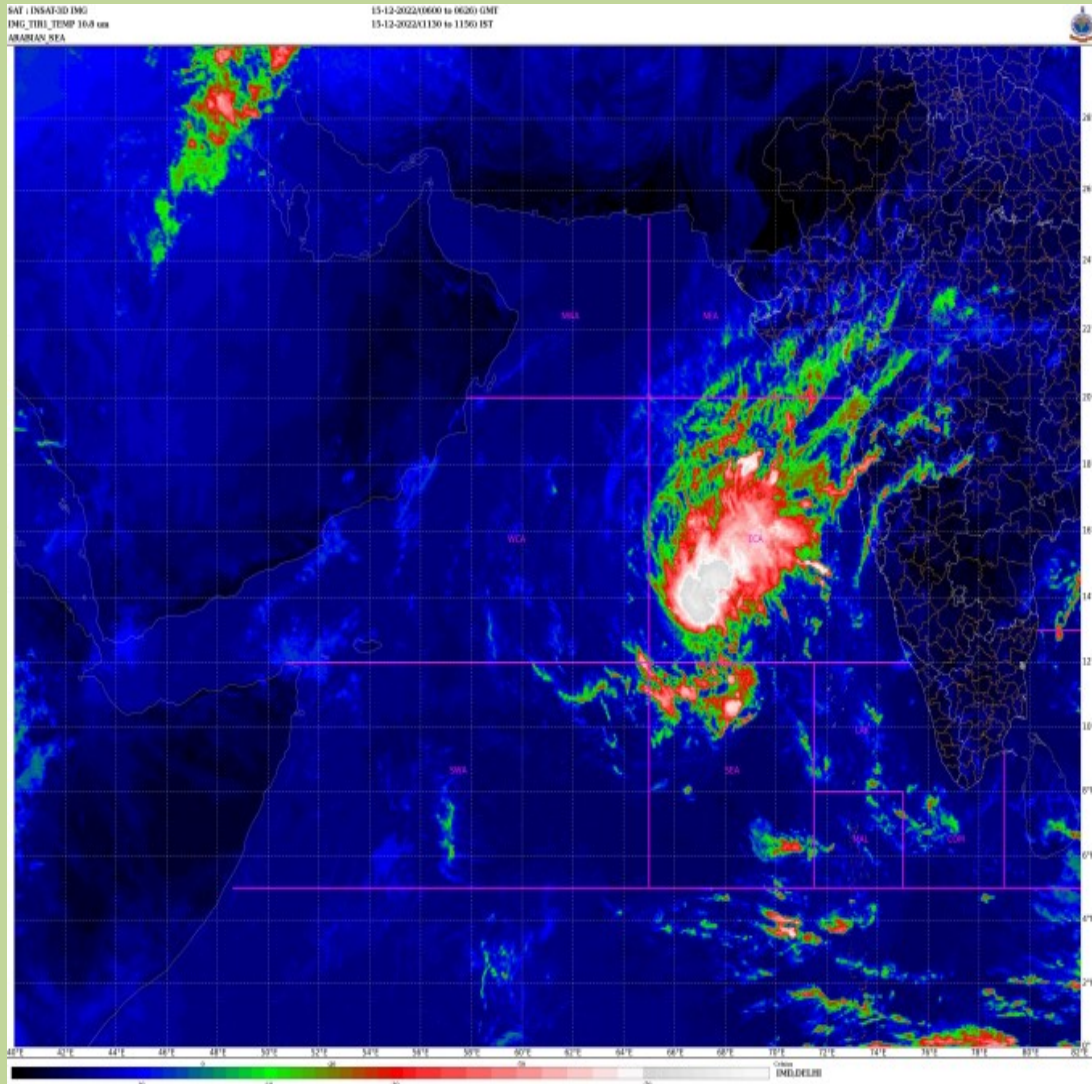




**GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT**

Deep Depression over Arabian Sea (14-17 December, 2022): A Report



Deep Depression over eastcentral and adjoining westcentral Arabian Sea during 14-17 December, 2022

1. Introduction

A remnant of Mandous cyclone entered eastcentral Arabian Sea as an upper air cyclonic circulation. Under its influence, a Low Pressure Area (LPA) formed over eastcentral and adjoining southeast Arabian Sea off north Kerala-Karnataka coasts during early morning of 13th Dec 2022 and became well marked low pressure area (WML) over the same region around 1730 UTC of the same day. It moved further northwestwards and lay as a well marked low pressure area over Eastcentral and Southeast Arabian Sea at 0830 IST of 14th December 2022. It concentrated into a depression over the same region and lay centered at 1430 IST of the 14th December 2022 near latitude 13.5°N and longitude 69.6°E. It then moved west-northwestwards and intensified into deep depression and lay centered at 0530 hours IST of 15th December 2022 over eastcentral and adjoining southeast Arabian Sea near latitude 13.9°N and longitude 68.2°E. It then moved nearly westwards and continued as a deep depression till noon of 16th Dec 2022 and lay centered at 1130 IST of 14th Dec 2022 over the eastcentral & adjoining westcentral arabian sea near latitude 13.8°N and longitude 64.4°E. It then moved west-northwestwards and weakened into depression and lay centered at 1730 IST of 16th Dec 2022, over westcentral & adjoining eastcentral arabian sea near latitude 14.0°N and longitude 63.8°E. While moving nearly westwards over westcentral Arabian Sea it maintained the intensity of depression till noon of 17th Dec 2022 and weakened into a well marked low pressure area over westcentral Arabian Sea in the evening of 17th December 2022. It then moved west-southwestwards and weakened further over the same region. The track of the system is shown in **Fig.1** and best track parameters are shown in **Table 1**.

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

- The track length of the deep depression during 14-17 December, 2022 was 875 km.
- The life period (D to D) of the system was 66 hours.
- It moved with 12-hour average translational speed of 13.2 kmph against the average of 16.0 kmph for depressions over the Arabian Sea based on data of 1990-2013. The six hourly average translational is shown in **Fig.2**.
- The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 2.4×10^2 knots, 0.97×10^4 knots² and 0.4×10^6 knots³ respectively.
- IMD commenced pre-genesis forecast of track and intensity from the stage of low-pressure area on 12th December (2 days prior to formation of depression over eastcentral and adjoining southeast Arabian Sea).
- A total of 21 national bulletins, 1 special messages with formation of LPA, and 21 RSMC bulletins were issued in association with this system.

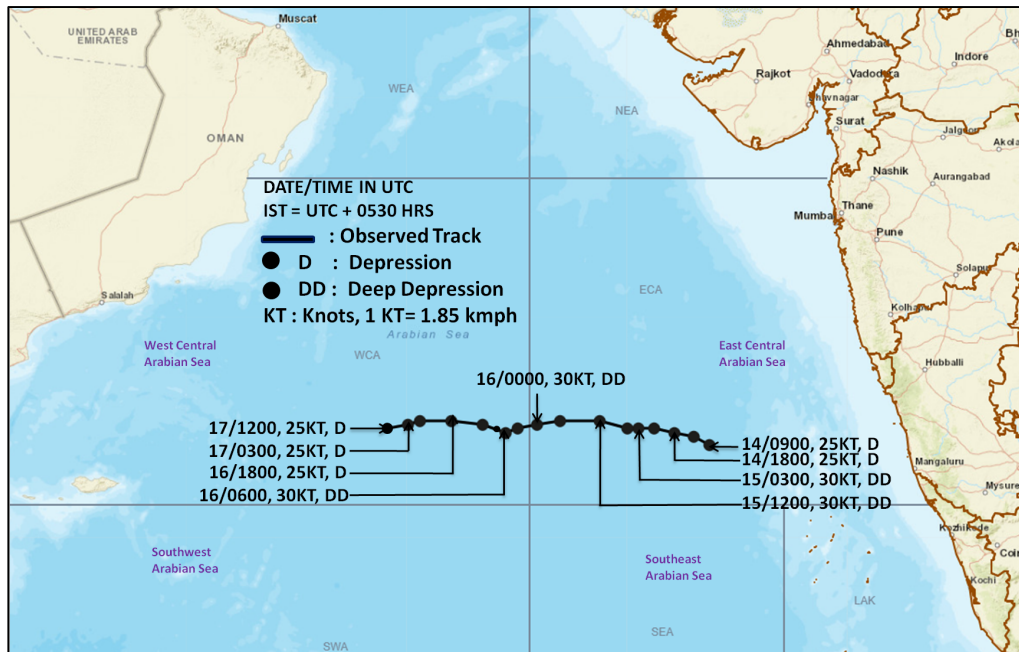


Fig. 1: Observed track of Deep Depression over Arabian Sea during 14th to 17th December 2022

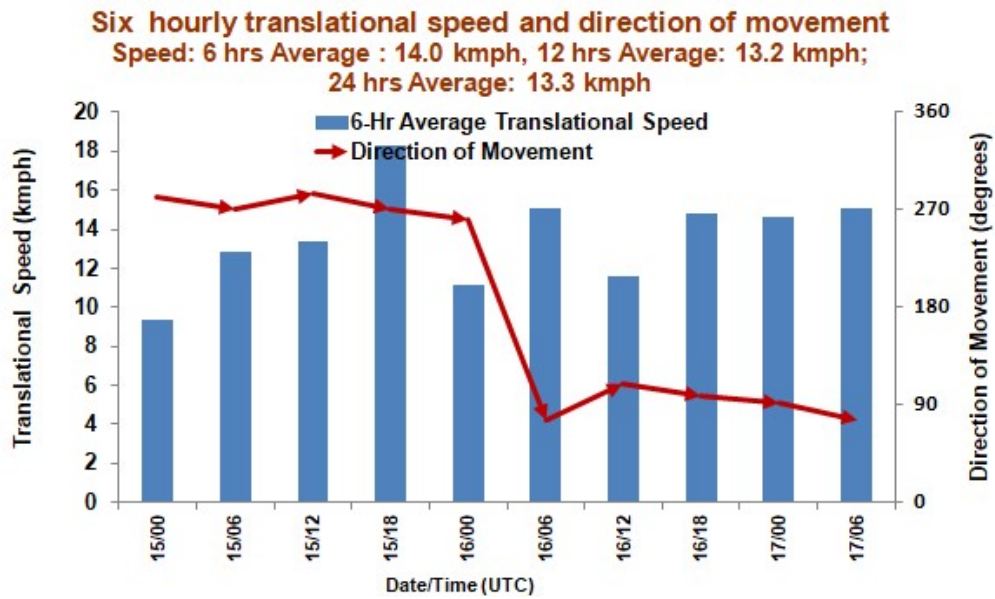


Fig. 2: Six hourly average translational speed and direction of movement

Table 1: Best track positions and other parameters of the Deep Depression over Arabian Sea during 14 - 17 December, 2022.

Date	Time (UTC)	Centre lat. ^o N/ long. ^o E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade	
14.12.2022	0900	13.5	69.6	1.5	1002	25	4	D
	1200	13.7	69.2	1.5	1002	25	4	D
	1800	13.8	68.7	1.5	1002	25	4	D
15.12.2022	0000	13.9	68.2	2.0	1001	30	5	DD
	0300	13.9	67.8	2.0	1000	30	6	DD
	0600	13.9	67.5	2.0	1000	30	6	DD
	1200	14.1	66.8	2.0	1000	30	6	DD
	1800	14.1	65.8	2.0	1000	30	6	DD
16.12.2022	0000	14.0	65.2	2.0	1000	30	6	DD
	0300	13.9	64.7	2.0	1000	30	6	DD
	0600	13.8	64.4	2.0	1001	30	5	DD
	1200	14.0	63.8	1.5	1002	25	4	D
	1800	14.1	63.0	1.5	1002	25	4	D
17.12.2022	0000	14.1	62.2	1.5	1002	25	4	D
	0300	14.0	61.9	1.5	1002	25	4	D
	0600	13.9	61.4	1.5	1002	25	4	D
	1200	Weakened into a well-marked low pressure area over westcentral Arabian Sea.						

3. Brief life history

3.1. Genesis

Under the influence of upper air circulation over eastcentral arabian sea, a low pressure area (lpa) formed over eastcentral and adjoining southeast Arabian Sea off north Kerala-Karnataka coasts during early morning of 13th Dec. 2022 and became well marked low pressure area (WML) over the same region around 1730 IST of the same day. Sea surface temperature as on 1130 IST of 14th Dec 2022 was about 28-29°C over eastcentral and adjoining southeast Arabian sea became 27°C to the west of 67°E. Low level relative vorticity decreased to 50x10⁻⁶ s⁻¹ to the south of system centre. Low level convergence was about 05x10⁻⁵ s⁻¹ to the southeast of system centre. Upper level divergence was about 20x10⁻⁵ s⁻¹ to the north of the system centre. Moderate to high vertical wind shear of about 15-25 knots was prevailing around system area and was increased towards west and northwest Arabian Sea. Under these conditions, the well marked low pressure area concentrated into a depression over the same region and lay centered at 1430 IST of the 14th December 2022 over eastcentral Arabian Sea near latitude 13.5°N and longitude 69.6°E.

3.2. Intensification and movement:

The depression over eastcentral southeast Arabian Sea then moved west-northwestwards and intensified into deep depression and lay centered at 0530 IST of 15th

Dec 2022 over eastcentral Arabian Sea near latitude 13.9°N and longitude 68.2°E. Sea surface temperature was about 28-29°C over eastcentral and adjoining southeast Arabian Sea becoming 26°C to the west of 67°E. Low level relative vorticity was around $100 \times 10^{-5} \text{ s}^{-1}$ at the southwest of the system centre. Low level convergence was about $5 \times 10^{-5} \text{ s}^{-1}$ to the northeast sector of system centre. Upper level divergence was about $10\text{-}20 \times 10^{-5} \text{ s}^{-1}$ to the northeast of the system centre. Moderate vertical wind shear of about 15-20 knots was prevailing around the system and high along its forecasted path. Multi-satellite winds were indicating stronger winds in the northeast sector.

The system maintained its intensity as deep depression while moving west-northwestwards till afternoon of 16th Dec 2022 and weakened as depression over eastcentral and adjoining westcentral Arabian Sea and lay centered near latitude 14.0°N, longitude 63.8°E at 1730 IST of 16th Dec 2022. Sea surface temperature was about 26-28°C over westcentral and adjoining eastcentral & south Arabian Sea and 26°C to the west of 65°E. Low level relative vorticity was around $100 \times 10^{-6} \text{ s}^{-1}$ to the southwest of the system centre. Low level convergence has decreased and was about $05 \times 10^{-5} \text{ s}^{-1}$ to the south of system centre. However, negative convergence zone was seen over westcentral Arabian Sea along forecast path.

The depression over westcentral Arabian Sea moved west-southwestwards and weakened into well marked low pressure area at 1730 IST of 17th Dec 2022 over the same region. The system weakened as it entered into unfavorable environmental conditions such as colder sea, dry cold air intrusion, high to moderate vertical wind shear, decrease in moisture in middle levels. Sea surface temperature was about 25-26°C over westcentral Arabian Sea. Low level relative vorticity was around $50\text{-}60 \times 10^{-6} \text{ s}^{-1}$ to south of the system. Low level convergence was about $5 \times 10^{-5} \text{ s}^{-1}$ to the northeast of the system. Upper level divergence was about $05 \times 10^{-5} \text{ s}^{-1}$ to the northeast of the system. High vertical wind shear of about 25-30 knots was observed near the system. The system then moved further west-southwestwards and weakened further over the same region.

4. Monitoring through satellite and radar:

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the system was monitored since 12th March. The system was monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites and available ships & buoy observations in the region. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions, global models and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the system. A digitized forecasting system of IMD was utilized for analysis and comparison of various models' guidance, decision making process and warning products generation.

5. Detailed feature observed through Satellites:

As per INSAT-3D imagery at 1430 IST of 14th Dec 2022, the clouds have organized in shear pattern. Intensity of the system is T 1.5. Associated scattered to broken low and medium clouds with embedded intense to very intense convection lay over eastcentral Arabian Sea adjoining southeast Arabian Sea & Lakshdweep islands area. Minimum cloud top temperature was minus 93°C. As per INSAT-3D imagery at 0530 IST of 15th Dec 2022, intensity of the system was T2.0. Associated scattered to broken low and medium clouds with embedded intense to very intense convection lay over eastcentral Arabian Sea

adjoining southeast Arabian Sea. Minimum cloud top temperature was minus 93 deg C. As per INSAT-3D imagery at 0530 IST of 16th Dec 2022, intensity of the system was T2.0. Associated scattered to broken low and medium clouds with embedded intense to very intense convection lay over eastcentral Arabian Sea & adjoining areas between latitude 13.5°N & 16.5°N and long 65.8°E & 69.0°E. Minimum cloud top temperature was minus 90°celcius. At 1730 IST of 16th Dec 2022, intensity of the system was T1.5/2.0. The associated cloud mass was sheared to the northeast of system centre, under the influence of mid-latitude westerly winds. Scattered to broken low and medium clouds with embedded intense to very intense convection lay over eastcentral Arabian Sea & adjoining westcentral Arabian Sea between latitude 13.5°N & 18.0°N and long 64.0°E & 68.5°E. Minimum cloud top temperature was minus 81°celcius. At 0530 IST of 17th Dec 2022, intensity of the system was T1.5/1.5. The associated scattered to broken low and medium clouds with embedded intense to very intense convection lay over west central parts of Arabian Sea. Minimum cloud top temperature was minus 82°celcius. At 1730 IST of 17th Dec 2022, intensity of the system is T1.0/1.0. The associated scattered to broken low and medium clouds with embedded moderate to intense convection lay over central parts of central Arabian Sea. Minimum cloud top temperature is minus 63°celcius. The typical satellite imageries are shown in **Fig. 3**.

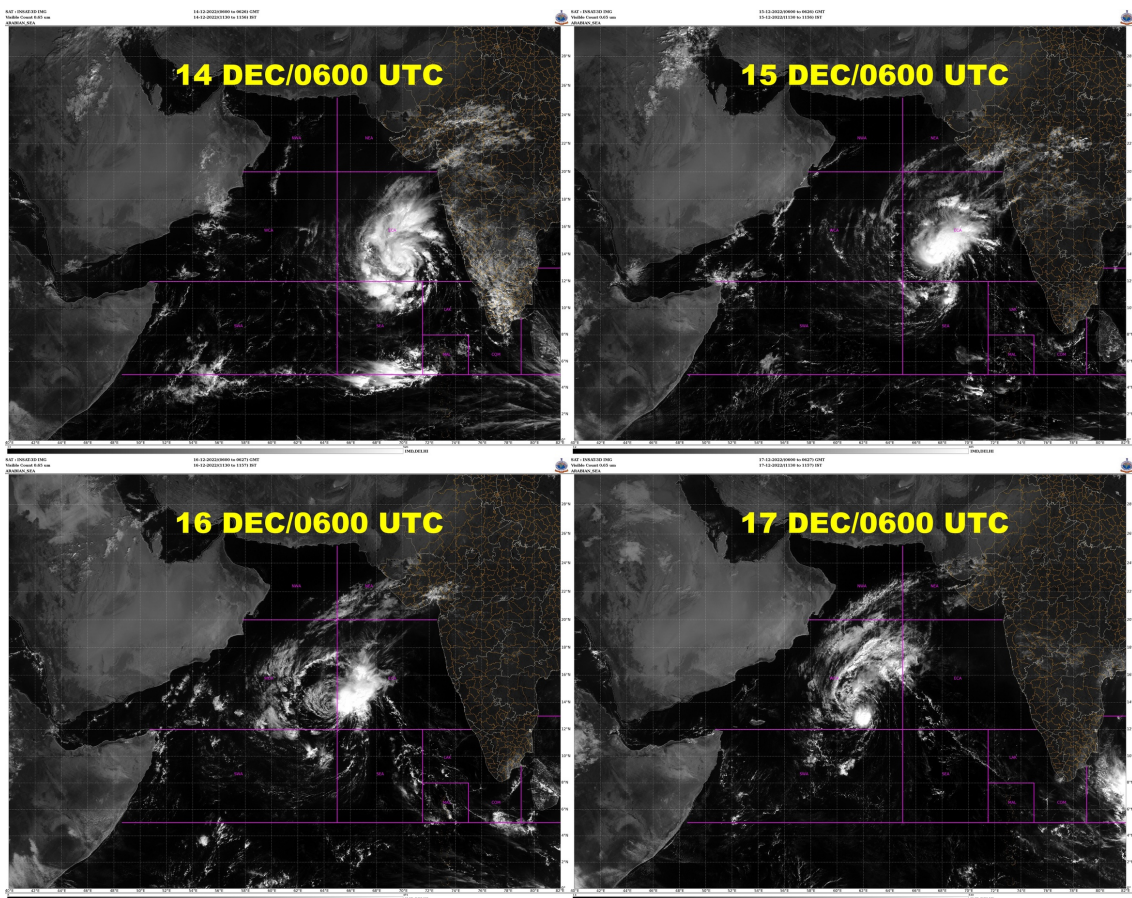


Fig.3(i): INSAT-3D Visible imageries of Deep Depression(14-17th Dec, 2022)

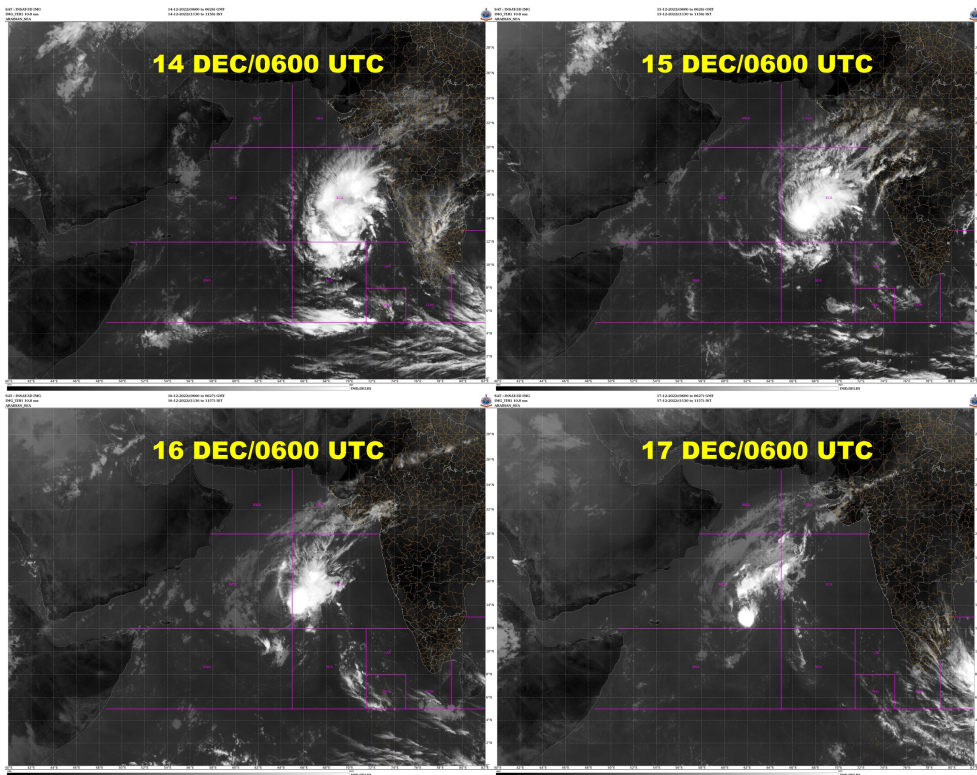


Fig. 3(ii): INSAT-3D IR1 imageries of Deep Depression(14-17th Dec, 2022)

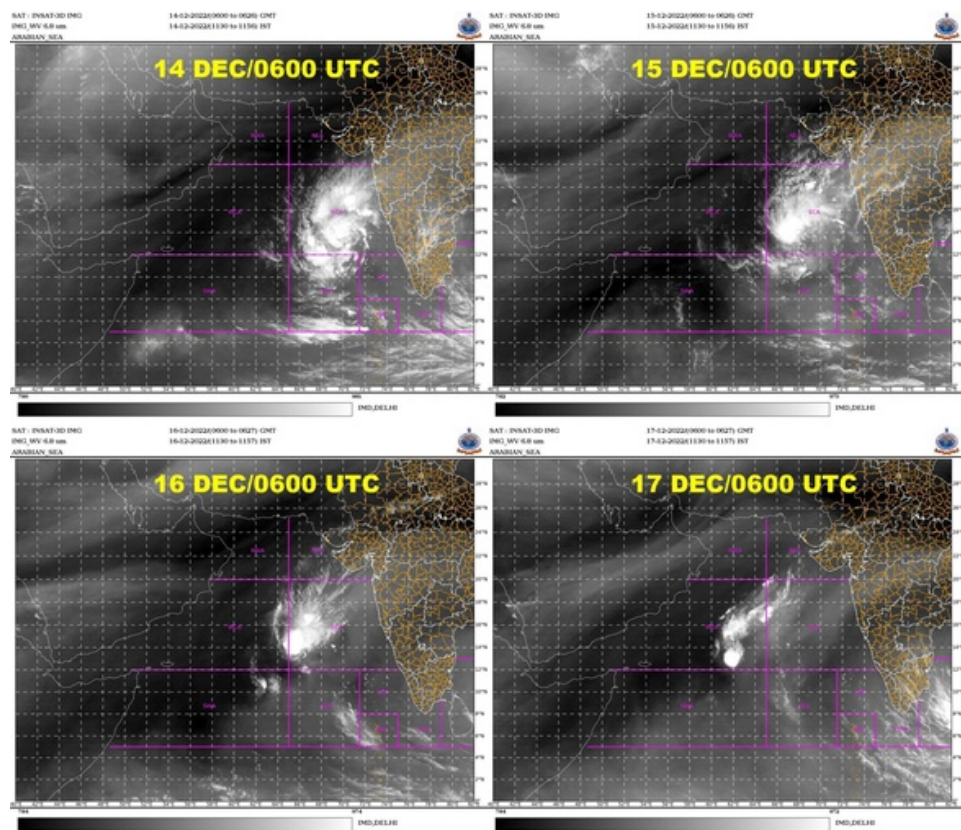


Fig. 3(iii): INSAT-3D WV imageries of Deep Depression(14-17th Dec, 2022)

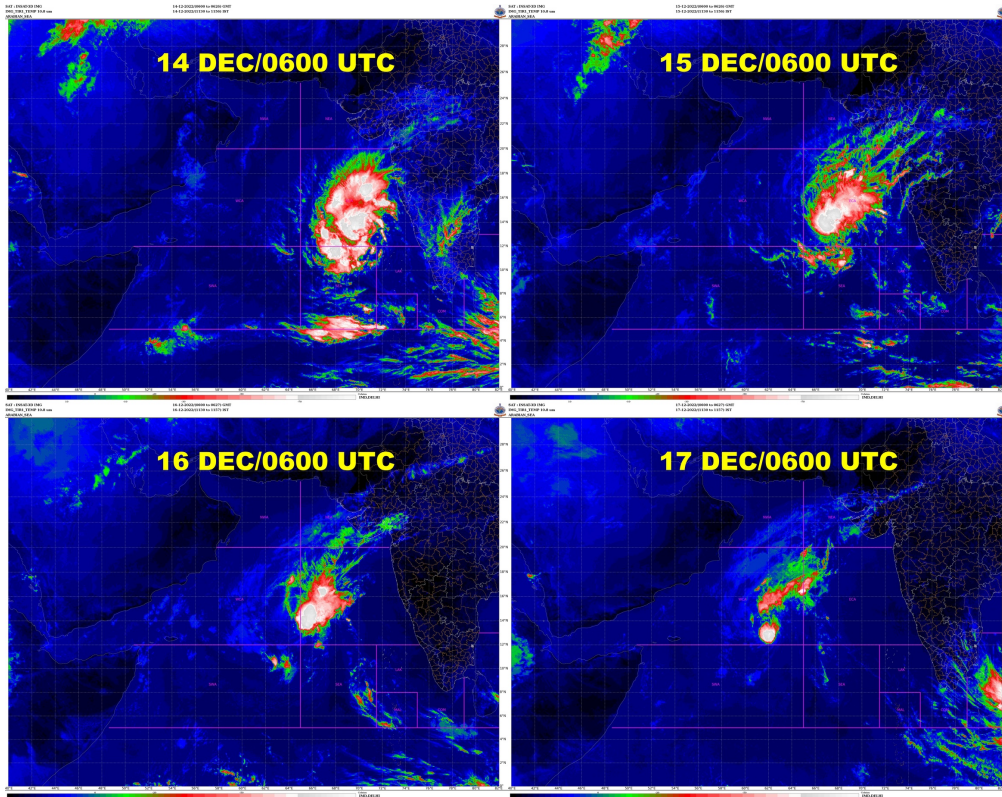


Fig. 3(iv): INSAT-3D NHC imageries of Deep Depression(14-17th Dec, 2022)

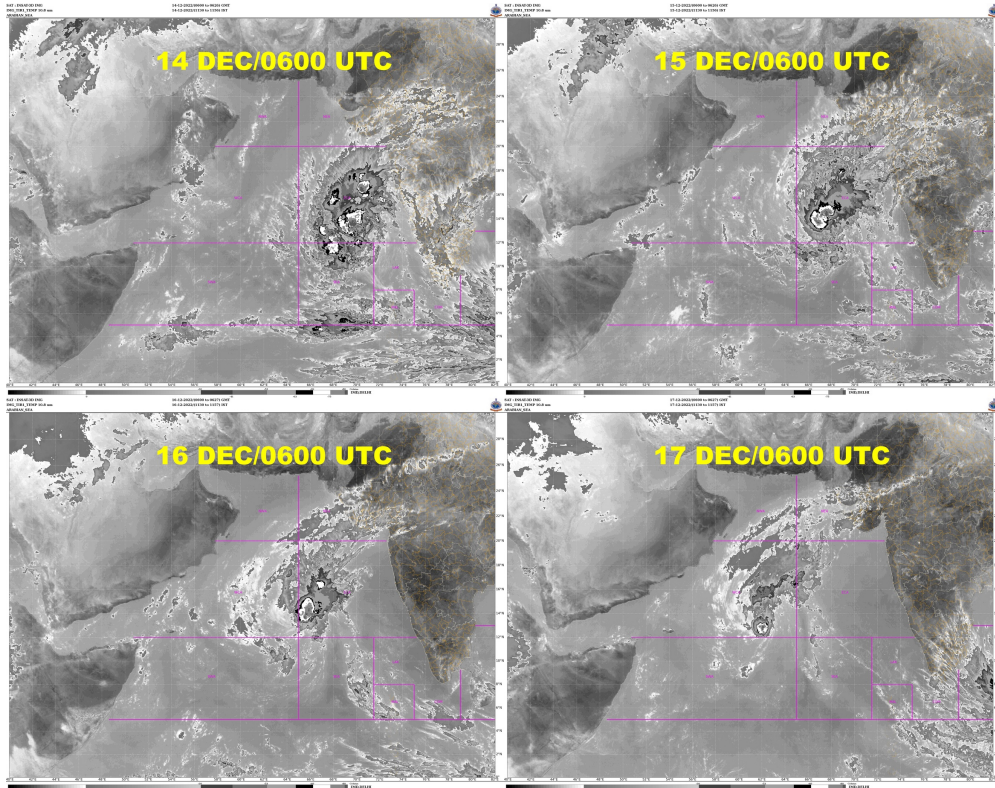


Fig. 3(v): INSAT-3D BD imageries of Deep Depression (14th -17th Dec , 2022)The

SCATSAT (METOP-C) imageries during 14-17 December 2022 is provided in **Fig.4**. These ASCAT imageries indicated stronger wind in the southern sector of the system during 14th and in the northern sector during 15th. These winds are in agreement with the intensity of the system.

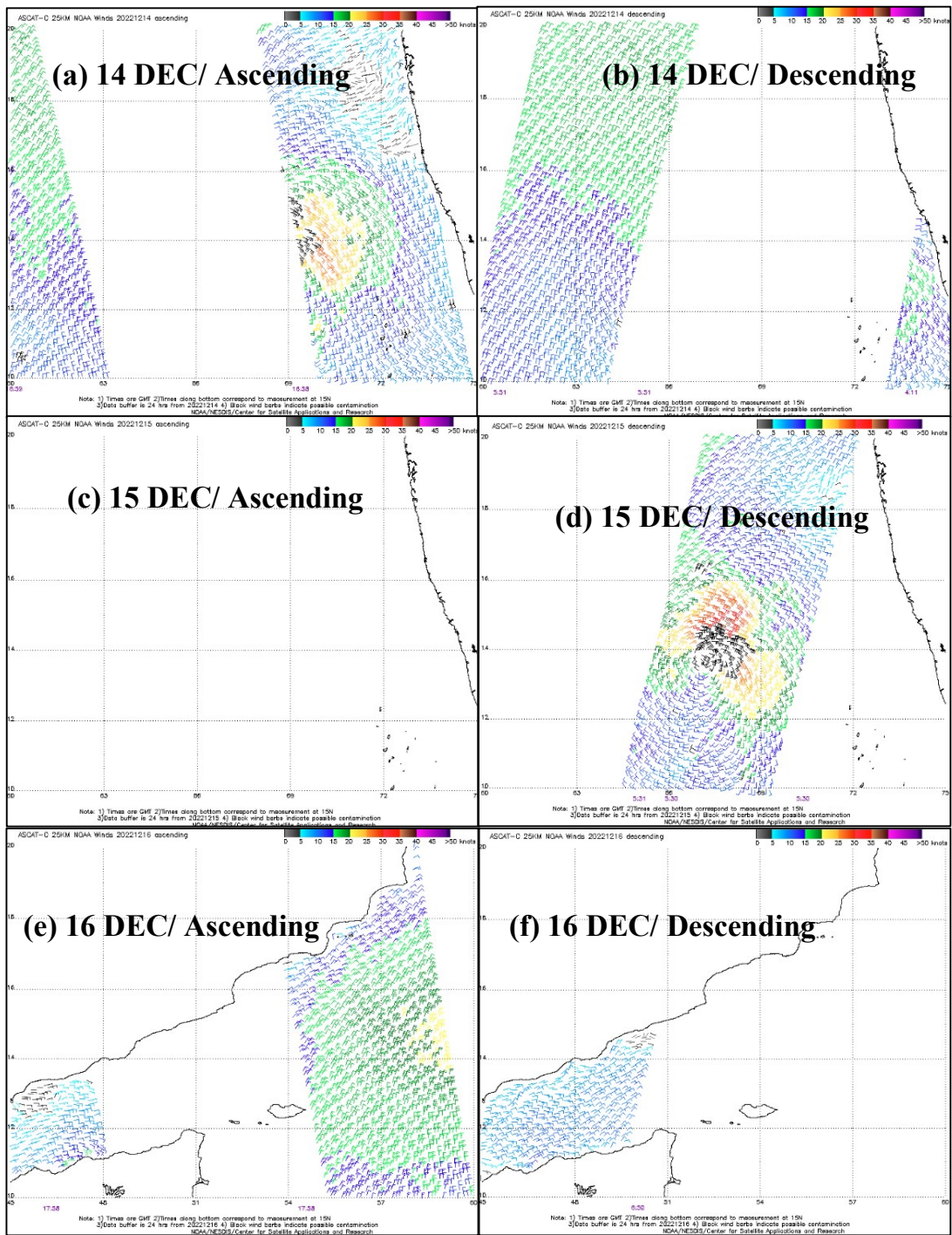


Fig.4: ASCAT imageries during Deep Depression (14-17 December, 2022)

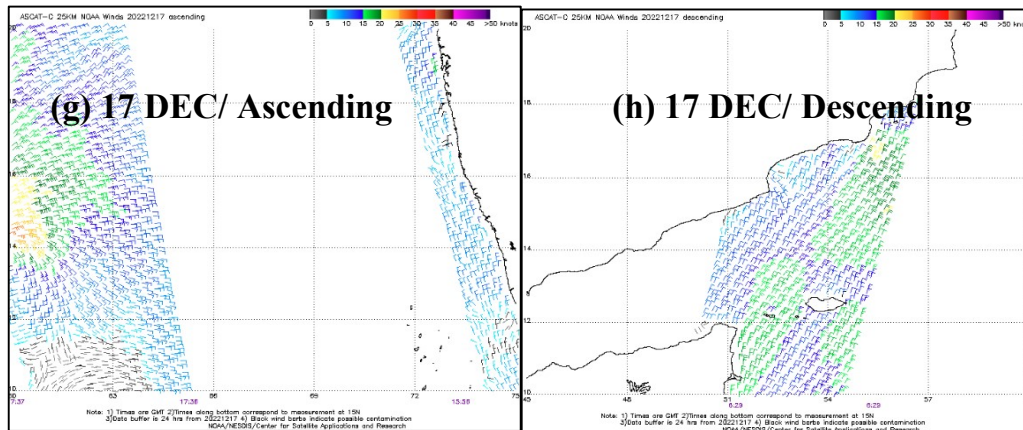


Fig.4 (contd): ASCAT imageries during Deep Depression (14-17 Dec., 2022)

6. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10 m, 850, 500 and 200 hPa levels on 0000 UTC of 14th Dec are presented in Fig.5(i). The IMD GFS fields of 14-17 Dec 2022 indicated a WML/depression over southeast Arabian Sea with vertical extension upto 500 hPa level. West-southwesterly winds prevailed in the upper level.

The analysis field of IMD GFS at 0000 UTC of 15th December over southeast Arabian Sea indicated its west-northwestwards movement and intensification into a deep depression. Hence, the model is in par with the actual intensity as on 15th December.

The analysis field of IMD GFS at 0000 UTC of 15th December over southwest and adjoining westcentral Arabian Sea indicated its west-northwestwards movement and remain as deep depression. Hence, the model is in par with the actual intensity as on 16th December.

The analysis field of IMD GFS at 0000 UTC of 17th December over southwest and adjoining westcentral Arabian Sea indicated its west-northwestwards movement and weakening into depression. Hence, the model is in par with the actual intensity as on 17th December.

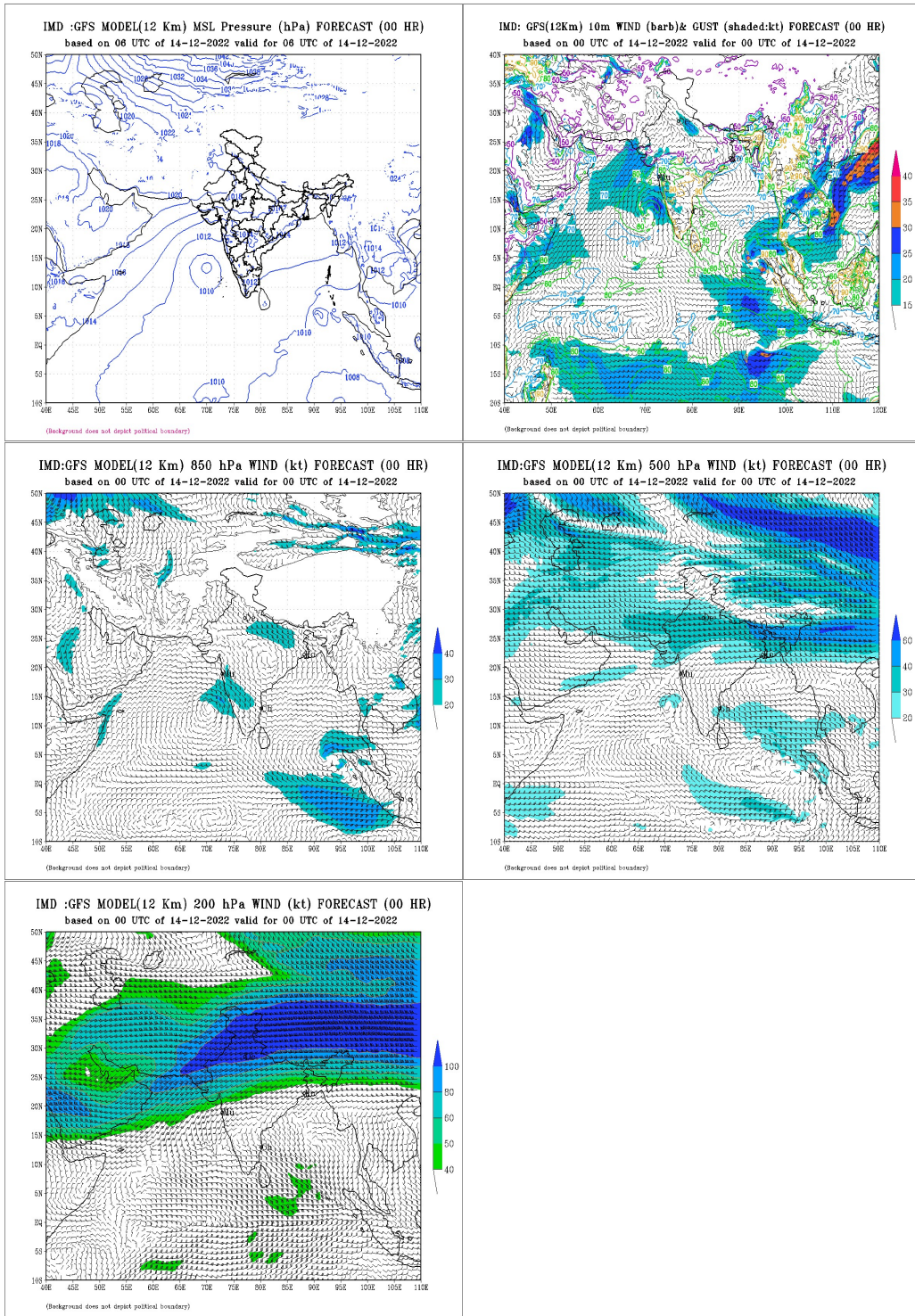


Fig5 (i): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 14th Dec 2022

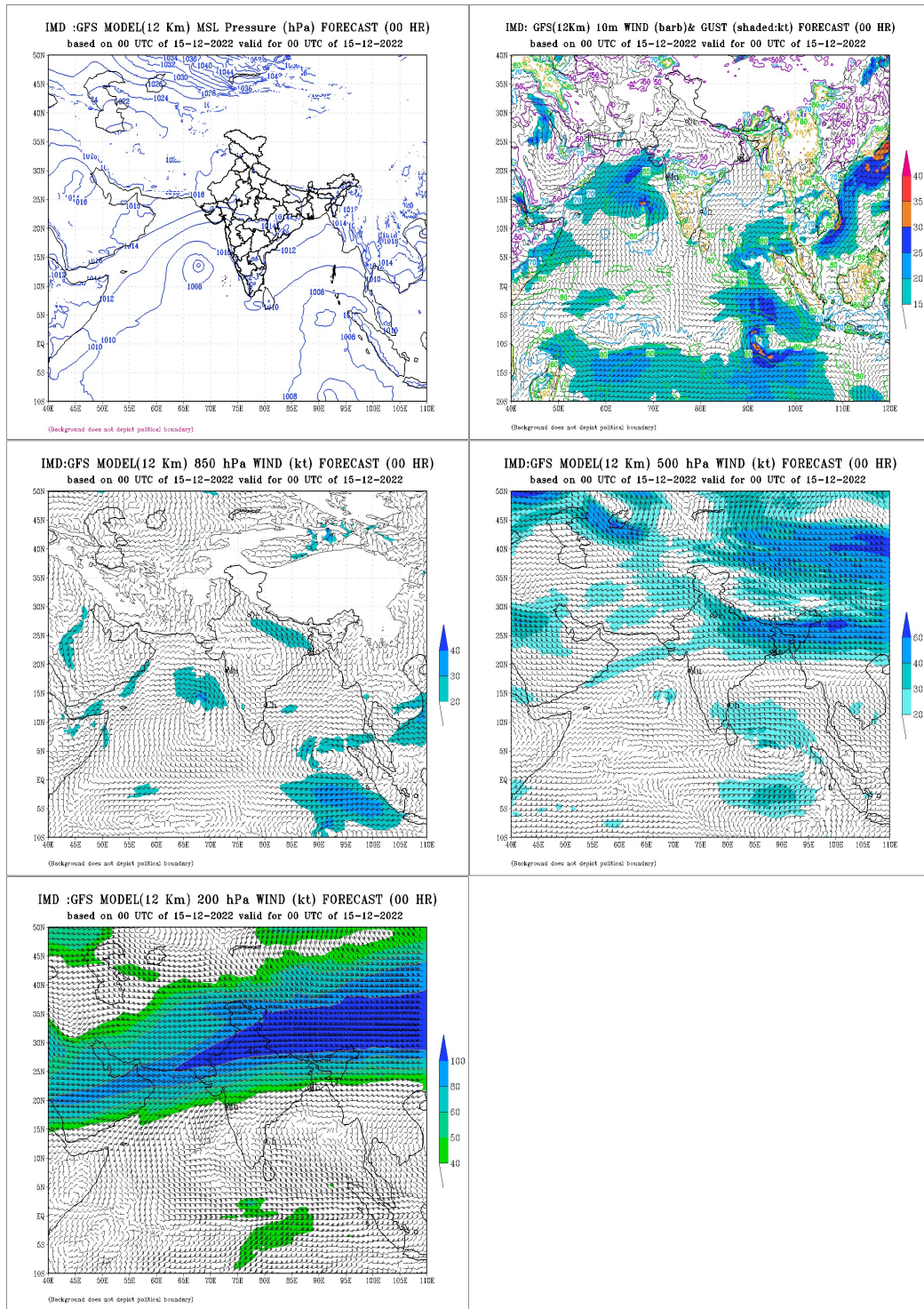


Fig5 (ii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 15th Dec 2022

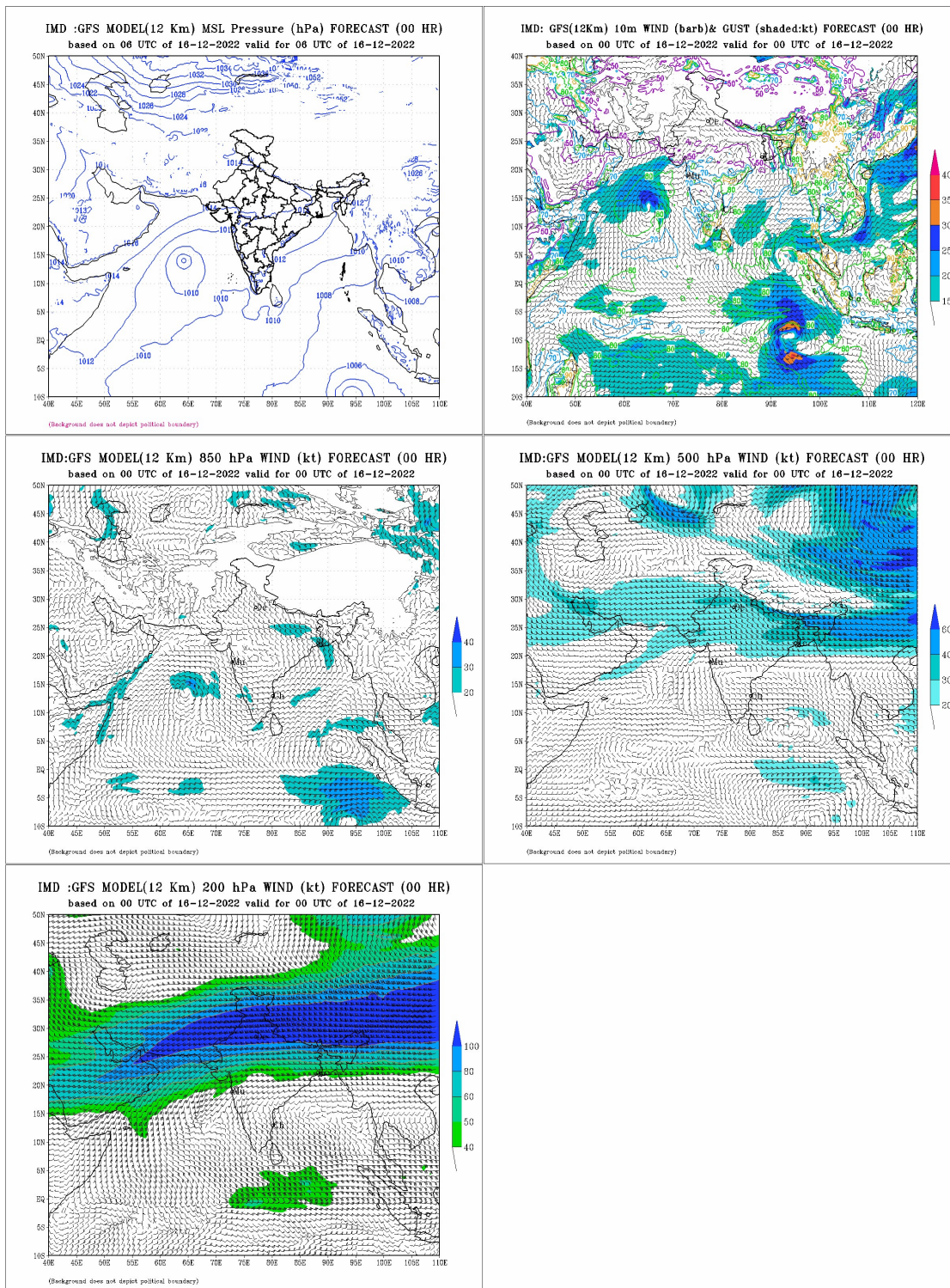


Fig5 (iii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 16th Dec 2022

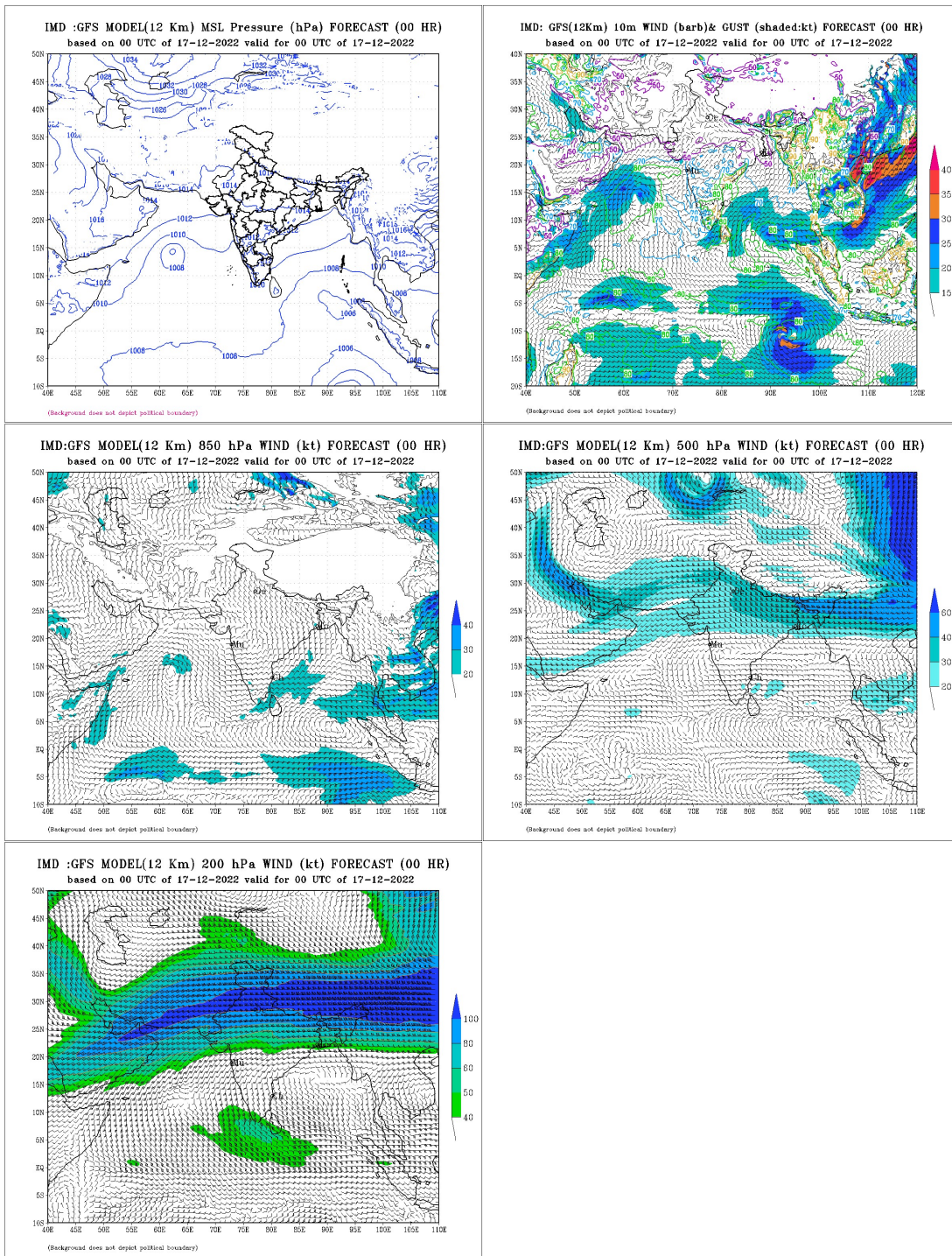


Fig5 (iv): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 17th Dec 2022

Thus, IMD GFS could capture the genesis, intensity and movement correctly.

6. Realized Weather:

6.1 Rainfall:

Under the influence of deep depression, rainfall occurred mainly over the sea area throughout the life period. However widespread rainfall occurred along and off Kerala and Karnataka coasts during 12th and 13th Dec 2022. Daily rainfall distribution based on merged grided rainfall data of IMD/NCMRWF during 11 - 18 December, 2022 is shown in **Fig.6**.

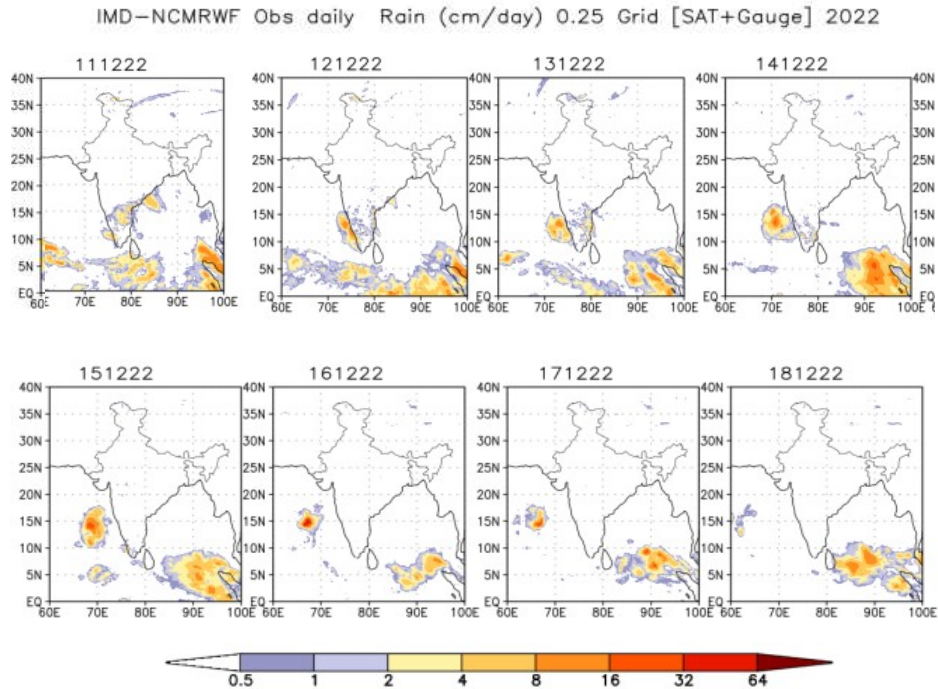


Fig.6: Daily rainfall distribution based on merged grided rainfall data of IMD/NCMRWF during 11 December- 18 December, 2022.

7. Warnings issued by IMD

IMD issued regular bulletins to WMO/ESCAP Panel member countries, National & State Disaster Management, public and media. Regular Bulletins every six hourly were issued since formation of depression. In addition, RSMC New Delhi also issued Press Release and SMS to registered users.

IMD continuously monitored the Arabian Sea region and issued warnings to all concerned at central and state level since 12th December, even before the formation of any cyclonic circulation over the region. A total of 21 national bulletins, 21 RSMC bulletins to WMO/ESCAP Panel member countries, regular Press Release, six hourly SMS to coastal population including fishermen and farmers were issued. Regular bulletins were issued at National level by Cyclone Warning Division and at State level by concerned Meteorological Centres of IMD.

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

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

S. No.	Bulletins	No. of Bulletins	Issued to
1	National Bulletin	21	1. IMD's website 2. FAX and e-mail to Control Room NDM, Ministry of Home affairs, Control Room NDMA, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Director Indian Railways, Indian Navy, IAF, Administrator, Andaman & Nicobar Islands, Chief Secretary: Kerala, Karnataka, Maharashtra, Gujarat.
2	RSMC Bulletin	21	1. IMD's website 2. All WMO/ESCAP member countries through GTS and E-mail. 3. Indian Navy, IAF by E-mail
3	Press Release	1	1. Disaster Managers, Media persons by email and uploaded on website
4	Facebook /Twitter	21 times	Highlights uploaded on facebook/twitter since formation of low pressure area.

8. Operational Forecast Performance

- i. The extended range outlook issued on 8th December (4 days prior to formation of LPA) indicated development of a cyclonic circulation over eastcentral and adjoining southeast Arabian Sea around 12th December leading to enhanced convective activity over the region. Actually, under the influence of this cyclonic circulation, a low pressure area formed over the same region on 13th December.
- ii. The tropical weather outlook issued on 13th December (48 hours prior to formation of depression) indicated the formation of depression over Arabian Sea and movement away from Indian coasts.
- iii. A special tropical weather outlook issued on 14th March (24 hours prior to formation of deep depression) indicated intensification of the system into deep depression over eastcentral Arabian Sea on 15th December and its west-northwestward movement.
- iv. Actually, deep depression formed over eastcentral Arabian Sea on 15th December and moved nearly west-northwestward.

The track forecast errors for 24 and 48 hrs lead period were 42 km each against the long period average (LPA) errors (2017-21) of 73 and 106 respectively (**Fig. 7a, Table 3**). **The error in track forecast were appreciably less than the LPA errors for all lead periods.** The skill in track forecast for 24 and 48 hrs lead period was 76% and 89% against the long period average (LPA) skill (2017-21) of 65% and 77%

respectively. Hence, for all lead period, it was a skillful forecast better than LPA (Fig. 7b).

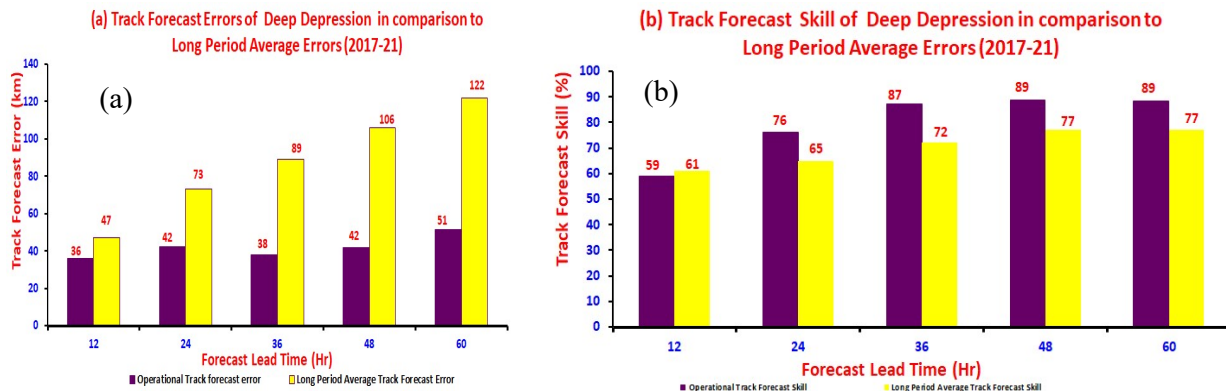


Fig.7:(a) track forecast errors for 24 and 48 hrs lead period, **(b)** long period average (LPA) errors (2017-21).

Table 3: Operational Track forecast errors and skill of Deep Depression as compared to long period average (2017-21)

Lead Period (hrs)	N	Operational Track forecast error (km)	Operational Track Forecast Skill (%)	Long Period Average (2017-21)	
				Track Forecast Error (km)	Track Forecast Skill (%)
12	10	36	87	59	61
24	8	42	179	76	65
36	6	38	299	87	72
48	4	42	373	89	77
60	2	51	448	89	77
12	10	36	87	59	61

N: no. of observations verified

- ❖ The absolute error (AE) of intensity (wind) forecast for 24 and 48 hrs lead period were 1.9 and 2.5 knots against the LPA errors of 7.8 and 11.5 knots during 2017-21 respectively (Fig.8a, Table 4). **The error in intensity forecast were appreciably less than the LPA errors for all lead periods.** The skill based on AE in intensity forecast for 24 and 48 hrs lead period was 88% and 90% against the LPA skill of 55% and 74% during 2017-21 respectively (Fig.8 b).
- ❖ **The skill in intensity forecast was appreciably better than the LPA for all lead periods.** The root mean square (RMSE) of intensity (wind) forecast for 24 and 48 hrs lead period were 2.0 and 2.5 knots against the LPA errors of 15.2 and 13.8 knots during 2017-21 respectively (Fig.8c). **The error in intensity forecast were appreciably less than the LPA errors for all lead periods.** The skill based on RMSE in intensity forecast for 24 and 48 hrs lead period was 92% and 84% against the LPA skill of 42% and 61% during 2017-21 respectively (Fig.8d). **The skill in intensity forecast was appreciably better than the LPA for all lead periods.**

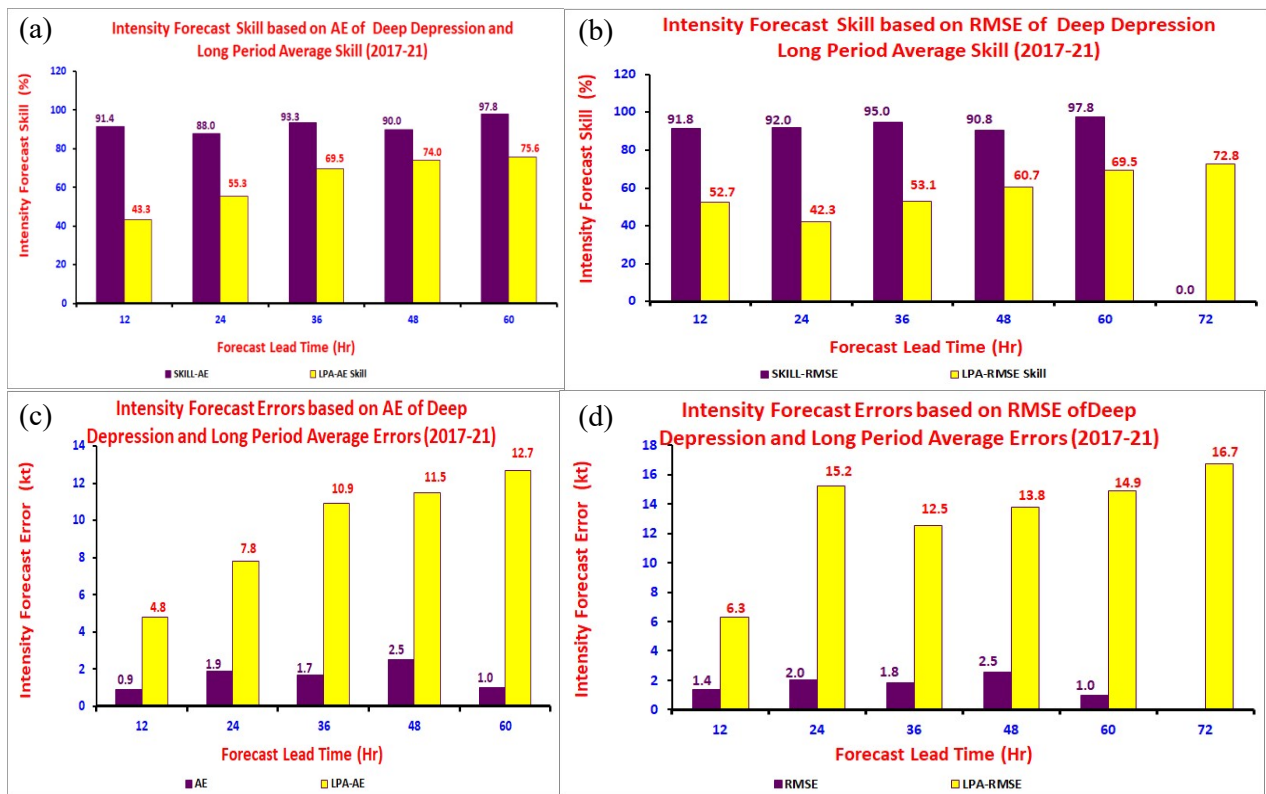


Fig.8(a-b): Operational intensity forecast (a) absolute errors and (b) skill based on compared to long period average during 2017- 21 Fig.8(c-d): Operational intensity forecast (c) root mean square errors and (d) skill based on compared to long period average during 2017- 21

Table 4: Operational Absolute errors (AE) and Root Mean Square errors (RMSE) and corresponding skill in intensity forecast of Deep Depression as compared to long period average (2017-21)

Lead Period	N	AE	RMSE	Skill-AE	Skill-RMSE	Long Period Average (2017-21)			
						AE	RMSE	Skill-AE	Skill-RMSE
12	10	0.9	1.4	91.4	91.8	4.8	6.3	43.3	52.7
24	8	1.9	2.0	88.0	92.0	7.8	15.2	55.3	42.3
36	6	1.7	1.8	93.3	95.0	10.9	12.5	69.5	53.1
48	4	2.5	2.5	90.0	90.8	11.5	13.8	74.0	60.7
60	2	1.0	1.0	97.8	97.8	12.7	14.9	75.6	69.5

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

8. Acknowledgements:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge the contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning

service of system. 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, WMO/ESCAP Panel countries, research institutes including Indian Space Research Organisation for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai, contribution from Numerical Weather Prediction Division, Satellite and Radar Division, Surface & Upper air instruments Divisions, New Delhi and Information System and Services Division at IMD is also duly acknowledged.