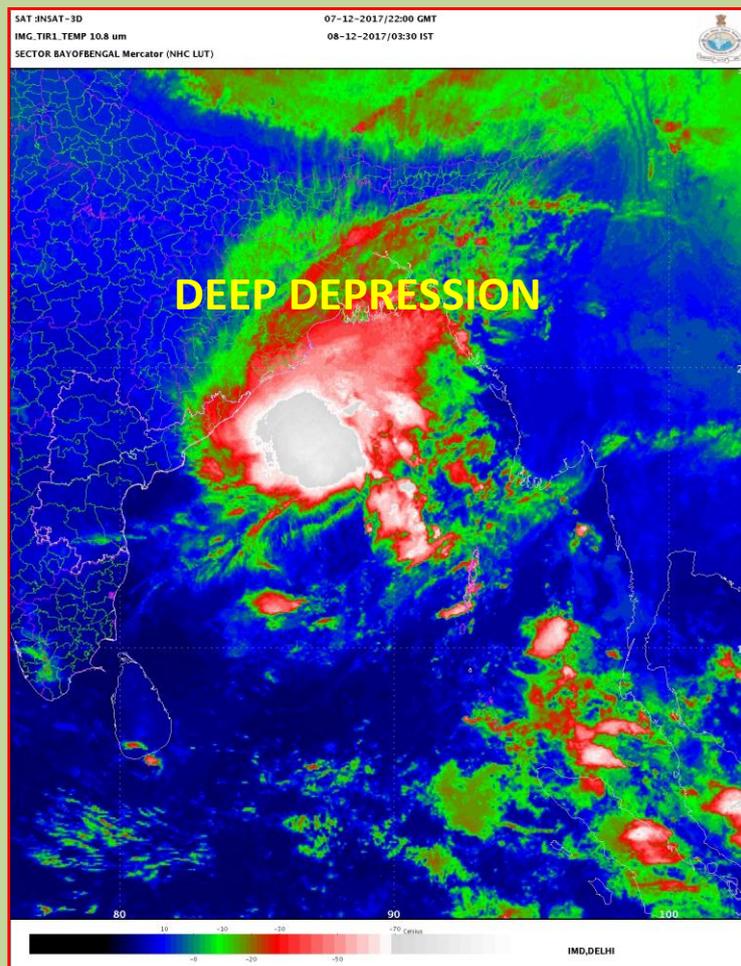




**GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT**

**Deep Depression over southeast Bay of Bengal
(06-09 December, 2017): A Report**



INSAT-3D enhanced coloured IR imagery based on 2200 UTC of 6th December

**Cyclone Warning Division
India Meteorological Department
New Delhi
December 2017**

2. Brief life history

2.1. Genesis

A low pressure area (LPA) formed over Malay Peninsula and adjoining Andaman Sea in the morning of 30th November, 2017. It lay as a well marked low pressure area (WML) over south Andaman Sea & adjoining Strait of Malacca on 1st December, over Sumatra coast and adjoining south Andaman Sea on 2nd, over southeast Bay of Bengal & adjoining south Andaman Sea and equatorial Indian Ocean on 3rd and 4th and over southeast Bay of Bengal (BoB) & neighbourhood on 5th. It concentrated into a Depression (D) over southeast BoB & neighbourhood in the morning of 6th December and lay centred near latitude 8.5° N and longitude 88.5 °E, about 1160 km to the southeast of Machillipatnam and 1250 km south-southeast of Gopalpur. .

Considering the environmental conditions, at 0300 UTC of 6th, the sea surface temperature (SST) over the region was 29-30°C. SST showed decreasing tendency towards north and west. The ocean thermal energy was about 100 KJ/cm² over the area. It also showed decreasing tendency towards north. The vertical wind shear between upper and lower levels was high around the system centre. It was increasing towards north and west. The vertical wind shear between middle and lower levels was low (5-10 knots). The low level relative vorticity was around $100 \times 10^{-6} \text{ s}^{-1}$ to the southwest of system centre. Low level convergence was about $30 \times 10^{-5} \text{ s}^{-1}$ to the north-northwest of system centre. The upper level divergence was around $30 \times 10^{-5} \text{ s}^{-1}$ to the north of system centre. The Madden Julian Oscillation (MJO) index lay in phase 5 with amplitude > 1. The upper tropospheric ridge at 200 hPa level ran along 17° N over BoB. A trough ran roughly along Long 65°E to the north of Lat. 18°N at 5.8 km above mean sea level. Even though the system lay over favourable ocean thermal conditions, it was embedded in a high wind shear regime. It indicated that the system would not intensify rapidly and its intensification would be limited upto deep depression stage. Further, the system would encounter colder sea, lower ocean thermal energy and increased shear due to the strong upper level winds in association with a deep trough in westerlies near coast. All these conditions indicated weakening of the system near the coast.

2.2. Intensification and Movement:

At 0300 UTC of 7th, the sea surface temperature (SST) over the region was 28-29°C. SST showed decreasing tendency towards north and west. The ocean thermal energy was about 60-80 KJ/cm² over the area. It also showed decreasing tendency towards north and west. The vertical wind shear between upper and lower levels was high around the system centre. It was increasing towards north and west. The vertical wind shear between middle and lower levels was low (5-10 knots). The low level relative vorticity was around $100 \times 10^{-6} \text{ s}^{-1}$ to the south of system centre. Low level convergence was about $20 \times 10^{-5} \text{ s}^{-1}$ to the northwest of system centre. The upper level divergence was around $40 \times 10^{-5} \text{ s}^{-1}$ to the northwest of system centre. The Madden Julian Oscillation (MJO) index lay in phase 5 with amplitude > 1. The upper tropospheric ridge at 200 hPa level ran along 17° N over BoB in association with anti cyclonic circulation over eastcentral BOB. A trough ran roughly along Long 72°E to the north of Lat. 18°N at 5.8 km above mean sea level. Under this scenario, the southeasterly to south-southeasterly winds prevailed over the system at upper level, which suggested the north-northwestward movement of the system. Deep layer mean wind also suggested similar movement of the system. Under these features, the system maintained it's intensity and moved nearly north-northwestward.

At 0000 UTC of 8th, similar environmental features continued and the system intensified into a deep depression over central BoB near latitude 14.3 °N and longitude 87.0 °E, about 590 km south-southeast of Gopalpur and 660 km east-southeast of Machilipatnam mainly due to favourable poleward outflow.

At 1800 UTC of 8th, the system entered the colder sea. SST over the region was 25-26°C. SST showed decreasing tendency towards north and west. The ocean thermal energy was about 50 KJ/cm² over the area and the system weakened into a depression over northwest and adjoining northeast BoB. At 0300 UTC of 9th, the low level relative vorticity was around $150 \times 10^{-6} \text{ s}^{-1}$ around the system centre. Low level convergence was about $30 \times 10^{-5} \text{ s}^{-1}$ to the northeast of system centre. The upper level divergence was around $40 \times 10^{-5} \text{ s}^{-1}$ to the northeast of system centre. Though the system entered colder sea region, it maintained its intensity as there was relative increase in low level relative vorticity, convergence, upper level divergence and moderate wind shear. The upper tropospheric ridge at 200 hPa level ran along 18°N over BoB. A trough ran roughly along long.60°E to the north of lat. 25°N at 5.8 km above mean sea level. Under these conditions, the system moved north-northeastwards and lay centered over northwest BoB near latitude 19.2 °N and longitude 86.5 °E, about 170 km east of Gopalpur, 120 km south-southwest of Paradip and 320 km south-southwest of Digha. Moving further north-northeastwards, it weakened into a well marked low pressure area over northwest BoB at 1200 UTC of 9th December. The best track parameters of the system are presented in Table 1.

Table 1: Best track positions and other parameters of the Deep Depression over the southeast Bay of Bengal during 06-09 December, 2017

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
06/12/2017	0300	8.5/88.5	1.5	1004	25	4	D
	0600	8.8/88.3	1.5	1004	25	4	D
	1200	9.8/88.0	1.5	1004	25	4	D
	1800	10.0/88.0	1.5	1004	25	4	D
07/12/2017	0000	11.1/88.0	1.5	1004	25	4	D
	0300	12.0/88.0	1.5	1004	25	4	D
	0600	12.2/87.9	1.5	1004	25	4	D
	1200	12.8/87.7	1.5	1004	25	4	D
	1800	13.4/87.6	1.5	1004	25	4	D
08/12/2017	0000	14.3/87.0	2.0	1002	30	6	DD
	0300	15.0/86.8	2.0	1002	30	6	DD
	0600	15.5/86.7	2.0	1002	30	6	DD
	1200	16.5/86.3	2.0	1002	30	6	DD
	1800	18.0/86.2	1.5	1004	25	4	D
09/12/2017	0000	19.0/86.3	1.5	1004	25	4	D
	0300	19.2/86.5	1.5	1004	25	4	D
	0600	19.5/86.7	1.5	1004	25	3	D
	1200	Weakened into a well marked low pressure area over northwest Bay of Bengal at 1200 UTC					

3. Features observed through satellite and Radar

Satellite monitoring of the system was mainly done by using half hourly Kalpana-1 and INSAT-3D imageries. Satellite imageries from SCATSAT and international geostationary satellites Meteosat-7 & MTSAT, microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered for monitoring the system.

3.1 INSAT-3D features

Typical INSAT-3D visible, IR and enhanced colored imageries are presented in Fig.2. At 0300 UTC of 6th, intensity of the system was T 1.5. Broken low & medium clouds with embedded moderate to intense convection lay over southeast BoB and adjoining Andaman Sea. Scatterometer wind observations indicated maximum sustained winds of about 25 knots. Broken low & medium clouds with embedded intense to very intense convection lay over southeast & adjoining central BoB, southwest BoB and south Andaman Sea. The cloud pattern indicated organization. However, majority of cloud mass was displaced northwards from low level circulation centre. At 0000 UTC of 8th, intensity of the system was T 2.0. Broken low & medium clouds with embedded intense to very intense convection lay over BoB between latitude 13.0⁰N & 21.0⁰N east of longitude 83.0⁰E. At 1200 UTC of 8th, broken low & medium clouds with embedded intense to very intense convection lay over BoB between latitude 15.0⁰N & 21.5⁰N and longitude 83.5⁰E & 91.0⁰E. At 1800 UTC, the system entered colder sea area and weakened into a depression. At 0300 UTC of 9th, intensity of the system was T 1.5. Broken low & medium clouds with embedded intense to very intense convection lay over BoB between latitude 15.0⁰N & 21.5⁰N and longitude 83.5⁰E & 91.0⁰E, coastal Odisha, southwest Bengal and south Bangladesh. Moving north-northeastwards, it weakened into a well marked low pressure area at 1200 UTC of 9th and broken low to medium clouds with embedded moderate to intense convection lay over north Bay, south Bangladesh, Mizoram, Tripura and adjoining areas of Myanmar.

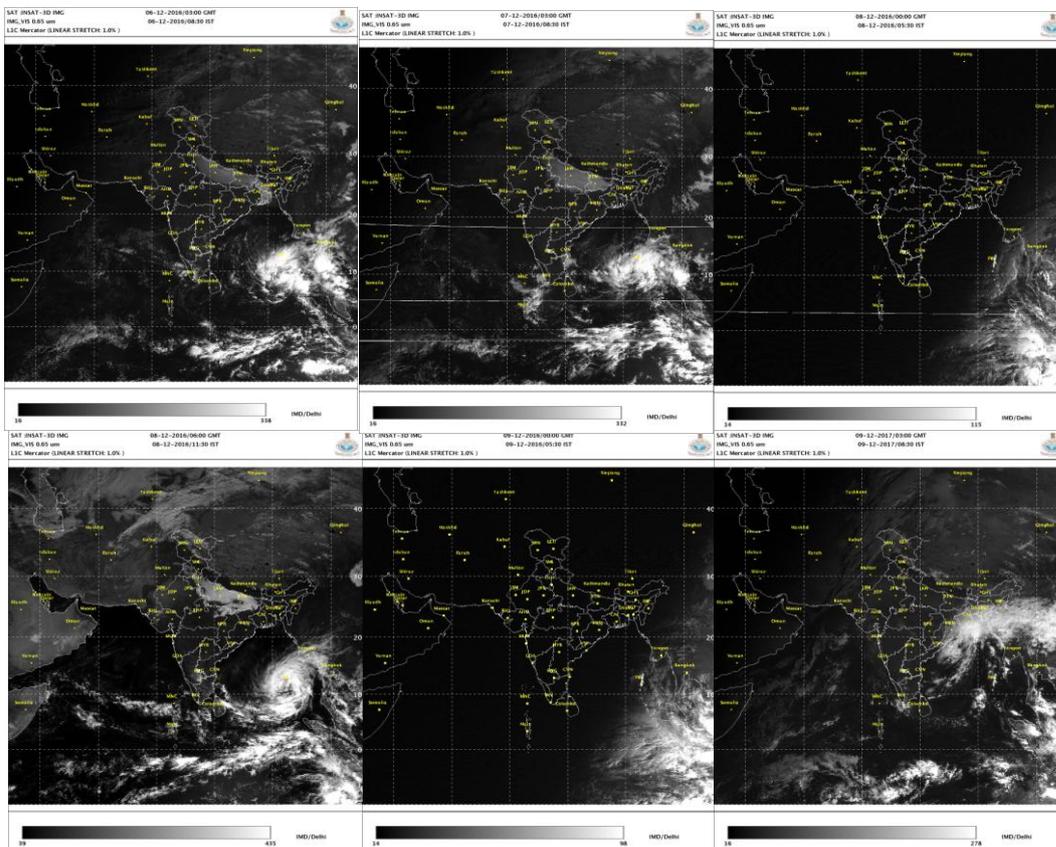


Fig. 2(i): INSAT-3D Visible imageries of Depression (06-09 December, 2017)

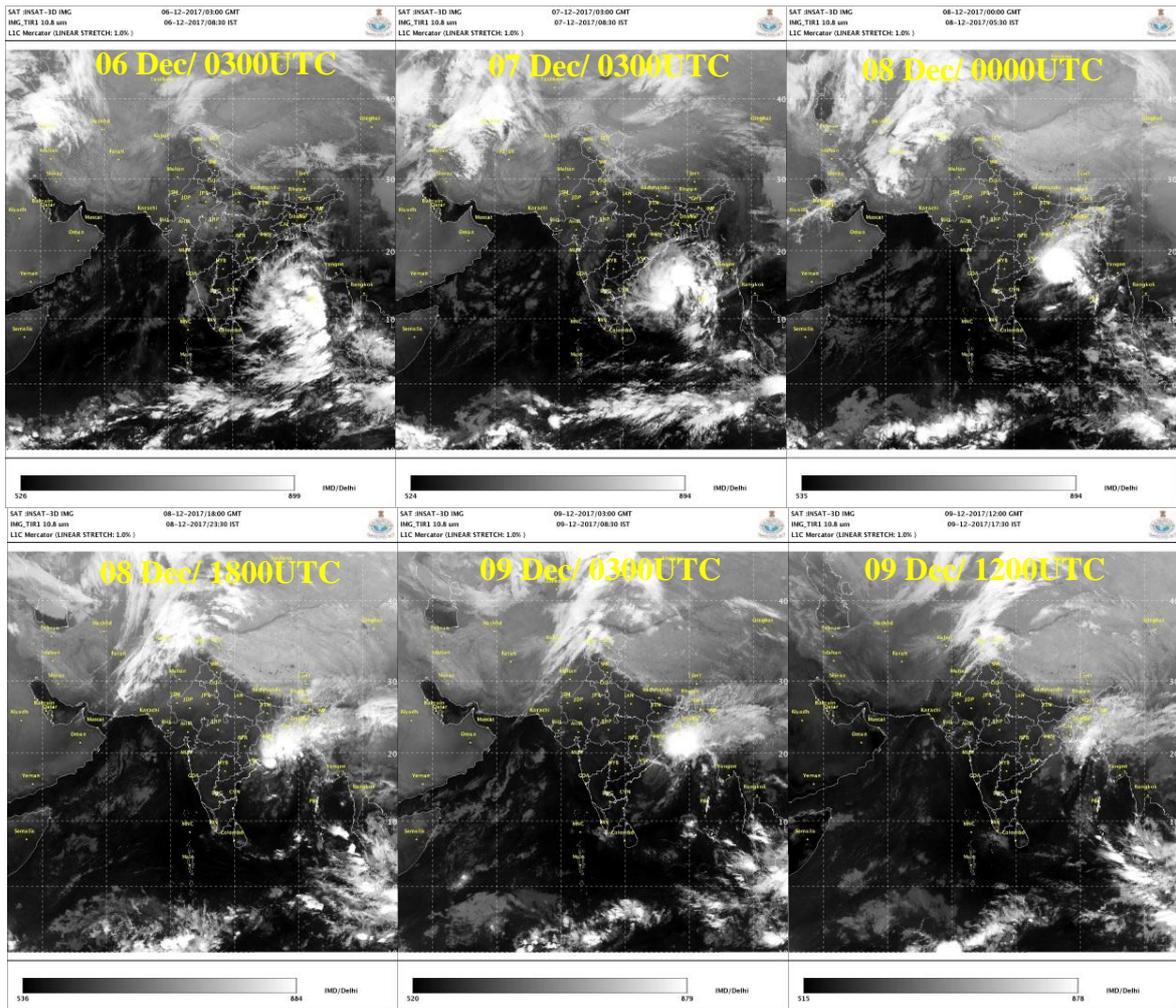


Fig. 2(ii): INSAT-3D IR imageries of Depression (06-09 December, 2017)

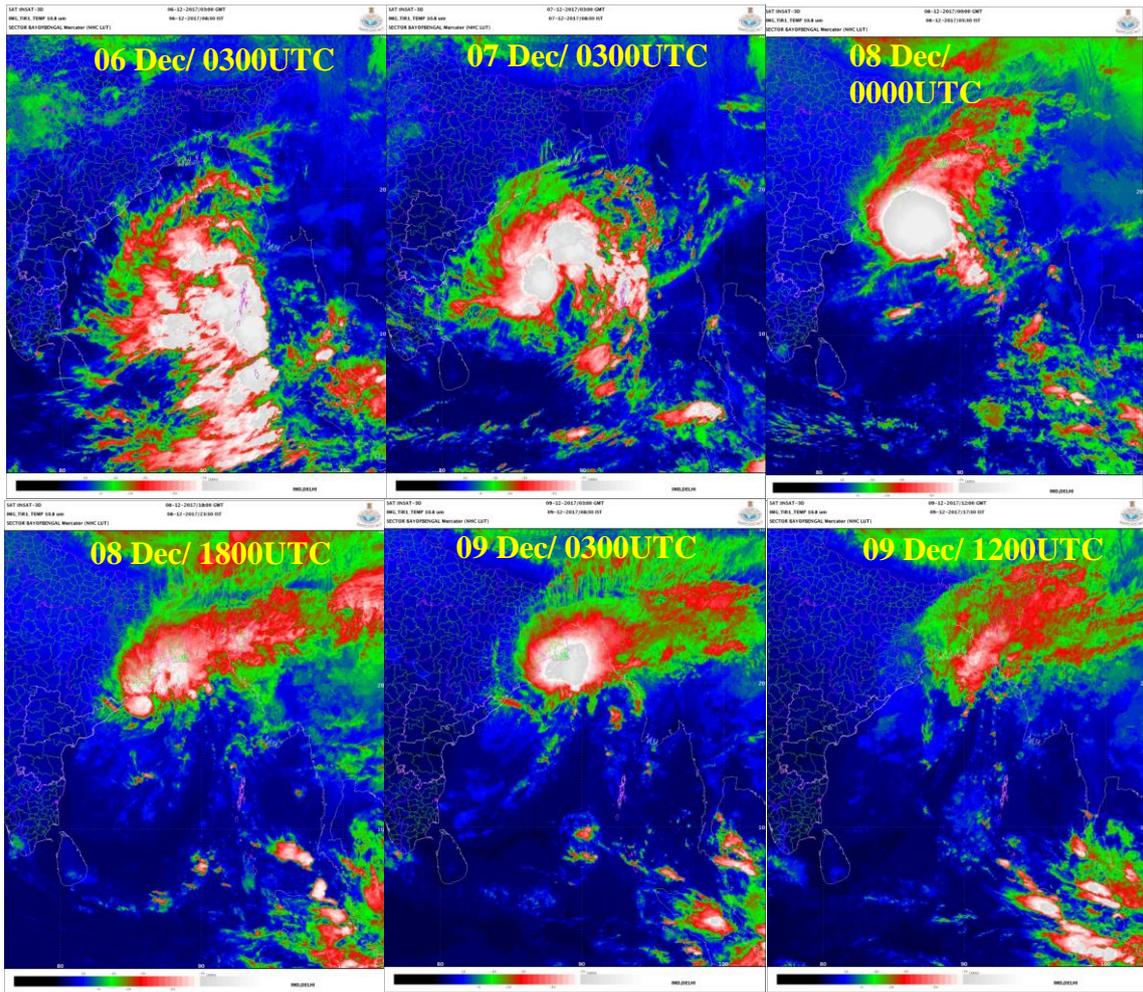


Fig. 2(iii): INSAT-3D enhanced coloured imageries of Depression (06-09 December, 2017)

3.3. Features observed through Radar:

DWR Paradip and Kolkata monitored the system when it was in their range. These imageries were utilized for determining the location and movement of system. Typical DWR imagery from Kolkata Radar is presented in Fig.3.

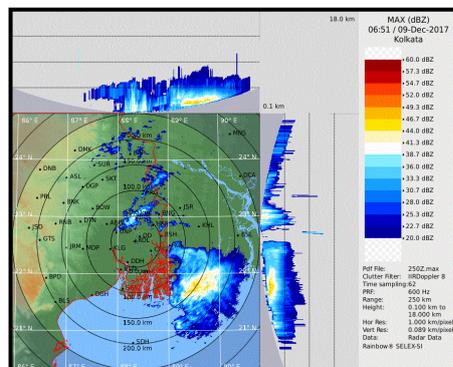


Fig. 3: Typical DWR imageries during Depression (09 December, 2017)

4. Dynamical features

IMD GFS (T1534) analysis and forecast of mean sea level pressure (MSLP), winds at 10 m, 850, 500 and 200 hPa levels are presented in Fig.4. IMD GFS (T1534) could well simulate the genesis of the system on 6th December, its north-northeastward movement and dissipation on 9th. It could also capture broad scale features like trough in westerlies along 62°E to the north of 20°N.

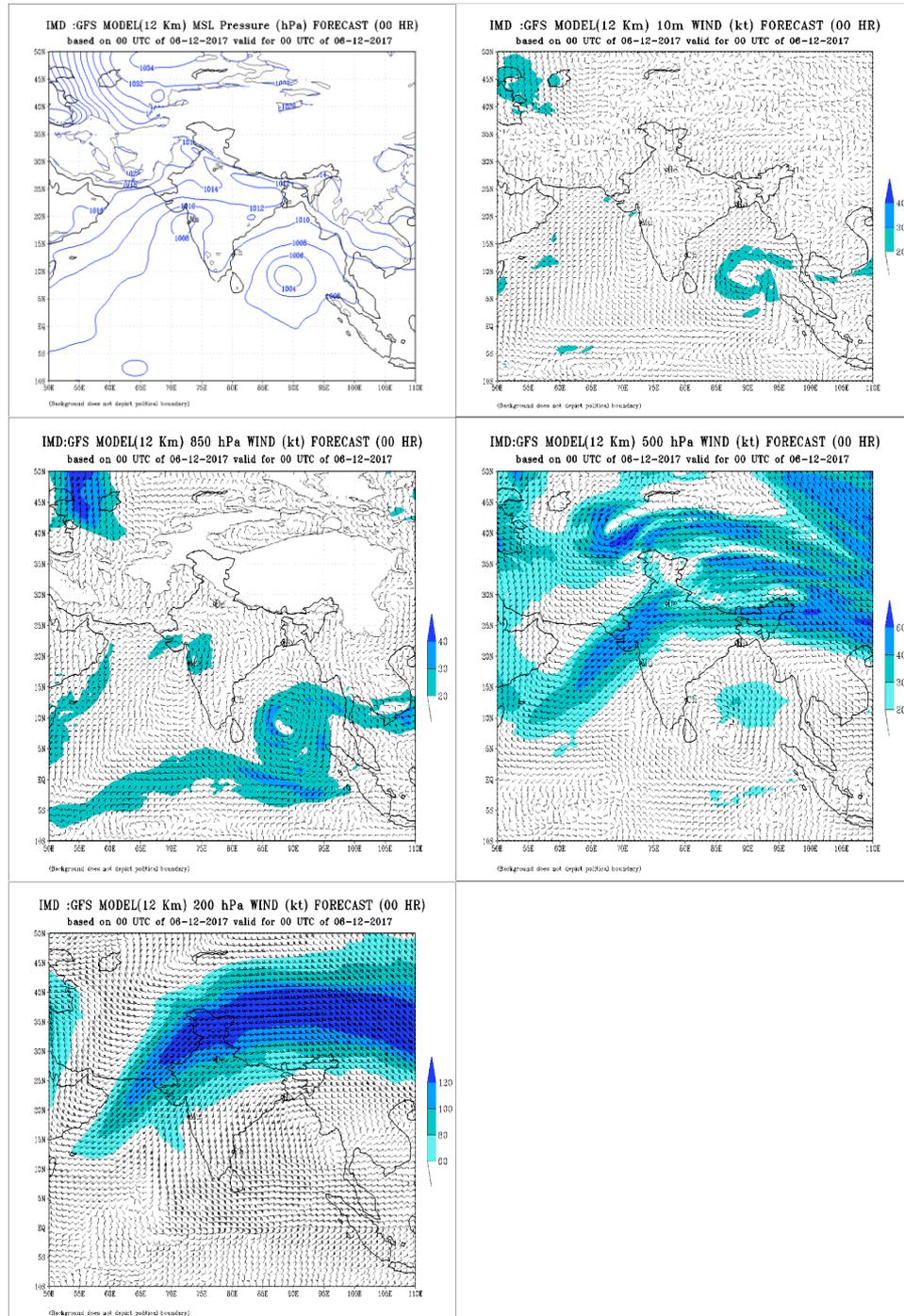


Fig. 4 (i): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 6th December 2017

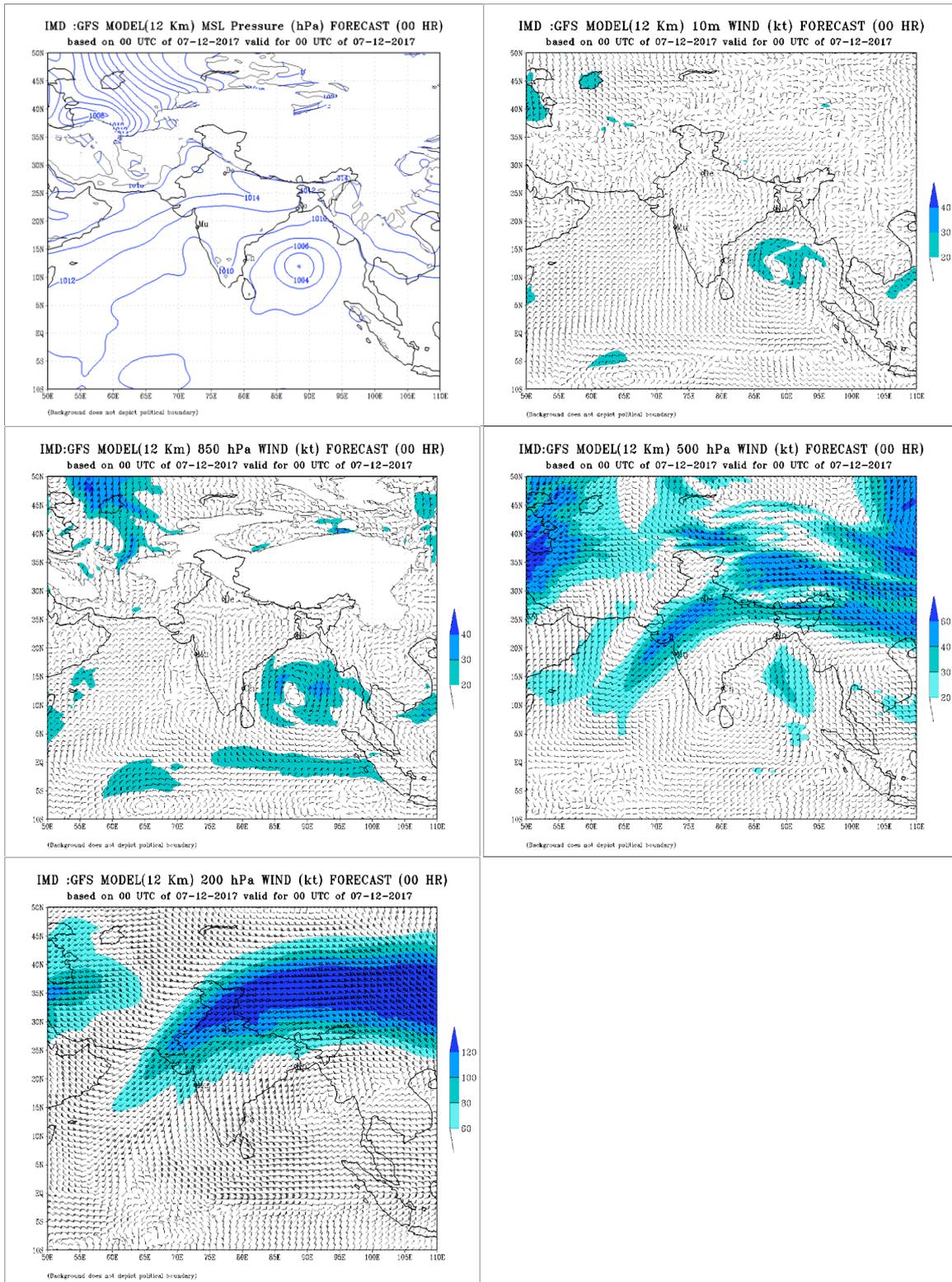


Fig. 4 (ii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 7th December 2017

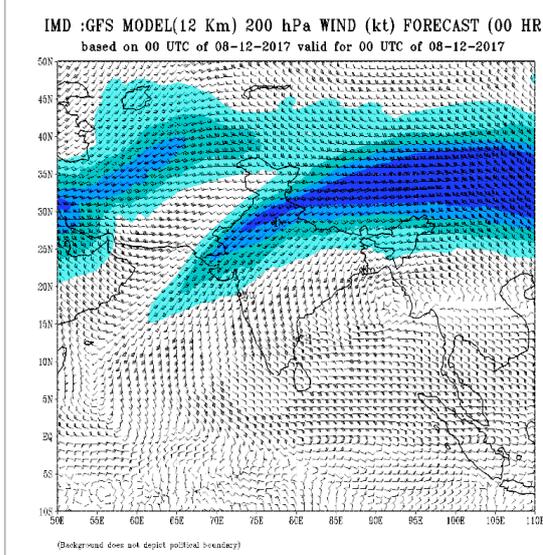
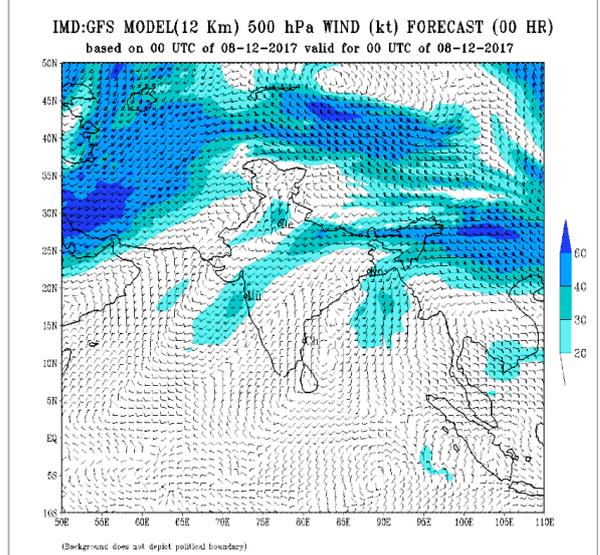
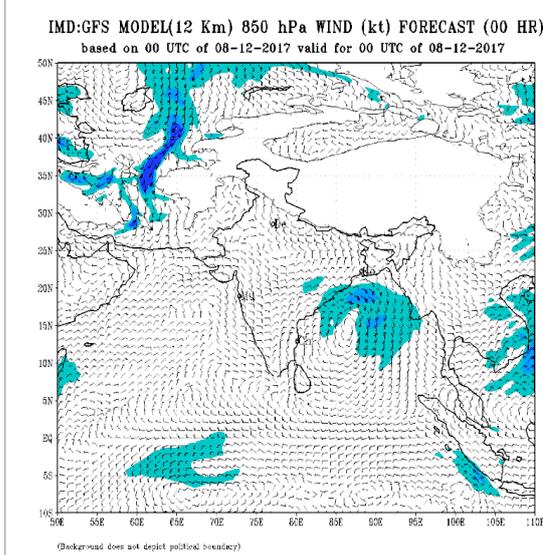
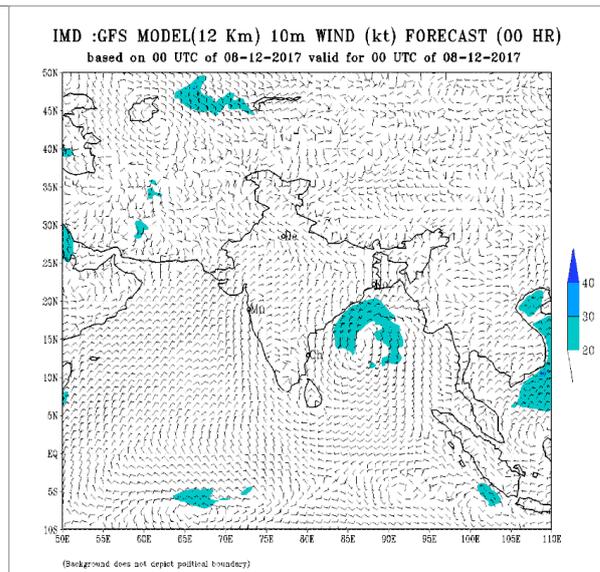
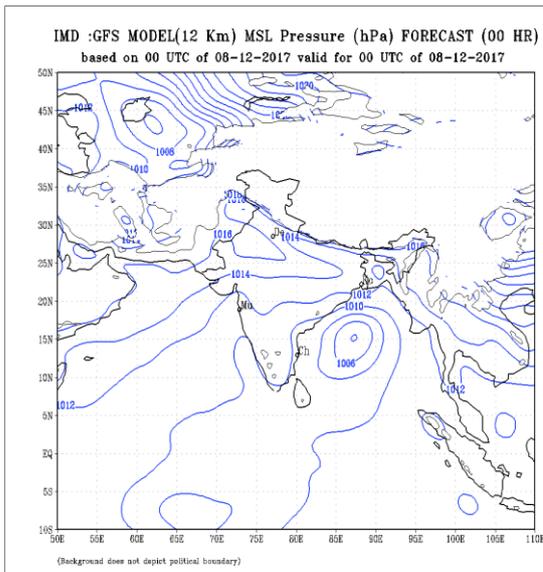


Fig. 4 (iii): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 8th December 2017

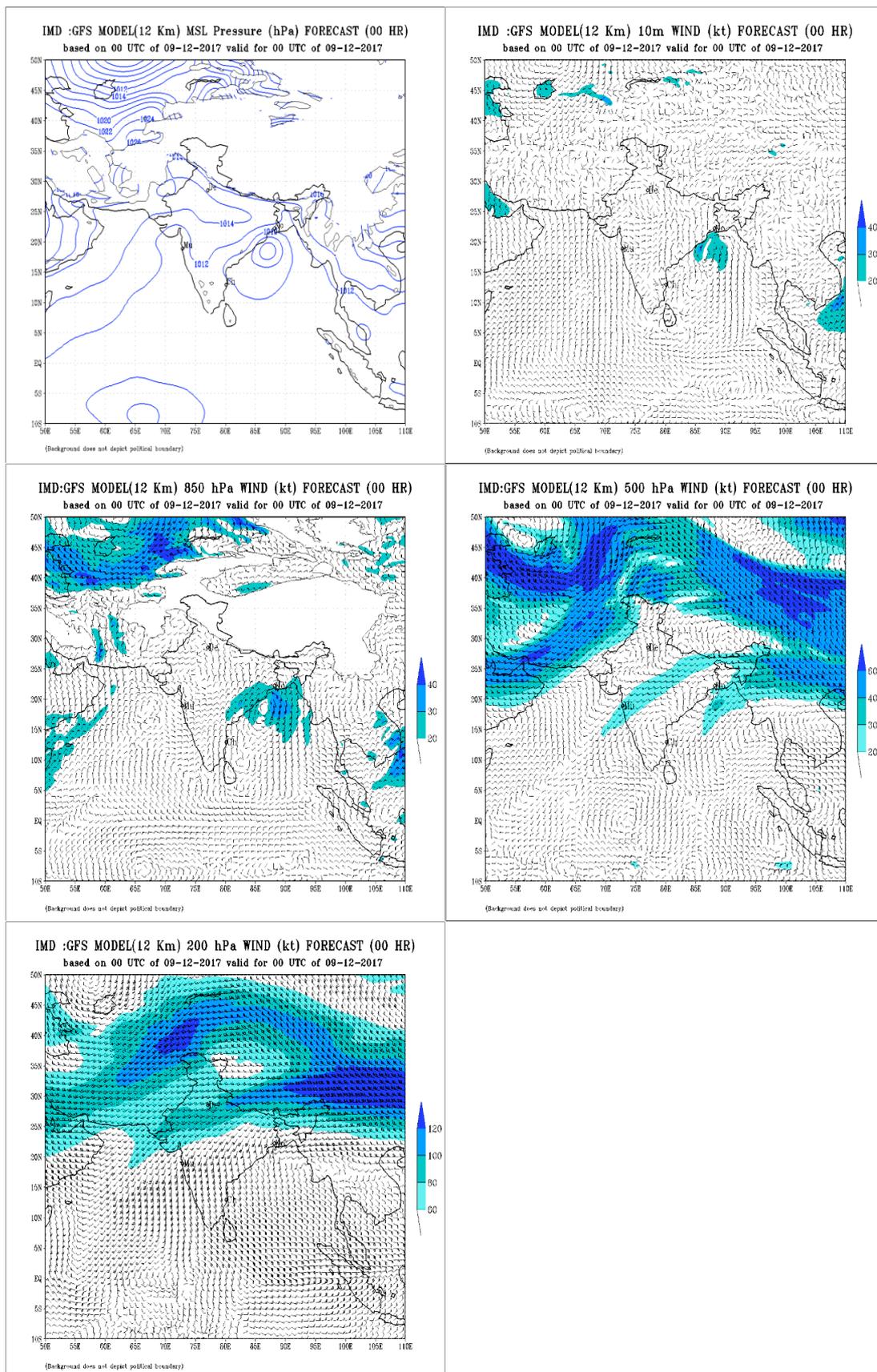


Fig. 4 (iv): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 9th December 2017

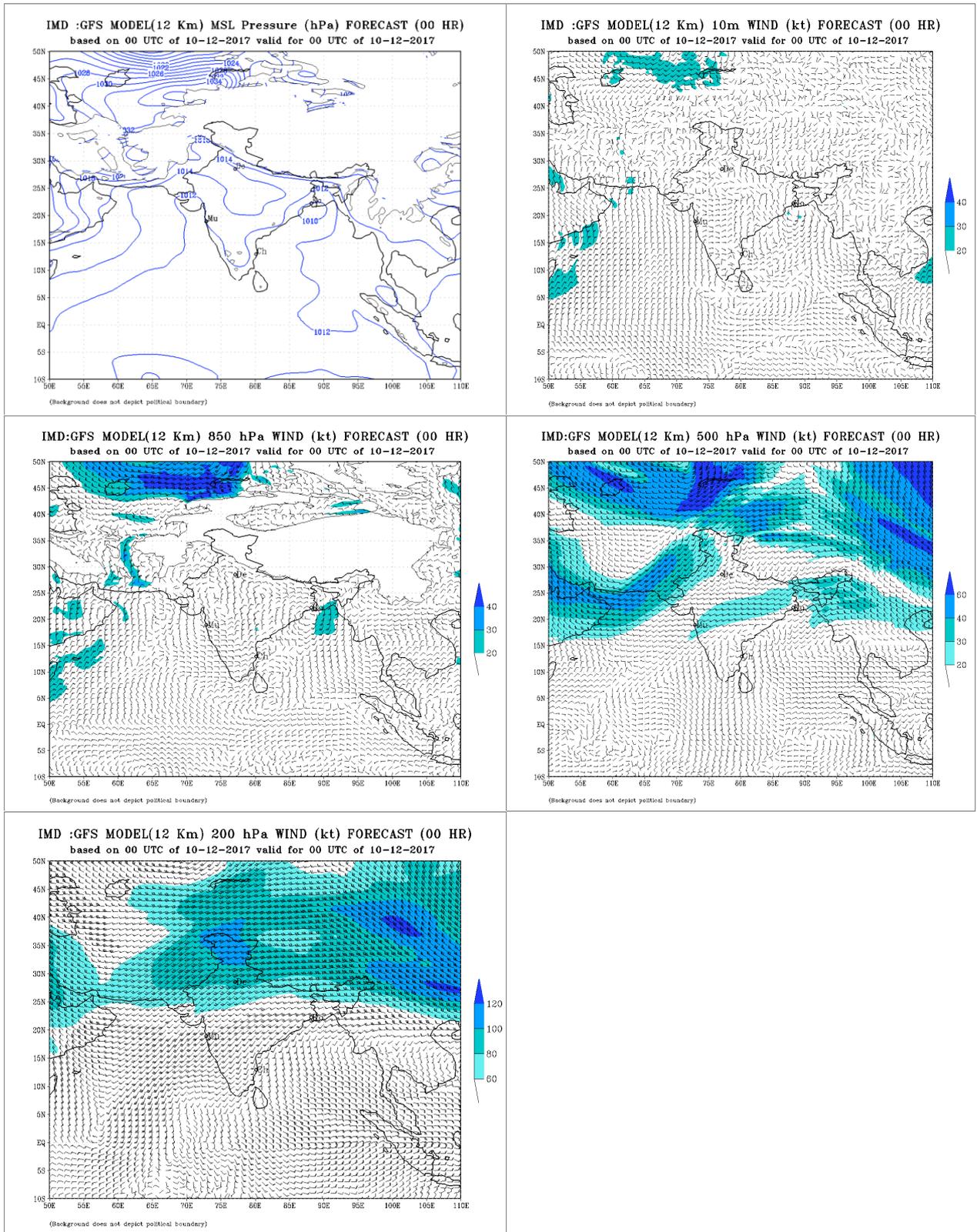


Fig. 4 (v): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 10th December 2017

5. Realized Weather:

The system caused light to moderate rainfall at few places with isolated heavy falls occurred over Tamilnadu & Puducherry on 6th and 7th Dec. Light to moderate rainfall at many places with isolated heavy falls occurred over coastal Odisha and adjoining districts of interior Odisha on 8th. Light to moderate rainfall also occurred at many places over coastal districts of West Bengal, south Assam, Meghalaya, Mizoram and Tripura with isolated heavy falls over Tripura on 9th. Realized 24 hrs accumulated rainfall ($\geq 5\text{cm}$) ending at 0830 hrs IST of date during the life cycle of the system is presented below. The rainfall is categorized as: heavy rain: 64.5 – 115.5 mm, very heavy rain: 115.6 – 200.4 mm, extremely heavy rain: 200.5 mm or more.

7 December 2017

Tamilnadu & Puducherry: Virudunagar AWS-11, Sivagiri-6 and Virudhunagar & Sivakasi-5 each

8 December 2017

Tamilnadu & Puducherry: Gobichettipalayam-8, Rajapalayam-7, Srivilliputhur-6, Kovilpatti-5

9 December, 2017

Odisha: Kakatpur- 12 cm, Gop- 11 cm; Paradeep, Puri & Astaranga -10 cm each, Balikuda & Kujanga -9 cm each; Niali -8 cm; Satyabadi & Tirtol- 7 cm each; Alipingal, Krishnaprasad, Nimpara & Jagatsinghpur - 6 cm each; Marsaghai, Derabis, Raghunathpur & Pipili - 5 cm each.

10 December, 2017

Assam: Karimganj & Amraghat-5 cm each.

Mizoram: Serchip – 6 cm.

Tripura: Kailashahar -7 cm, Arundhutinagar & Gokulpur-5 cm each.

The daily rainfall distribution based on merged gridded rainfall data of IMD/NCMRWF during depression period is shown in Fig.5.

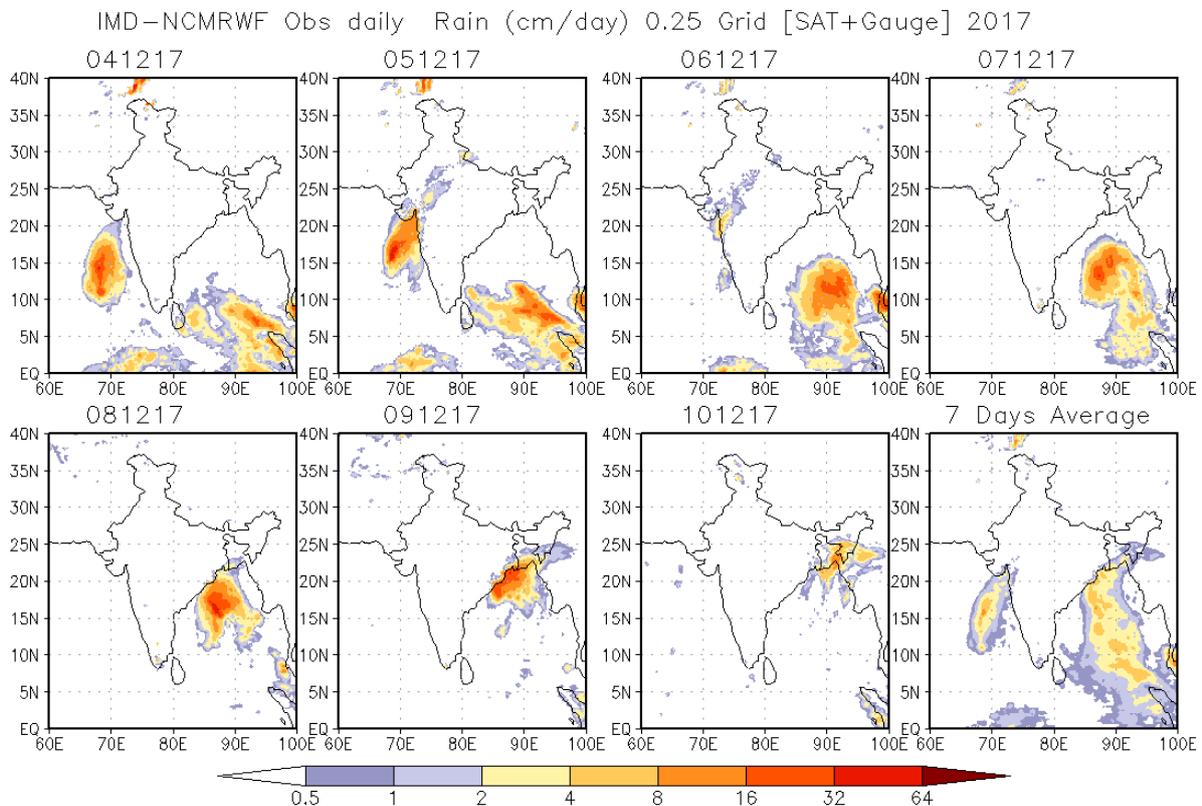


Fig.5: Daily rainfall distribution ending at 0300 UTC (0830 IST) of date based on merged gridded rainfall data of IMD/NCMRWF during 06-10 December, 2017

5. Bulletins issued by IMD

- IMD continuously monitored, predicted and issued bulletins containing track and intensity of the system till weakened into a low pressure area.
- The prognostics and diagnostics of the systems were described in the RSMC bulletins.
- Warnings bulletins for adverse weather like heavy rain, gale wind were issued with every three hourly update during life cycle of the system to the central, state and district level disaster management agencies including MHA, NDRF, NDMA, Chief Secretaries Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Assam, Meghalaya, Mizoram, Tripura. These bulletins were also issued to Railways, Surface Transport, Defence including Indian Navy & Indian Air Force, Ministry of Agriculture, Ministry of Information and Broadcasting etc.
- The graphical display of the observed track was disseminated by email and uploaded in the RSMC, New Delhi website (<http://rsmcnewdelhi.imd.gov.in/>) regularly.
- Regular updates were uploaded on facebook and tweeter regularly during the life period of the system.
- Electronic media were given daily updates since inception of system through e-mail, website and SMS.
- The bulletins were also issued by the cyclone warning centres of IMD at Chennai, Visakhapatnam and Bhubaneswar to ports, fishermen, coastal and high sea shipping community

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

Table 2. Verification of heavy rainfall warning in association with Deep depression (06-09 Dec. 2017)

S.No.	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	18	1. IMD's website 2. FAX and e-mail to Control Room NDM, Ministry of Home affairs, Control Room NDMA, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Director Indian Railways, Indian Navy, IAF, Chief Secretary: Tamil Nadu, Andhra Pradesh, Odisha and West Bengal, Mizoram, Tripura, Assam, Meghalaya
2	RSMC Bulletin	11	1. IMD's website 2. WMO/ESCAP member countries through GTS and E-mail 3. Indian Navy, IAF by E-mail
3	Facebook/ Tweet	Daily	Cyclone Warnings were uploaded on Social networking sites like Face book and Tweeter since inception till weakening of system
4	SMS	Once daily	SMS through (i) IMD network for disaster managers at national level and concerned states (ii) Department of Electronics and Information Technology-

6. Operational Forecast Performance:

(i) Genesis Forecast:

- First information about the formation of depression over BoB during next 48 hrs was issued on 1st November (noon). The same was updated in 2nd-4th December noon for development of depression during next 48 hours. On 5th December (forenoon), it was updated as depression would form during next 24 hrs. The depression formed over southeast BoB in the morning of 6th December.

(ii) Intensity forecast

- On 3rd December, when the system was a low pressure area, it was predicted that it would become the Deep depression subsequently after the formation of Depression.
- In the first bulletin issued around noon of 6th December, IMD predicted that it would become deep depression during next 48 hrs.
- The depression intensified into a Deep Depression in the early morning of 8th December.
- Similarly in the first bulletin issued on 6th December noon, it was predicted that the system will show sign of weakening, when it reaches near Andhra Pradesh coast around 8th December evening.
- The Deep depression weakened into a Depression in the mid-night of 8th and into a well marked low in the evening of 9th December 2017.

(iii) Track forecast

- On 1st December, when the system was a well marked low pressure area over south Andaman Sea, it was predicted that it would move towards north Tamil Nadu and south Andhra Pradesh coast during next 3-4 days.
- With the formation of the depression on 6th December, in the first bulletin itself, it was predicted that it would move northwestwards and reach near Andhra Pradesh coast around 8th December evening.
- On 7th December morning, it was predicted that it would move north-northwestwards and reach near north Andhra Pradesh coast and south Odisha coast around 9th December morning.
- It reached closest to north Andhra Pradesh and south Odisha coast on 9th December forenoon

(iv) Cyclone warning

- No cyclone Alert or warning was issued for any state, as it was not predicted to cross any coast.

(v) Fishermen warning

- In the first bulletin issued around noon of 6th Dec. 2017, fishermen along and off Nicobar Islands were advised not to venture into sea till the forenoon of 7th Dec. Fishermen along and off north Tamil Nadu, Andhra Pradesh and south Odisha coasts were advised not to venture into sea till 9th Dec.
- Regular updates were provided thereafter
- On 8th Dec., fishermen along and off south Andhra Pradesh coast were advised not to venture into Sea during next 24 hrs and fishermen along and off north Andhra Pradesh, Odisha and west Bengal coasts were advised not to venture into Sea during next 36 hrs.

(vi) Heavy rainfall warning

- IMD issued warning bulletins to the concerned central and state disaster management authorities & press and media. The verification of heavy rainfall warnings issued by IMD for deep depression during 6-9 December 2017 are shown in Table 3

- The gridded rainfall during 4-10 December is presented in Fig.5.
- It can be found that the occurrence of heavy rainfall in association with the system could be predicted well in advance.

Table 4: Verification of heavy rainfall warning issued by IMD for Deep Depression over southeast Bay of Bengal (06-09 December, 2017)

Time of issue (time of observation) of Date	Heavy rainfall warning	Realised heavy rainfall (5cm or more) ending at 0830 hrs IST of date
1150 IST (0830 IST) of 6 th December 2017	<ul style="list-style-type: none"> • Isolated heavy rainfall very likely over Nicobar Islands during next 2 days • Isolated heavy falls over north Andhra Pradesh and south Odisha on 8th and 9th. 	<p><u>7 December 2017</u> Tamil Nadu: Virudunagar AWS-11, Sivagiri-6 and Virudhunagar & Sivakasi-5 each <u>8 December 2017</u></p>
1130 IST (0830 IST) of 7 th December 2017	<ul style="list-style-type: none"> • Isolated heavy falls over north Andhra Pradesh on 8th and 9th, over Odisha during 8th to 10th, over coastal districts of West Bengal on 8th December, 2017. 	<p>Tamil Nadu: Gobichettipalayam-8, Rajapalayam-7, Srivilliputhur-6, Kovilpatti-5 <u>9 December, 2017</u></p>
1145 IST (0830 IST) of 8 th December 2017	<ul style="list-style-type: none"> • Isolated heavy rainfall over north Andhra Pradesh (Visakhapatnam, Vijayanagaram, Srikakulam districts) during next 24 hrs, over coastal and adjoining interior districts of Odisha during 8th to 9th and over coastal districts of West Bengal during 8th to 10th. • Isolated heavy falls over south Assam, Meghalaya, Mizoram and Tripura during 9th to 11th December 2017. 	<p>Odisha: Kakatpur- 12 cm, GOP- 11 cm; Paradeep, Puri & Astaranga -10 cm each, Balikuda & Kujanga -9 cm each; Niali -8 cm; Satyabadi & Tirtol- 7 cm each; Alipingal, Krishnaprasad, Nimpara & Jagatsinghpur - 6 cm each and Marsaghai, Derabis, Raghunathpur & Pipili - 5 cm each.</p>
1150 IST (0830 IST) of 9 th December 2017	<ul style="list-style-type: none"> • Isolated heavy to very heavy falls over north and south 24 Pargana districts of West Bengal and heavy falls at isolated places over the remaining coastal districts of West Bengal during next 24 hours. • Heavy falls at isolated places over south Assam, eastern Meghalaya, Mizoram and Tripura during next 48 hours. 	<p><u>10 December, 2017</u> Assam: Karimganj & Amraghat-5 cm each. Mizoram: Serchip – 6 cm. Tripura: Kailashahar -7 cm, Arundhutinagar & Gokulpur-5 cm each.</p>

8. Acknowledgements:

India Meteorological Department (IMD) duly thanks contribution from all the stake holders who contributed to the successful monitoring, prediction and warning service of the depression by

IMD. We acknowledge the contribution of National Centre for Medium Range Weather Forecasting Centre (NCMRWF), NOIDA, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, National Institute of Ocean Technology (NIOT), Chennai and Space Application Centre and Indian Space Research Organisation (SAC-ISRO), Ahmedabad for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai & Kolkata, Cyclone Warning Centre (CWC) Bhubaneswar, DWR Paradip, Visakhapatnam, Kolkata AND Agartala, Agricultural Meteorology Division, Pune, Numerical Weather Prediction Division, Satellite Division and Information System and Services Division at IMD, New Delhi is also acknowledged.
