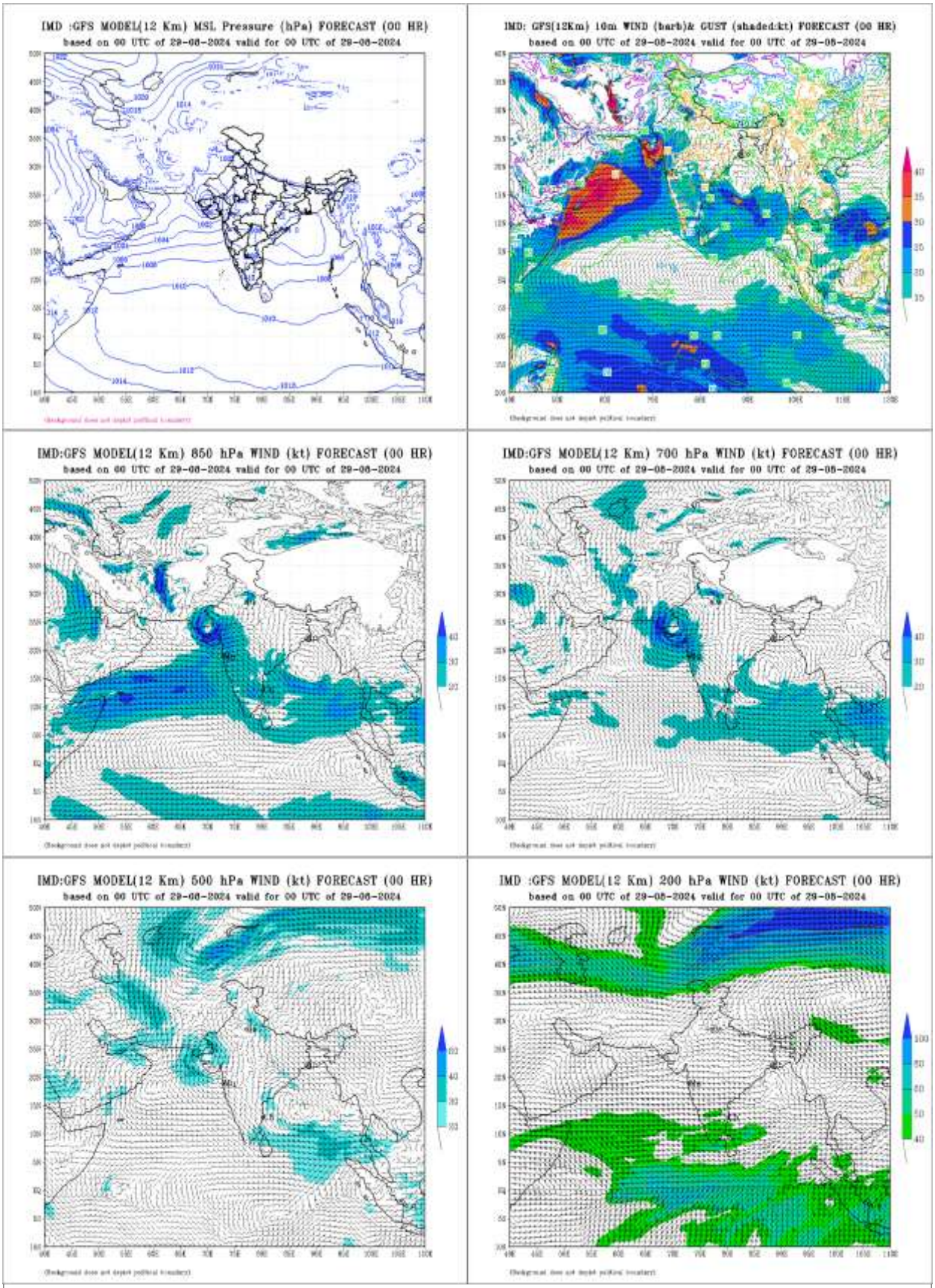


Fig.7.5: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 29th August, 2024

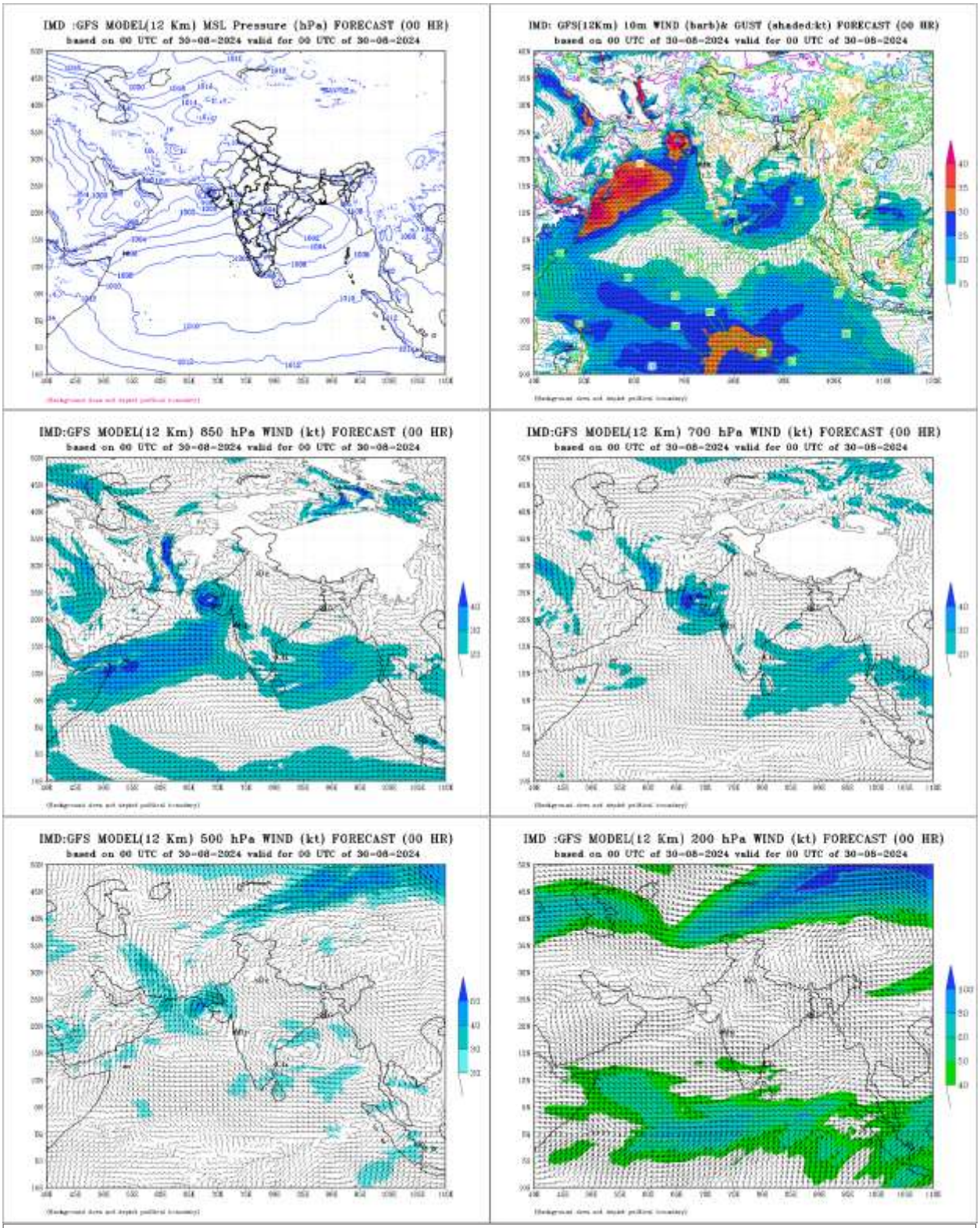


Fig.7.6: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 30th August, 2024

The GFS model analysis for 30th August **(Fig. 7.6)** indicated the system over the Northeast Arabian Sea off Kachchh and the adjoining Pakistan coast with 4 or more closed isobars, indicating further intensification of the system with associated cyclonic circulation extending up to 500 hPa level. The 200 hPa level wind indicated a northeast-southwest oriented trough passing close to the system's centre. It may be mentioned here that the system intensified into a cyclonic storm at 0600 UTC of 30th August.

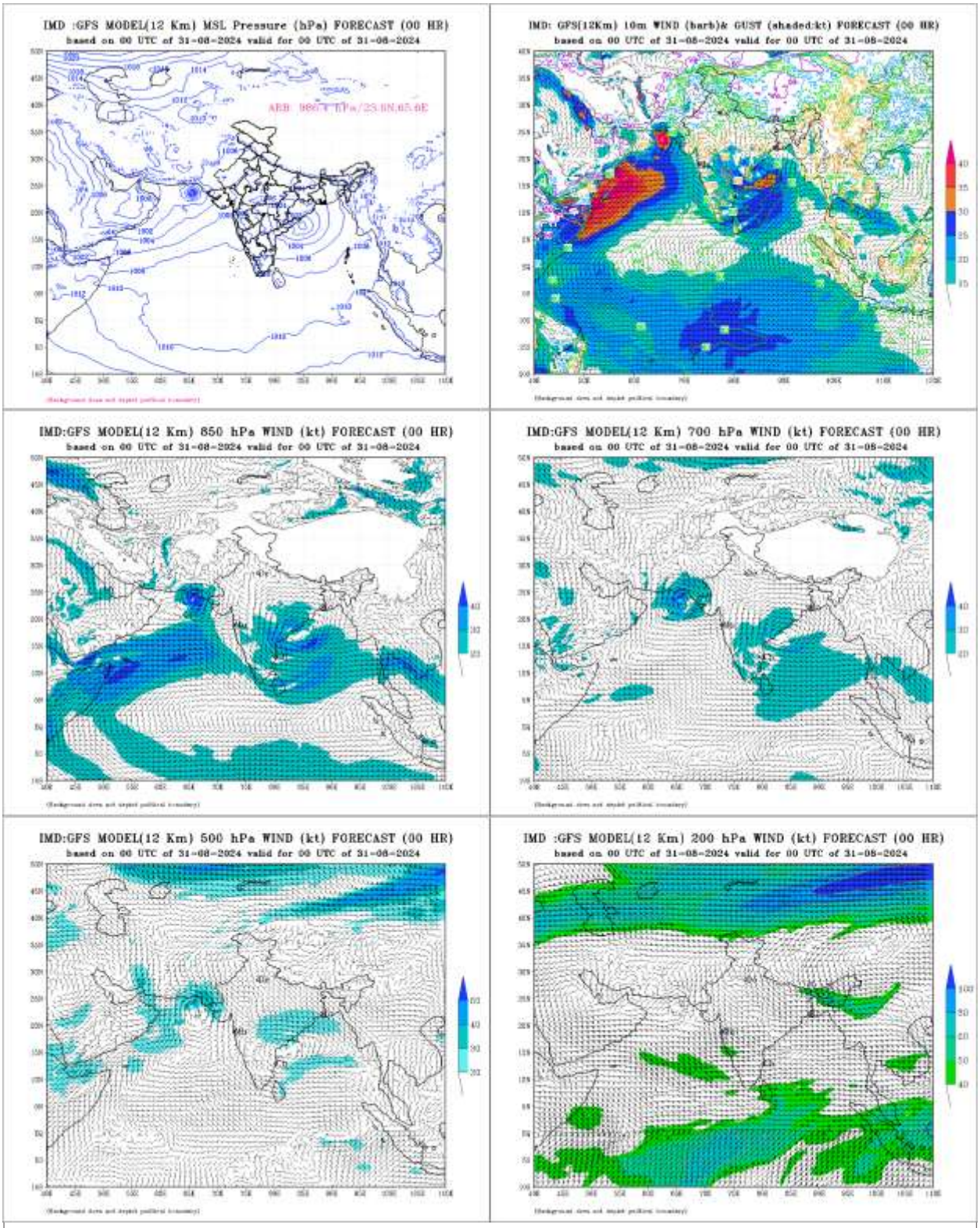


Fig.7.7.: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 31st August, 2024

The GFS model analysis for 31st August **(Fig. 7.7)** indicated the system over the Northeast Arabian Sea with more than 4 closed isobars, indicating further intensification of the system with associated cyclonic circulation extending up to 500 hPa level. The 200 hPa level wind indicated feeble cyclonic centre indicating intensification of the system with increasing its vertical extension. It may be mentioned here that the system reached its peak intensity of 40 kts at 0000 UTC of 31st August.

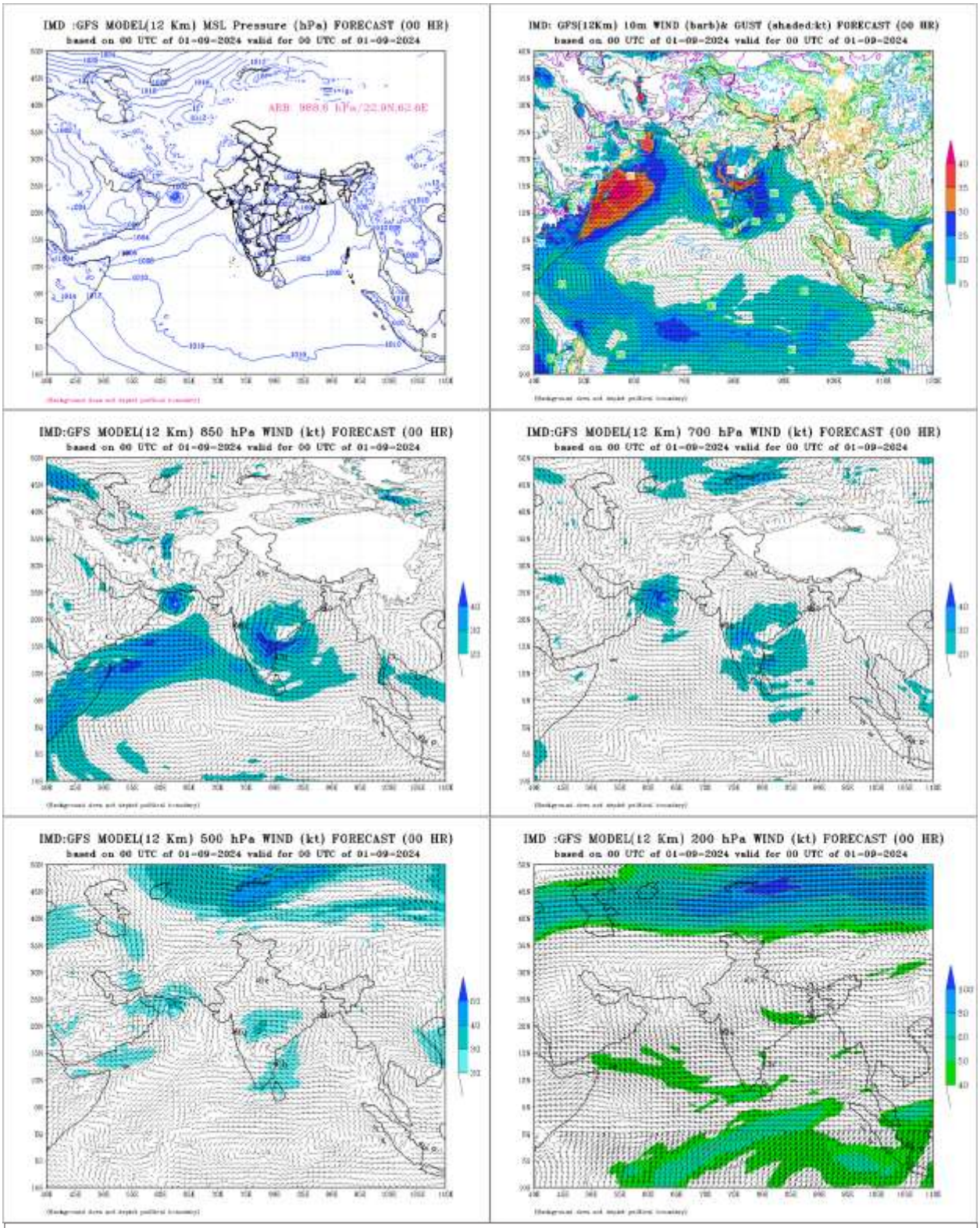


Fig 7.8: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 1st September, 2024

The GFS model analysis for 1st September 0000 UTC **(Fig. 7.8)** indicated the system over the Northwest Arabian Sea maintaining its intensity of tropical cyclone with 4 closed isobars and associated cyclonic circulation extending up to 500 hPa level.

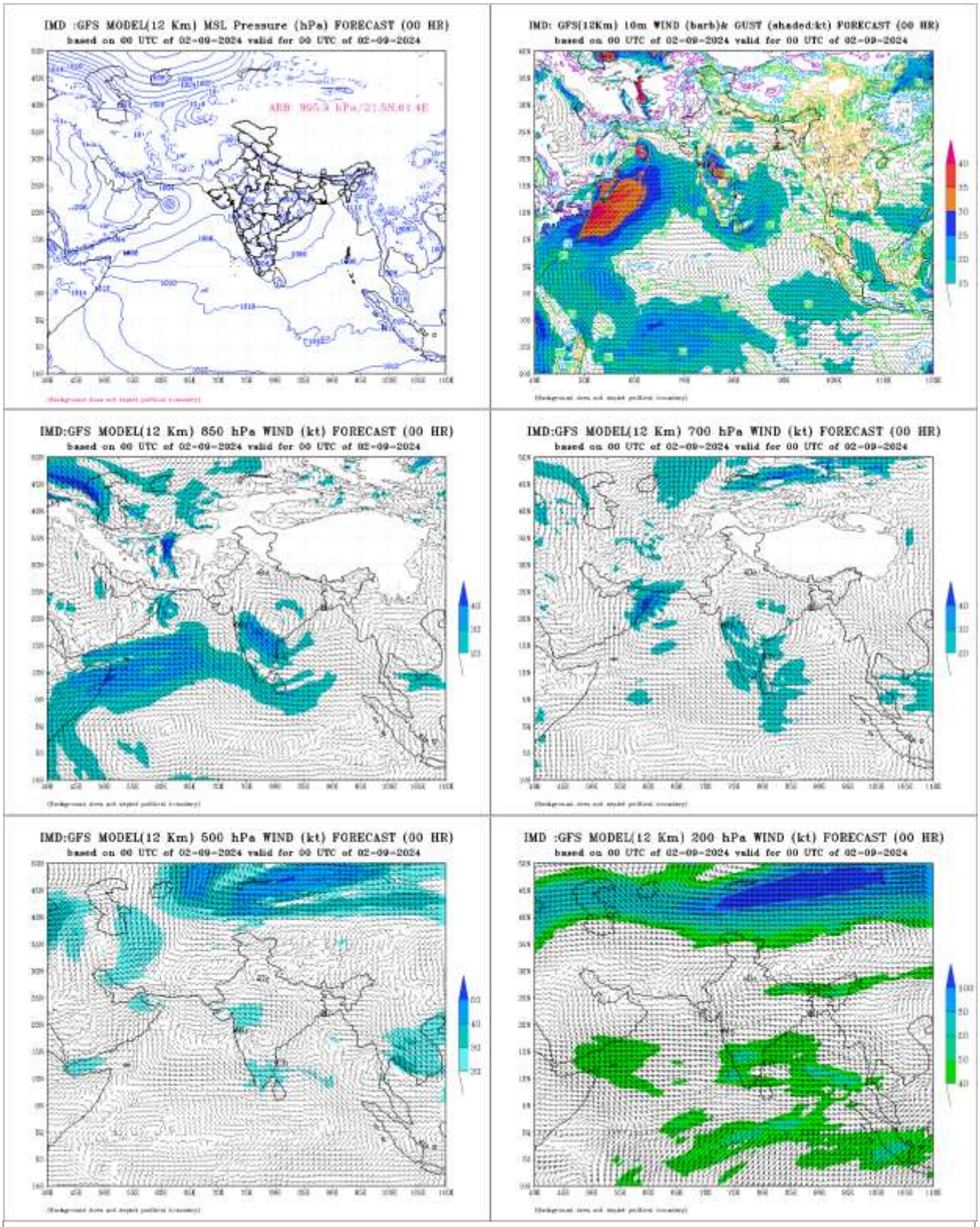


Fig.7.9: IMD GFS mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 2nd September, 2024

The GFS model analysis of 2nd September **(Fig. 7.9)** indicated a weakening of the system over the northwest Arabian Sea with reduced size and number of closed isobars remaining 2 to 3 only. The associated cyclonic circulation at 500 hPa is very feeble. It may be mentioned here that the system had weakened into a Depression on 2nd morning over the northwest Arabian Sea and on the same day it weakened into a low-pressure area in the afternoon.

6. Realized Weather

6.1. Realized rainfall

Date	Forecast of H Rainfall based on 0300 UTC of date Heavy: H, Very Heavy: VH, Extremely Heavy: EH	Realized Rainfall at 0300 UTC of date
24th August, 2024	**Madhya Pradesh:** H to VH rainfall at a few places on 24th to 26th with EH rainfall at isolated places on 24th & 25th August over West Madhya Pradesh. **Gujarat region:** H rainfall at isolated places during 24th to 28th with isolated EH rainfall on 24th to 26th. **Saurashtra & Kutch:** H rainfall at isolated places during 24th to 29th and H to EH rainfall at isolated places on 24th to 27th. **Konkan & Goa:** H rainfall at isolated places during 24th to 29th. **Madhya Maharashtra:** H rainfall at isolated places during 24th to 29th and EH rainfall at isolated places on 24th & 26th. **Odisha:** VH rainfall at isolated places on 24th and H rainfall at isolated places on 26th **Gangetic West Bengal:** VH rainfall at isolated places on 24th to 26th. **Jharkhand:** H rainfall at isolated places during 24th to 27th	**25th August:** **Gujarat Region:** Vapi 36, Pardi 35, Kaprada, Valsad- 34 each, Umerpada 31, Khergam , Daman , Daman- 29 each, Silvassa , Ukai , Dharampur- 27 each, Daman26, Madhbun 24, Sagbara , Khanvel- 20 each, Vyara 19, Vansda 18, Songadh 17, Waghai , Dang , Dangs , Mangrol- 15 each, Subir 15, Umergam 14, Valsad 14, Narmada 13, Khanpur , Chhota Udepur , Kadi , Garbada- 12 each, Uchchhal , Palsana- 11 each, Kamrej , Valod , Quant , Dahod , Dahod , Dahod- 10 each, Chikhli , Mandvi , Dolvan 9, Patan , Tarapur , Morva Hadaf – 9 each, Dediapada , Limkheda , Mansa , Kukarmunda , Gandevi , Surat , Deesa- 8 each, Mahesana , Netrang , Dholka , Jambughoda , Virpur , Vyara , Surat City , Vijapur , Kalol , Ghoghamba , Mahuva , Poshina , Bardoli , Garudeshwar , Kalol , Anand – 7 each. **West Madhya Pradesh:** Kathiwada 21, Biaora , Alirajpur- 14 each, Begumganj , Navibagh- 13 each, Bairagarh Airport , Maheshwar- 11 each, Badarwas , Raisen- , Bhimpur , Budhni , Khategaon- 9 each, Seoni Malwa , Chicholi , Bhopal Arera Hills , Kurwai , Rehti- 8 each, Shahpur , Rahatgaon , Godadongri , Tal , Satwas , Sitamau , Hatpiplaya , Sarangpur , Bagli , Shajapur , Sonkatch , A lot- 7 each **Madhya Maharashtra:** Velhe 18, Lonavala_agri , Peth , Harsul – 16 each, Navapur , Igatpuri- 14 each, Surgana 13, Dhadgaon/akrani-Hydro 12, Akole , Mahabaleshwar-
25th August, 2024	**West Madhya Pradesh:** H to VH rainfall at a few places on 25th& 26th with EH rainfall at isolated places on 25th August. **East Madhya Pradesh:**Light to	

	moderate rainfall at many places with H to VH rainfall at isolated places on 25th and 26th August. **East Rajasthan:** H to VH rainfall at a few places and EH rainfall at isolated places on 25th and 26th August. **West Rajasthan:** H to VH rainfall at isolated places during 25th to 27th . **South Rajasthan:** isolated H to EH rainfall over South Rajasthan on 27th August. **Gujarat region:** H to VH rainfall at a few places and isolated EH rainfall on 25th and 26th and H to VH with isolated EH rainfall over south Gujarat on 27th August. **Saurashtra & Kutch:** H to VH rainfall at a few places and EH rainfall at isolated places during 25th -28thAugust and H to EH rainfall at isolated places on 29thAugust. **Konkan & Goa:** H to VH rainfall at a few places and EH rainfall at isolated places on 25th and 26th and H to VH rainfall on 27th August. **Madhya Maharashtra:** H to VH rainfall at a few places and EH rainfall at isolated places on 25th & 26th and H to VH rainfall at isolated places on 27th August. **Odisha:** H to VH rainfall at isolated places on 25th and 26th August. **Gangetic West Bengal:** H to VH rainfall at isolated places on 25th and 26th August. **Jharkhand:** Light to moderate rainfall at many places with H to VH rainfall at isolated places on 25th and 26th August.	Imd Obsy , Ozharkheda - , Paud Mulshi – 11 each, Nandurbar , Gidhade - , Dhule , Bodwad , Akkalkuwa- 8 each, Jamner , Taloda , Mulher , Vani, Chalisgaon , Trimbakshwar , Chandgad – 7 each **Konkan & Goa:** Pernem 16, Matheran 15, Vikramgad , Valpoi , Dahanu , Quepem , Sangameshwar Devrukh – 14 each, Dabolim- Navy , Khalapur , Mapusa , Talasari , Tala , Sanguem – 13 each, Kudal , Mokheda , Lanja , Mormugao , Devgad- 12 each, Pen , Dodamarg , Jawhar , Panjim , Ratnagiri , Karjat_agri , Khed , Margao – 11 each, Mulde , Thane , Murud , Canacona – 10 each, Panvel , Tbia , Sawantwadi , Malvan , Palghar, Roha , Rajapur , Mahad – 9 each, Dapoli , Santacruz , Ulhasnagar , Vaibhavwadi , Rameshwar_agri , Ponda , Murbad , Guhagarh , Awalegaon- 8 each, Vengurla , Mangaon , Bhiwandi , Uran , Shahapur , Wakwali, Pawarwadi - Arg , Poladpur- 7 each **East Madhya Pradesh:** Badamalhera , Tendukheda – 14 each, Panagar 12, Khurai , Tikamgarh- 11 each, Badwara 10, Bina , Buxwaha , Orchha- 9 each, Badagaon Dhasan , Karkeli , Baldevgarh , Chandia , Jabera- 7 each **East Rajasthan:** Dausa 14, Reodar 13, Chothkabarwara 12, Sangod , Baran , Kishanganj- 9 each, Pindwara , Banera Sr , Ajmer, Pratapgarh , Ajmer , Kherwara, Khandar- 8 each, Nasirabad , Kotri , Sarmathura , Malerainadunger , Jawaja , Malpura , Garhi , Mangliawas- 7 each. **Chhattisgarh:** Gangalur 11, Lalpur Thana 7; **Saurashtra & Kutch:** Talala 10, Mendarda 9, Visavadar 8, Keshod , Babra- 7 each **Odisha:** Khaira 10, Banki ,

26th August	**East & West Madhya Pradesh:** H to VH rainfall at a few places on 26th August. **East & West Rajasthan:** H to VH rainfall at a few places and EH rainfall at isolated places on 26th August. H to VH rainfall at isolated places on 27th August. **Gujarat region:** H to VH rainfall at a few places and isolated EH rainfall on 26th and 27th August and H rainfall at isolated places on 28th August. **Saurashtra & Kutch:** H to VH rainfall at a few places and EH rainfall at isolated places on 26th and 27th August; H to VH rainfall at isolated places on 28th & 29th August and H rainfall at isolated places on 30th August. **Konkan & Goa:** H to VH rainfall at a few places on 26th and H rainfall on 27th & 28th August. **Madhya Maharashtra:** H to VH rainfall at a few places on 26th and H rainfall at isolated places on 27th & 28th August. **Odisha:** H rainfall at isolated places during 26th to 28th August. **Gangetic West Bengal:** H to VH rainfall at isolated places on 26th August and H rainfall at isolated places on 27th August. **Jharkhand:** Light to moderate rainfall at many places with H to VH rainfall at isolated places on 26th August and H rainfall at isolated places on 27th &	Ghasipura , Chendipada- 9 each, Kaptipada , Swam-patna , Anandpur , Laikera , Jhumpura , Kirmira -8 each, Bijatala , Udala , Oupada , Jaipur – 7 each **Jharkhand:** Chakulia 9, Bau Kanke 7; **Vidarbha:** Nagbhir 8, Chikhalda 7; **West Rajasthan:** Raniwada Sr 7; **<u>26th August:</u>** **Gujarat Region:**Khergam 35, Dangs 29, Waghai 26,Dang 24, Kaprada , Santrampur ,Dharampur- 23 each, Subir 22, Shahera 21, Ukai , Vansda , Madhbun- 20 each, Nadiad 19,Valsad , Nandod , Dediapada – 18 each,Fatepura , Kukarmunda , Khanvel ,Mahudha – 17 each, Sagbara , Kadana , Anand , Karjan – 16 each, Quant , Dahod ,Narmada , Silvassa -15 each, Modasa 14, **East Rajasthan:** Pipalkhunt 26, Bhungra , Banswara- 19 each, Sallopat 16, Bagidora , Arthuna , Garhi , Sajjangarh- 15 each, Pratapgarh , Kesarpura , Chikali , Danpur- 13 each, Loharia , Shergarh , Arnod- 11 each, Sabla10, **Saurashtra & Kutch:** Rajkot 23, Muli , Chotila- 21 each, Wankaner 20, Halvad 18, Paddhari 17, Thangadh , Surendranagar- 14 each, Wadhvan 13, Surendranagar , Dhrangadhra , Sayla- 11 each, Lodhika 10, **West Madhya Pradesh:** Alirajpur 19, Malhargarh 15, Pansemal 13, Jaora , Kathiwada , Raoti- 12 each, Jawad , Shamshabad- 11 each, Sailana , Mandsaur- , Neemuch- 10 each, **Madhya Maharashtra:**Surgana 24, Dhadgaon/akrani- Hydro 19, Radhanagari , Peth- 16 each, Mahabaleshwar- 14, Lonavalaagri 13, Trimbakshwar 12, Igatpuri , Taloda- 11 each, Bhor 10,

	28th August. **Bihar:** Light to moderate rainfall at many places with H rainfall at isolated places during 26th to 28th August.	**Konkan & Goa:**Palgharagri , Jawhar- 15 each, Vikramgad , Wada- 13 each, Talasari , Dahanu- 12 each, Mangaon , Kankavli , Valpoi- 11 each, Mahad , Ponda , Mhasla , Matheran- 10 each, **Jharkhand:** Maheshpur12; **Chhattisgarh**: Sukma 10, **West Rajasthan:**Jaitran 7, **<u>27th August:</u>** **Saurashtra & Kutch:** Tankara 36, Wankaner 34, Rajkot 32, Kalavad 26, Mandvi , Khambhalia- 25 each, Lodhika 23, Chotila , Morbi , Nakhatrana- 22 each, Thangadh , Lalpur- 21 each, Kotdasangani 17, Chuda , Jodia- 16 each, Dhrol , Sayla- 14 each, Lakhtar , Barvala- 13 each, Jamnagar , Gadhda , Dasada , Vadia , Paddhari , Gondal , Botad- 12 each, Visavadar , Ranpur , Muli , Wadhvan , Jasdan , Dwarka , Naliya , Babra- 11 each, Kalyanpur , Jamnagar , Okha , Surendranagar , Keshod- 10 each. **Gujarat Region:** Morva Hadaf 34, Tarapur 31, Nadiad , Khambhat- 29 each, Borsad , Padra , Vadodara- 28 each, Godhra , Sojitra- 27 each, Wanakbori 26, Anand 24, Mahemdavad 23, Vaso 22, Balasinor , Mahudha- 21 each, Dholka 20, Bilodara_aws , Matar , Kheda , Meghraj- 19 each, Halol , Ghoghamba , Jotana- 18 each, Galteshwar , Shahera , Santrampur , Jambughoda , Limkheda , Dhandhuka- 17 each, Arnej_aws 16, Siddhpur , Fatepura , Kadi- each 15, Singvad , Dhandhuka , Mansa , Abad City , Kathalal , Chhota Udepur , Khanpur , Anklav- 14 each, Umreth , Visnagar , Modasa , Dascroi , Mc Ahmedabad , Mandal , Waghai- 13 each, Bavla , Virpur , Savli , Dholera , Becharaji- 12 each, Viramgam , Jhalod , Dang , Vadodara , Desar , Harij , Waghodia , Petlad , Bayad , Jetpur Pavi , Vadnagar , Godra_aws , Bodeli- 11 each, Vijapur , Subir , Dhanpur , Gandhinagar , Mahesana , Kalol , Sanjeli , Dahegam , Detroj ,
27th August	**Gujarat State:** **(a) North Gujarat region:** H to VH rainfall at isolated places is over North Gujarat on 27th August and H rainfall at isolated places on 28th & 29th August. **(b) South Gujarat Region:** H to VH rainfall at a few places and EH rainfall at isolated places on 27th H to VH rainfall at isolated places on 28th August and H rainfall at isolated places during 29th to 31st August. **(c) Saurashtra & Kutch:** H to VH rainfall at a few places and EH rainfall at isolated places during 27th to 29th and H rainfall at isolated places on 30th August. **South Rajasthan:** H to VH rainfall at isolated places is on 27th and H rainfall at isolated places on 28th August. **Madhya Maharashtra:** H to VH rainfall at isolated places on 27th and H rainfall at isolated places on 28th August. **Konkan & Goa:** H to VH rainfall at isolated places on 27th and H rainfall at isolated places on 28th August. **West Madhya Pradesh:** H rainfall at isolated places over West Madhya Pradesh is on 27th August. **Odisha:** H rainfall at isolated places during 27th to 28th August and H to VH rainfall on 29th August.	

	Gangetic West Bengal: H rainfall at isolated places on 27th August. **Jharkhand:** Light to moderate rainfall at many places with H to VH rainfall at isolated places on 27th and H rainfall at isolated places on 28th August. **Bihar:** Light to moderate rainfall at many places with H rainfall at isolated places during 27th to 28th August.	Prantij- 10 each. **Chhattisgarh:** Kusmi 25, Wandrafnagar 15, Raghunath Nagar , Manora- 9 each, Sanna 7 **East Rajasthan:** Bagidora 20, Sallopat , Shergarh- 17 each, Dhambola 14, Veja 13, Arthuna 11, Sajjangarh 10, Loharia , Khushalgarh , Chikali- 9 each, Garhi 8, Kanva , Galiakot , Sanganer Tehsil-7 each. **East Madhya Pradesh:** Kusmi 15, Sidhi , Churhat- 14 each, Nagode , Beohari , Bahri- 11 each, Rampur 10, Majhauli , Devser , Sihawal- 9 each, Orchha , Bilhari- 8 each, Naigarhi , Semariya , Gudh , Lavkushnagar- 7 each. **Madhya** **Maharashtra:** Gaganbawada , Mahabaleshwar- 13 each, Surgana 12, Lonavala_agri , Trimbakshwar- 11 each, Shahuwadi 10, Ajra , Chandgad , Radhanagari , Velhe- 9 each, Peth 8, Patan , Igatpuri , Harsul- 7 each **Konkan & Goa:** Jawhar 12, Awalegaon - Arg 10, Matheran , Pawarwadi- 8 each, Lanja , Mandangad , Mokheda , Vikramgad , Rajapur- 7 each. **West Madhya Pradesh:** Kathiwada 10, Bhabhra 9, Meghnagar , Udaigarh , Thandla- 7 each **Bihar:** Khaira , Silao , Sono- 7 each. **Jharkhand:** Rania 14, Kharsema 13, Maithon , Dumri- 12 each, Bagodari 11, Panchet , Nandadih , Panchet , Nawadih , Dumri -9 each, Hunterganj , Chandil , Markachou , Gobindpur , Madhupur , Chakulia- 8 each, Torpa , Giridih Bengbad , Giridih , Jamtara , Diyakel Khunti- 7 each. **Orissa**: Jagatsinghpur 11, Cuttack , Bhuban , Kantapada- 9 each, Athgarh , Mundali , Banki- 7 each. **Chhattisgarh:** Kusmi 25, Wandrafnagar 15, Raghunath Nagar , Manora- 9 each, Sanna 7 **Gangetic West Bengal**: Bankura 13, Luchipur , Diamond Harbour- 11
28th August	**Gujarat State:** **(a) Saurashtra & Kachchh:** H to VH rainfall at a few places and EH rainfall at isolated places on 28th August; H to EH rainfall at isolated places on 29th August and H rainfall at isolated places on 30th August. **India Meteorological Department** **(Ministry of Earth Sciences)** **(b) Gujarat region:** Light to moderate rainfall at many places with H rainfall at isolated places is on 28th August. **South Rajasthan:** Light to moderate rainfall at many places with H rainfall at isolated places is on 28th August. **Madhya Maharashtra:** H rainfall at isolated places on 28th August. **Konkan& Goa:** H rainfall at isolated places on 28th August.	
29th August	**Gujarat State:** **Saurashtra & Kachchh:** H to EH rainfall at isolated places on 29th, H to VH rainfall at isolated places on 30th August and H rainfall at isolated places over coastal districts on 31st August.	
30th Aug2024	**Odisha**: H to VH rainfall at isolated places during 30th to 31st August.	

	isolated heavy rainfall likely on 1st September. **Coastal Andhra Pradesh:** H rainfall at isolated places during 30th August to 1st September and heavy to VH rainfall at isolated places on 30th and 31st August.	each, Bankura 10, Asansol , Asansol- 9 each, Jhargram , Burnpur- 8 each, Kalaikunda , Midnapore- 7 each **28th August:** **Saurashtra & Kutch:** Khambhalia 43, Jamnagar 38, Jamjodhpur 32, Dwarka 31, Lalpur 30, Porbandar , Ranavav- 28 each, Bhanvad , Kalavad- 24 each, Kalyanpur 24, Kotdasangani 23, Dhrol 18, Lodhika 17, Dhoraji , Jamkandorna- 16 each, Jodia , Gondal- 15 each, Kutiana 13, Morbi , Mangrol , Tankara , Visavadar , Rajkot- 12 each, Upleta , Vanthali , Manavadar- 11 each, Bhesan , Talala , Jetpur , Paddhari- 10 each, Junagadh , Naliya- 9 each, Mendarda , Wankaner , Keshod , Babra , Abdasa- 8 each, Botad 7 **Gujarat Region:** Nadiad 8, Kapadvanj 7, **East Rajasthan:** Mounnt Abu 9, 29th August: **Odisha:** Birmaharajpur , Jeypore- 10 each, Nandapur 8, Tangarpali 8, Hirakud 7, **Gujarat Region:** Umerpada 7, **Saurashtra & Kutch:** Naliya 30, Bhanvad 29, Abdasa 27, Kalyanpur 26, Dwarka , Lakhpat , Khambhalia- 23 each, Jamjodhpur 22, Nakhatrana 20, Mandvi18, Kalavad , Lalpur- 17 each, Kandla Airport 16, Dhoraji , Lodhika- 15 each, Kutiana , Jamkandorna- 13 each, Anjar , Ranavav- 12 each, Jamnagar 11, Jetpur , Mundra- 10 each, Bhuj , Porbandar , Rajkot , Manavadar , Upleta , Gondal- 9 each, Vanthali , Wankaner , Jamnagar-8 each, Gandhidham , Kandla New , Bhesan , Kotdasangani , Jodia- 7 each. **Madhya Maharashtra:** Igatpuri 8,
31st Aug 2024	**Odisha and Chhattisgarh:** HVH rainfall at isolated places on 31st August & 1st September over south Odisha and south Chhattisgarh. **Coastal Andhra Pradesh:** HVH rainfall at a few places and EH rainfall at isolated places likely on 31st August. **Telangana:** Light to moderate rainfall at most places EH rainfall at a few places and extremely heavy rainfall at isolated places on 31st August and isolated heavy to very heavy rainfall on 1st September.	
01st Sep 2024	**South Odisha and south Chhattisgarh**: H rainfall at isolated places likely on 1st September. **North Andhra Pradesh:** isolated HVH rainfall likely during next 24 hours. **Telangana**: isolated H to EH rainfall at isolated places over Telangana on 1st September and isolated heavy rainfall over north Telangana on 2nd September. Vidarbha. H to EH rainfall at a few places and extremely heavy rainfall at isolated places on 1st and 2nd September. **Marathwada:** H to VH rainfall at isolated places on 1st and 2nd September. **East Madhya Pradesh:** HVH rainfall at isolated places is likely on 1st and 2nd September.	

	West Madhya Pradesh: heavy rainfall at isolated places on 1st and HVH rainfall at isolated places on 2nd September. **Gujarat region:** H rainfall at isolated places on 1st and heavy to very heavy rainfall at isolated places on 2nd September.	**30th Aug** **1.Gujarat** Mandvi 39, Mundra 22, Okha 17, Abdasa16; Naliya16, Dwarka, Anjar-8 each, Gandhidham 7. **31st Aug** **Odisha:** Malkangiri 11, Nandapur 8, Junagarh 5 **Chhattisgarh**: Dornapal 11, Konta 10. **East Rajasthan**: Bhungra 11, Devel, Sajjangarh, Kherwara 10 each, Ganeshpur, Kesarpura, Sallopat 7 each. **Vidarbha**: Mangrulpir 8. **Odisha**: Padia 14. **Chhattisgarh**: Dornapal 11, Konta 10. **Marathwada**: Kinwat 18, Himayatnagar 17, Mahur 11, Hadgaon, Bhokar 7 each. **West Madhya Pradesh**: Maksudangarh 7. **East Madhya Pradesh**: Harrai, Kirnapur 9 each. **Gujarat Region**: Waghai 11, Bodeli 7. **Madhya Maharashtra**: Pathardi 9. **West Rajasthan**: Nawa 7. **Vidarbha**: Pusad 10, Digras 7. **Gujarat Region**: Valia 37, Songadh, Mangrol 25 each, Vyara 22, Maktampur 20, Bharuch 19, Nadiad, Netrang, Tilakwada 17 each, Dolvan 16, Vansda, Uchchhal, Subir 15 each, Daman 14, Bayad 13, Kapadvanj 13, Karjan, Lunawada, Valod, Nandod, Valsad, Mandvi, Prantij 12 each, Kathalal, Himatanagar, Bayad,
02nd Sep 2024	**Gujarat region:** HVH to EH rainfall at isolated places on 2st and 3rd September. **Madhya Maharashtra**: very H to EH rainfall at isolated places on 2nd September and isolated heavy rainfall on 3rd September. **Marathwada:** HVH rainfall at isolated places on 2nd September. **Vidarbha:** isolated HVH rainfall at a few places on 2nd September and isolated heavy rainfall on 3rd September. **East Madhya Pradesh:** H rainfall at isolated places is likely on 2nd September. **West Madhya Pradesh:** HVH rainfall at isolated places on 2nd and 3rd September. **East Rajasthan:** H rainfall at isolated places on 2nd September. **Telangana:** H rainfall over north Telangana on 2nd September.	

	Saurashtra & Kachchh: H rainfall at isolated places on 2st and very heavy rainfall on 3rd September	Mahesana 11 each, Waghai, Garudeshwar, Umerpada, Virpur, Vagra, Balasinor, Kamrej 10 each. **Madhya Maharashtra**: Navapur 16, Nandgaon 9, Gaganbawada, Gidhade 7 each. **West Madhya Pradesh**: Gandhwani 16, Kukshi 14, Sardarpur 13, Bagh 13, Jabot 12, Jhabua, Dahi, Rama 11 each, Alirajpur 10, Udaigarh, Meghnagar 8 each, Ranapur, Manawar, Khalwa 7 each. **East Rajasthan**: Bhungra 11, Devel, Sajjangarh, Kherwara 10 each, Ganeshpur, Kesarpura, Sallopat 7 each. **Vidarbha**: Mangrulpir 8.

H: Heavy rainfall, VH: Very heavy rainfall, EH: Extremely heavy rainfall

Maximum sustained wind speed (MSW)

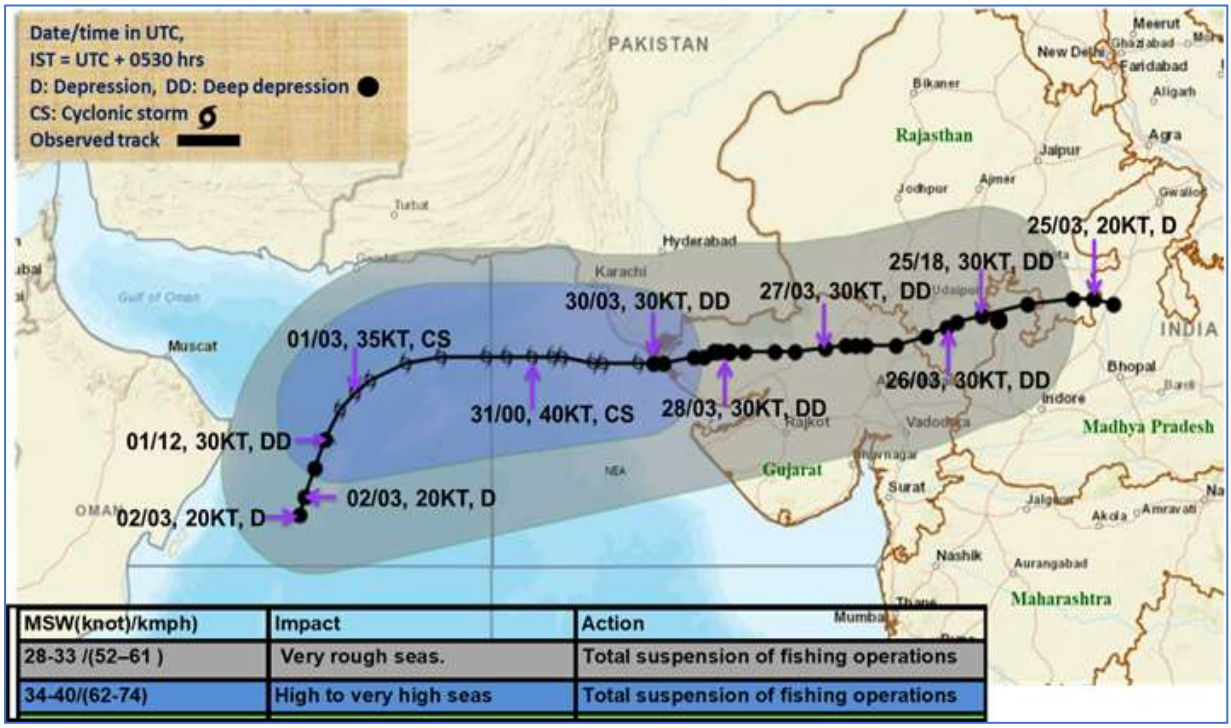


Fig. 8: Estimated maximum sustained wind during the life cycle of CS ASNA.

The system reached its peak intensity of maximum sustained wind speed of 40 knots gusting to 50 knots (70-80 kmph gusting to 90 kmph) at 0000 UTC (0530 IST) 31st August

with estimated central pressure (ECP) of 990 hPa and pressure drop of about 8 hPa over Northeast Arabian Sea **(Fig. 8).**

7. Damage due to CS ASNA

As per media reports, Flooding in Gujarat killed 49 people between 25 and 31 August. The flooding also resulted in the death of 2,618 livestock. Crops were destroyed in several districts in Kutch and Saurashtra regions. In Vadodara and elsewhere, there was extensive damage to houses, shops and businesses. 4,173 km of roads were damaged. Total 6,931 villages and 17 cities were affected by the loss of electricity. Total 88 substations were shut down during the flooding. An old bridge between Bodeli and Chhota Udepur on the national highway collapsed. An initial survey reported that the Government of Gujarat suffered damages worth more than ₹250 crore (US$29 million) to government properties and public infrastructure. **Fig. 9.**

Fig. 9: (a) A Flooded Area at Kothara village in Kutch District, Image: Ahmedabad Mirror, (b): A flooded area at Kothara village in Kutch district, Image: DNA, (c) : Image: PTI

8. Performance of operational NWP models

Various global models and dynamical-statistical models run by Ministry of Earth Sciences (MoES) institutions including IMD, NCMRWF, IITM & INCOIS and guidance from models from various international agencies under bilateral arrangement. IMD operationally runs Global and regional models short-range (3-days) to medium-range (10 days) prediction of tropical cyclones over North Indian Ocean region. The IMD Global Forecast System (IMD-GFS-T1534L64) at the resolution of 12 km with 6 hourly assimilation cycle with Global Data Assimilation System (GDAS) was utilized for medium range prediction (10 days). The WRF-VAR model was run at the horizontal resolution of 3 km to produce forecasts for 3 days over a domain covering the area of responsibility for RSMC, New Delhi. Initial and boundary conditions were obtained from the IMD Global Forecast System (IMD-GFS). The boundary conditions are updated at every six hours interval. The cyclone specific triple-nested (18x6x2 km) coupled Hurricane Weather Research Forecast (HWRF) model were utilized to predict the genesis, track, landfall and intensity of the cyclone as well as associated severe weather. Global models are also run at NCMRWF. These unified models NCUM adapted from UK Meteorological Office. In addition to the above deterministic NWP models, there were two different ensemble prediction systems i.e. Global Ensemble Forecast System based on IMD-GFS model and NCMRWF Ensemble Prediction System (NEPS). Both EPSs run with 12 km horizontal resolution to produce forecast for 10 days daily based on initial condition at 0000 UTC. Multi-model ensemble (MME) prediction systems are operational in IMD to generate track and intensity forecasts (at 12h interval up to 120h) of tropical cyclones for the Indian Seas. The MME system is developed using available global forecasts from various models. In this report performance of the individual models and MME forecasts for cyclonic storm “ASNA” are presented and discussed. The forecasts were mainly based on multi-model ensemble technique developed by IMD. which was further value added to arrive at consensus forecast by considering various prognostic & diagnostic features, observational features, initial conditions and consistency of individual models etc. A digitized forecasting system of IMD was utilized for analysis and comparison of various observations and numerical weather prediction model’s guidance, decision making process and warning products generation.

9.2 Track and intensity prediction by NWP models: -

The figures **10(a) and 10(b)** represent track and intensity predictions by different NWP model forecasts generated within IMD. Every individual figure represented the model forecasts based on the initial conditions at 0000 UTC of 28th Aug 2025.

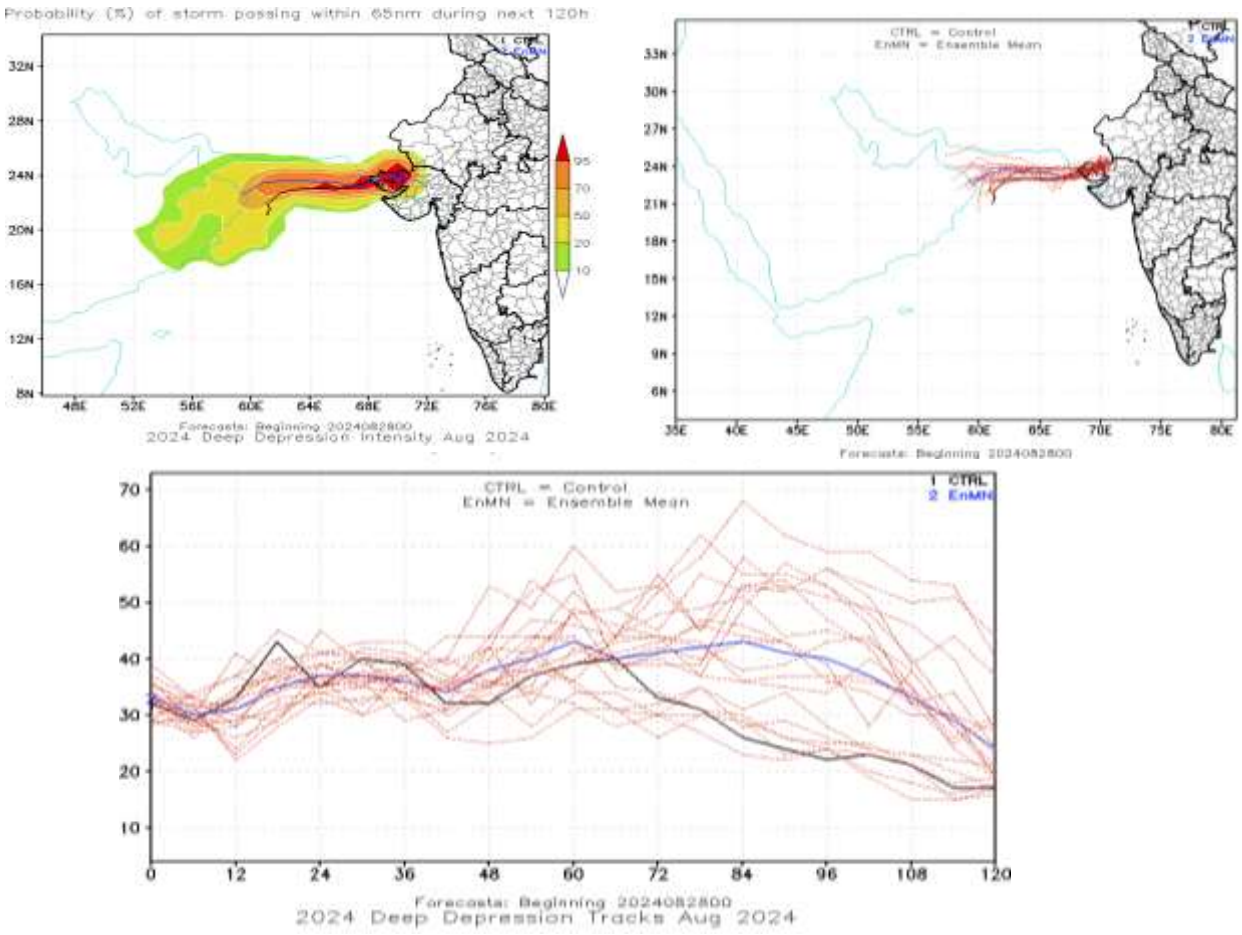


Fig. 10(a): NWP (GEFS) model track forecast based on 0000 UTC of 28.08.2024

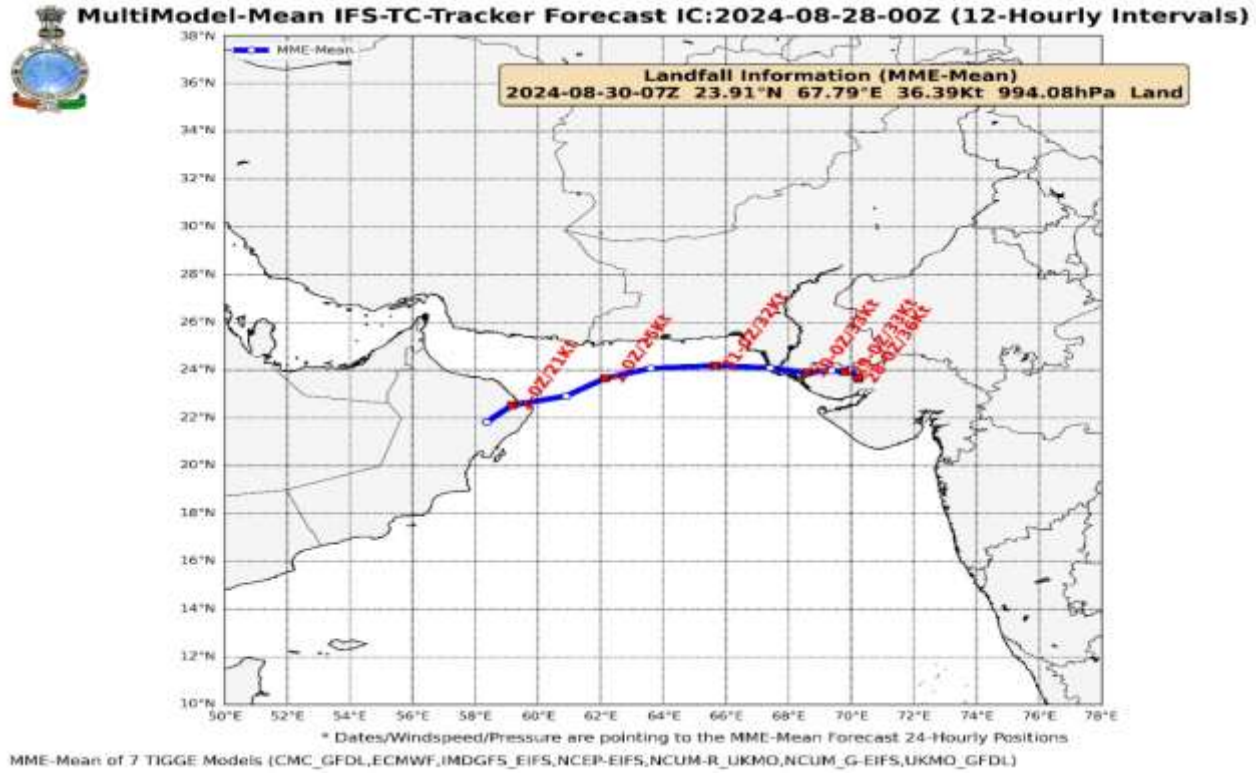


Fig. 10(b): MME model track forecast based on 0000 UTC of 28.08.2024

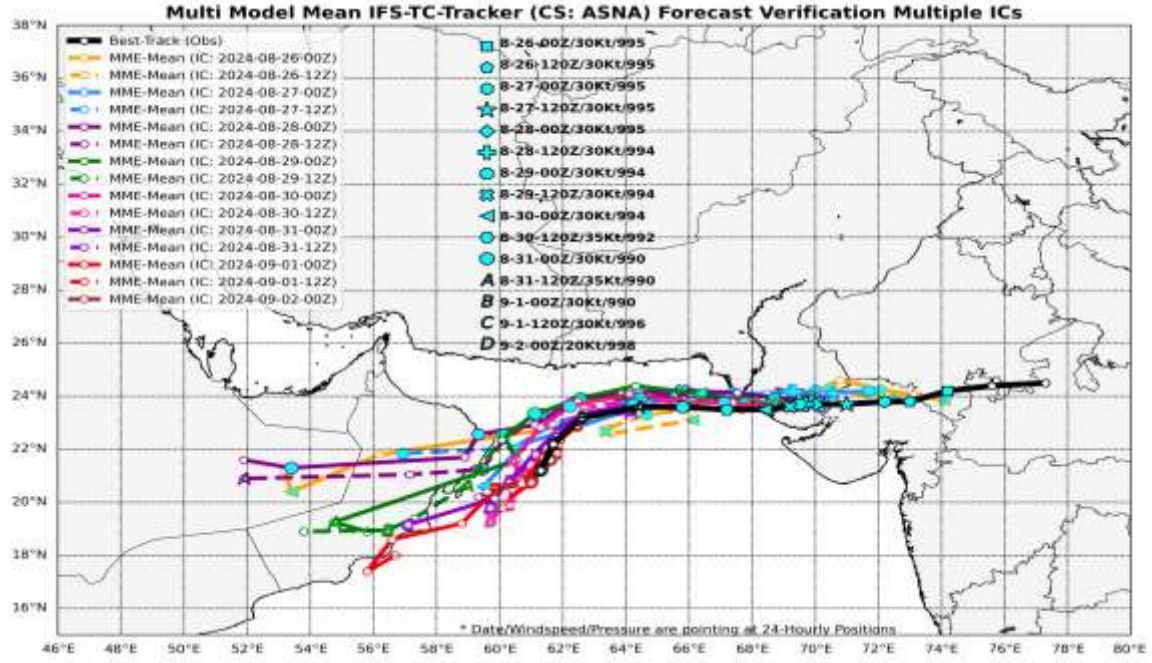
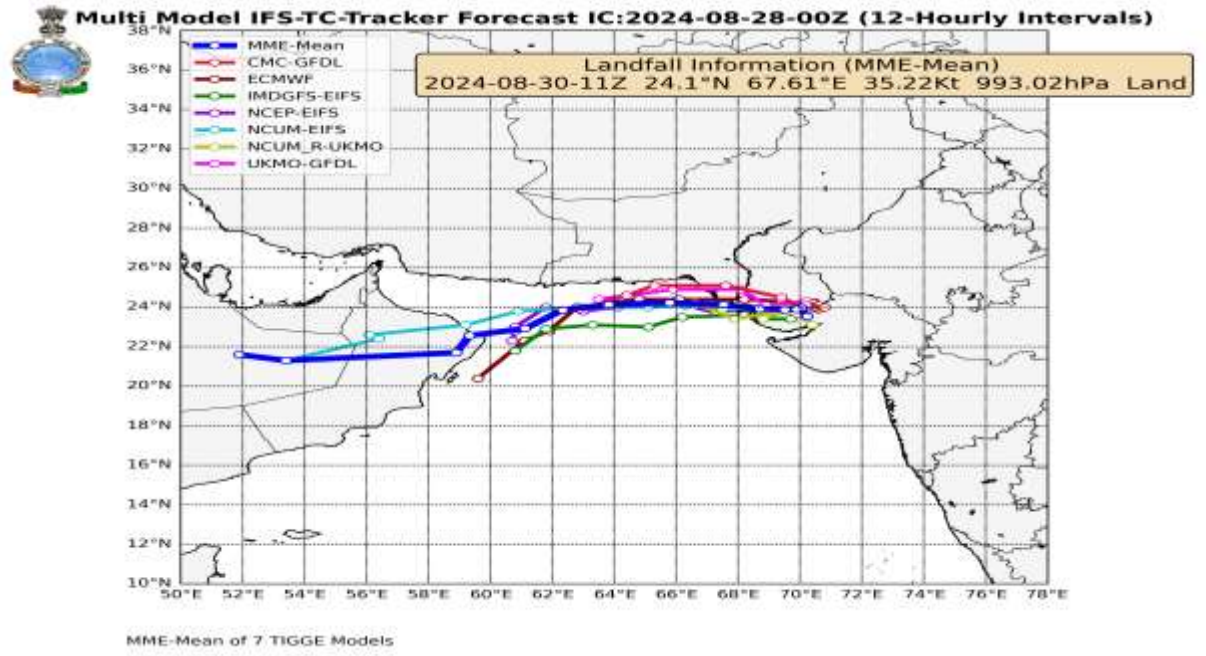


Fig. 10 (c) : MME-based track forecasts based on ICs from 26th August 0000 UTC to 2nd Sep 0000 UTC along with the best track.

At 0000 UTC of 28th September, 2024: The Fig. 10(a) displayed the GEFS track & intensity forecasts, which indicated initial west-southwestwards movement till 0000 UTC of 1st September and then nearly southwestwards. In Fig. 10(b) MME mean track was very much close to the best track as it was very close to Saurashtra & Kachchh before likely to move slowly west-southwestwards across Saurashtra & Kachchh region and reach Saurashtra & Kachchh coast & adjoining areas of Pakistan after the system emerged over

the sea while moving from land over northeast Arabian Sea around 0000 UTC of 29th august. The MME forecast was closer to the best estimate track information. The intensity forecasts of the cyclone in the MME forecast indicated maximum sustained wind of 36.5 kts at 0600 UTC of 30th August 2024.

MME-based track forecasts based on ICs from 26th August 0000 UTC to 2nd Sep 0000 UTC along with the best track shown in Fig. 10c indicated a broad temporal consistency with respect to the forecast tracks with all ICs indicating initial westward and subsequent west-southwestward movement like the observed track.



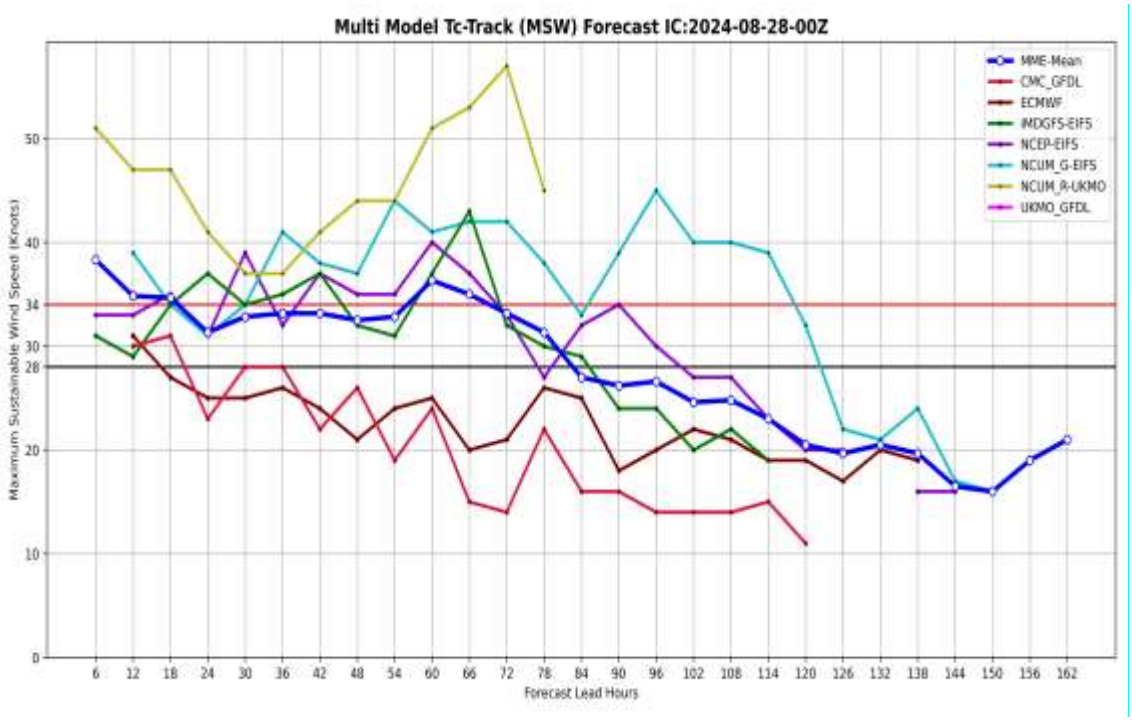


Fig. 10d shows the track and intensity forecasts based on the IC of 28th August 0000 UTC.

Fig. 10d shows the track and intensity forecasts based on the IC of 28th August 0000 UTC. As can be seen, there is a broad consensus among individual models regarding the predicted tracks of the system, which are similar to the observed track. However, with respect to the intensity of the system, the model differs from each other with NCUM-R indicating a much stronger system with maximum sustained wind speed exceeding 50 knots. The NCUM-G also slightly over-predicted. The other models like CMC-GFDL and ECMWF under-predicted the intensity as it didn't show the intensity of tropical cyclones reaching MSW of 34 knots.

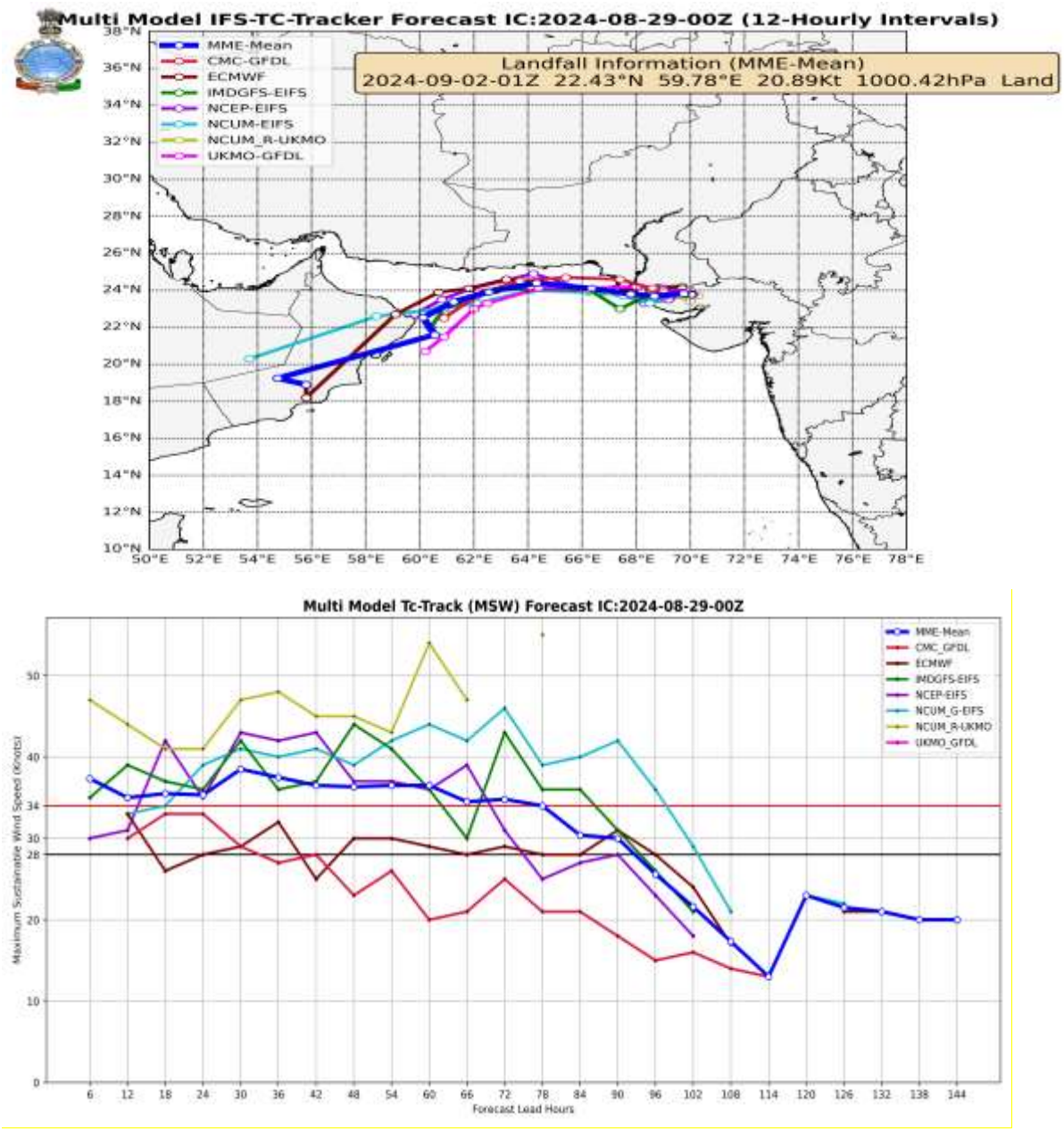


Fig. 10e shows the track and intensity forecasts based on the IC of 29th August 0000 UTC.

Fig. 10e shows the track and intensity forecasts based on the IC of 29th August 0000 UTC. It shows similar patterns like that seen with respect to the IC of 28th August shown in Fig. 10d. As can be seen in Fig. 10e, there is a broad consensus among individual models regarding the predicted tracks of the system with initial westward movement over the northeast Arabian Sea followed by west-southwestward movement over the northwest Arabian Sea.

With respect to the intensity of the system, the model varies with NCUM-R indicating a much stronger system with maximum sustained wind speed exceeding 50 knots. The NCUM-G is also slightly over-predicted. The other models like CMC-GFDL and ECMWF under-predicted the intensity as it didn't show the intensity of tropical cyclones reaching MSW of 34 knots.

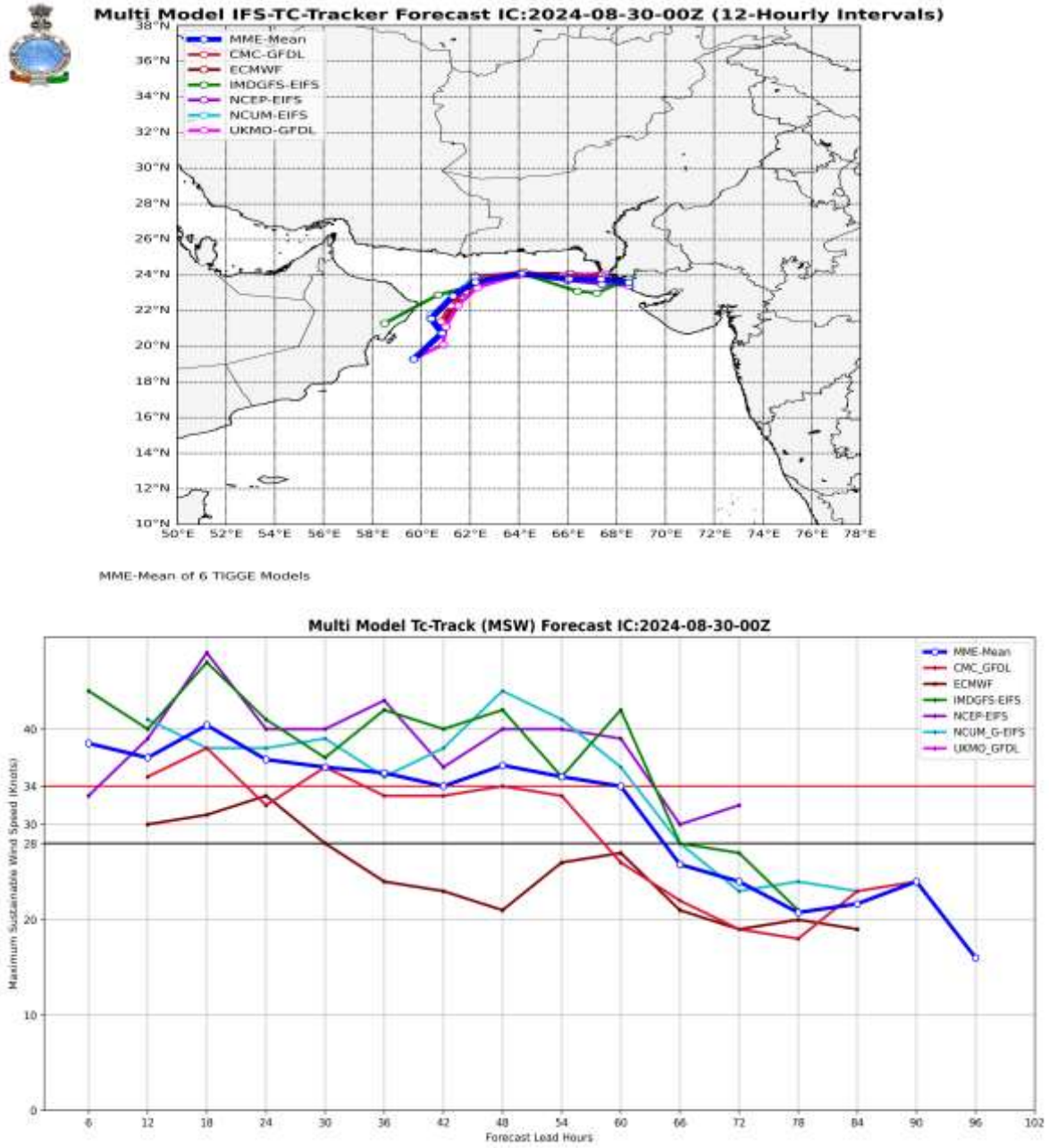
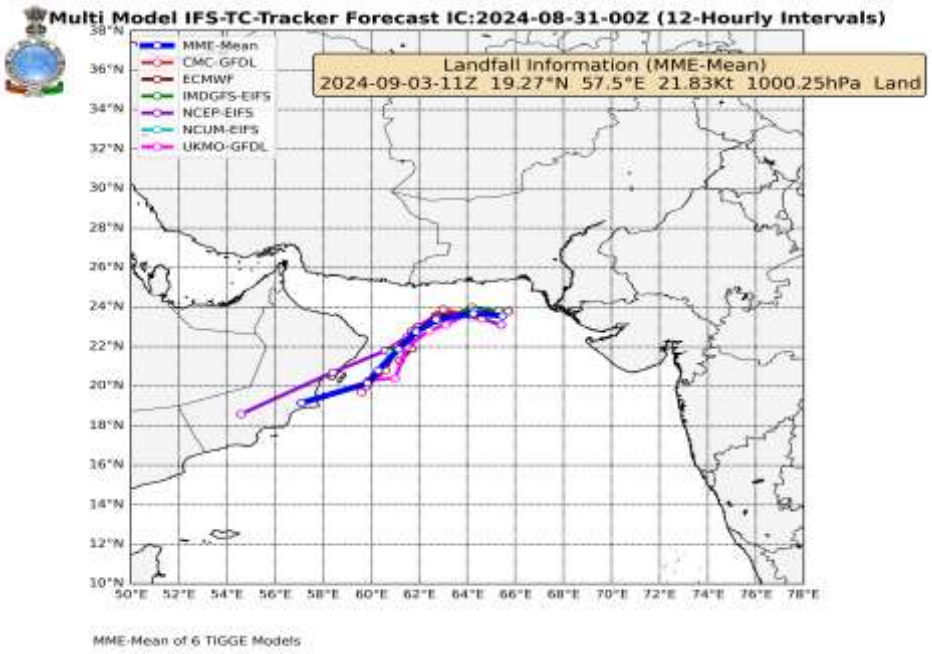


Fig. 10f shows the track and intensity forecasts based on the IC of 30th August 0000 UTC.



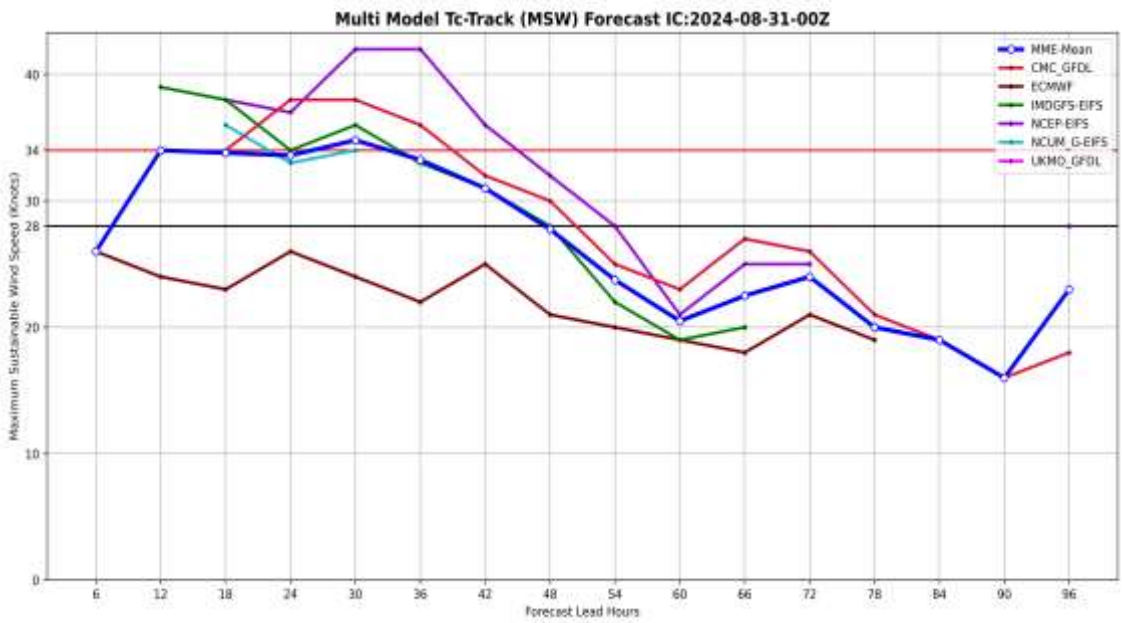


Fig. 10g shows the track and intensity forecasts based on the IC of 31st August 0000 UTC.

Fig. 10f and Fig. 10g show the track and intensity forecasts based on the IC of 30th 0000 and 31st August 0000 UTC respectively. It may be mentioned here that on 30th August it was having the intensity of Deep Depression and on 31st August it had already reached to the cyclone stage. As seen in Fig. 10f, there is a broad consensus among individual models regarding the predicted tracks of the system with initial westward movement followed by southwestward movement over the northwest Arabian Sea except the IMD GFS model which indicated initial westward and subsequent west-southwestward movement over the northwest Arabian Sea. Based on 31st August all models show southwestward movement.

With respect to the intensity, the ECMWF model under-predicted the intensity as it didn't show the intensity of tropical cyclones reaching MSW of 34 knots (Fig. 10f and 10g).

9.3 Track forecast errors by various NWP Models

The average track forecast errors (Direct Position Error) in km at different lead periods (hr) of various models are presented in Table 2.1. As it is seen, the MME performed better than the individual model and is very close to or better than IMD's operational forecasts.

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr	120 H
NCUM_R-UKMO	58.17 (8)	72.7 (7)	84.18 (7)	74.42 (6)	73.4 (6)	80.57 (5)	nan (0)	nan (0)	nan (0)	nan (0)
NCEP-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
HWRF-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
ECMWF-EIFS	54.52 (11)	75.91 (11)	78.31 (11)	98.16 (10)	100.63 (9)	101.67 (8)	130.23 (7)	135.4 (6)	116.24 (5)	160.79 (4)
IMDGFS-EIFS	52.64 (13)	60.44 (12)	69.58 (11)	48.39 (10)	74.66 (9)	104.47 (8)	122.47 (7)	99.23 (7)	85.14 (5)	123.14 (4)
IMDGFS-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
IMDGEFS_mean_GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
NCEP-EIFS	40.76 (14)	55.32 (13)	75.94 (12)	80.67 (11)	103.41 (10)	116.19 (8)	125.92 (8)	156.42 (6)	138.65 (3)	123.26 (2)
NCUM_G-EIFS	51.24 (7)	49.14 (7)	54.25 (7)	73.31 (7)	76.61 (7)	86.41 (7)	130.09 (6)	228.03 (5)	238.54 (4)	332.52 (3)
NCUM_G-UKMO	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
UKMO_GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
CMC_GFDL	54.78 (14)	81.96 (13)	115.28 (12)	127.14 (11)	158.0 (10)	189.75 (9)	215.98 (8)	295.95 (7)	344.16 (5)	546.42 (3)
MMEM	33.91 (14)	44.25 (13)	50.97 (12)	51.93 (11)	62.24 (10)	80.95 (9)	100.2 (8)	106.99 (7)	124.03 (6)	163.09 (5)
IMDOPER	24.52 (7)	48.02 (6)	69.22 (5)	99.43 (4)	162.08 (3)	173.1 (2)	nan (0)	nan (0)	nan (0)	nan (0)

Table 2.1. Average track forecast errors (Direct Position Error) in km at different lead periods (Number of forecasts verified is given in parentheses).

Lead Time	06 Hr	18 Hr	30 Hr	42 Hr	54 Hr	66 Hr	78 hr
NCUM_R-UKMO	12.86 (7)	10.71 (7)	19.33 (6)	18.67 (6)	22.33 (6)	23.2 (5)	nan (0)
NCEP-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
HWRF-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
ECMWF-EIFS	3.91 (11)	4.36 (11)	6.09 (11)	4.8 (10)	5.89 (9)	5.5 (8)	5.57 (7)
IMDGFS-EIFS	4.54 (13)	3.75 (12)	4.64 (11)	5.6 (10)	4.44 (9)	3.88 (8)	4.14 (7)
IMDGFS-GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
IMDGEFS_mean_GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
NCEP-EIFS	5.36 (14)	6.46 (13)	5.5 (12)	5.09 (11)	3.4 (10)	5.0 (8)	4.5 (8)
NCUM_G-EIFS	4.43 (7)	5.29 (7)	5.43 (7)	7.86 (7)	7.71 (7)	4.57 (7)	8.67 (6)
NCUM_G-UKMO	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
UKMO_GFDL	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)	nan (0)
CMC_GFDL	5.21 (14)	4.38 (13)	6.58 (12)	4.73 (11)	7.4 (10)	10.0 (9)	11.12 (8)
MMEM	4.43 (14)	3.46 (13)	4.09 (12)	3.8 (11)	3.53 (10)	2.02 (9)	3.88 (8)
IMDOPER	2.86 (7)	3.33 (6)	3.0 (5)	3.75 (4)	3.33 (3)	2.5 (2)	nan (0)

Table 2.2. Average Intensity Forecast Errors of maximum sustained wind in knots (Number of forecasts verified is given in parentheses). The negative sign indicates an underestimation of intensity and vice versa.

10. Operational Forecast Performance

10.1 Genesis, track, landfall and intensity forecast:

i) Pre-Genesis Forecast performance

- First information about the likelihood of cyclogenesis (formation of Depression) with moderate confidence (34-67%) was issued in the extended range outlook issued on 15th August (about 10 days ahead of the formation of depression on 25th August).
- The extended range outlook was further updated on 24th August. It indicated the likely formation of a depression over Northwest Madhya Pradesh with high confidence (68-100%) (about 1 day ahead of the formation of the depression) and the probable emergence of the system into the northeast Arabian Sea.
- Daily tropical weather outlook issued since 24th August indicated the probability of formation of a depression over land around 26th Aug.

ii) Operational track, intensity and landfall forecast performance

(a) On formation of depression in the early morning of 25th August, the track and intensity forecast issued at 0530 hours IST of 25th August indicated initial northwestwards movement followed by west-southwestwards movement towards Gujarat region.

(b) Subsequently, all forecasts were continued consistently without any significant change.

(c) Thus, the genesis, track and intensity and landfall time of cyclone ASNA were predicted correctly well in advance.

(d) The track forecast errors for 24, 48 and 72 hrs lead period were 56, 110 and 174 km respectively against the long period average (LPA) errors of 72, 112 and 156 km respectively based on data of 2019-23 (**Fig. 11a**). The track forecast skills calculated against Climatology & Persistence (CLIPER) forecast for 24, 48 and 72 hrs lead period were 51, 53 and 70 km respectively against the long period average (LPA) skill of 66, 75 and 76% respectively based on data of 2019-23 (**Fig. 11b**). The operational track forecast errors were less than the LPA errors for all lead periods upto 48 hours.

(e) The absolute errors (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 3.2, 5.0 and 1.7 knots against the LPA errors of 7.1, 10.3 and 13.8 knots based on data of 2019-23 respectively (**Fig.12a**). The skills in intensity forecast based on AE calculated against persistence-based forecast for 24, 48 and 72 hrs lead period were 71, 71 and 50% against the LPA skills of 57, 71 and 77% based on data of 2019-23 respectively (**Fig.12b**). For all lead periods, the operational intensity forecast errors were less than the LPA.

(f) The root mean square errors (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 4.0, 5.0 and 2.9 knots against the LPA errors of 9.2, 12.8 and 16.5 knots based on data of 2019-23 respectively (**Fig.13a**). The skills in intensity forecast based on RMSE calculated against persistence-based forecast for 24, 48 and 72 hrs lead period were 72, 76 and 50% against the LPA skills of 63, 73 and 81% based on data of 2019-23 respectively (**Fig 13b**). For all lead periods, the operational intensity forecast errors were less and for most lead periods, skills were more than the LPA.

Thus, the genesis, track and intensity of cyclonic storm ASNA were correctly predicted with reasonable lead period (about 3-4 days in advance), which helped the disaster managers to take appropriate response actions for reducing the loss of life and property.

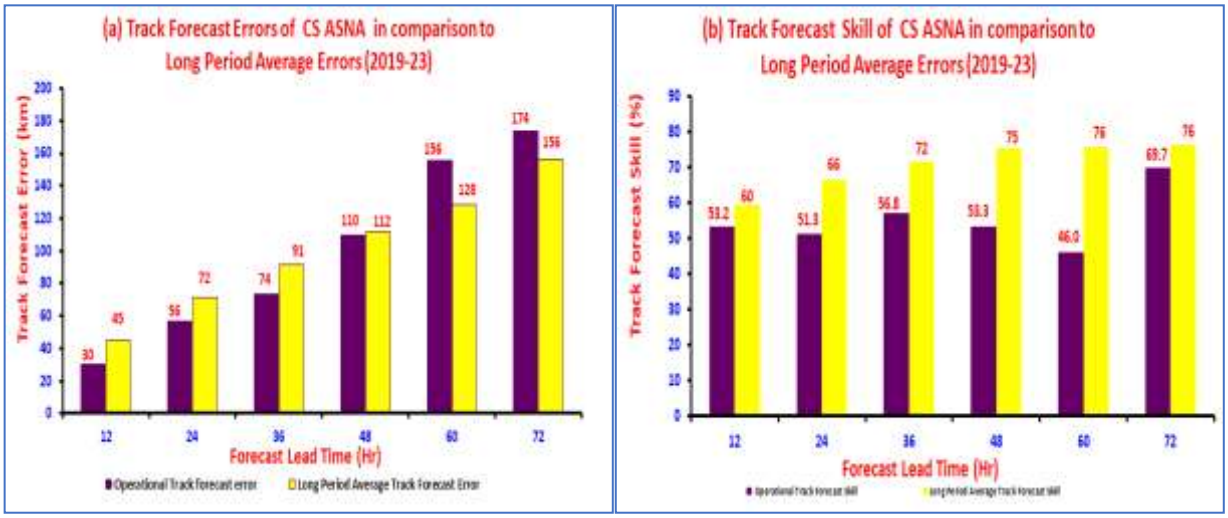


Fig. 11(a): Track forecast error and (b) skill against Climatology & Persistence (CLIPER) forecast compared to long period average (LPA of 2019-2023) errors & skills respectively

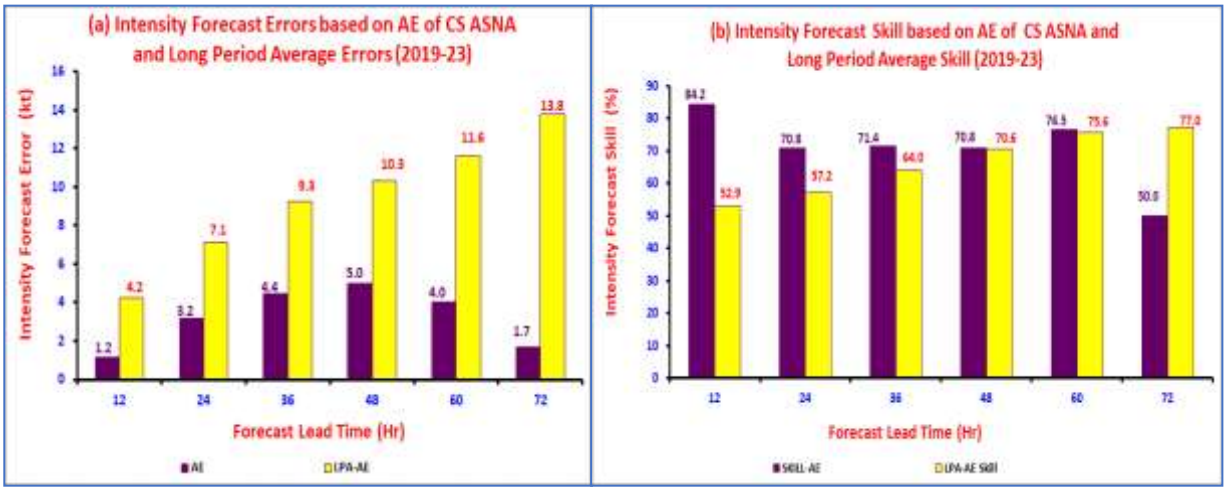


Fig. 12(a): Absolute Error (AE) intensity forecast and (b) skill against Persistence forecast compared to long period average (LPA of 2019-23) error & skill respectively based on absolute error (AE).

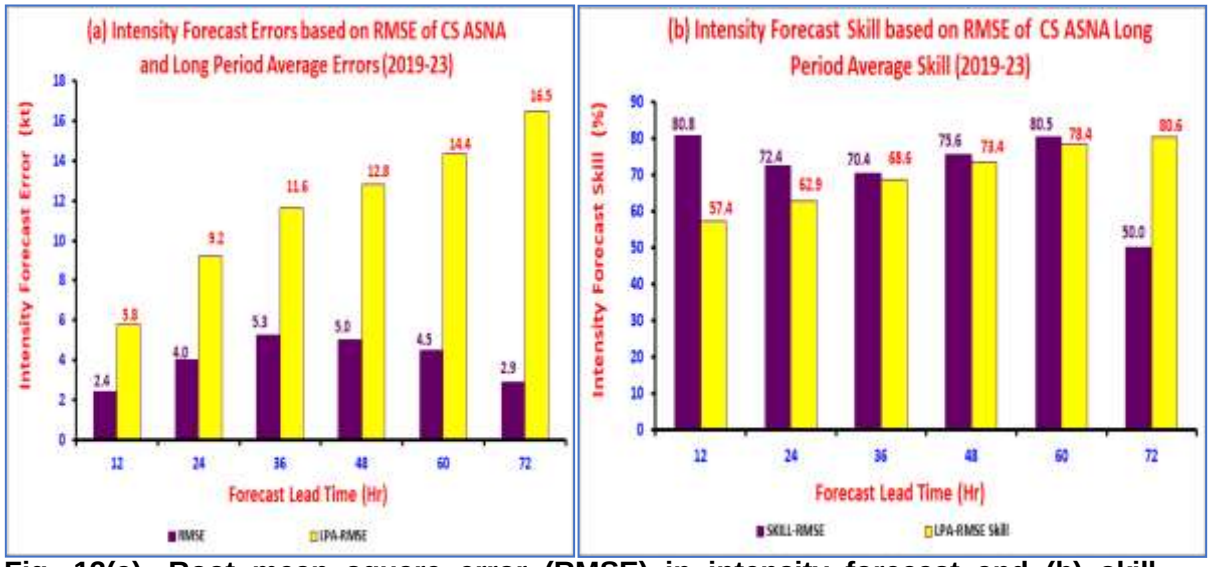


Fig. 13(a): Root mean square error (RMSE) in intensity forecast and (b) skill against Persistence forecast compared to long period average (LPA of 2019-2023) error & skill respectively

Table 3: Operational Track forecast errors and skill of CS "ASNA" as compared to the long period average (2019-23)

Lead Period (hrs)	N	Operational Track forecast error (km)	Operational Track Forecast Skill (%)	Long Period Average (2019-23)	
				Track Forecast Error (km)	Track Forecast Skill (%)
12	13	30	53.2	45	60
24	11	56	51.3	72	66
36	9	74	56.8	91	72
48	7	110	53.3	112	75
60	5	156	46.0	128	76
72	3	174	69.7	156	76

N: no. of observations verified

Table 4: Operational Absolute errors (AE) and Root Mean Square errors (RMSE) and corresponding skill in intensity forecast of CS "ASNA" as compared to the long period average (2019-23)

Lead Period	N	AE	RMSE	Skill-AE	Skill-RMSE	Long Period Average (2019-23)			
						AE	RMSE	Skill-AE	Skill-RMSE
12	13	1.2	2.4	84.2	80.8	4.2	5.8	52.9	57.4
24	11	3.2	4.0	70.8	72.4	7.1	9.2	57.2	62.9
36	9	4.4	5.3	71.4	70.4	9.3	11.6	64.0	68.6
48	7	5.0	5.0	70.8	75.6	10.3	12.8	70.6	73.4
60	5	4.0	4.5	76.5	80.5	11.6	14.4	75.6	78.4
72	3	1.7	2.9	50.0	50.0	13.8	16.5	77.0	80.6

N: No. of observations verified, AE: Absolute error, RMSE: Root Mean Square Error, LPA: Long Period Average

11. Warning & advisories issued by IMD

Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track and intensity forecast for +06, +12, +18, +24, +36, +48 and up to +72 hrs lead period commencing from 29th August till the system weakened into a low-pressure area. The above forecasts were issued along with the cone of uncertainty in the track forecast, five times a day during depression stage, five times a day during deep depression stage and every three hourlies during the cyclone period **(Fig. 14a).**
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥28 and ≥34 knots wind in four geographical quadrants of cyclone were issued along with graphics, commencing from 29th August **(Fig.14b).**

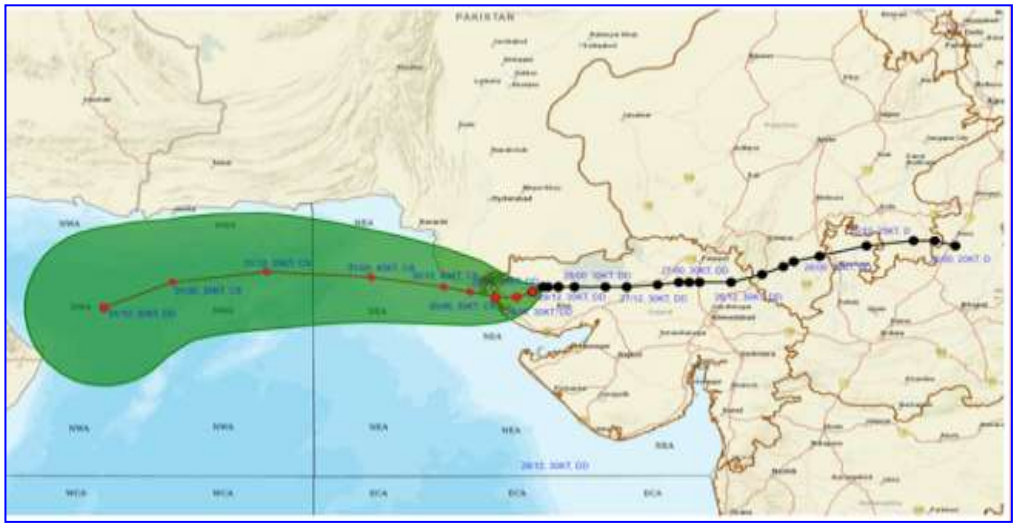


Fig.14(a): Typical track forecast along with cone of uncertainty based on 1200 UTC of 29th August

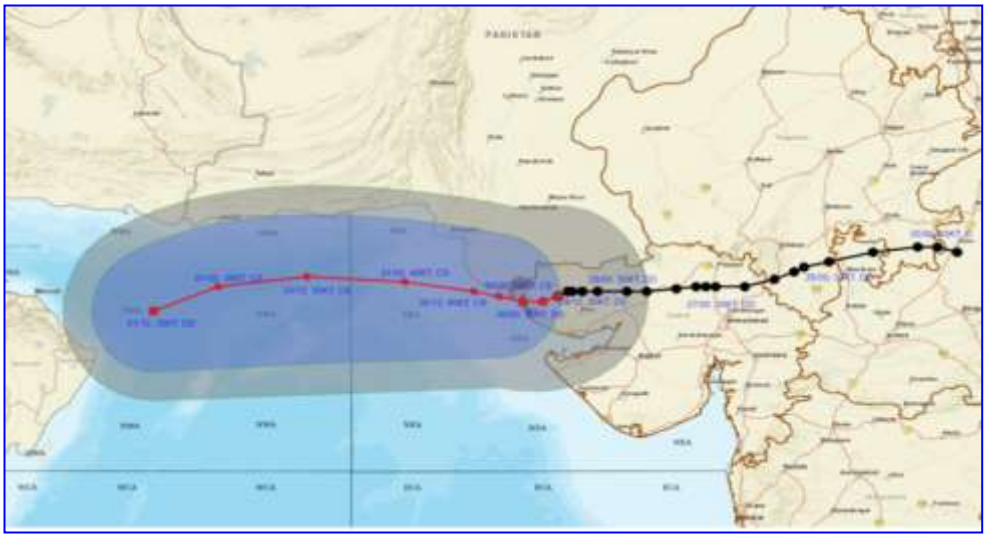
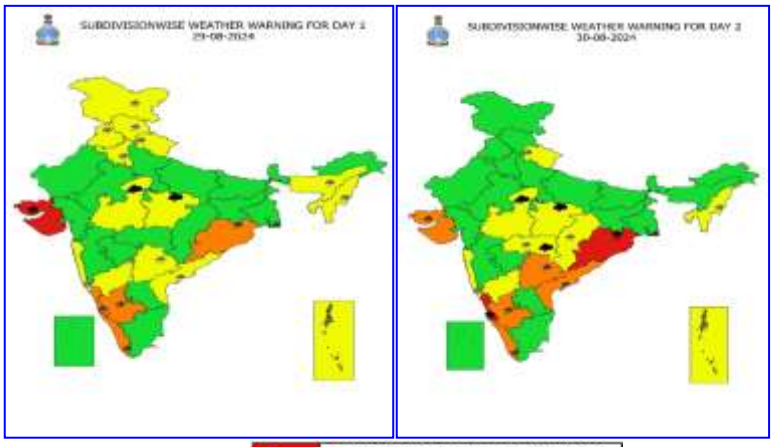


Fig.14(b): Typical track forecast along with wind distribution around the centre of the storm based on 1200 UTC of 29th August

- **Adverse weather warning bulletins:** The tropical cyclone forecasts along with expected adverse weather like heavy rainfall, flash flood, gale wind and state of sea for Arabian Sea, Pakistan, Gujarat, Maharashtra were issued with every six/three hourly update to central, state and district level disaster management agencies including Ministry of Home Affairs (MHA), National Disaster Response Force (NDRF), National Disaster Management Authority (NDMA) and state disaster management agencies. The bulletins also contained the suggested actions for disaster managers and general public, in particular for fishermen, ports, offshore & onshore industries and installations and people. These bulletins were also issued to Defence including Indian Navy & Indian Air Force, NDRF, Indian Coast Guard, Ports, Shipping, Mines, Fishery, Railways, Surface transport and aviation authorities etc. For cyclone “ASNA” the advisories for winds & sea condition for fishermen over Arabian Sea were also provided to WMO and WMO/ESCAP Panel countries including Pakistan, Iran and Oman. Typical example of heavy rainfall warning issued sub-divisonwise at National level and districtwise at state level is presented in **Fig. 15.**



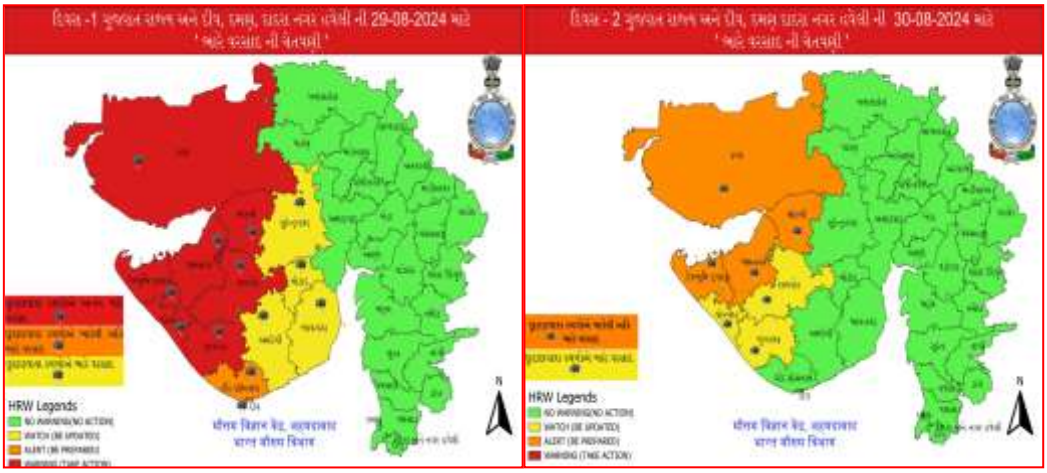
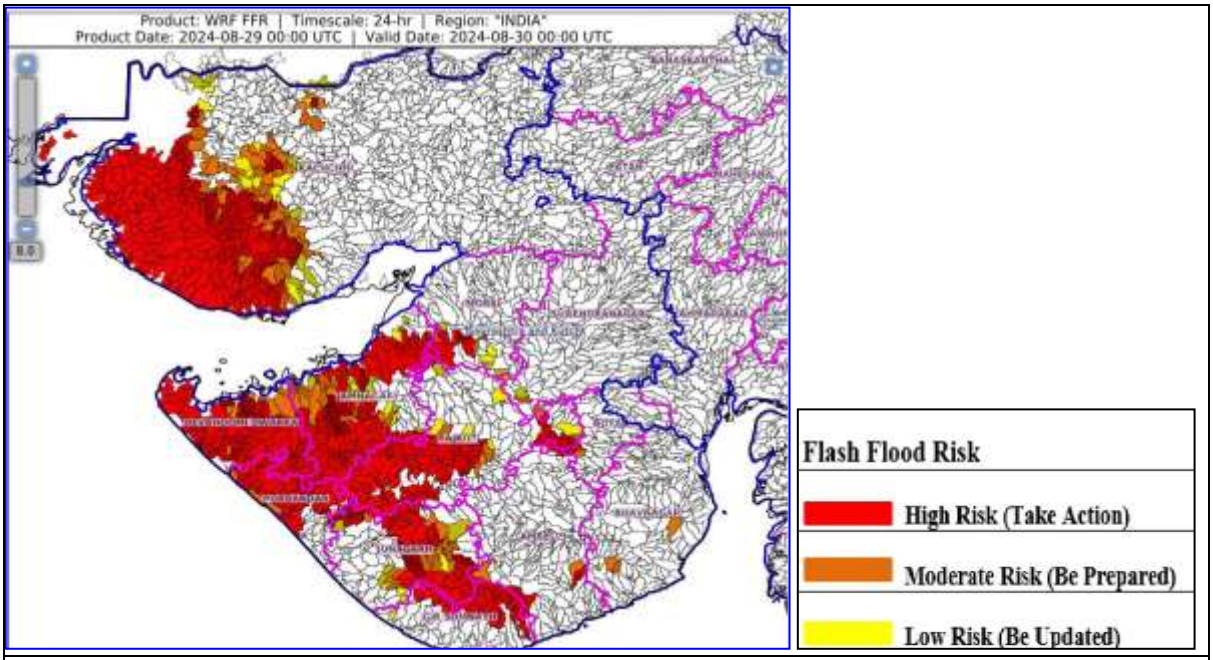


Fig. 15: Typical subdivision-wise and district-wise heavy rainfall warning for Gujarat State issued on 29th August, 2024 for 29th & 30th August

Flash Flood Guidance:

IMD, New Delhi acts as WMO's Regional Centre for Flash Flood Guidance at a watershed level over the South Asian region (Nepal, Bhutan, Bangladesh, Sri Lanka and India). It covers about 1 lakh watersheds in the region. During the formative stage of cyclone "ASNA" flash flood guidance for Gujarat, Maharashtra, Madhya Pradesh were issued twice daily. A sample flash flood guidance issued for Gujarat state is placed at **Fig. 16.**



24 hours Outlook for the Flash Flood Risk (FFR) till 0530 IST of 30-08-2024 :
Moderate flash flood risk is likely over few watersheds & neighbourhoods of the following Met Sub-divisions during the next 24 hours.

Saurashtra & Kutch - Amreli, Bhavnagar, Botad, Devbhoomi Dwarka, Gir Somnath, Jamnagar, Junagarh, Porbandar, Rajkot, Surendranagar, Morbi and Kachchh districts.

Surface runoff/ Inundation may occur at some fully saturated soils & low-lying areas over AoC as shown in the map due to expected rainfall occurrence in the next 24 hours.

Fig. 16: Typical Flash Flood Guidance issued for Gujarat issued at 0000 UTC of 29th August.

- **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 fishermen were also presented in graphics along with colour codes in the website.
- **Warnings and advisories through social media:** Daily updates (every three hour or whenever there was any significant change in intensity/track/landfall) were uploaded on Facebook and Twitter during the life period of the system since the development of low pressure area.

- **Press Conference, press release and Media briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website, video capsules 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, Cyclone Warning Centres at Bhubaneswar and Visakhapatnam for coastal and high sea shipping community.

- **Fishermen Warning:** Regular warnings for fishermen in Bay of Bengal and Andaman Sea were issued since 25th August by IMD HQ and Cyclones Warning Centres of IMD. Typical example of fishermen warning graphics issued on 31st August is presented in **Fig. 17**.

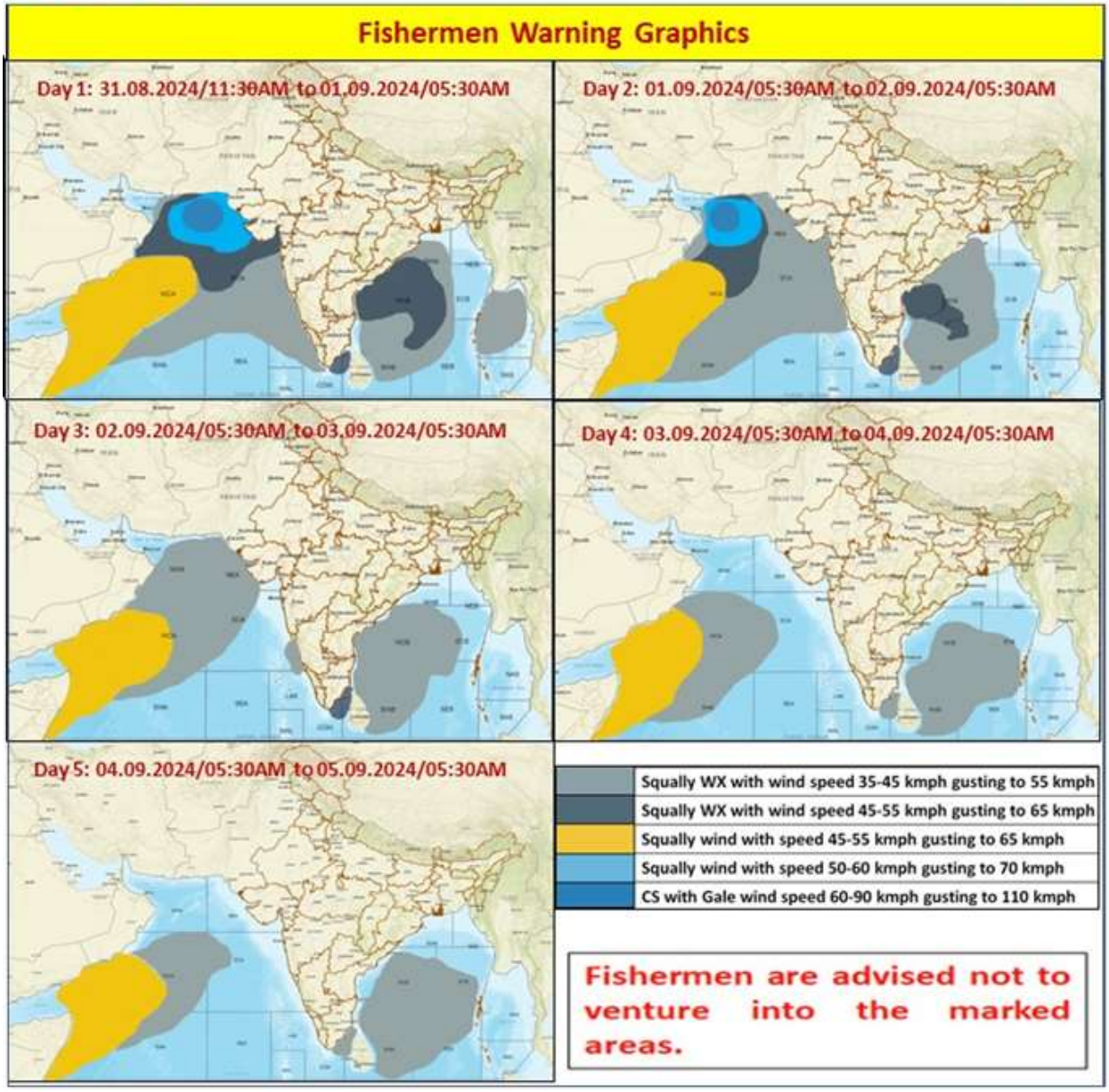


Fig. 17: Fishermen Warning graphics issued on 31st August, 2024 on formation of depression indicating the forbidden area for fishermen and expected wind speed over different regions of BoB.

As seen in **Fig. 18** the rainfall over north BoB and the adjoining coastal region of Odisha on 23rd August. The belt gradually moved westward along with the movement of the system over central and western parts of India covering Chhattisgarh, Madhya Pradesh, Maharashtra, Rajasthan and Gujarat.

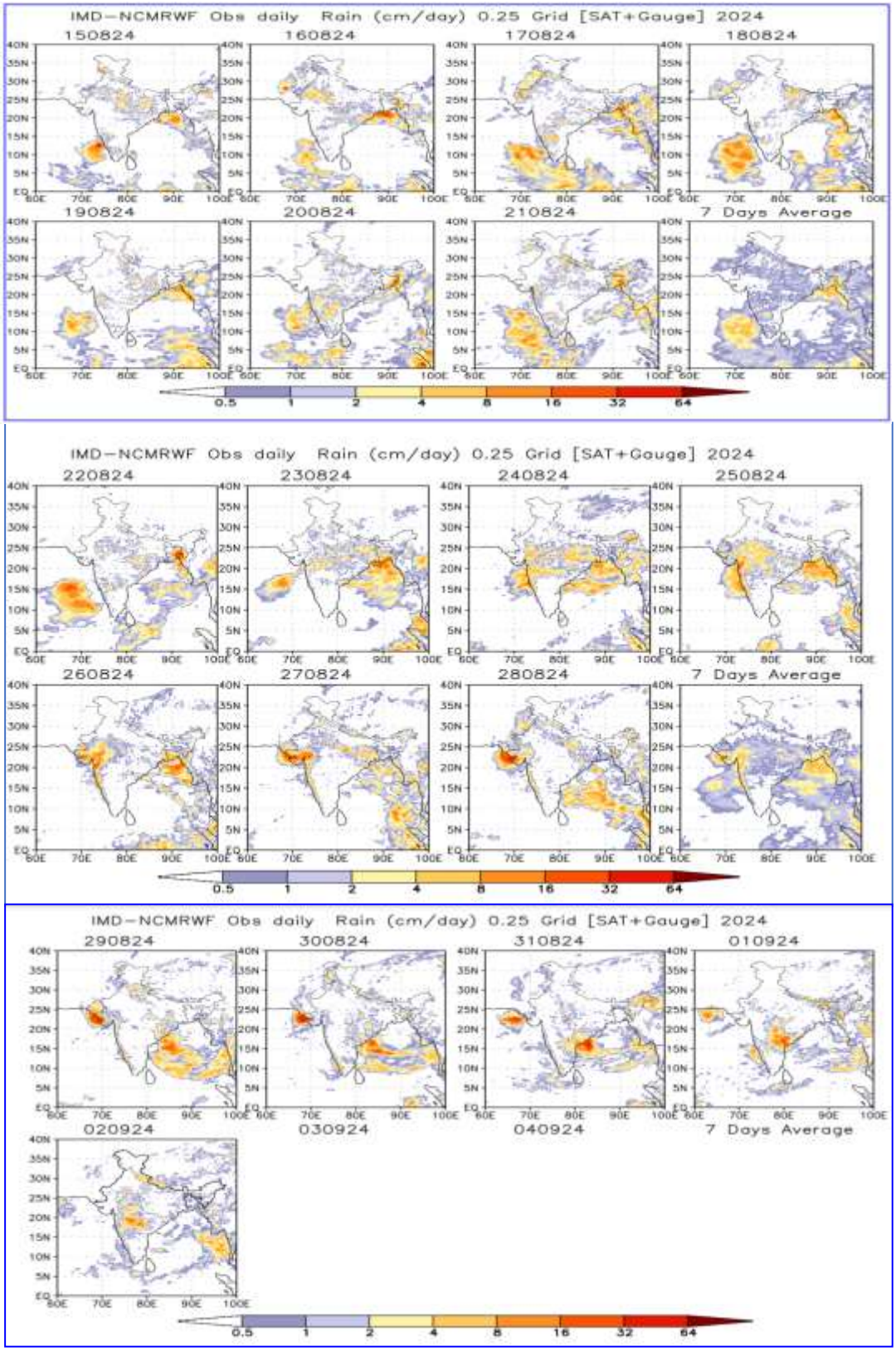


Fig. 18: NCMRWF-IMD satellite gauge merged data plots of 24 hours accumulated realized rainfall ending at 0830 IST of 15th August to 2nd September, 2024

- **Diagnostic and prognostic features of cyclone:** The prognostic and diagnostic features of the cyclone based on all meteorological observations and numerical model guidance were described in each RSMC bulletin since 25th August during the period.
- **Director General of Meteorology** and other experts in Cyclone Warning Centres addressed media and disaster management agencies regularly. Regular online discussions were also held with the forecasters of Pakistan, Iran and Oman

Statistics of bulletins issued by Cyclone Warning Division, RSMC New Delhi are given in Table 5.

Table 5: Bulletins issued by Cyclone Warning Division, New Delhi

S. No.	Bulletin type	No. Of Bulletins	Issued to
1	National Bulletin	51	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, Secretary MOES, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, PIB MOES, DG National Disaster Response Force, Director Punctuality, Indian Railways, Secretaries to Govt of India for Surface Transport, Mines, Agriculture, Ports, Shipping & Waterways, Fishery, Aviation, Power, Telecommunication, Petroleum & Natural Gas etc. and Chief Secretary to Government of Odisha, West Bengal, Madhya Pradesh, Rajasthan, Maharashtra, Gujarat, Karnataka, Daman & Diu, Dadra and Nagar Haveli and Goa
2	RSMC Bulletin	51	1. IMD's website 2. WMO/ESCAP member countries through GTS and E-mail
3	Flash Flood Guidance Bulletin	18	Email to National level disaster managers, Central Water Commission, Ministry of Home Affairs, Ministry of Water Resources, South Asian countries including Bangladesh Meteorological Department, Flood Met Offices, social media, RSMC & Mausam website
4	GMDSS Bulletins	15	1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
5	Tropical Cyclone Advisory Centre Bulletin	13	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
6	Tropical	13	Modelling group of IMD, National Centre for Medium

	Cyclone Vital Bulletin		Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc.
7	Warnings through SMS	Frequently	SMS to disaster managers at national level and concerned states (every time when there was change in track, intensity and landfall characteristics) (i) 1,71,051 to General Public by IMD Headquarters
8	Warnings through Social Media	50 times	Cyclone Warnings were uploaded on social networking sites (Facebook and Tweeter) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics).
9	Warnings through WhatsApp	50 times	Warnings and bulletins were shared through WhatsApp with Disaster managers, media, WMO/ESCAP Panel member countries
10	Press Release	10	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefings	Daily	Regular briefing frequently

13. Acknowledgement:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge contribution from WMO and WMO/ESCAP member countries for observational data. The contribution from all the stakeholders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of CS ASNA is also duly acknowledged. We acknowledge the contribution of all sister organisations 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), Indian Institute of Tropical Meteorology (IITM) Pune. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Mumbai, Cyclone Warning Centres Ahmedabad, Regional Meteorological Centre Mumbai is duly acknowledged. The contribution from Numerical Weather Prediction Division, Satellite and Radar Divisions, Surface & Upper Air Instruments Divisions, Agromet Advisory Services Division, Information System and Services Division, National Weather Forecasting Centre and Cyclone Warning Division at IMD is also duly acknowledged

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