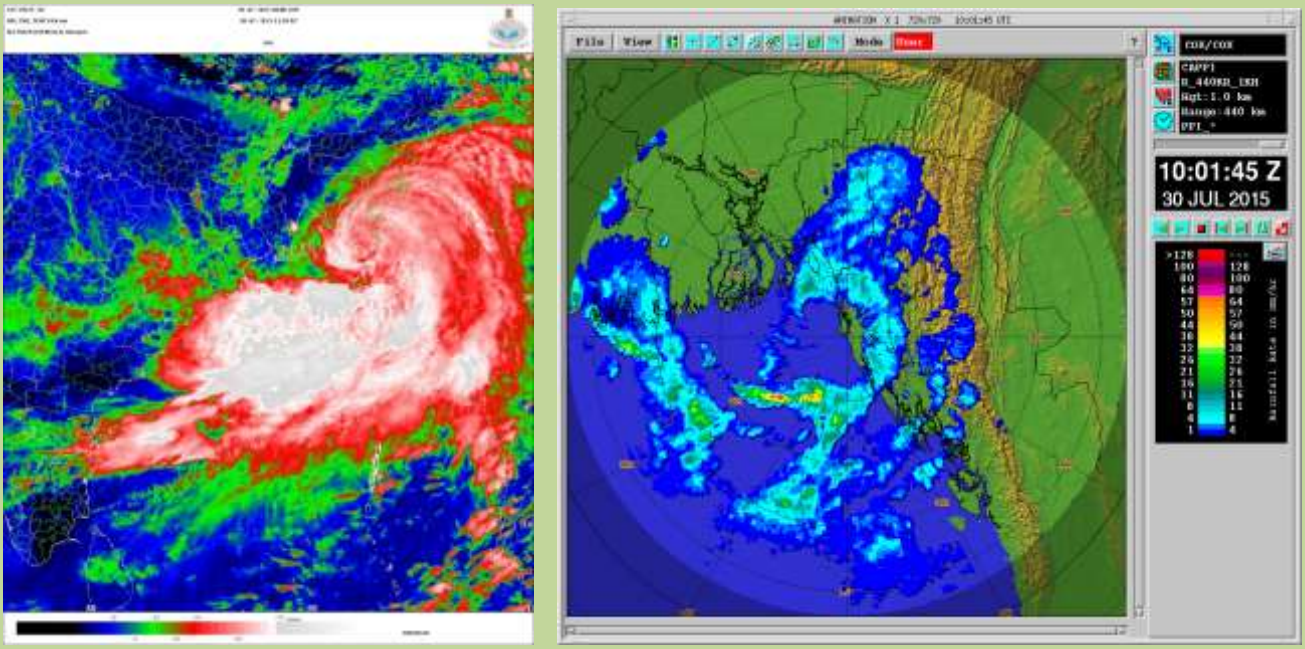
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
EARTH SYSTEM SCIENCE ORGANISATION
INDIA METEOROLOGICAL DEPARTMENT

Cyclonic Storm, KOMEN over the Bay of Bengal (26 July-02 August, 2015): A Report



Insat-3D Satellite imagery and DWR Cox's Bazar imagery of CS KOMEN

Cyclone Warning Division

India Meteorological Department

New Delhi

August 2015

Cyclonic Storm (CS) Komen over the Bay of Bengal (26 July-02 August 2015)

1. Introduction

The cyclonic storm (CS), KOMEN over the Bay of Bengal (BoB) developed from a low pressure area which lay over northeast BoB and adjoining Bangladesh & Gangetic West Bengal on 25th July evening and concentrated into a depression over the same area in the morning of 26th July. It followed a semi-circular track over northeast Bay of Bengal and then crossed Bangladesh coast between Hatia and Sandwip near lat. 22.5^{0}N and long. 91.4^{0}E during 1400 and 1500 UTC of 30th July. After landfall, it moved initially north-northwestwards, then westwards and west-southwestwards across Bangladesh, Gangetic West Bengal and Jharkhand. It weakened gradually into a well marked low pressure area over Jharkhand and adjoining north Odisha and north Chhattisgarh at 1200 UTC of 02nd August.

The salient features of this cyclone are as follows.

i. It was the fourth system during the monsoon month of July which intensified into a CS during the satellite era (1965-2015). Of the three systems before CS Komen, the CS in July 1972 & 1973 and the CS in July 1989 crossed Odisha and Andhra Pradesh coast respectively.
ii. The CS Komen had a unique track, as it developed near Bangladesh coast, followed a semi-circular track over the northeast Bay of Bengal and finally moved northward to cross Bangladesh coast.

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

2. Monitoring of CS, KOMEN

The CS KOMEN was monitored & predicted continuously since its inception by the India Meteorological Department (IMD). The forecast of its genesis (formation of Depression) on 26th July., its track, intensity, point & time of landfall, as well as associated adverse weather like heavy rain, gale wind & storm surge were predicted well with sufficient lead time which helped the disaster managers to maximize the management of cyclone.

At the genesis stage, which occurred close to Bangladesh coast, the system was monitored mainly with surface observations from India, Bangladesh and Myanmar, supported by meteorological buoys and scatterometer based surface wind observations from satellite. As the system entered into the northeast Bay of Bengal moving southward away from the coast, it was monitored additionally by satellite observations 29th July early morning. It was also tracked by the Doppler Weather Radar (DWR) at Khepupara and Cox's Bazar (Bangladesh) throughout its life period.

Various national and international NWP models and dynamical-statistical models including IMD and National Centre for Medium Range Weather Forecasting (NCMRWF) global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the storm. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation.

3. Brief life history

3.1. Genesis

Under the influence of active monsoon conditions, a low pressure area formed over northeast BoB and adjoining Bangladesh & Gangetic West Bengal on 25th evening. It persisted over the same region and concentrated into a depression at 0300 UTC of 26th July near lat 22.0^{0}N and long. 90.8^{0}E, close to Bangladesh coast.

The winds were stronger in southern sector (25-30 knots) under the influence of southwest monsoon current and were about 15-20 knots in northern sector. The vertical wind shear was low (5-10 knots) around the system centre. The low level relative vorticity was about 100-150 x 10^{-5} second^{-1} and low level convergence was 40 x 10^{-5} second^{-1}. The upper level divergence was 40 x 10^{-5} second^{-1}. The region of maxima in low level vorticity, low level convergence and upper level divergence lay to the southeast of system centre. As a result, maximum convection in association with the system lay to the southeast of the system centre.

3.2. Track and intensification

Best track parameters of cyclonic storm, KOMEN over BoB (26th July-2nd August, 2015) are given in Table 1. The observed track of the system is also shown in Fig.1.

The environmental features as mentioned in the previous section continued during 26-30th July favouring the intensification of the system to a CS, Komen. However, it could not intensify further, as it interacted with the land surface and the Ocean thermal energy was less than 50 KJ/cm^{2}, though the sea surface temperature was about 31^{0}C. The large scale feature like Madden Julian Oscillation index lay over phase 2 (west equatorial Indian Ocean with amplitude less than 1 and hence it was not favourable for intensification. There was a cyclonic circulation to the north-northeast of the CS. It helped in dry air intrusion in the CS field which inhibited further intensification.

The Depression moved slowly westwards and lay centred at 1200 UTC of 26th July near lat. 22.0^{0}N and long. 90.5^{0}E. It remained stationary there till 0300 UTC of 28th and then moved slowly southwestwards and lay centred at 1200 UTC of 28th July near lat. 21.5^{0}N and long. 90.2^{0}E. It then moved southeastwards, intensified into a Deep Depression and lay centred at 0000 UTC of 29th July near lat. 21.0^{0}N and long. 91.0^{0}E. The Deep Depression moved east-northeastwards initially and then north-northeastwards till 1200 UTC of 29th July. It then moved nearly northward, intensified into a CS, KOMEN and lay centred at 1800 UTC of 29th July near lat. 21.6^{0}N and long. 91.4^{0}E. It continued to move nearly northwards and crossed Bangladesh coast between Hatia and Sandwip (near lat. 22.5^{0}N and long. 91.4^{0}E) during 1400 and 1500 UTC of

30th July. After the landfall it moved north-northwestwards and gradually weakened into a Deep Depression at 2100 UTC of 30th July over Bangladesh near lat. 23.0^{0}N and long. 91.0^{0}E. It then moved west-northwestwards and further weakened into a Depression at 1200 UTC of 31st July and lay centred over Bangladesh and adjoining Gangetic West Bengal near lat. 23.1^{0}N and long. 89.5^{0}E. It continued its west-northwestward movement till 1200 UTC of 1st August and then moved initially westwards and then west-southwestwards and weakened into a well marked low pressure area over Jharkhand and adjoining north Odisha and north Chhattisgarh at 1200 UTC of 02nd August.

The system was steered by the low to middle level monsoon circulation leading to a semi-circular path till 29th July. Thereafter, the anti-cyclonic circulation to the east of the system centre located over Myanmar and adjoining Bangladesh helped in providing northward steering current. As a result the CS, Komen moved nearly northward on 30th July till landfall. After that the system was steered by the Tibetan anti-cyclonic circulation and hence moved westwards. The anti-cyclonic circulation to the west of the system centre limited the translational speed of the cyclone towards the west on 31st July and further pushed the system west-southwestwards on 2nd August.

During the initial period of the CS, Komen, there was a deep depression over Gujarat, which moved north-northwestwards across Rajasthan and weakened gradually, while the depression over northeast Bay of Bengal moved south-southeastward and strengthened gradually. It needs therefore further investigation to find out the interaction, if any, between the deep depression over Gujarat/ Rajasthan and the deep depression over northeast Bay of Bengal.

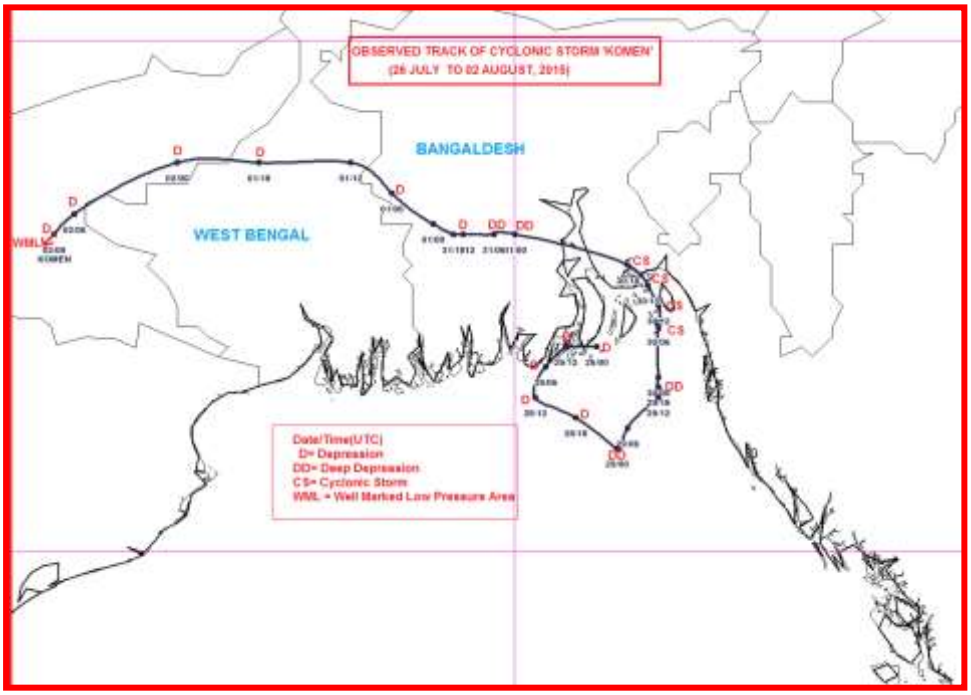


Fig.1 Observed track of CS Komen during 26th July to 02nd August 2015.

Table 1. Best track parameters of cyclonic storm, KOMEN over Bay of Bengal (26th July-2nd August, 2015)

Date	Time (UTC)	Centre lat.^{0} N/ long.^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
26/07/2015	0000	22.0/90.8	1.5	994	20	3	D
	0300	22.0/90.8	1.5	994	20	3	D
	0600	22.0/90.5	1.5	994	20	3	D
	1200	22.0/90.5	1.5	994	20	3	D
	1800	22.0/90.5	1.5	994	20	3	D
27/07/2015	0000	22.0/90.5	1.5	994	20	3	D
	0300	22.0/90.5	1.5	994	25	4	D
	0600	22.0/90.5	1.5	994	25	4	D
	1200	22.0/90.5	1.5	994	25	4	D
	1800	22.0/90.5	1.5	994	25	4	D
28/07/2015	0000	22.0/90.5	1.5	994	25	4	D
	0300	22.0/90.5	1.5	994	25	4	D
	0600	21.8/90.3	1.5	994	25	4	D
	1200	21.5/90.2	1.5	994	25	4	D
	1800	21.3/90.6	1.5	992	25	4	D
29/07/2015	0000	21.0/91.0	2.0	990	30	5	DD
	0300	21.1/91.0	2.0	990	30	5	DD
	0600	21.2/91.1	2.0	990	30	5	DD
	1200	21.5/91.4	2.0	988	30	6	DD
	1800	21.6/91.4	2.0	986	35	7	CS
30/07/2015	0000	21.7/91.4	2.0	986	35	7	CS
	0300	22.0/91.4	2.5	986	35	7	CS
	0600	22.2/91.4	2.5	986	40	8	CS
	0900	22.3/91.4	2.5	986	40	8	CS
	1200	22.4/91.4	2.5	988	35	7	CS
	Crossed Bangladesh coast near longitude 91.4^{0}E during 1400-1500 UTC						
	1500	22.6/91.3	-	988	35	7	CS
	1800	22.8/91.1	-	988	35	7	CS
	2100	23.0/91.0	-	988	30	6	DD
31/07/2015	0000	23.1/90.0	-	990	30	5	DD
	0300	23.1/90.0	-	990	30	5	DD
	0600	23.1/89.8	-	992	30	5	DD
	1200	23.1/89.5	-	994	25	4	D
	1800	23.1/89.4	-	994	25	4	D

01/08/2015	0000	23.2/89.2	-	994	20	4	D
	0300	23.2/89.2	-	994	20	4	D
	0600	23.5/88.8	-	994	20	4	D
	1200	23.8/88.4	-	994	20	4	D
	1800	23.8/87.5	-	994	20	4	D
02/08/2015	0000	23.8/86.7	-	996	20	3	D
	0300	23.5/86.0	-	996	20	3	D
	0600	23.3/85.7	-	996	20	3	D
	0900	23.1/85.5	-	996	20	3	D
	1200	Well Marked Low over Jharkhand and adjoining north Odisha and north Chhattisgarh					

3.3. Maximum Sustained Surface Wind speed and estimated central pressure:

The MSW in association with a cyclone affecting Indian coasts is defined as the average surface wind speed over a period of 3 minutes measured at a height of 10 meters. The MSW is either estimated by the remotely sensed observations or recorded by the surface based instruments. As the CS, Komen developed over northeast Bay of Bengal and crossed Bangladesh coast near long. 91.4^0E, the surface observations as well as radar and satellite observations played crucial role in determining the MSW. The highest MSW has been estimated as 40 knots. However, Teknaf (Bangladesh) reported 55 knots (in the southeastern sector of the CS, Komen) in the early hours of 30^{th} July for a short period. It reported 76 kmph (40 kts) at 0600 UTC of 30th July. Maungdaw (48061) and Sittwe (47062) which lay to the southeast of the centre of the cyclonic storm reported maximum wind of 67 kt at 2300 UTC and 58 kt at 0400 UTC of 30th July respectively which may be due to the squall in association with the .cyclonic storm.

The lowest estimated central pressure has been 986 hPa. The MSLP of about 986.5 hPa has been reported from southeastern coast of Bangladesh, when the CS was moving northward close to that coast.

4. Climatological aspects

Climatologically, during the monsoon month of July, low pressure systems (LPS) forming over the BoB do not intensify into tropical cyclones as the mean area of formation lies over the head Bay of Bengal which is very close to land and the mean vertical wind shear is quite high. During the satellite era of last 50 years period (1965-2015) over BOB, only three LPS intensified into cyclones. The tracks of these three cyclones are shown in Fig. 2. All these three systems crossed coast as a CS. All the three systems, intensified into CS and maintained the intensity of CS for a short duration of time for about a day, tracked along the climatological track of west-northwest to northwestwards towards Odisha and north Andhra Pradesh coasts before landfall.

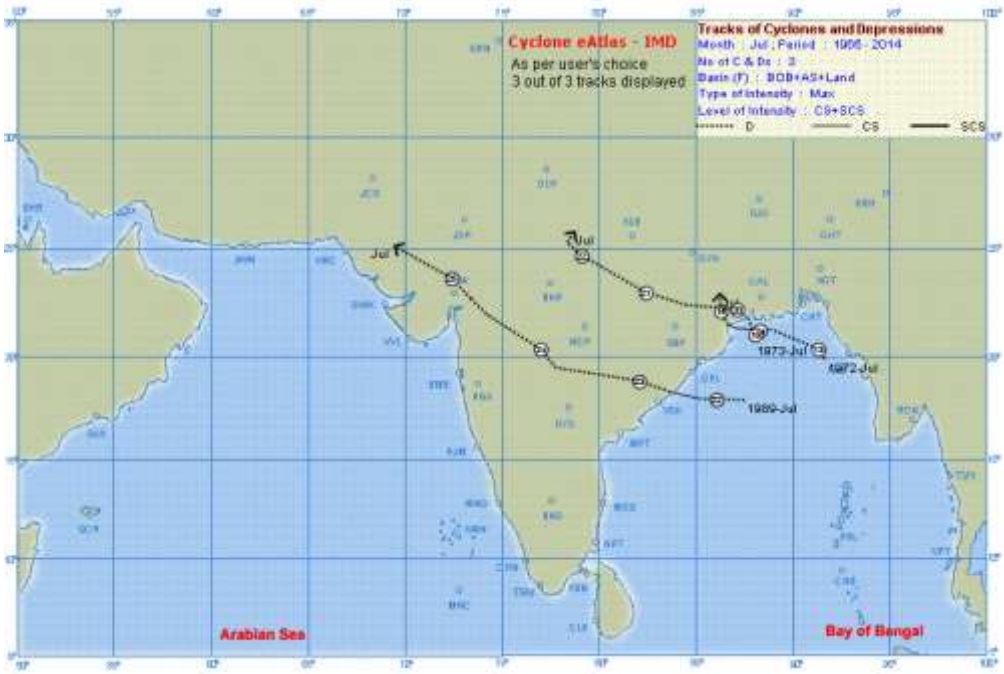


Fig. 2 Tracks of tropical cyclones over BOB during the month of July during the period 1965-2014

5. Features observed through satellite

Half hourly Kalpana-1 and INSAT-3D imageries were utilised for monitoring of CS, Komen. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries (visible, IR, IRBD and enhanced colour imageries) of CS Komen representing the life cycle of the cyclone are shown in Fig. 3-6.

According to INSAT-3D imageries and products, the system was seen as a low level cyclonic circulation on 26th July when the system was declared as a depression based on synoptic observations. It got organized on 27th and acquired shear pattern with T 1.0 at 27/0300 UTC and the intensity was increased to T 1.5 at 28/0300 UTC. The distance between centre and cloud mass imagery was 100 km and the cloud mass was sheared to the southeast of the centre of low level circulation. The intensity was upgraded to T2.5 at 29/2100 UTC corresponding to 35 knots. At 31/0300 UTC, it indicated that the storm was over land.

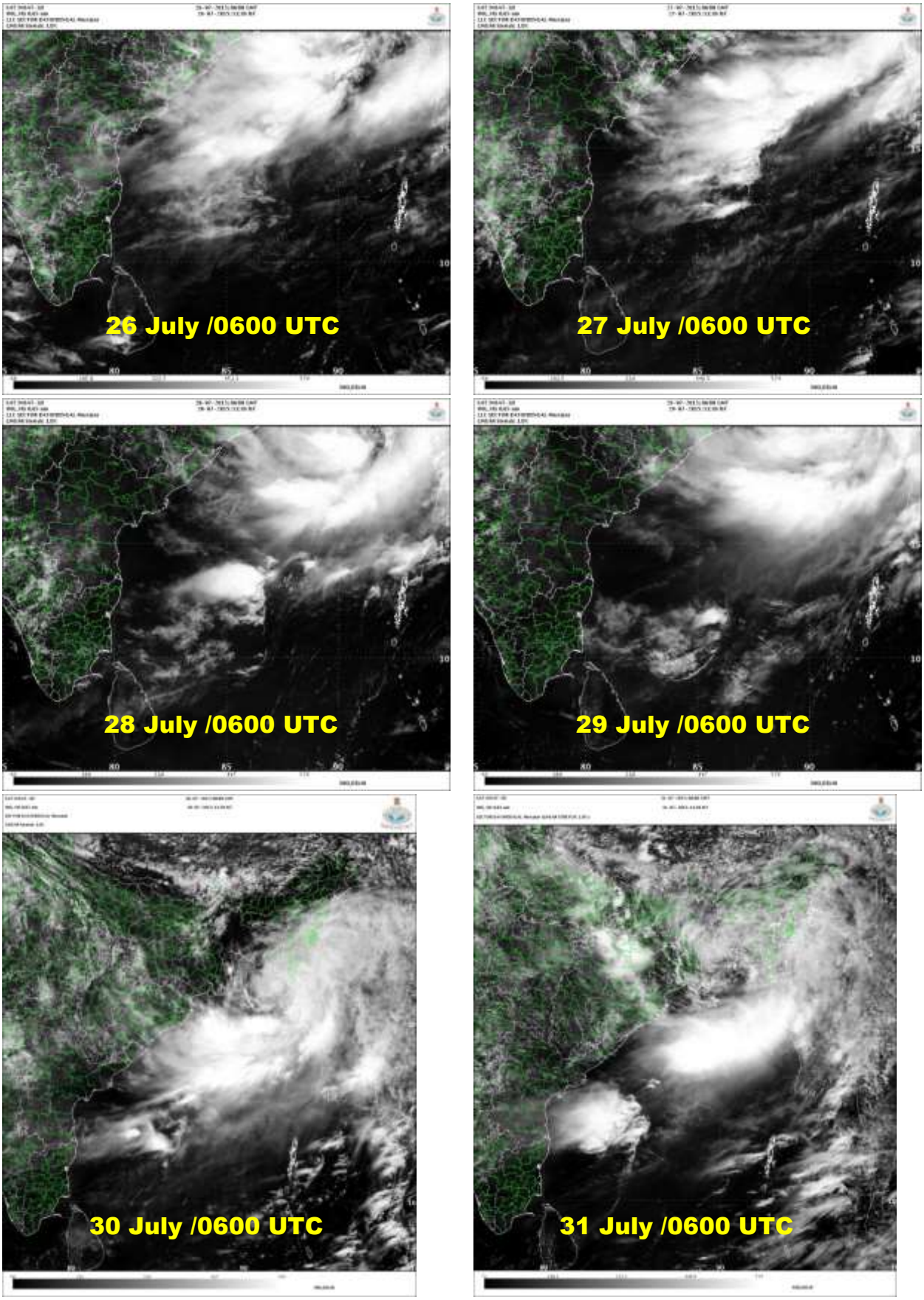


Fig. 3: INSAT-3D Visible imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

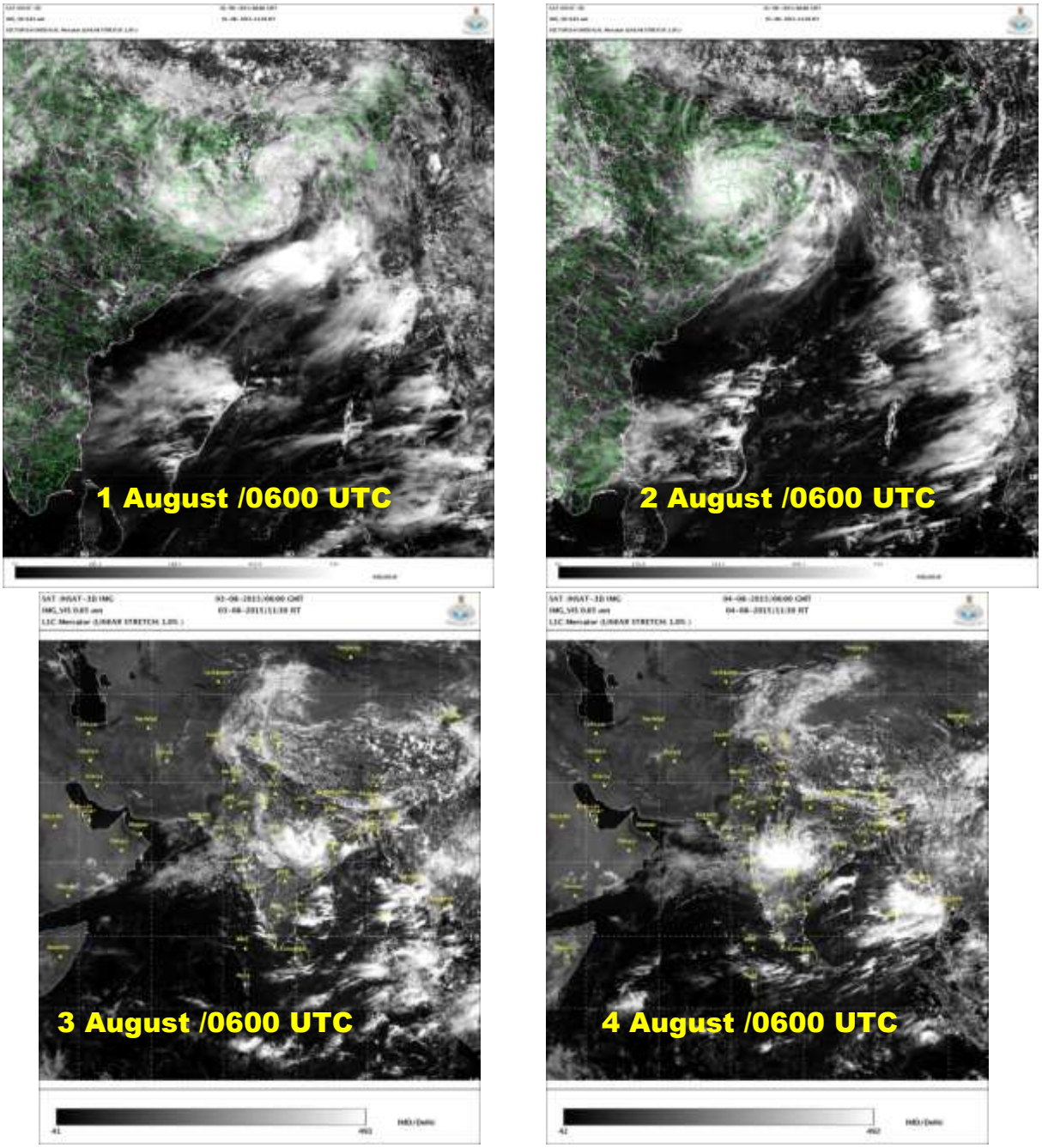


Fig. 3 contd.: INSAT-3D Visible imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

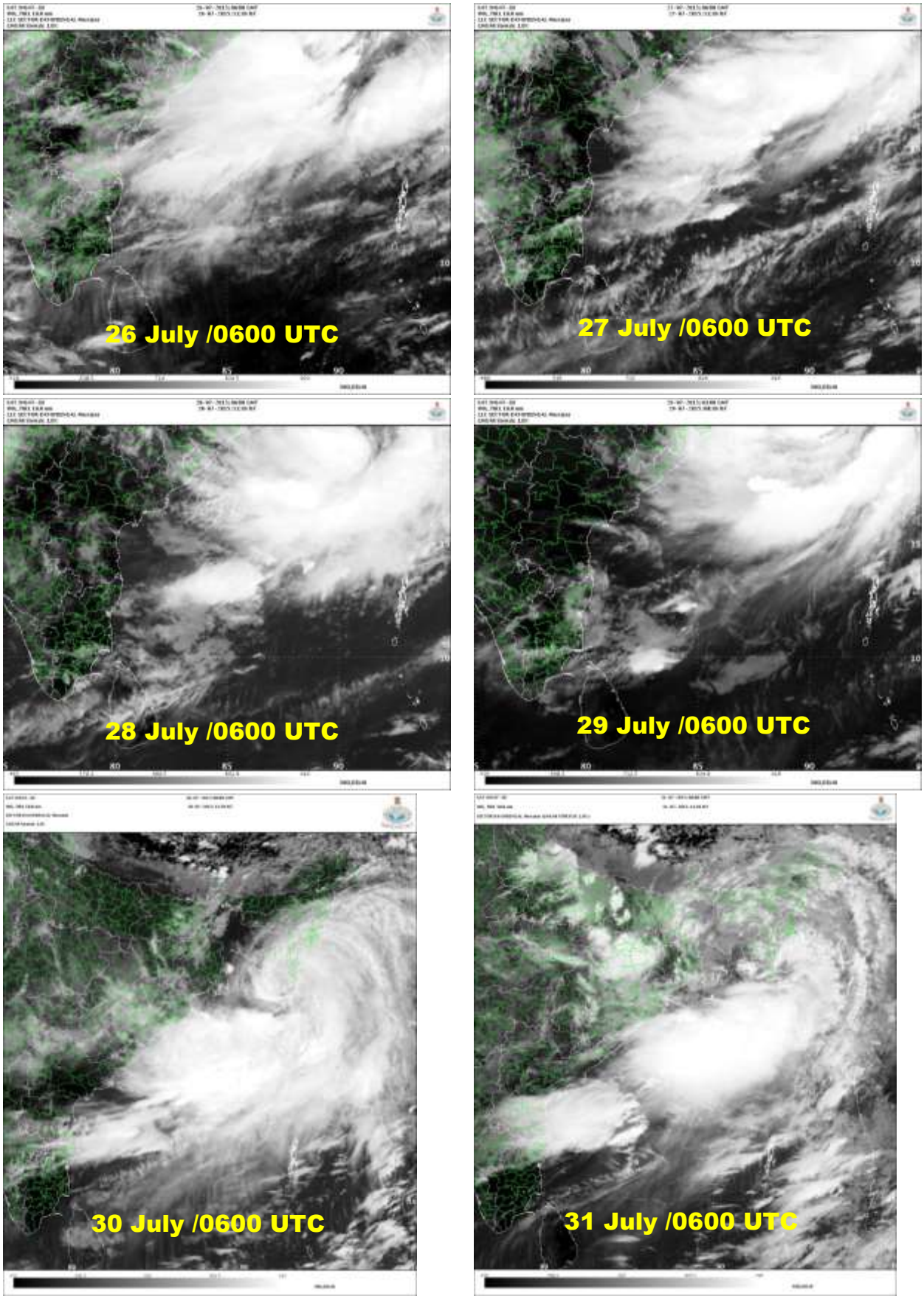


Fig. 4: INSAT-3D IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

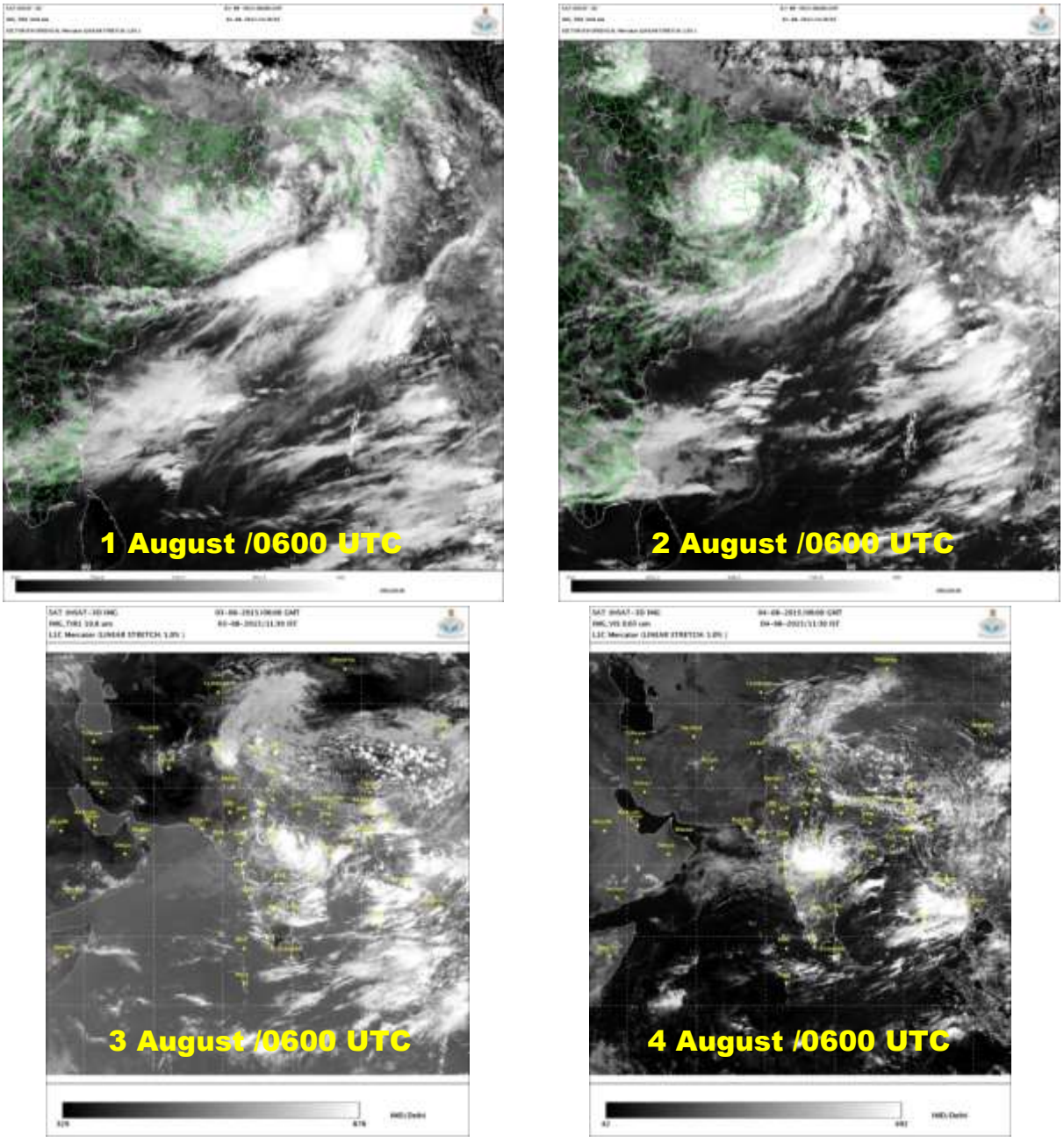


Fig. 4 contd.: INSAT-3D IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

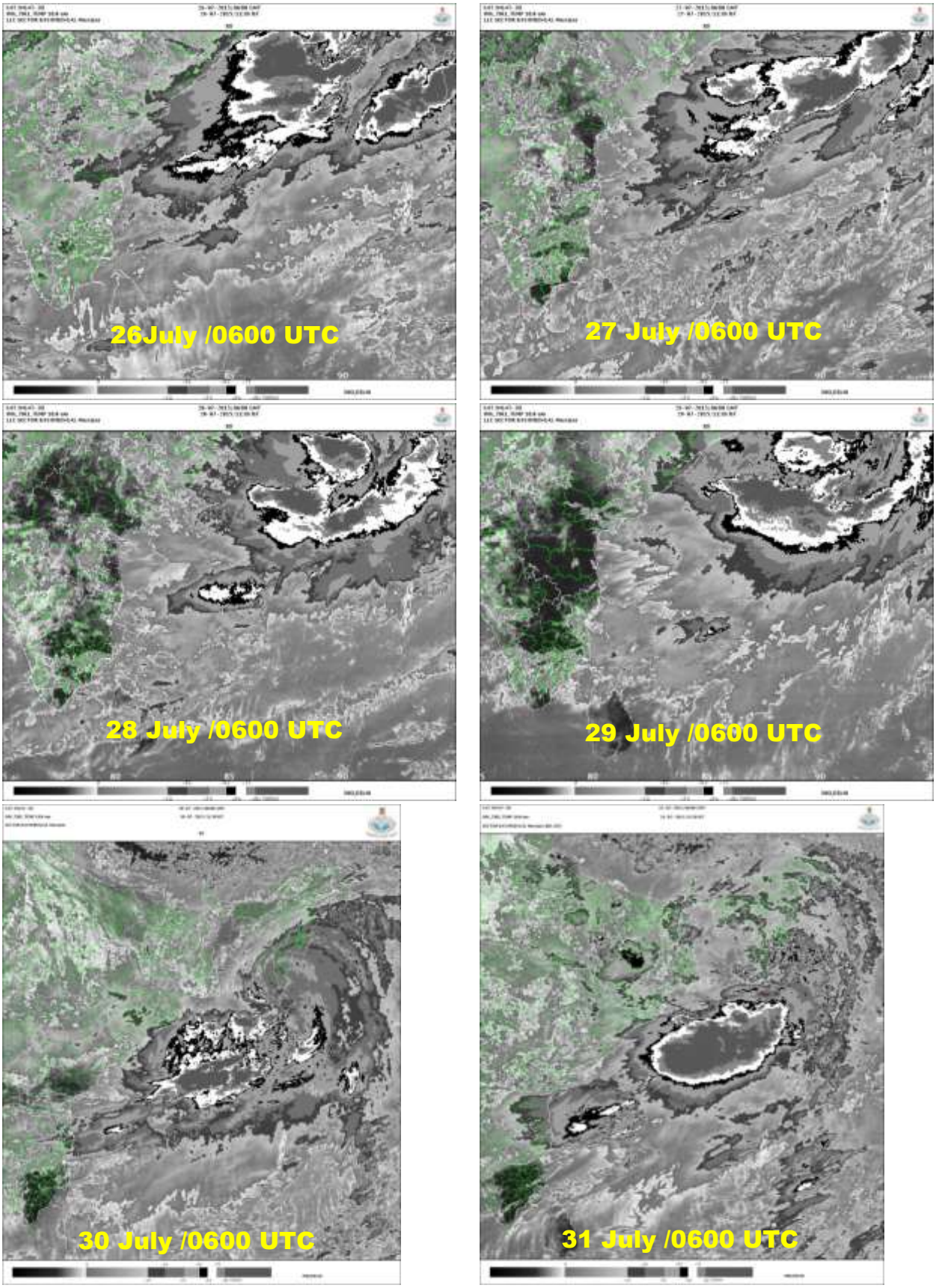
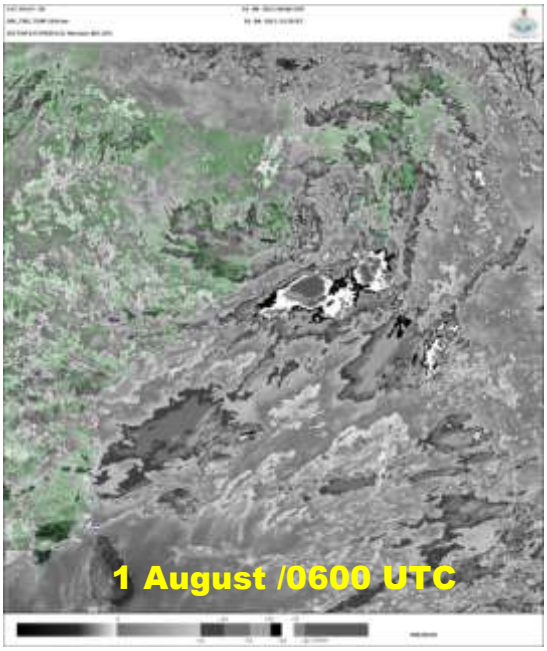
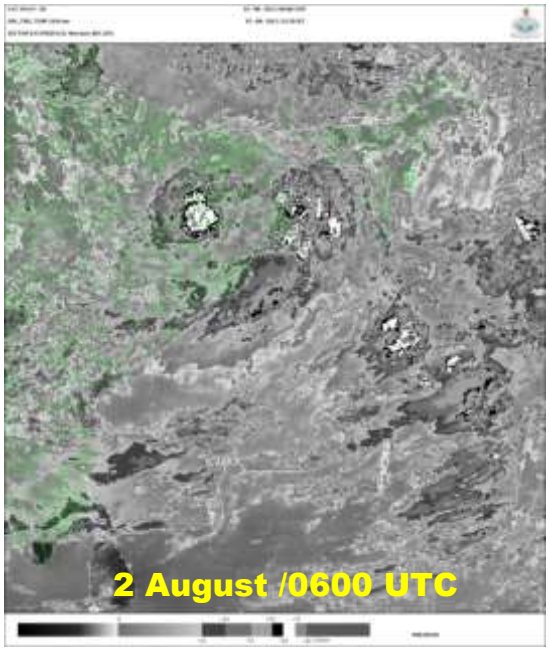
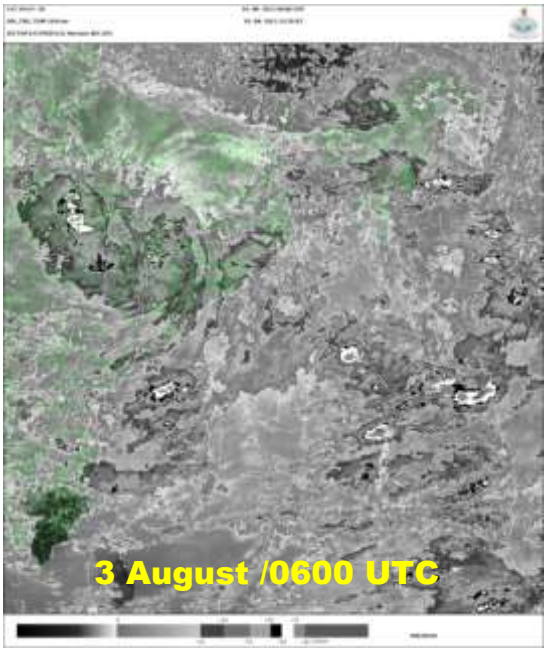


Fig. 5: INSAT-3D enhanced IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015







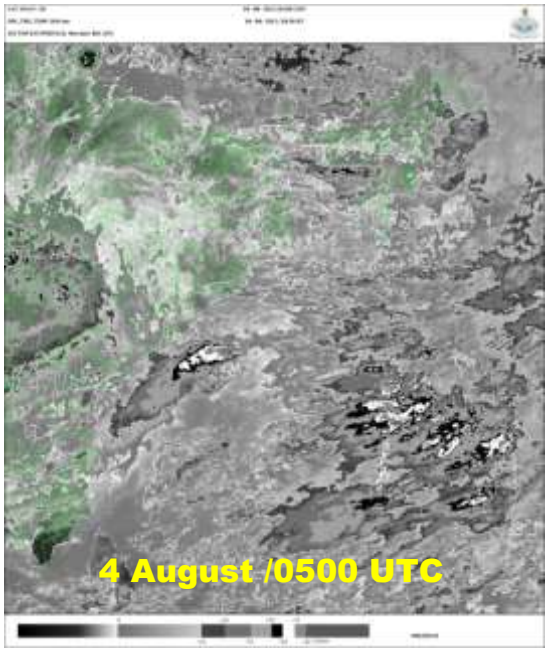


Fig.5 contd.: INSAT 3D enhanced IR imageries of CS Komen over Bay of Bengal during 26 July – 4 August 2015

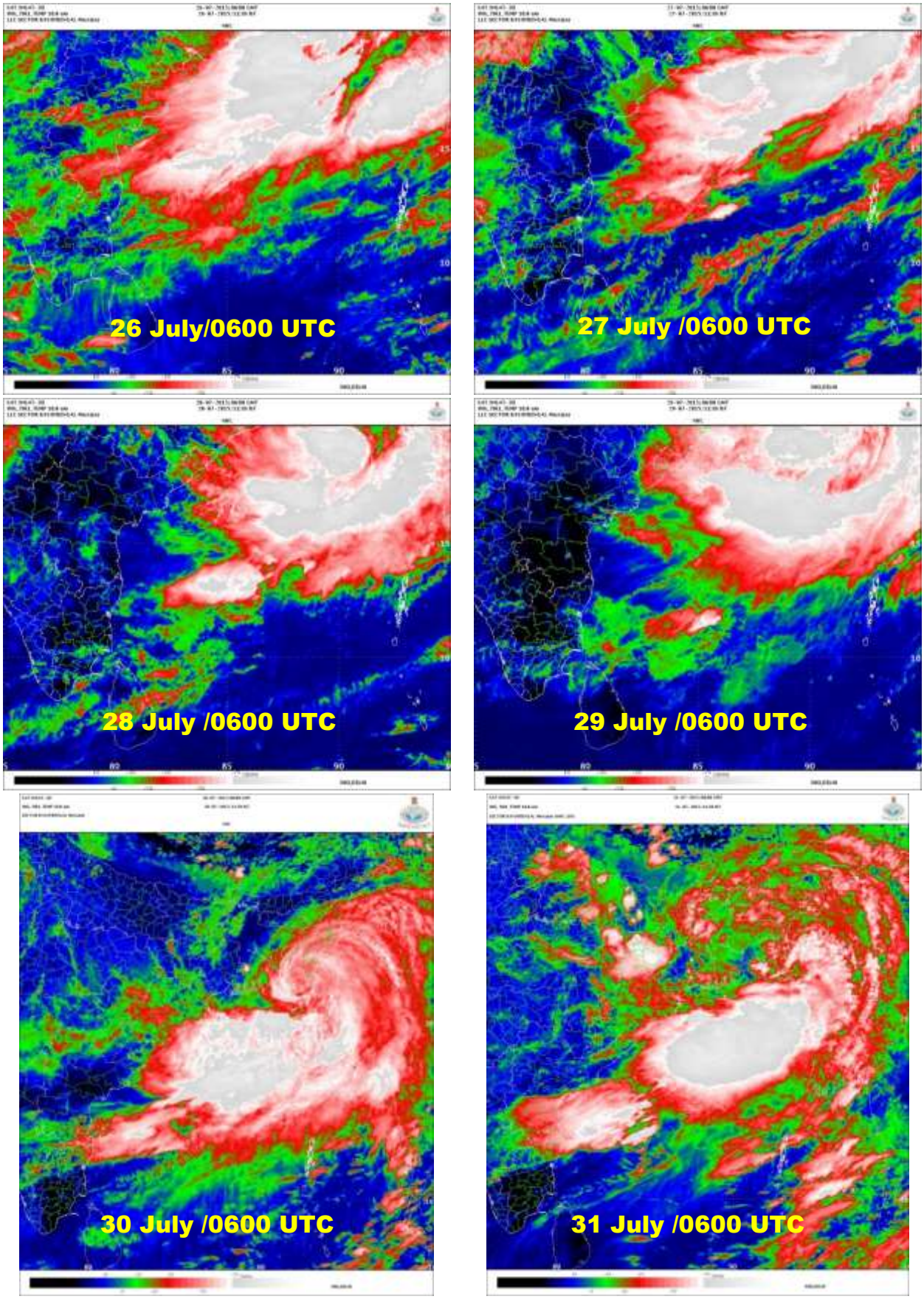


Fig. 6: Enhanced colour INSAT-3D imageries of CS Komen over Bay of Bengal during 26 July – 2 August 2015

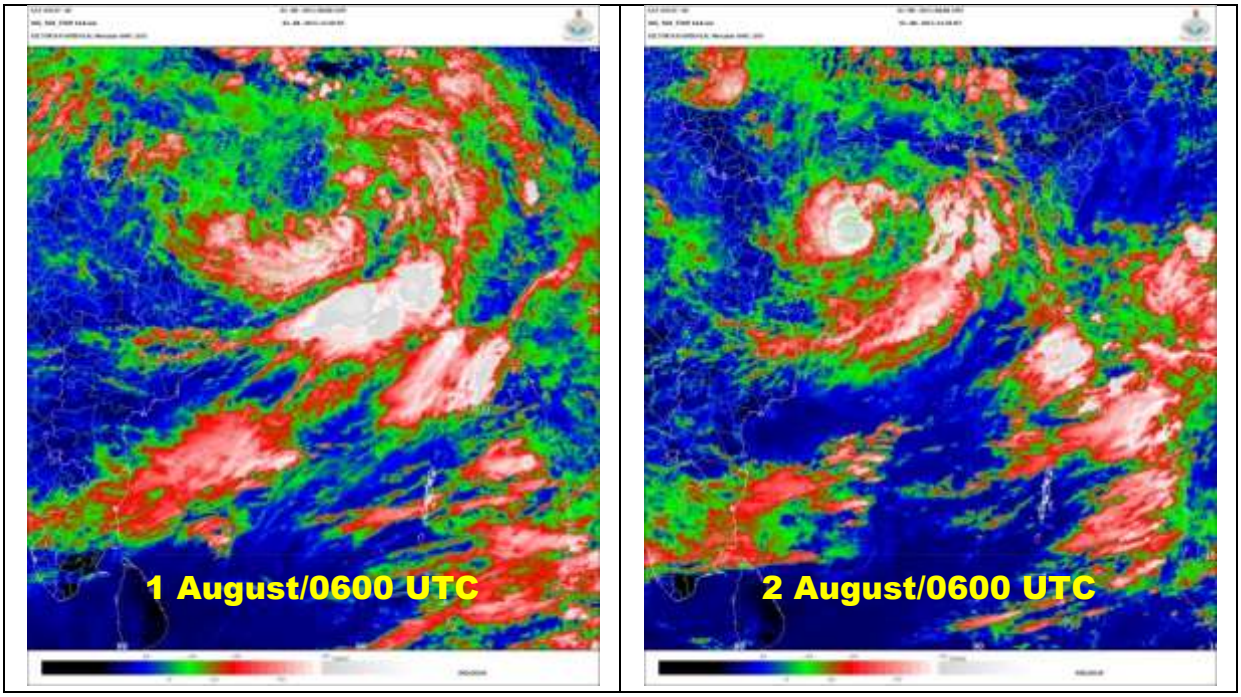
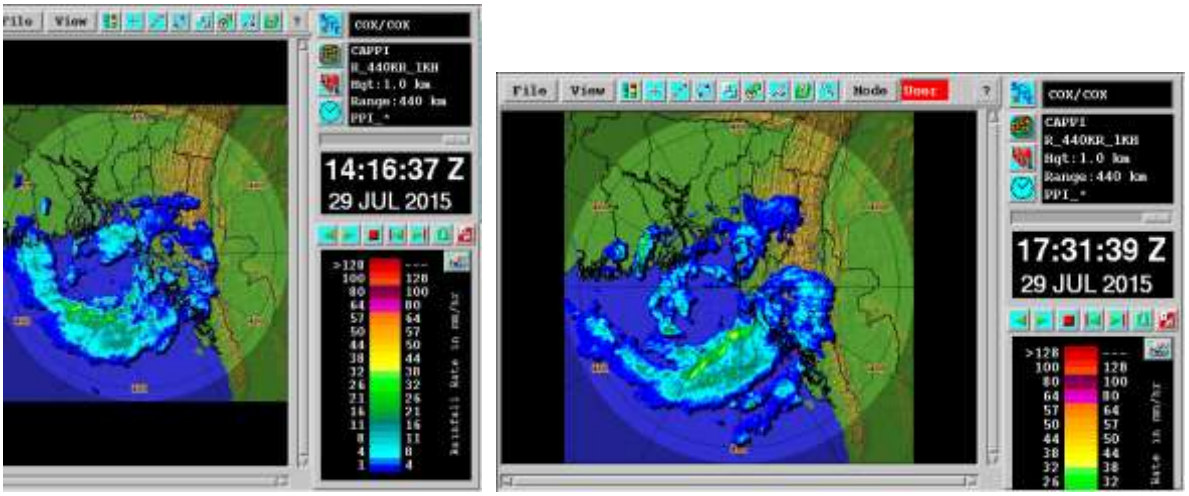


Fig. 6 contd.: Enhanced colour INSAT-3D imageries of CS Komen over Bay of Bengal during 26 July – 2 August 2015

6. Features observed through Radar

On 29th and 30th, when the system was well within the radar range of DWRs at Cox's Bazar and Khepupara (Bangladesh), it was tracked continuously by these radars. The system showed spiral band structure with an ill-defined eye. The DWR observations from Khepupara and Cox's Bazar indicated well defined circulation with strong banding feature in southern semi circle similar to the features observed through satellite. There was weak banding in the northern sector, as long as the CS over the Sea. When the system was over the sea, maximum convection was observed in the southeastern sector. However, as the system approached the coast and after coastal crossing, convection shifted to the southwestern sector. Fig.7 (a & b) shows the Constant Altitude Plan Position Indicator (CAPPI) imageries of (a) Cox's Bazar (at about 14 & 17 UTC of 29th and 10 and 12 UTC of 30th) and (b) Khepupara radars (at about 0530 and 15 UTC of 29th and 1130 UTC of 30th).



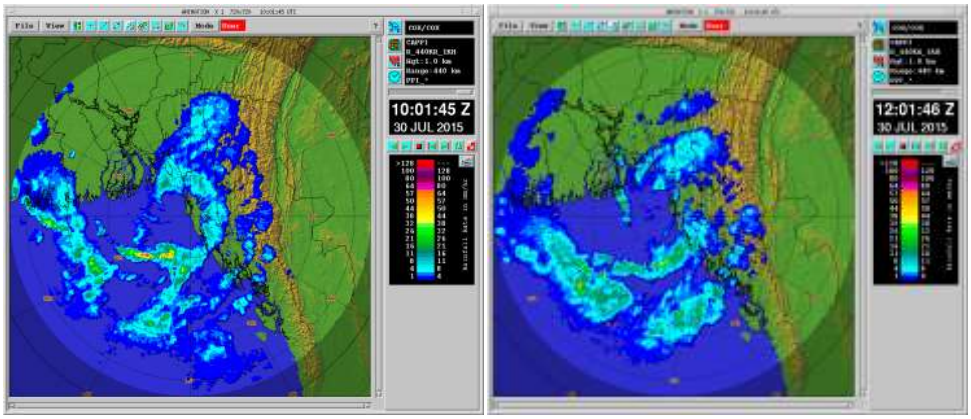


Fig.7(a) CAPPI imageries of Cox's Bazar (Bangladesh) at about 1416 & 1730 UTC of 29th and 1000 and 1200 UTC of 30th

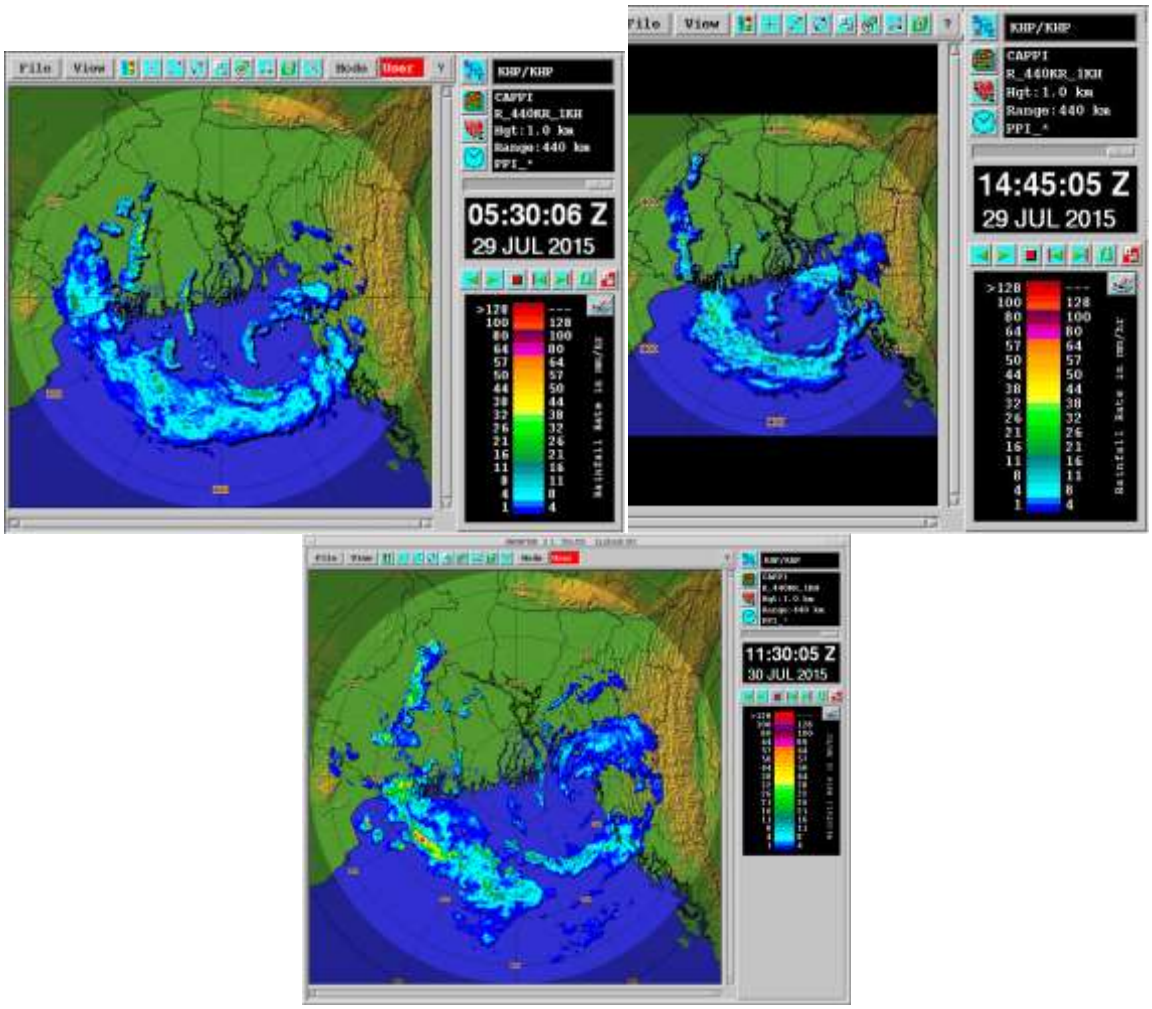


Fig. 7 (b) CAPPI imageries of Khepupara (Bangladesh) at about 0530 & 1445 UTC of 29th and 1130 UTC of 30th

7. Dynamical features

To analyse the dynamical features, the IMD-GFS model analyses based on the initial conditions of 0000 UTC of 27-31 July are shown in Fig.-8. It is observed that the model could very well simulate the genesis and intensification though there was under-

estimation of the intensity. Further it could simulate the track well and establish the interaction between the depression over Rajasthan and CS, Komen over the Bay of Bengal. It could simulate the gradual north-northwest movement and later the northeastward movement of the Depression over Rajasthan along with gradual initial intensification and weakening in the later stage during the period of 27-31 July 2015. During the same period, the opposite trend in intensification and movement of CS, Komen could also be simulated by the model. Further, the model could simulate the higher wind speed in the southern sector and relatively less wind in the northern sector of Komen, while it was over the sea. However, the unique track showing the semi-circular movement over the Bay of Bengal could not be simulated very well. Further, the model could not simulate the cyclonic circulation lying to the northeast of the system centre on 29th and 30th July, which helped in dry air incursion into the system and hence limited its further intensification. It also failed to simulate the anti-cyclonic circulation in middle and upper tropospheric level over Myanmar and Bangladesh which helped in steering the system northward on 30th July.

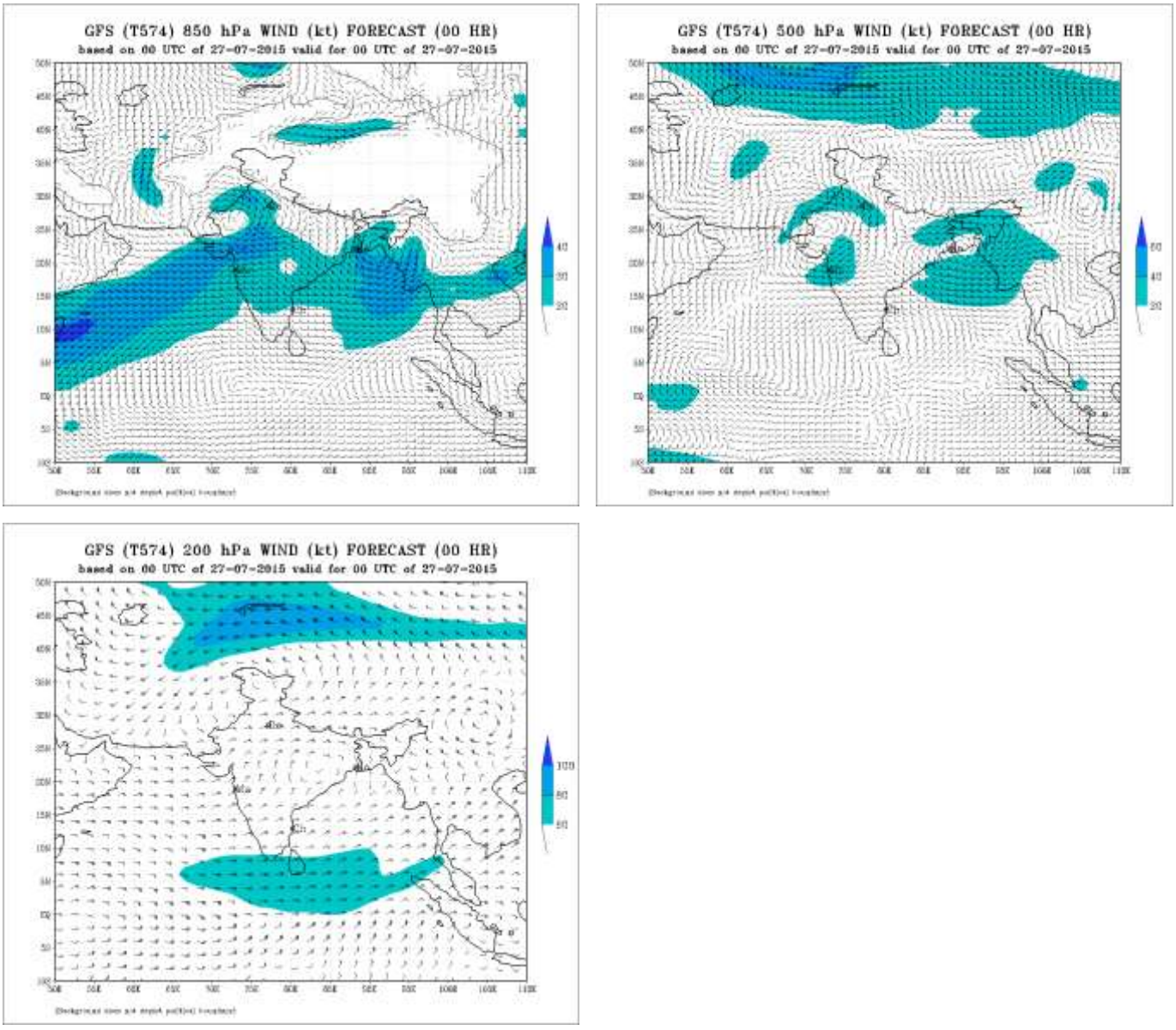


Fig 8 (i) : IMD-GFS analyses of winds at (a) 850 hPa ,(b) 500 hPa and (c) 200 hPa levels based on 0000 UTC of 27th July, 2015

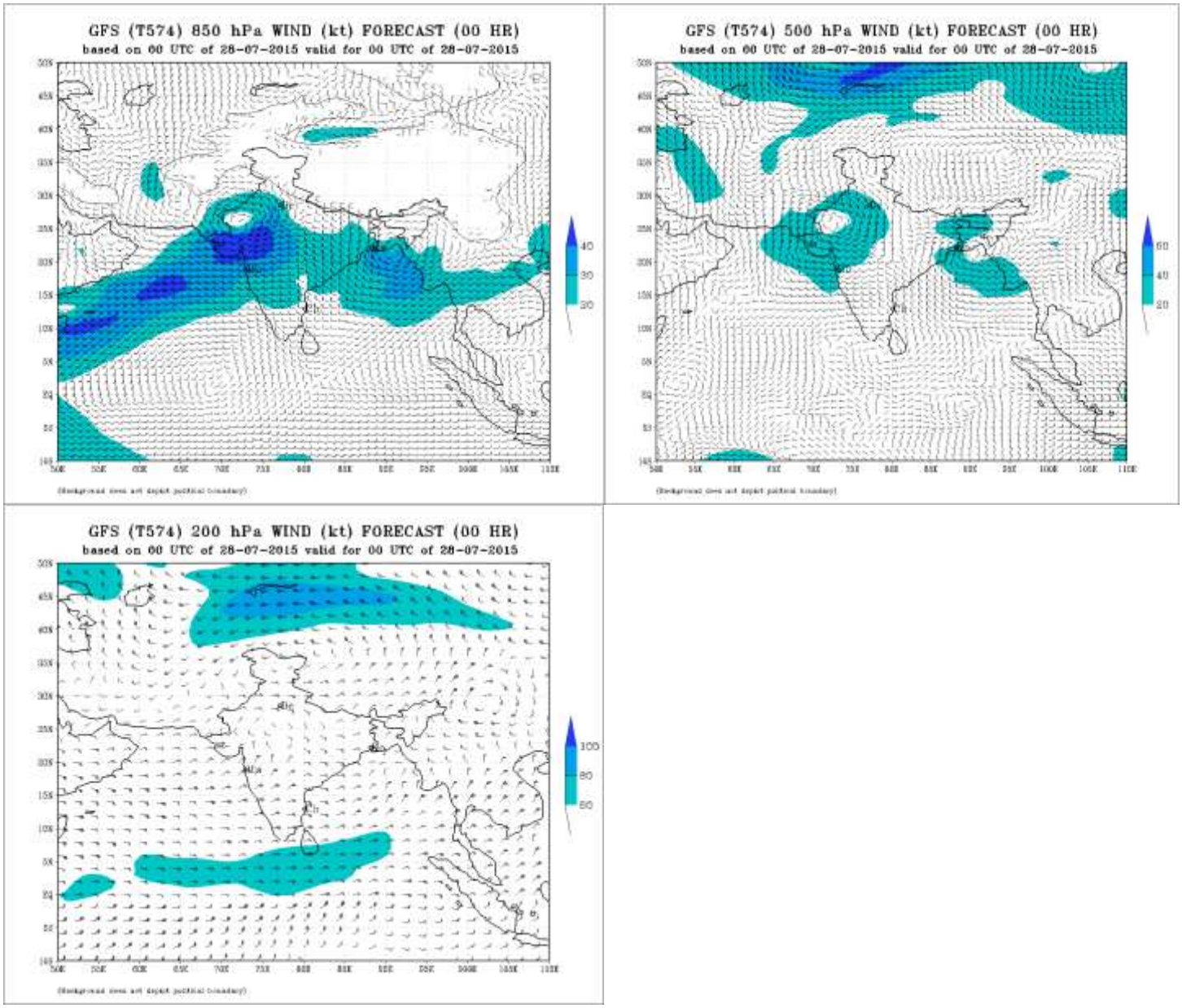


Fig 8 (ii) : IMD-GFS analyses of winds at (a) 850 hPa, (b) 500 hPa and (c) 200 hPa levels based on 0000 UTC of 28th July, 2015

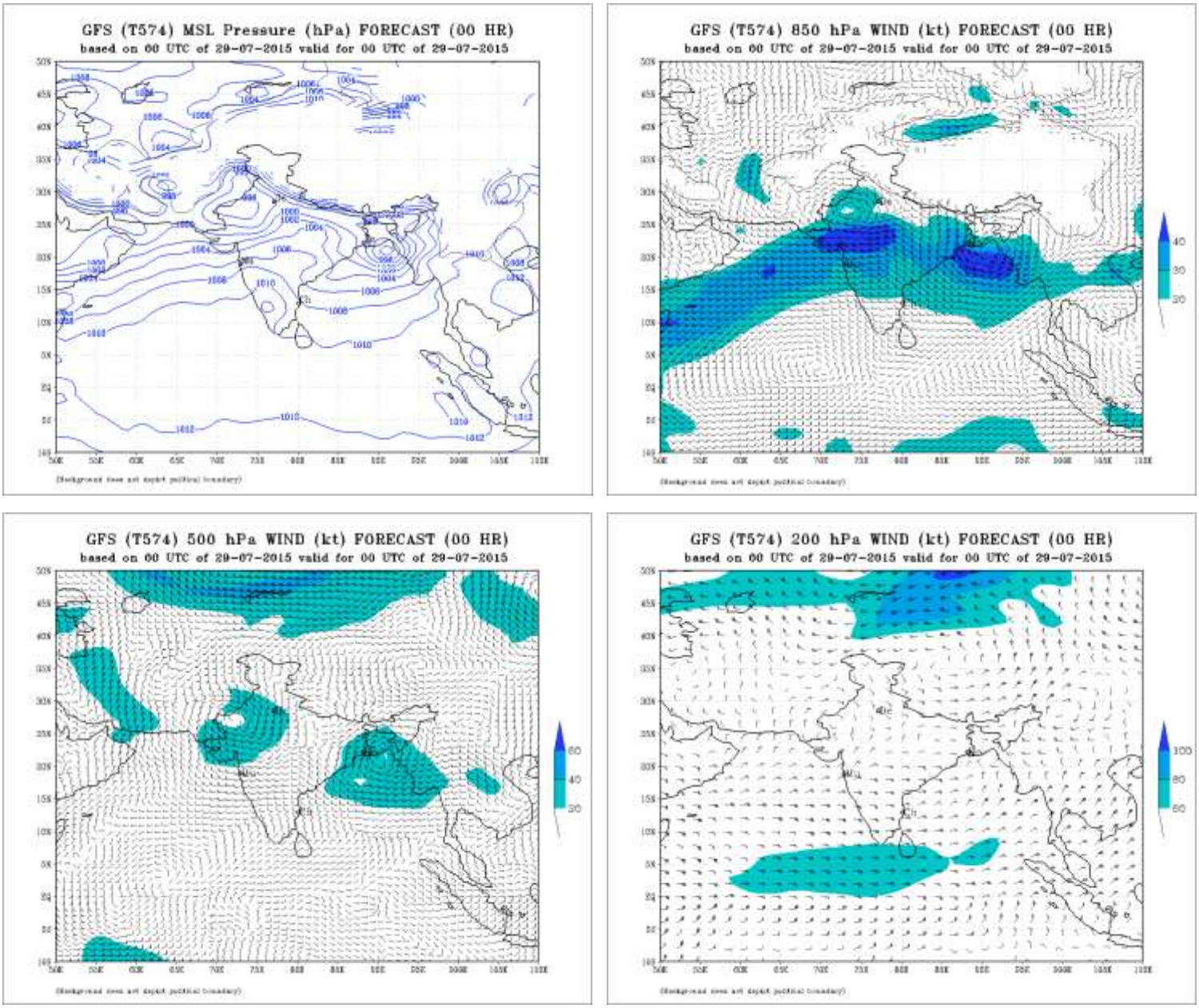


Fig 8 (iii) : IMD-GFS analyses of (a) MSLP and winds at (b) 850 hPa ,(c) 500 hPa & (d) 200 hPa levels based on 0000 UTC of 29th July, 2015

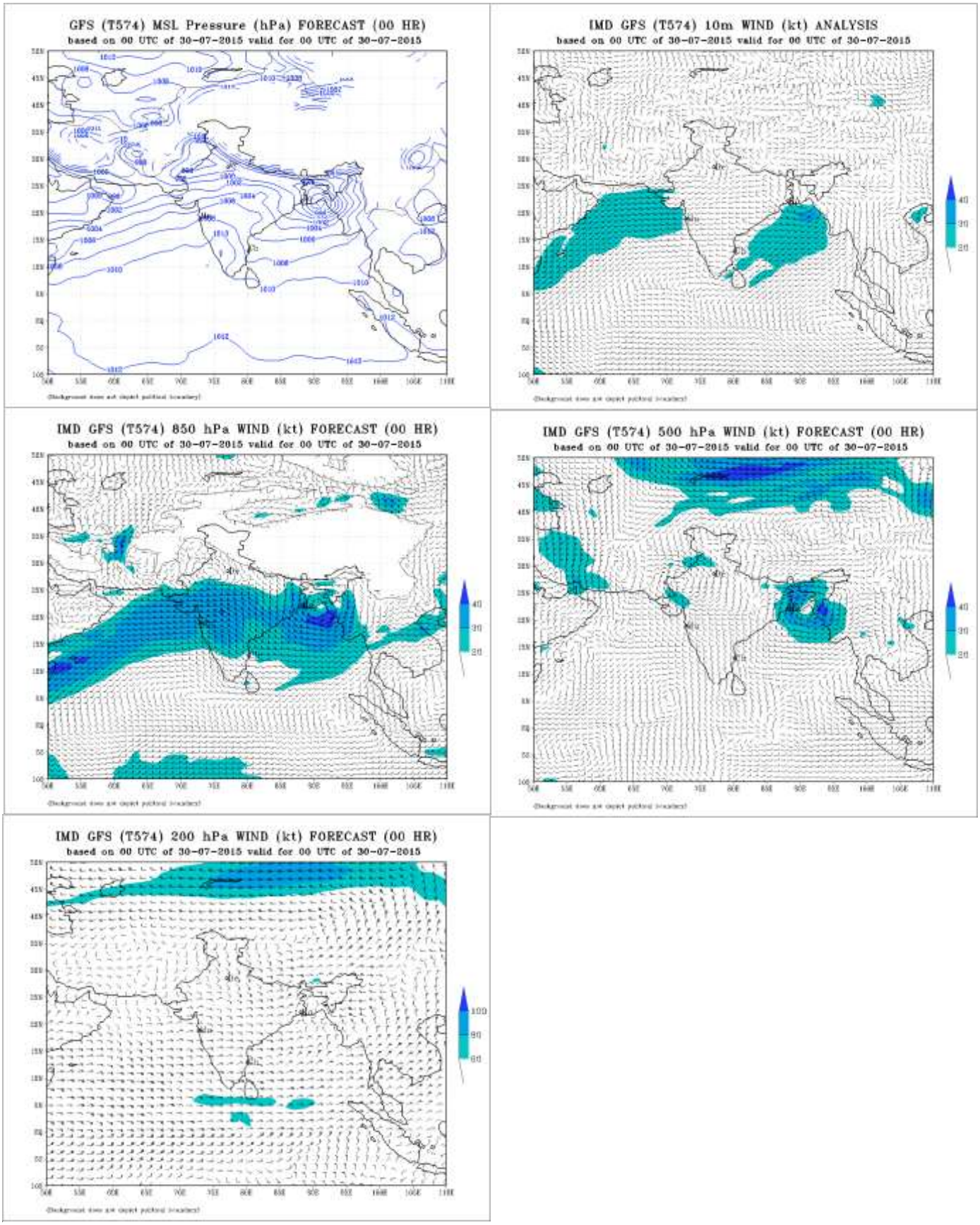


Fig 8 (iv) : IMD-GFS analysis of (a) MSLP, (b) 10m wind, winds at (c) 850 hPa,(d) 500 hPa & (e) 200 hPa levels and based on 0000 UTC of 30th July, 2015

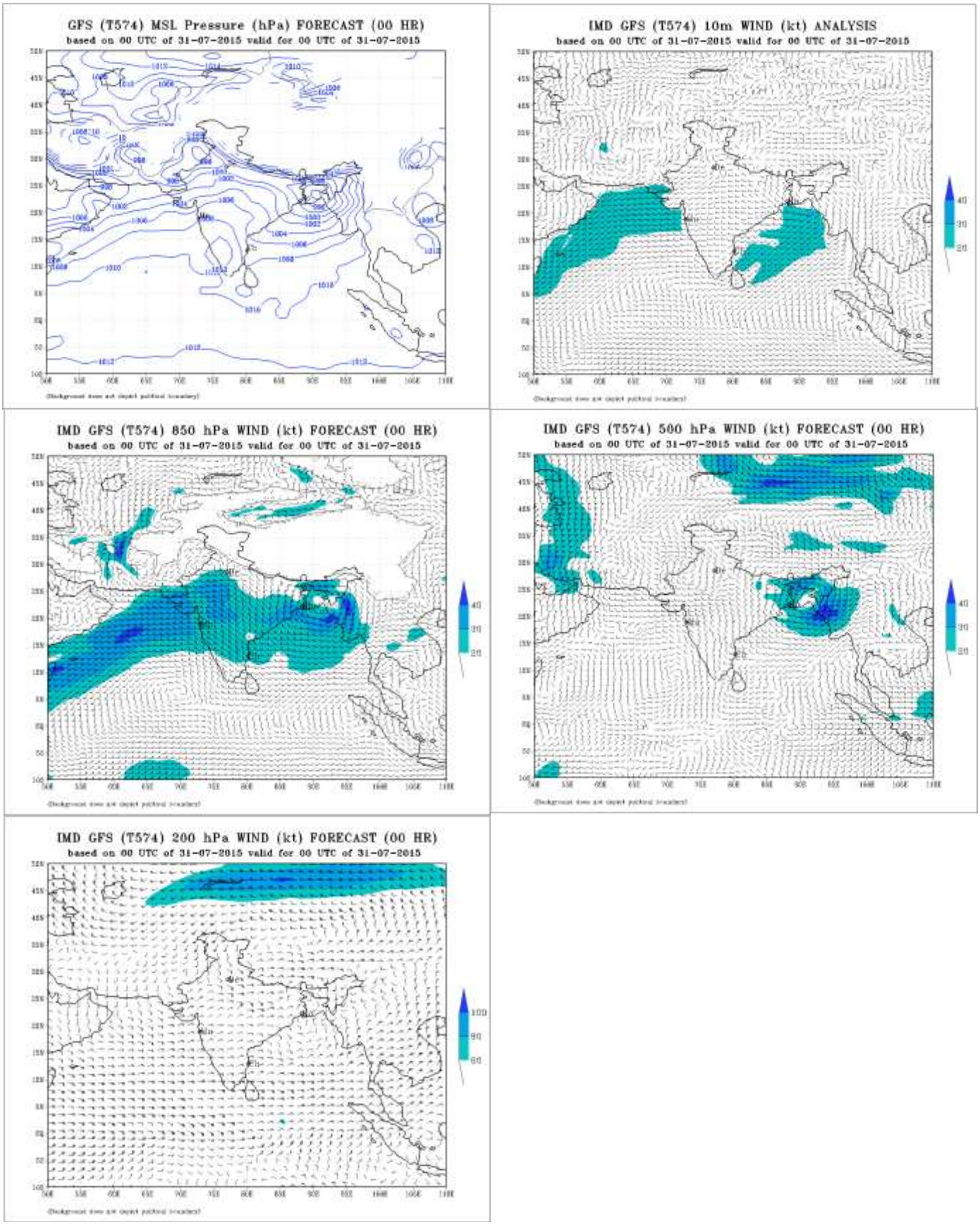


Fig 8 (v) : IMD-GFS analysis of (a) MSLP, (b) 10m wind, winds at (c) 850 hPa, (d) 500 hPa & (e) 200 hPa levels and based on 0000 UTC of 31st July, 2015

8. Realized Weather:

8.1 Heavy rainfall due to KOMEN:

The CS Komen caused heavy to very heavy rainfall in Myanmar during 26-31 July and heavy rainfall in Bangladesh during 28 - 30 July 2015.

The Cyclonic storm also caused *isolated heavy to very heavy rainfall* over Odisha, Gangetic West Bengal, Jharkhand, Nagaland, Manipur, Mizoram, Tripura, Assam, Meghalaya, Arunachal Pradesh, East Madhya Pradesh and Chhattisgarh. The chief amounts of past 24 hr rainfall realised (≥ 7 cm) ending at 0300 UTC of date during the period of CS KOMEN are furnished below:

(Description of rainfall terminologies: ***Heavy***: 64.5 to 124.4 mm; ***Very Heavy***: 124.5 to 244.4 mm and ***Extremely Heavy***: ≥244.5 mm) as well as spatial distribution [***Isolated (ISOL)***: (1-25% of stations reporting rainfall); ***Scattered (SCT / A few places)*** : 26-50% of stations reporting rainfall; ***Fairly Widespread (FWS/ Many places)***: 51-75% of stations reporting rainfall; ***Widespread (WS/ Most places)***: 76-100% of stations reporting rainfall during the last 24 hours ending at 0300 UTC of every day).

26th July, 2015: (Rainfall in centimeter)

India

Nagaland, Manipur, Mizoram & Tripura: Bungtlang (ARG)-11, Chhuarllung (ARG)-9

Gangetic West Bengal: Dhaniakhali ARG-10, Canning-9, Uluberia, Kansabati Dam & Harinkhola-8 each and Bagati-7.

Odisha: Mandira Dam-9, Khandapara-9, Kuchinda-8 and Danagadi ARG & Panposh-7 each.

Bihar: Dehri-10.

Myanmar

Ann 21, Maungdaw 19, Sittwe & Myauk U 18 each, Kyauktaw 17, Paletwa 15, Kyaukpyu 14, Thandwe & Mawlamyine 12 each, Taungkok, Khayan & Kyeikkhame 11 each, Thaton, Myaungmya & Ngathyinechang 9 each, Pinlaung 8, Mudon, Shwegyin, Hakha, Nyaung Lay Bin & Phyarpon 7 each.

27 July 2015

India

Nagaland, Manipur, Mizoram & Tripura: Sabroom-9 And Bungtlang (Arg)-7

Gangetic West Bengal: Bankura (CWC)-14, Kansabati Dam, Phulberia & Bankura-10 each and Kharidwar-9.

Odisha: Lahunipara-17, Jamankira-15, Deogarh-12, Banaigarh AWS & Keiri AWS-11 each , Tensa & Rengali-10 each, Naktideul, Reamal, Chendipada, Barkote & Chandanpur-9 each, Batagaon, Karanjia, Kujanga ARG & Kaniha ARG-8 each and Marsaghai ARG, Swam-Patna, Joda ARG, Ghatagaon, Chandbali, Pallahara & Rairakhol-7 each.

Jharkhand: Nimdih & Chandil-8 each and Jamshedpur-7.

Myanmar
Myauk U 30, Sittwe & Kyauktaw 20 each, Maungdaw & Khayan 18 each, Gwa 16, Thandwe 15, Paletwa 14, Hakha 13, Launglon & Taungkok 10 each, Kyeikkhame & Kyopinkauk 9, Hpa-An, Yay, Kyaukpyu, Belin, Kalay & Gangaw 8 each and Phyu 7.

28th July, 2015:

India
Gangetic West Bengal: Purihansa-24, Tusuma-13, Purulia-12, Simula-11, Kharidwar-9 and Phulberia-7.
Odisha: Tiring-23, Rairangpur-21, Balikuda ARG-19, Tirtol ARG-18, Dhamnagar ARG, Paradeep CWR, Binjharpur ARG & Salepur ARG-17 each, Kujanga ARG, Marsaghai ARG & Korei ARG-16 each, Kendrapara, Raghunathpur ARG, Garadapur ARG, Jagatsinghpur AWS, Swam-Patna, Banki ARG, Pattamundai, Jajpur & Jenapur-15 each, Joshipur & Karanjia-14 Each, Nawana, Derabis ARG, Bonth & Chandanpur-13 each, Bari ARG, Mahanga ARG, Danagadi ARG & Daitari-12 each , Bhuban ARG & Anandpur-11 each, Thakurmunda-10, Alipingal, Tihidi ARG, Hindol, Kantapada ARG & Ghatagaon-9 each, Mandira Dam, Betanati ARG, Sukinda & Kakatpur-8 each and Kaniha ARG, Rajkanika & Bangiriposi-7 each.
Jharkhand: Jamshedpur AERO-20, Ghatsila-10, Putki & Topchanchi-9 each, Nimdih & Nandadih-8 each and Dumka & Dumri-7 each.
Bihar: Sheikhpura-9

Myanmar
Sittwe 13, Phyu 12, Taungkok 11, Thieinzayet & Thaton 10 each, Hmawbi, Kyopinkauk, Zaungtu, Mudon & Khayan 9 each.

Bangladesh
Noakhali 12, Barisal 10, Teknaf, Chandpur 7.

29th July, 2015:

India
Gangetic West Bengal: Uluberia-21, Tamluk (AWS)-19, Contai-14, Dhaniakhali (ARG)-11, Harinkhola-10, Labpur-9, Narayanpur & Sri Niketan-8 each.
Odisha: Chandanpur-16, Rairangpur & Bhograi-13 each, Bangiriposi-12, Nawana-10, Jaleswar-7.
Jharkhand: Ghatsila-15, Dhanbad-10, Sarath-8, Dumka-7.

Myanmar
Thieinzayet 22, Kyeikkhame & Paletwa 16 each, Thandwe 13, Hmawbi & Phyarpon 11 each, Kabaaye & Loikaw 10 each, Taungkok, Sittwe & Hakha 9 each, Kyaukpyu 8

Bangladesh
Barguna 11, Barisal 10, Teknaf 9, Patuakhali 7.

30th July, 2015:

India
Gangetic West Bengal: Manteswar-20, Harinkhola-19, Salar-11, Amtala, Dhaniakhali ARG & Burdwan (PTO)-9 each, Murarai, Contai, Narayanpur & Mangalkote-8 each and Durgachack-7.

Myanmar
Kyeikkhame 24, Hmawbi 23, Phyu 19, Paletwa, Thieinzayet 17, Kabaaye 15, Loikaw, Pinlaung 14, Phyarpon, Mindat 13, Kyopinkauk 12, Thandwe, Manaung, Myauk U 9, Taunggu(Aviation Met.), Thaton, Shwegyin 8 each, Mingalardon and Mudon 7 each.

Bangladesh
Teknaf 12, Khulna 11, Satkhira 8.

31st July, 2015:

India
Nagaland, Manipur, Mizoram & Tripura: Chhuarllung (ARG)-14, Bungtlang (ARG)-13.
Gangetic West Bengal: Digha & Hetampur-8 each.
Odisha: Bhograi-8.
Jharkhand: Maheshpur-17, Dumka & Jarmindi-15 each, Moharo & Sarath-9 each and Giridih, Topchanchi, Jamtara & Messenjore-7each.

Myanmar
Bago 23, Paletwa 22, Thieinzayet 21, Mindat 20, Kyeikkhame 18, Kabaaye 17, Loikaw 16, Khayan 14, Kyopinkauk, Myauk U, Manaung 11, Mudon 10, Katha 9, Launglon, Myaungmya, Heho 8.

01st August, 2015:

India
Assam & Meghalaya: Cherrapunji (RKM)-15, Cherrapunji-9 and Shillong C.S.O. & Shillong (AWS)-7 each.
Nagaland, Manipur, Mizoram & Tripura: Thoubal (AWS) & Imphal T AERO-9 each.
Gangetic West Bengal: Contai-16, Basirhat (PT)-15, Kolkata (Alipore) & Kolkata (Dum Dum)-13 each, Barrackpur (LAF) & Mohanpur-10 each, Burdwan (PTO), Midnapore (CWC), Midnapore & Canning-9 each, Durgapur & Phulberia-8 each and Hetampur, Dhaniakhali (ARG), Asansol (CWC), Kalyani SMO, Suri (CWC), Tusuma, Panagarh (LAF), Tilpara Barrage, Mangalkote, Mankar & Bankura (CWC)-7 each.

Jharkhand: Dumri-13, Hazaribagh-9, Panki, Kuru & Messenjore-8 each, Daltonganj & Sarath-7 each.
Bihar: Buxar-11, Indrapuri-10, Daudnagar-9, Jalalpur & Bodh Gaya-8 each, Hathwa & Dehri-7 each.

02nd August, 2015:

India
Gangetic West Bengal: Mangalkote-11, Narayanpur & Burdwan (PTO)-9 each, Mankar-8 and Sri Niketan, Murarai, Harinkhola & Bankura (CWC)-7 each.
Odisha: Khairamal-10, Jujumura ARG-8, Kantapada ARG-7.
Jharkhand: Deoghar, Putki and Koner-11 each, Ramgarh, Barkisuriya & Barhi-10 each, Mandar-9, Rajdhanwar, Jarmindi, Pathalgada, Dhanbad, Hindgir & Tenughat-8 each and Lohar-Daga, Moharo, Chatra, Bokaro, Giridih, Papunki, Hazaribagh, Jamtara, Sarath and Jaridih-7 each.
Bihar: Rajauli-8, Nawada -7.

03rd August, 2015:

India
Arunachal Pradesh: Wakra (ARG)-11, Tezu-9, Passighat-7
Odisha: Bargaon-23, Jharsuguda, Rajgangpur& Lakhanpur ARG-19 each, Deogaon, Mandira Dam & Sundargarh-17 each, Kirmira ARG & Ambabhona-16 Each, Laikera-14, Hemgiri-13, Panposh-12, Kolabira ARG-9, Atabira ARG & Balisankara ARG-8 each and Bonth-7.
Jharkhand: Raidih-14, Kurdege-12, Bagodar I-11, Kuru, Hazaribagh & Simdega-10 Each, Daltonganj-8 and Palkot, Lohar-Daga, Torpa & Latehar-7 each.
East Madhya Pradesh: Mandla-AWS-13, Nagode-7.
Chhattisgarh: Raigarh-22, Gharghoda-10, Saraipali-7.

04th August, 2015:

India
East Madhya Pradesh: Amarwara & Balaghat-AWS-15 each, Narsinghpur-AWS-13, Seoni-AWS, Gotegaon & Chindwara-AWS-12 Each, Keolari & Katangi-11 each, Lakhnadon-10, Jabalpur-New—AWS, Gadarwara & Kareli-9 each, Malanjkhand & Deori-8 each and Dindori-AWS-7.
Chhattisgarh: Bemetara-12, Korba-10, Katghora-9, Pali-8, Raigarh-7

(AWS: Automatic Weather Station; ARG: Automatic Raingauge Station; CWC: Central Water Commission; IAF: Indian Air Force)

Rainfall associated with the cyclone when it was out in the sea is also determined based on satellite-gauge merged rainfall dataset generated by IMD and NCMRWF

(Mitra et al, 2009) for the North Indian Ocean region from 2013 onwards using the TRMM data. 24-hour accumulated rainfall associated with the CS KOMEN during the period 26 July-04 August as well as the 7-day average rainfall during the same period is furnished in the Fig. 9.

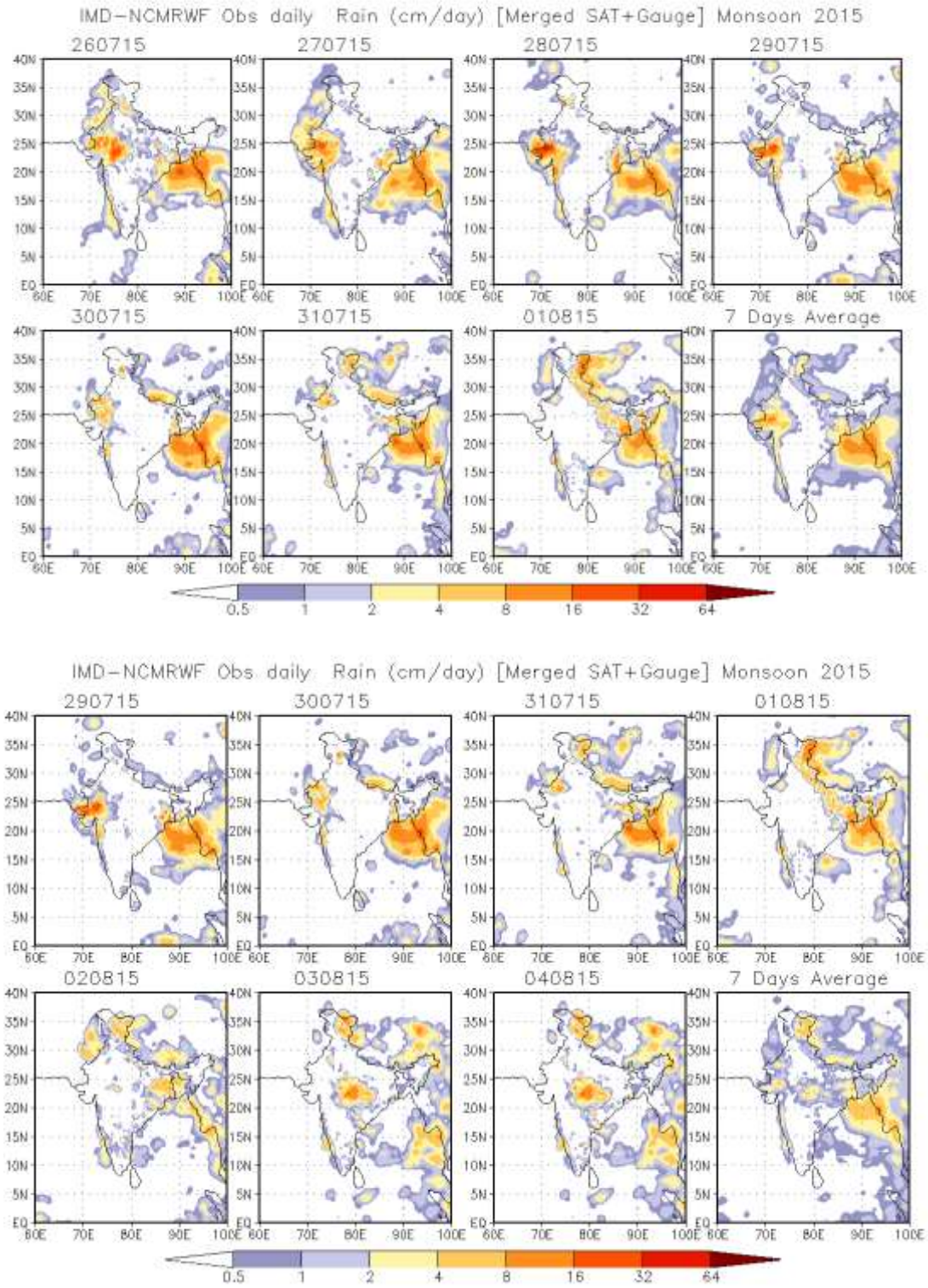


Fig. 9: IMD-NCMRWF (TRMM based) daily merged rainfall (a) during 26 July to 01 Aug & (b) 29 July to 04 Aug 2015 and 07-day average rain during the above periods.

From the figures it is observed that the maximum rainfall occured in the southeastern sector of the system centre when the system was in the sea i.e. during the period 26-30 July. After landfall, the maximum rainfall belt gradually shifted to southwest sector. This shift in the maximum rainfall regime is associated with gradual recurvature of the TC from northward movement over the sea to northwestward and west-northwestward movement after landfall. This spatial pattern of rainfall distribution was in expected lines as it has occurred in a similar fashion in earlier cases also.

8.2 Gale Wind

Maximum gale wind of 100 kmph prevailed over Teknaf (Bangladesh) on 29th July night when the CS was lying over northeast BoB close to southeastern coast of Bangladesh. However, the wind speed at the time of landfall was about 60-70 kmph along Bangladesh coast.

8.3 Storm Surge

RSMC New Delhi predicted that tidal wave (storm surge + astronomical tide) of about 2 meters would inundate low lying areas of Bangladesh coast around the time of landfall as the coastal inundation model of Bangladesh did not predict any significant storm surge and the tidal wave was expected to be about 2 meters.

9. Damage due to Cyclone 'KOMEN'

Damage in West Bengal

The details of the damages in West Bengal due to KOMEN are given below in Table 2.

Table -2 Damages associated with CS KOMEN

S No.	Specification	
1	Districts Affected	12
2	Block Affected (Nos.)	233
3	Municipality	53
4	Corporation	2
5	Gram Panchayat	781
6	Village Affected(Nos.)	16,309
7	People affected	61,29,965
8	Loss of human Loss	83
9	Loss of livestock	10,088
10.	Housing	
11	Number of Affected houses (no.)	41269
	(i) completely damaged	1,07,808
	(ii) partially damaged	3,68,238

Damage in Odisha

No damage was reported in Odisha.

Damage in Bangladesh

According to press and media reports, rain/floods and lightning claimed 6 lives in Bangladesh and about 88900 houses were damaged partially.

Damage in Myanmar

According to press and media reports, 2 persons died and 2 were injured. 86 houses and 4 primary schools were damaged.

9. NWP model forecast performance

IMD operationally runs a regional models, WRF for short-range prediction and one Global model T574L64 for medium range prediction (7 days). The WRF-Var model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^{o} S to 45^{o} N long 40^{o} E to 120^{o} E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 23 km. The boundary conditions are updated at every six hours interval. The QLM model (resolution 40 km) is used for cyclone track prediction in case of cyclone situation in the north Indian Ocean. IMD also makes use of NWP products prepared by some other operational NWP Centres like, ECMWF (European Centre for Medium Range Weather Forecasting), GFS (NCEP), JMA (Japan Meteorological Agency). Hurricane WRF (HWRF) model and Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones.

In addition to the above NWP models, IMD also run operationally dynamical statistical models. The dynamical statistical models have been developed for (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and I Predicting decaying intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, GFS (NCEP), ECMWF and JMA. The SCIP model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). Decay model is used for prediction of intensity after landfall. In this report performance of the individual models, MME forecasts, SCIP, GPP, RII and Decay model for cyclones during 2013 are presented and discussed.

Global models are also run at NCMRWF. These include GFS and unified model adapted from UK Meteorological Office. Apart from the observations that are used in the earlier system, the new observations assimilated at NCMRWF include (i) Precipitation rates from SSM/I and TRMM (ii) GPSRO occultation (iii) AIRS and AMSRE radiances (iv) MODIS winds. Additionally ASCAT ocean surface winds and INSAT-3D AMVs are

also assimilated.

NCUM (N512/L70) model features a horizontal resolution of 25km and 70 vertical levels. It uses 4D-Var assimilation and features no cyclone initialization/relocation. At NCMRWF the Global Ensemble Forecast System (NGEFS) provides analysis and forecast run out to 10 days based on 20 perturbed forecasts. Additionally verification and intercomparison is also provided for the forecast tracks from the Met Office UK (UKMO) and the Australian Bureau of Meteorology model ACCESS-TC. The model forecast integration are carried out at respective centers and the only forecast output is analyzed for verification and inter comparison. The results of these models guidance are presented and discussed below.

9.1 Genesis

The IMD GFS based genesis potential parameter could predict genesis well in advance as seen in the forecast charts based on initial contition of 1200 UTC of 24-291200 UTC (Fig. 10)

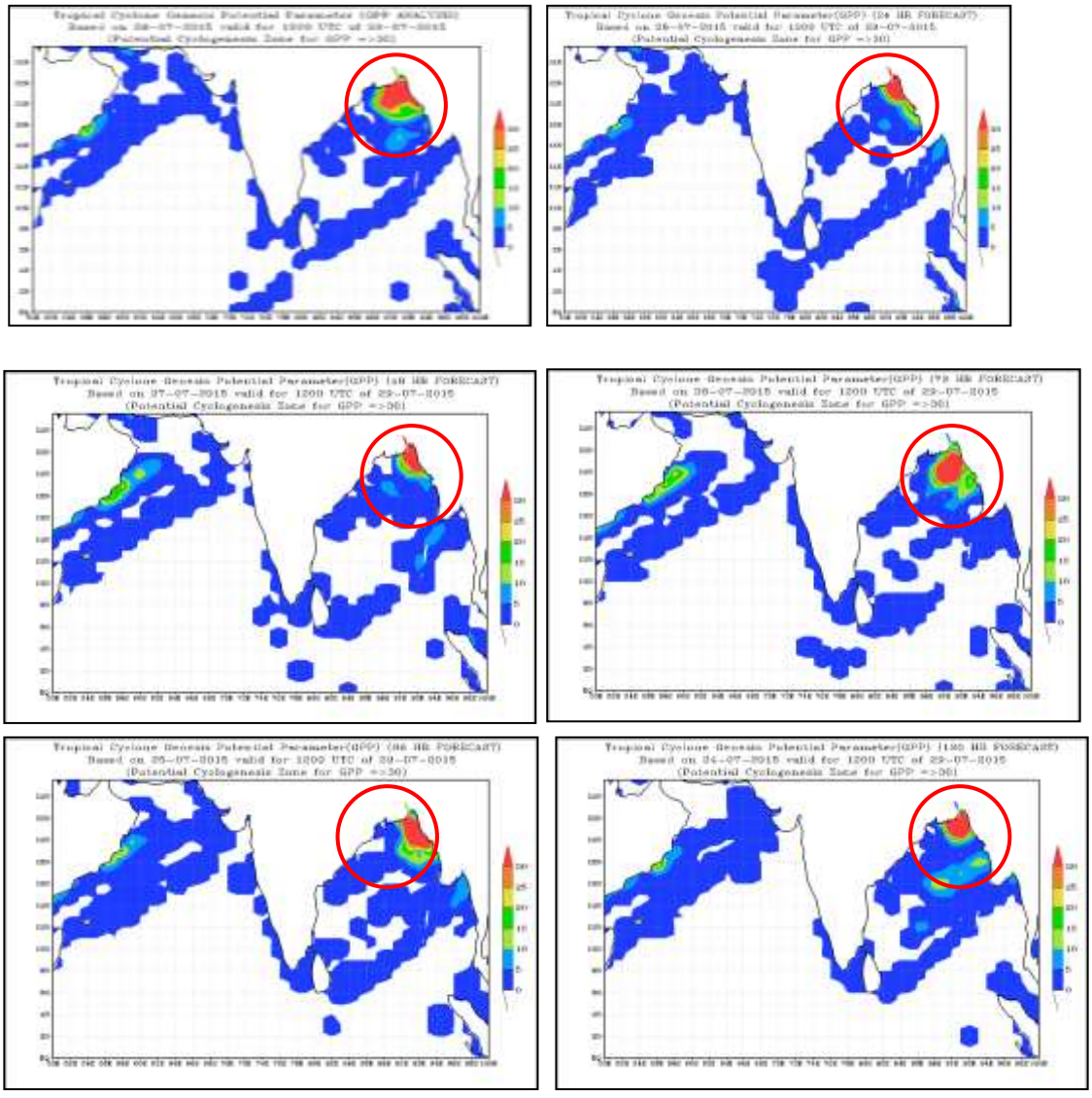


Figure 10(a-f): Predicted zone of cyclogenesis based on initial contition of 1200 UTC of 24-291200 UTC

9.2 Track forecast by NWP models

The forecast tracks of various individual deterministic NWP models, MME and EPS are shoen in Fig. 11-14.

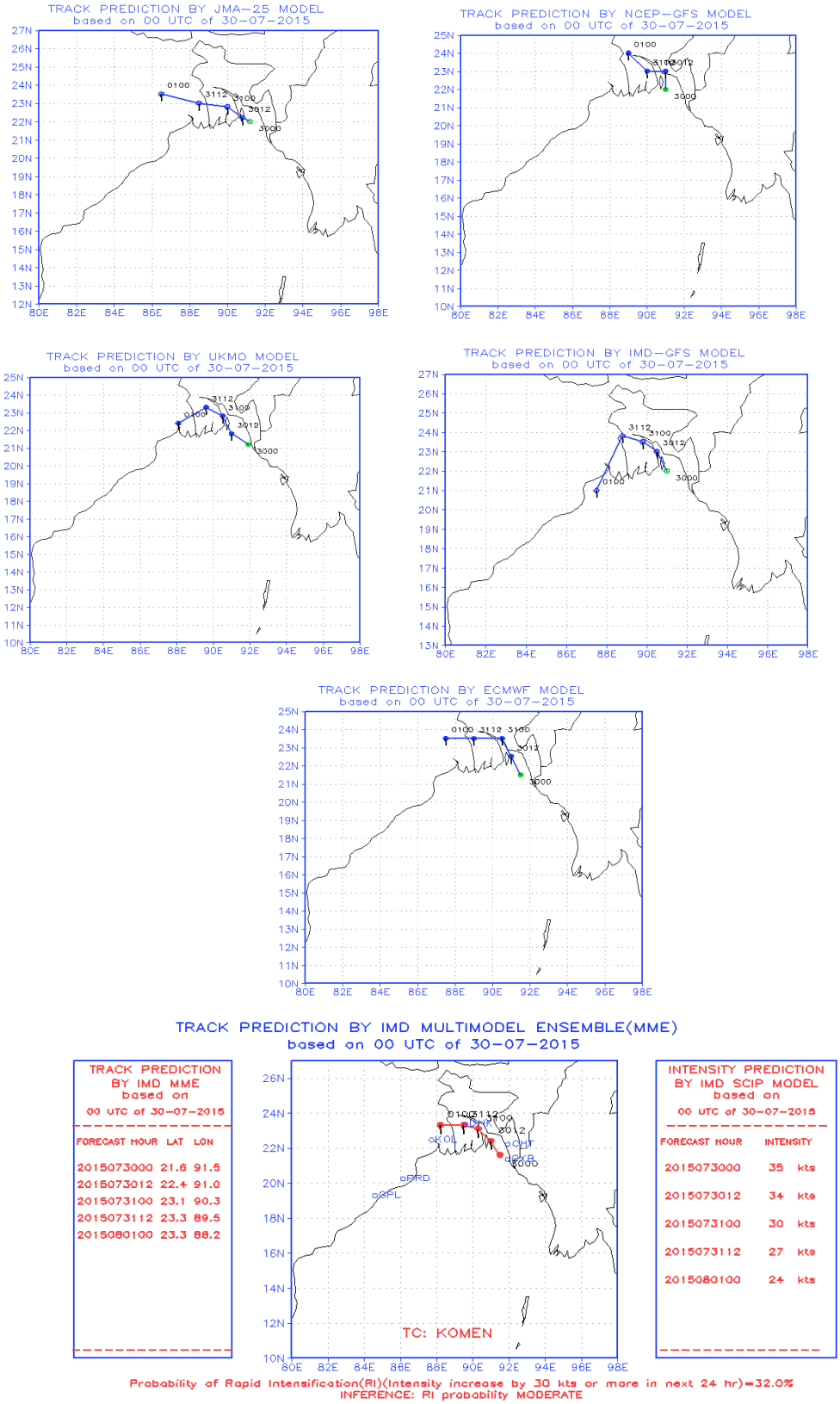


Fig.11. Forecast tracks from NGFS, NCUM, JMA, IMD-GFS and MME for CS Komen based on 00 UTC of 30th July 2015

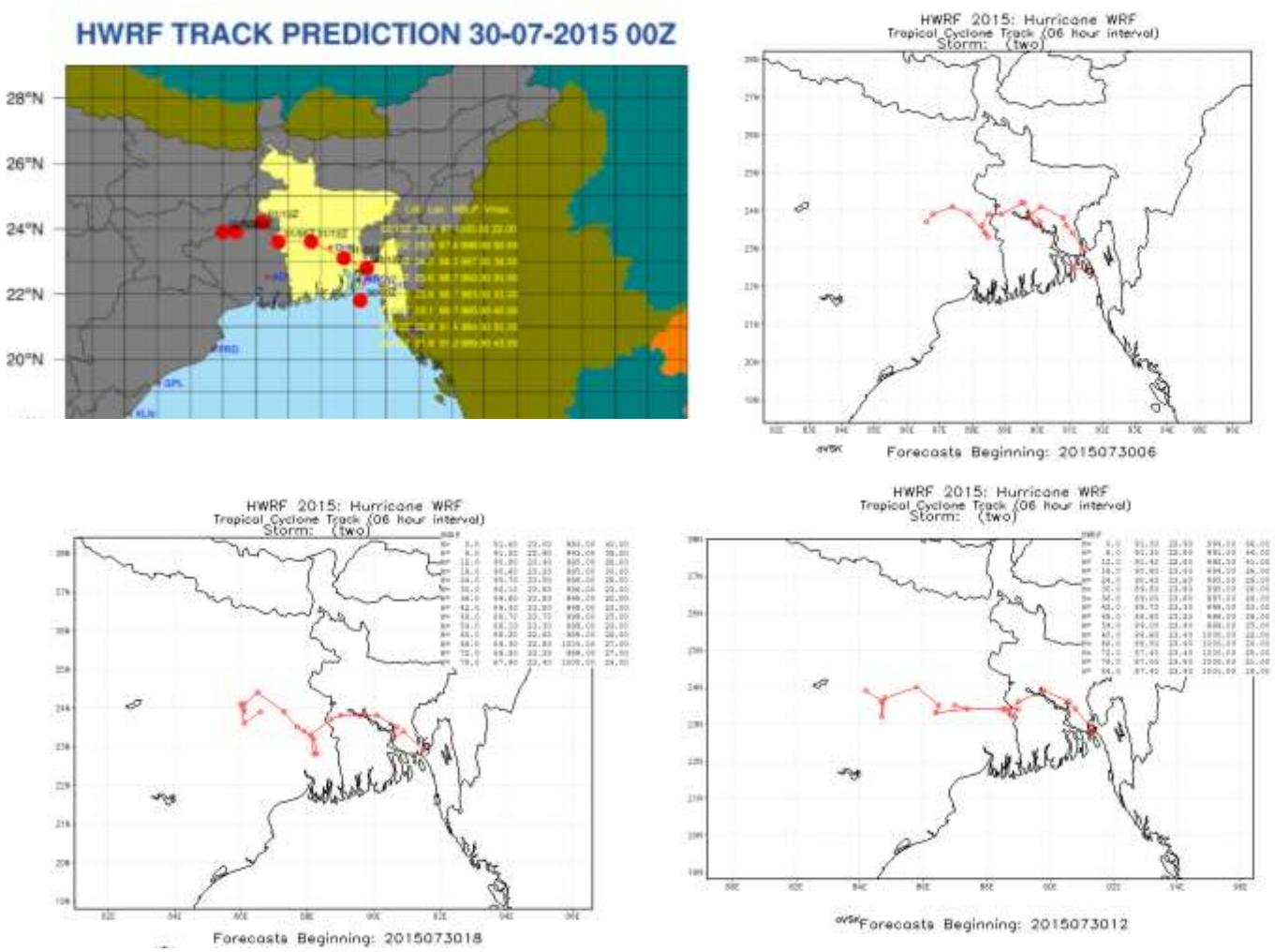


Fig.12. Predicted tracks of HWRF model based on 00, 06, 12 and 18 UTC of 30th July 2015.

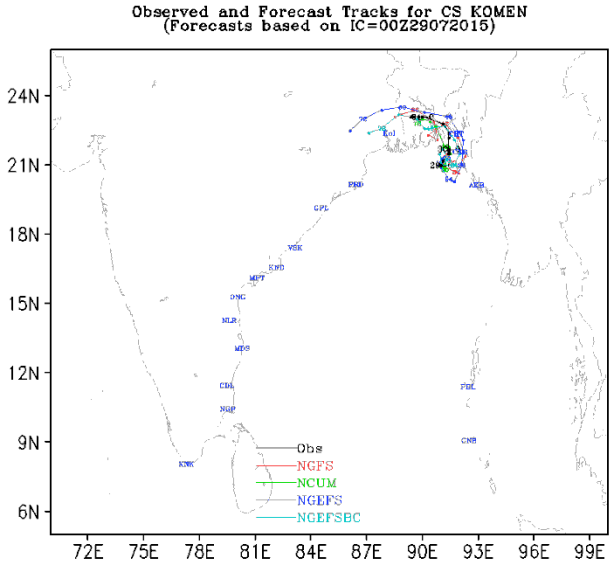


Figure 13: Forecast tracks from NGFS, NCUM, NGEFS and NGEFS_BC for Komen based on 00 UTC of 29th July 2015

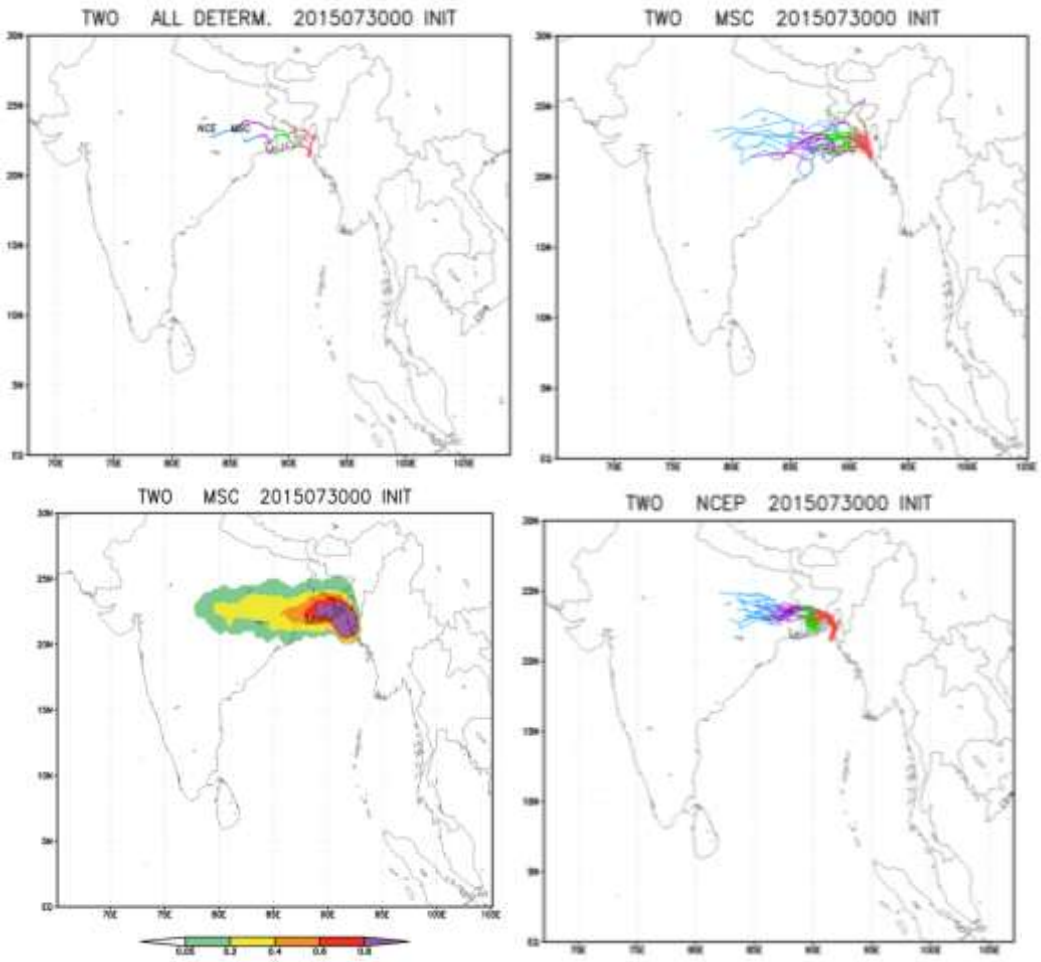


Figure 14(i): Ensemble Prediction System (EPS) run based on 0000 UTC of 30 July 2015 (on the day of landfall)

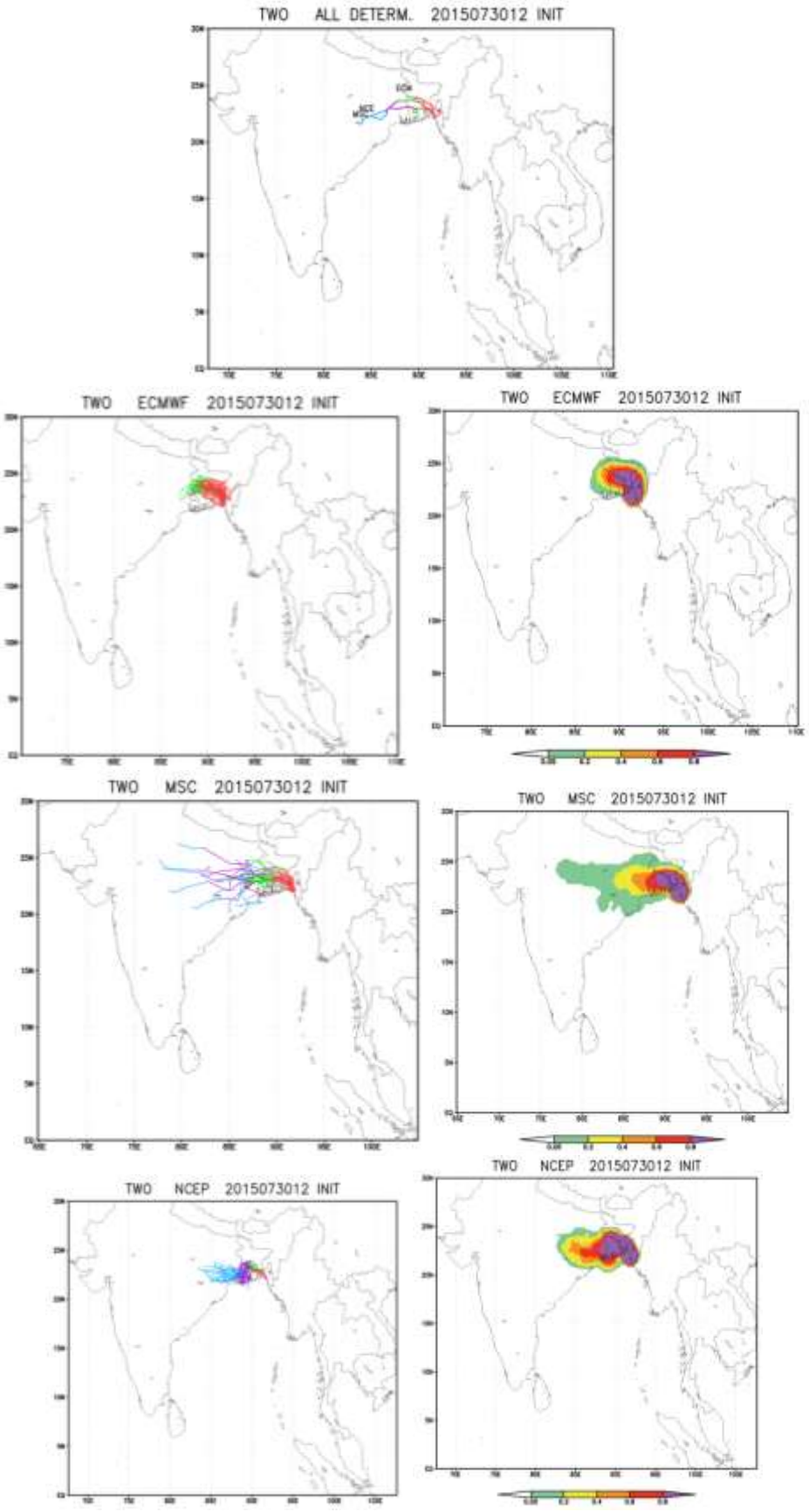


Figure 14(ii) : Ensemble Prediction System EPS run based on 0000 UTC of 30 July 2015 (on the day of landfall)

The average track forecast errors (Direct Position Error) in km at different lead time (hr) of various models are given in Table 3. From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors was minimum for MME. It was less than 50 km upto 36 hour forecast. Considering the individual deterministic models, the performance of NCEP-GFS was the best with track forecast error being 11 km, 52 km and 91 km respectively for 24, 36 and 48 hour respectively. The Average errors of intensity forecast by SCIP model and HWRF model are given in Tables 4 and 5 respectively.

Table-3. Average track forecast errors (Direct Position Error) in km

Lead time →	12 hr	24 hr	36 hr	48 hr
JMA	66	33	103	277
NCEP-GFS	78	11	52	91
UKMO	78	61	24	144
ECMWF	43	68	68	177
IMD-GFS	114	49	106	301
IMD-MME	41	31	22	103
NCMRWF-NGFS	88	175	90	94
NCMRWF-NGEFS	101	152	112	143
NCMRWF-NGEFS_BC	89	135	53	69
NCMRWF-NCUM	67	126	61	190
HWRF	92	123	84	102

Table-4 Average absolute errors of SCIP model of IMD for intensity prediction based on 00 UTC of 30th July, 2015

Lead time →	12 hr	24 hr	36 hr	48 hr
Observed (kt)	35	30	25	20
Predicted (kt)	34	30	27	24
Error (kt)	-1	0	2	4

Table-5 Intensity forecast errors of HWRF model

Lead Period	AE (kts)	RMSE (kts)
00	6.8	7.3
06	12.5	13.3
12	10.8	12
18	11	12.9
24	7.75	8.8
36	6.3	7.2
48	7.8	8.1

9.3. Heavy rainfall

The heavy rainfall guidance from various models was also used for heavy rainfall warning. An example of HWRF model and that of IMD-GFS are shown in Fig.15 and 16 respectively.

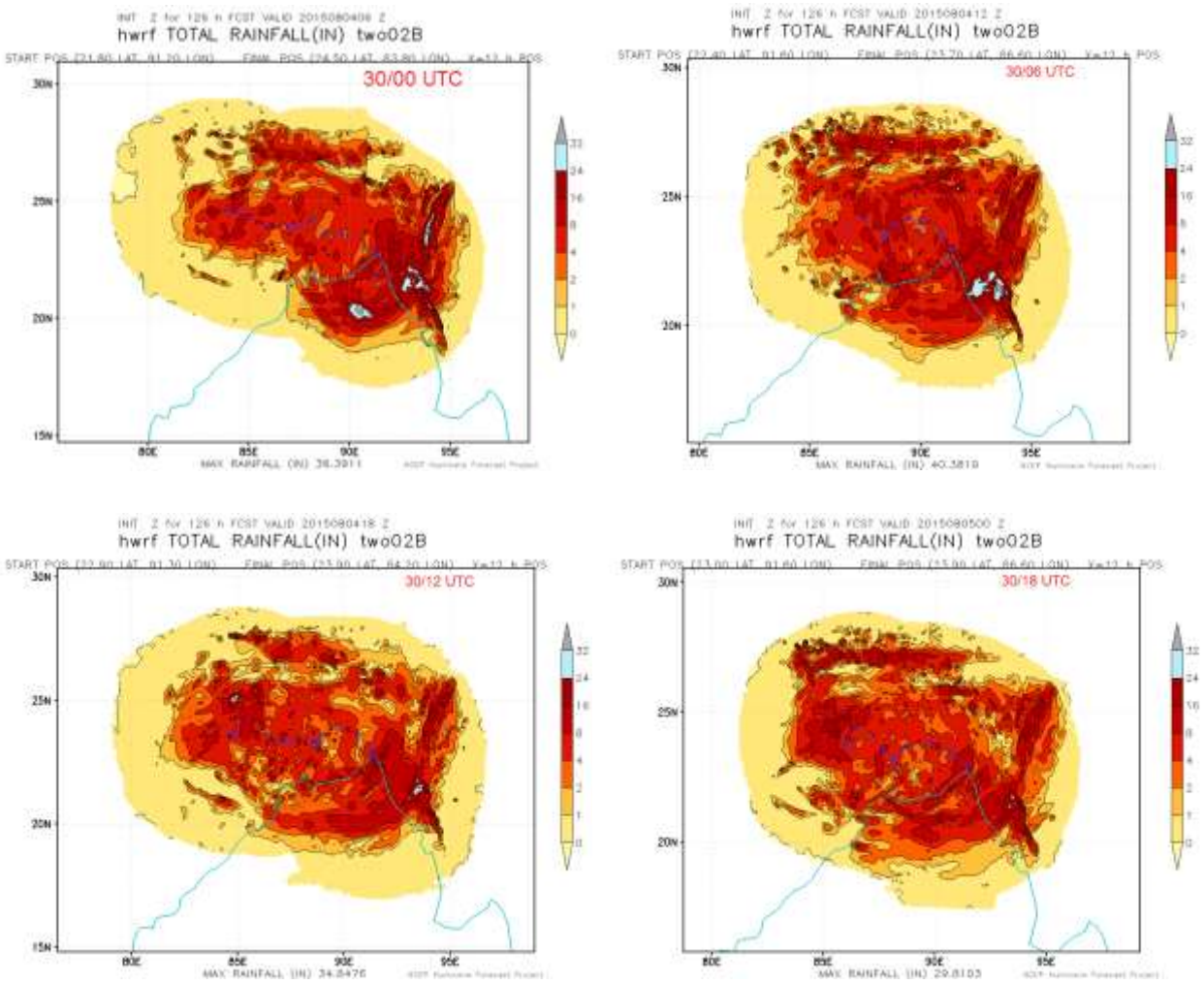


Fig.15: HWRF total rainfall (inch) for 126 h forecast period based on 00, 06, 12 and 18 UTC initial conditions of 30th July 2015 in association with CS KOMEN

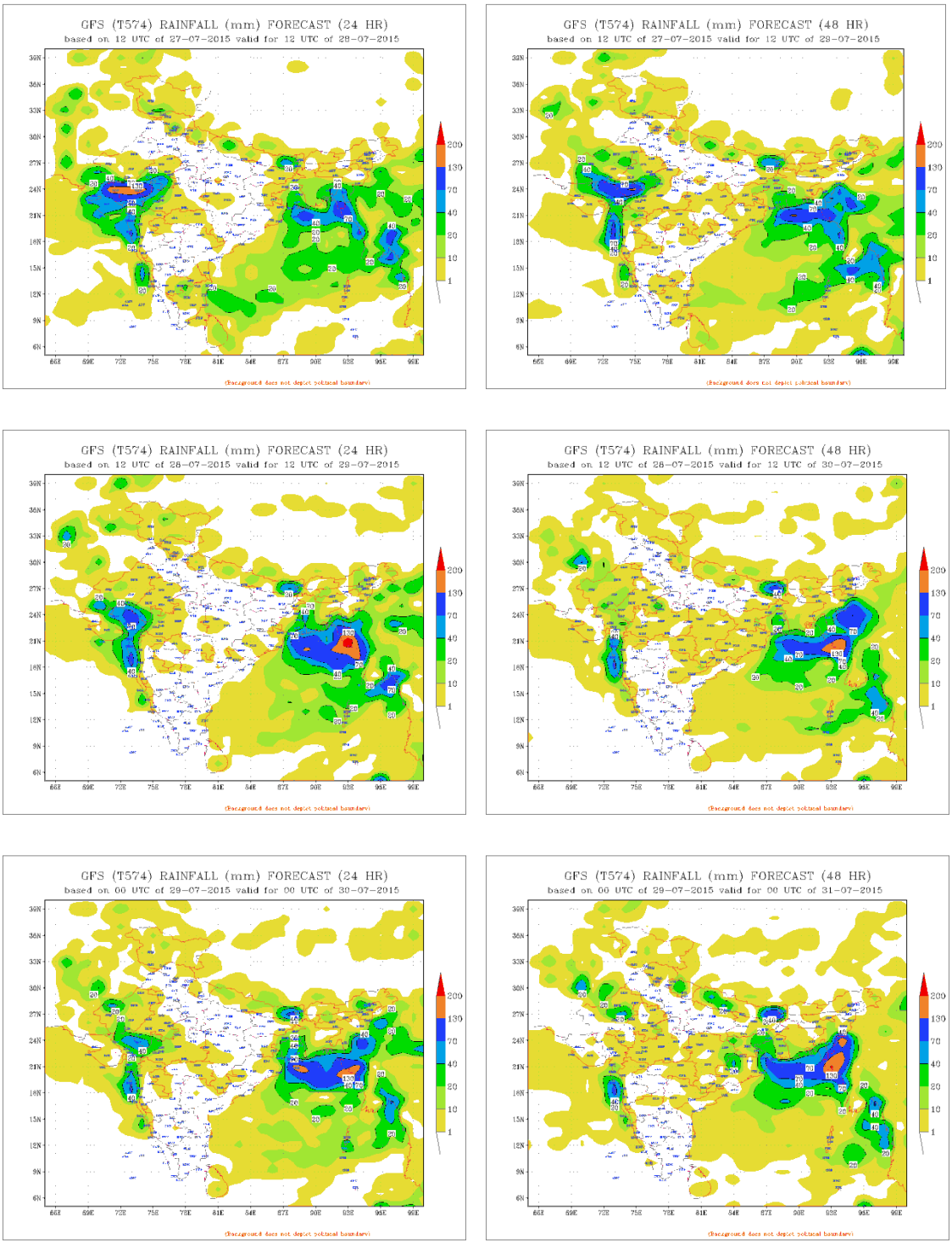


Fig.16 IMD-GFS rainfall forecast for 24 and 48 hours based on 1200 UTC of 28-29 July and based on 0000 UTC of 30 July-2 August 2015

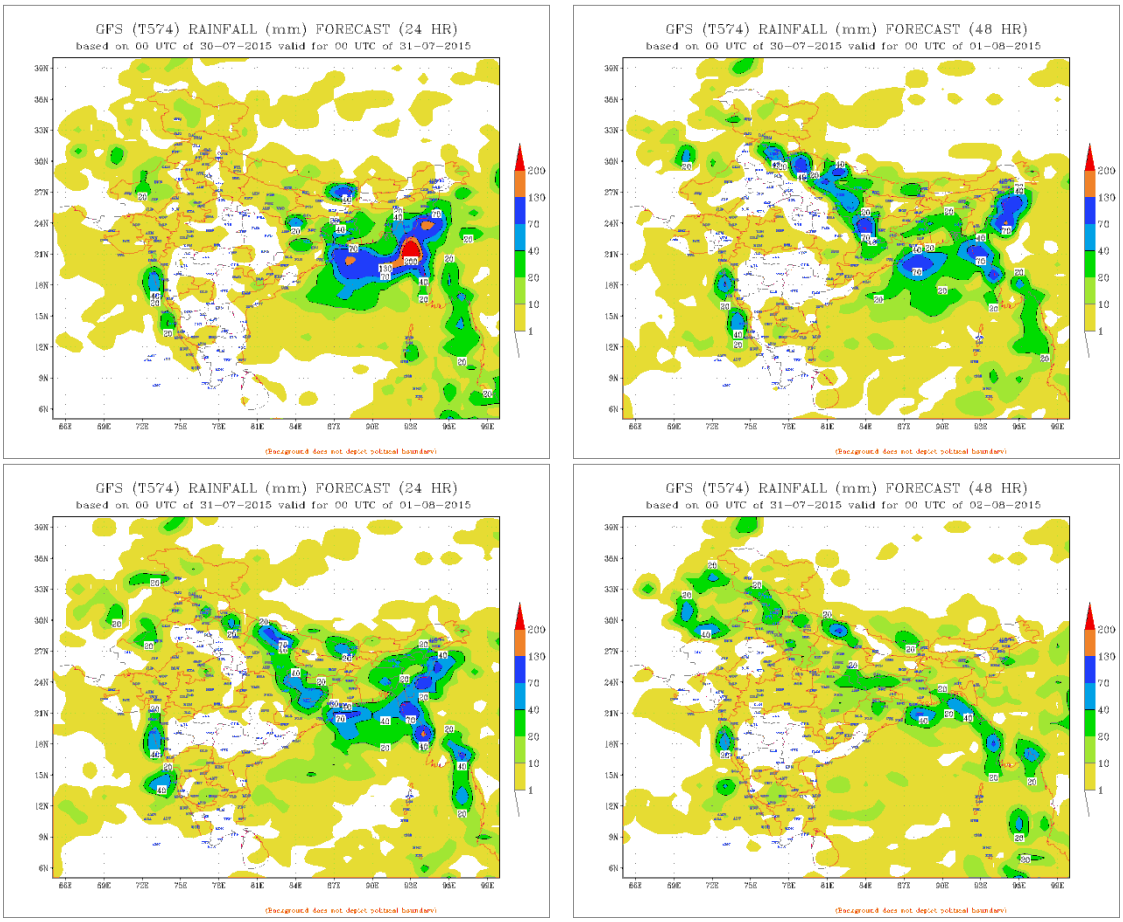


Fig.16 contd. IMD-GFS rainfall forecast for 24 and 48 hours based on 1200 UTC of 28-29 July and based on 0000 UTC of 30 July-2 August 2015

10. Bulletins issued by IMD

10.1 Bulletins issued by Cyclone Warning Division, New Delhi

IMD continuously monitored, predicted and issued bulletins containing track & intensity forecast at +06, +12, +18, +24, +36 till the system weakened into a low pressure area. The lead period was limited to 36 hrs as the life period of the system in deep depression and higher intensity stage was limited. The above structured track and intensity forecasts were issued from the stage of deep depression onwards. The cone of uncertainty in the track forecast was also given for all cyclones. The radius of maximum wind and radius of≥28 knots, ≥34 knots wind in four quadrants of cyclone was also issued for every six hours. The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The storm surge forecast was given based on INCOIS and IIT, Delhi model. The prognostics and diagnostics of the systems were described in the RSMC bulletins and tropical cyclone advisory bulletins. The TCAC bulletin was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Honkong like previous year. Tropical cyclone vitals were prepared every six hourly from deep depression stage onwards and sent to various NWP modeling groups in India for bogusing purpose.

Bulletins issued by Cyclone Warning services of IMD in association with CS, KOMEN are given in Tables 6 and 7a&b.

Table 6: Bulletins issued by Cyclone Warning Division, New Delhi

S. No.	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	29	1. Put up on IMD's website 2.Email / FAX to Control Room NDM, Cabinet Secretariat, Minister of Sc. & Tech and Earth Science, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Dir. Indian Navy, IAF, Chief Secretary-Govt. Officials of West Bengal, Odisha, Kolkata and Bhubaneshwar, Sikkim, Mizoram, Tripura, Meghalaya, Jharkhand. Assam, Madhya Pradesh, Chhattisgarh
2	RSMC Bulletin	08	1. Put up on IMD's website 2. Through GTS and Email to All WMO/ESCAP member countries. 3. Through e-mail to Indian Navy, IAF.
3	Press Release	02	1. Put up on IMD's website 2. Emails to : a. Senior Officers of NDMA, NDM, NDRF, MHA, b. Senior Officers of MoES, IMD c. Press and Electronic Media including AIR and Doordarshan
5	Personal Briefings At State level (West Bengal Odisha and North eastern states)		Crisis Management Committee, Chief Commissioners Briefings to Chief Secretary, State Relief Commissioner, Chief Disaster Management , District Collectors
6	Tropical Cyclone Advisory Centre (TCAC) Bulletin (Text & Graphics) for civil aviation	05	1. Put up on IMD's website 2. (Through GTS) to Meteorological Watch Offices in Asia Pacific and Middle East Region of issue of significant meteorological (SIGMET) forecast for International Civil Aviation
7	TCAC Bulletin to ADRR centre Hong Kong	05	(Through ftp)
8	TC vitals For creation of synthetic vortex in NWP Models	04	(Through ftp and Email) To: modelling group-NCMRWF, IIT, INCOIS, IMD NWP
9	Quadrant Wind	04	E-mail to modelling group- NCMRWF, IIT, INCOIS, IMD NWP. and put up on IMD's website
10	SMS to Senior Govt. Officials	2051	Disaster Management Officials, Delhi, NDRF, Media and registered user on RSMC Website of Odisha, West Bengal , Sikkim, Mizoram, Tripura, Meghalaya, Jharkhand, Assam

Table 7: Bulletins issued by Area Cyclone Warning Centre Kolkata

	Type of Bulletin	**Number**
1.	Port Warnings	32
2.	Fisherman Warning issued	33
3.	Sea Area Bulletin	29
4.	Coastal Weather Bulletin for West Bengal Coast	22
5.	Coastal Weather Bulletin for Andaman & Nicobar Coast	22
6.	Heavy Rainfall Warning (25th July to 2nd August)	36
7.	Information & Warning issued to State Government and other Agencies for west Bengal and Jharkhand on 30.07.15	1

Table 7b: Bulletins issued by Cyclone Warning Centre Bhubaneswar

	Type of Bulletin	**Number**
1.	Port Warnings	22
2.	Fisherman Warning issued	31
3.	Sea Area Bulletin	23
4.	Coastal Weather Bulletin for Odisha Coast	23
5.	Heavy Rainfall Warning (25th July to 4th August)	11
6.	Information & Warning issued to State Government and other Agencies for Odisha	23

11. Operational Forecast Performance

Following are the salient features of the bulletins issued by IMD.

(i) 25th July: Forecast for formation of depression over Bay of Bengal during next 24 hrs.

(ii) 26th July: Depression formed over northeast Bay of Bengal at 0300 UTC of 26th. Forecast was issued for intensification into deep depression during next 48 hrs.

(iii) 29th July: Deep depression formed over northeast Bay of Bengal and adjoining Bangladesh and West Bengal at 0000UTC of 29th. Forecast was issued that it would move nearly northwards and cross Bangladesh coast on 30th forenoon between longitude 90.5^{0}E and 91.5^{0}E. The CS formed at 1800 UTC of 29th July.

(iv) 30th July: Forecast was issued at 0000 UTC that it would move north-northwestwards and cross Bangladesh coast between longitude 90.5°E and 91.0°E by afternoon of 30th July 2015. After landfall, it would move west-northwestwards and weaken gradually.

(v) 30th July: Forecast was issued at 0300 UTC that Komen would cross Bangladesh coast around longitude 91.0°E by the afternoon of today, the 30th July 2015.

(vi) 30th July: Komen crossed Bangladesh coast between Hatia and Sandwip near lat. 22.5^{0}N and long. 91.4^{0}E between 1400 and 1500 UTC as a cyclonic storm.

11.1. Operational landfall forecast error

The operational landfall forecast error was 41 km for 12 to 36 hrs lead period (Table 8). The landfall time error varied from 6 to 10 hrs for 12 to 36 hrs lead period. An

example of forecast & actual track showing accurate prediction of landfall point & time is shown in Fig.17.

Table 8. Operational landfall point and time forecast errors of CS 'KOMEN'

Lead Time (Hrs)	Landfall Point Error (km)	Landfall Time Error (hrs)	Official long period average during 2010-14	
			Landfall Point Error (km)	Landfall Time Error (hrs)
12	41	6 h early	31.6	1.8
24	41	10 h early	58.5	3.4
36	41	10 h early	81.6	5.0

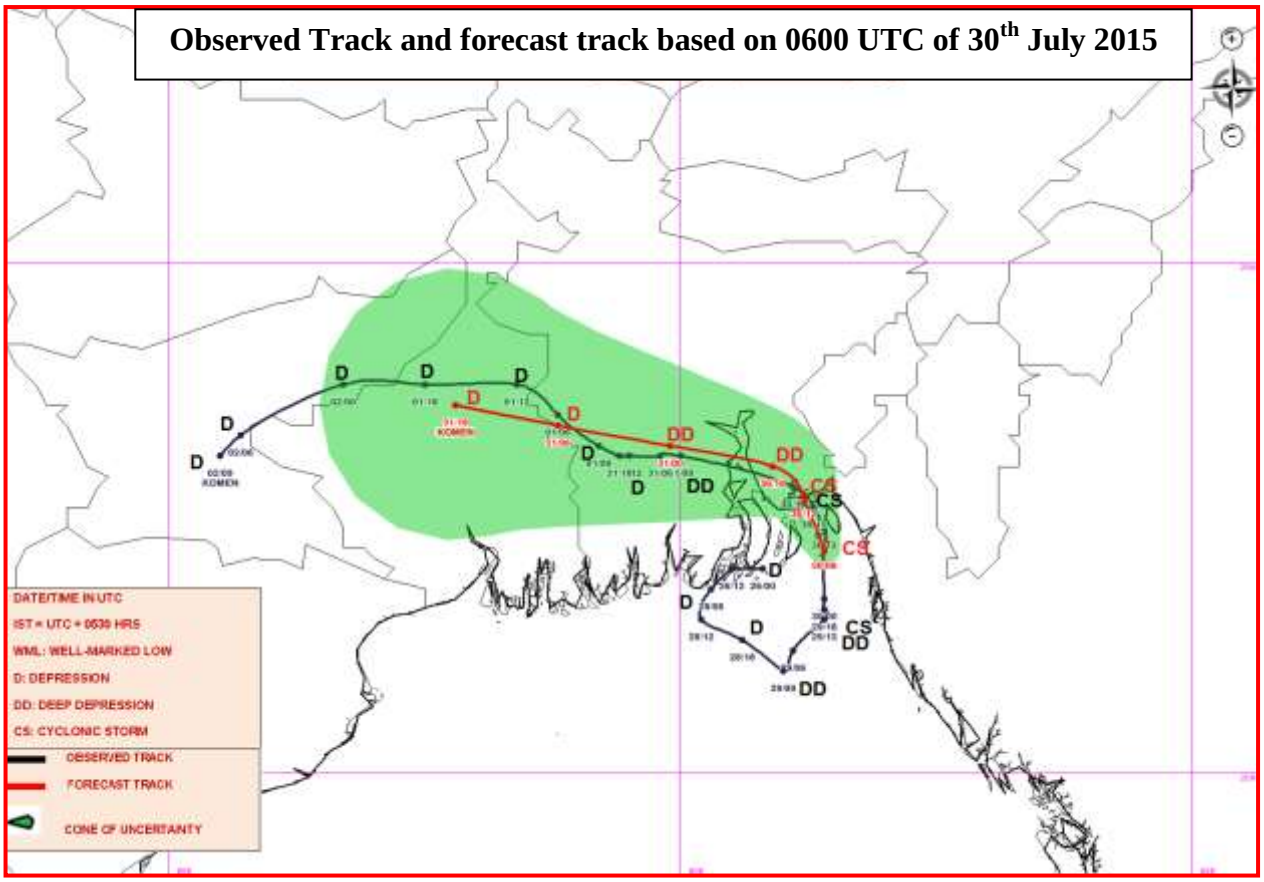


Fig.17. An example of forecast track along with cone of uncertainty issued on 00 UTC of 30th July 2015.

11.2. Operational track forecast error and skill

The operational average track forecast errors and skill are shown in Table 9. It was less than 100 km for all forecast time scales and significantly less than the long period average (2010-14) for lead period of 24 and 36 hrs. The track forecast skill varied from 19% to 44 % for various time scales.

Table 9. Operational Track Forecast Error (km) and Skill (%) of CS KOMEN

Lead Period (hrs)	No. of forecasts verified	Track forecast error (km)	Track forecast skill (%)	Official long period average based on 2010-14	
				Error (km)	Skill (%)
12	5	71.5	19.0	61.8	39.2
24	5	76.7	34.0	106.8	46.1
36	3	94.1	44.3	132.4	56.6

11.3. Operational Intensity forecast error and skill

The operational intensity forecast error in terms of absolute error (AE) and root mean square error (RMSE) are presented in Table 10. The intensity forecast error has been around 3.0 kts based on absolute error and root mean square error for various lead periods. The error was significantly less than the long period average error based on 2010-14. The skill in intensity forecast compared to persistence forecast based on AE varied from 25% to 78% for different lead periods and has been significantly higher for 24 and 36 hrs lead period as compared to long period average skill (Table 11). Considering the skill in intensity based on RMSE, it varied between 43 to 80% for CS, KOMEN and has been higher than long period average for all lead periods.

Table -10. Operational Intensity forecast errors

Lead period (hrs)	**No. of forecasts verified**	**Absolute Error (knots)**	**RMS Error (knots)**	**Official long period average (2010-2014) based on**	
				Absolute Error (knots)	**RMS Error (knots)**
12	5	3.0	3.1	7.2	10.1
24	5	2.9	3.3	11.1	14.6
36	3	2.9	3.3	14.3	18.5

Table - 11. Operational Intensity Forecast skill (%) of CS, KOMEN

Lead period (hrs)	**No. of forecasts verified**	**Skill in intensity forecast error (%) based on**		**Official long period average in skill during 2010-2014 based on**	
		Absolute Error	**RMS Error**	**Absolute Error (knots)**	**RMS Error (knots)**
12	5	25.0	43.6	26.7	34.6
24	5	67.8	72.5	45.2	45.2
36	3	78.2	80.4	53.1	53.1

11.4. Adverse weather forecast verification

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Table 12-14. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table - 12(a) .Verification of Heavy Rainfall Forecast

Date & Time	**Heavy rainfall warning issued**	**24-hour Heavy rainfall realised ending at 0300 UTC of date**
26.07.2015 0300 UTC	Heavy rainfall would occur at isolated places over Gangetic west Bengal during next 24 hours and heavy to very heavy during subsequent 24 hours. Heavy rainfall would occur at isolated places over Odisha on 27th. The rainfall intensity would increase significantly both over Gangetic West Bengal and Odisha from 28th July 2015.	**27.07.2015:** Heavy to very heavy rainfall at isolated places over **Odisha and Gangetic West Bengal.** Heavy rainfall at isolated places over **Nagaland, Manipur, Mizoram & Tripura and Jharkhand** **28.07.2015:** Heavy to very heavy rainfall at isolated places over **Odisha, Jharkhand and Gangetic West Bengal.** Heavy rainfall at isolated places over **Bihar.** **29.07.2015:** Heavy to very heavy rainfall at isolated places over **Gangetic West Bengal, Odisha and Jharkhand.** **30.07.2015:** Heavy to very heavy rainfall at isolated places over **Gangetic West Bengal.**
26.07.2015 1200 UTC	Heavy rainfall would occur at isolated places over Gangetic West Bengal during next 24 hours and heavy to very heavy during subsequent 24 hours. Heavy rainfall would occur at isolated places over Odisha on 27th. The rainfall intensity would increase significantly both over Gangetic West Bengal and Odisha from 28th July 2015.	
27.07.2015 0300 UTC	Heavy to very heavy rainfall would occur at isolated places over the **Gangetic West Bengal** during next 48 hours and heavy to very heavy at a few places during the subsequent 24 hours. Heavy rainfall would occur at isolated places over **Odisha** during next 48 hours and heavy to very heavy rainfall at a few places during subsequent 24 hours.	
27.07.2015 1200 UTC	Heavy to very heavy rainfall would occur at isolated places over the **Gangetic West Bengal** during next 48 hours and heavy to very heavy at a few places during the subsequent 24 hours. Heavy rainfall would occur at isolated places over **Odisha** during next 48 hours and heavy to very heavy rainfall at a few places during subsequent 24 hours.	
28.07.2015 0300 UTC	Heavy to very heavy rainfall would occur at isolated places over the **Gangetic West Bengal** during next 48 hours and heavy to very heavy at a few places during the subsequent 24 hours. Heavy rainfall would occur at isolated places over **Odisha** during next 48 hours and heavy to very heavy rainfall at a few places during subsequent 24 hours.	

28.07.2015 1200 UTC	Heavy to very heavy rainfall would occur at isolated places over the **Gangetic West Bengal** during next 48 hours and heavy to very heavy at a few places during the subsequent 24 hours. Heavy rainfall would occur at isolated places over **Odisha** during next 48 hours and heavy to very heavy rainfall at a few places during subsequent 24 hours.	**31.07.2015:** Heavy to very heavy rainfall at isolated places over **Nagaland, Manipur, Mizoram & Tripura and Jharkhand.** **01.08.2015:** Heavy to very heavy rainfall at isolated places over **Assam & Meghalaya, Gangetic West Bengal, Bihar and Jharkhand.** Heavy rainfall at isolated places over **Nagaland, Manipur, Mizoram & Tripura.** **02.08.2015:** Heavy to very heavy rainfall at isolated places over **Gangetic West Bengal, Odisha and Jharkhand.** Heavy rainfall at isolated places over **Bihar.** **03rd August, 2015:** Heavy to very heavy at isolated places over **Odisha, Jharkhand, East Madhya Pradesh and Chattisgarh.** Heavy rainfall at isolated places over **Arunachal Pradesh.** **04th August, 2015:** Heavy to very heavy at isolated places
29.07.2015 0300 UTC	Heavy to very heavy rainfall would occur at a few places over the **Gangetic West Bengal** on 29 July; heavy to very heavy falls at a few places with isolated extremely heavy falls on 30 July and heavy to very heavy falls at a few places on 31 July. Heavy rainfall would occur at isolated places over **Odisha** on 29 & 30 July and heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July.	
29.07.2015 1200 UTC	Heavy to very heavy rainfall would occur at a few places over the **Gangetic West Bengal** on 29 July; heavy to very heavy falls at a few places with isolated extremely heavy falls on 30 July and heavy to very heavy falls at a few places on 31 July. Heavy rainfall would occur at isolated places over **Odisha** on 29 & 30 July and heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July.	
30.07.2015 0300 UTC	Heavy to very heavy rainfall at a few places and extremely heavy at isolated places would occur over the **Gangetic West Bengal** on 30 &31 July; heavy to very heavy falls at a few places on 01 August. Heavy to very heavy rainfall at isolated places would occur over **Odisha** on 30 and heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July & 01 August. Heavy to very heavy rainfall at isolated places would occur over **Mizoram, Tripura and south Assam** on 30 & 31 July. Heavy to very heavy rainfall at isolated places would occur over **Jharkhand** on 31 July & 01 August.	
30.07.2015 1200 UTC	Heavy to very heavy rainfall at a few places and extremely heavy at isolated places would occur over the **Gangetic West Bengal** on 30 &31 July; heavy to very heavy falls at a few places on 01 August.	

	Heavy to very heavy rainfall at isolated places would occur over **Odisha** on 30 and heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July & 01 August. Heavy to very heavy rainfall at isolated places would occur over **Mizoram, Tripura, Meghalaya and south Assam** on 30 & 31 July. Heavy to very heavy rainfall at isolated places would occur over **Jharkhand** on 31 July & 01 August.	over **East Madhya Pradesh.** Heavy rainfall at isolated places over **Chhattisgarh.**
31.07.2015 0300 UTC	Heavy to very heavy rainfall at a few places over the **Gangetic West Bengal** on 31 July and 01 August. Heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July & 01 August would occur over **north Odisha** and isolated heavy to very heavy rainfall over **south Odisha** during same period. Heavy to very heavy rainfall at isolated places would occur over **sub-Himalayan West Bengal**, **Sikkim, Mizoram, Tripura, Meghalaya and south Assam** on 31 July. Heavy to very heavy rainfall at isolated places would occur over **Jharkhand** on 31 July & 01 August.	
31.07.2015 1200 UTC	Heavy to very heavy rainfall at a few places over the **Gangetic West Bengal** on 31 July and 01 August. Heavy to very heavy rainfall at a few places with isolated extremely heavy falls on 31 July & 01 August would occur over **north Odisha** and isolated heavy to very heavy rainfall over **south Odisha** during same period. Heavy to very heavy rainfall at isolated places would occur over **sub-Himalayan West Bengal**, **Sikkim, Mizoram, Tripura, Meghalaya and south Assam** on 31 July. Heavy to very heavy rainfall at isolated places would occur over **Jharkhand** on 31 July & 01 August. Heavy to very heavy rainfall at isolated places would occur over **north Chhattisgarh, east Madhya Pradesh** on 01 August and heavy to very heavy rainfall at few places on 02 and 03 August.	
01.08.2015 0300 UTC	Heavy to very heavy rainfall at a few places would occur over the **Gangetic West Bengal** during next 24 hrs and isolated heavy to very heavy rainfall thereafter. Heavy to very heavy rainfall at a few places with isolated extremely heavy falls would occur over	

	north Odisha and **Jharkhand** during next 24 hrs and heavy to very heavy rainfall at a few places over **north Odisha** and isolated heavy to very heavy rainfall over **Jharkhand** in subsequent 24 hrs. Isolated heavy to very heavy rainfall would occur over **south Odisha** during same period. Heavy to very heavy rainfall at isolated places would occur over **north Chhattisgarh and east Madhya Pradesh** on 01 August and heavy to very heavy rainfall at few places with isolated extremely heavy falls on 02 August over **north Chhattisgarh** and on 03 August over **east Madhya Pradesh**. Heavy to very heavy rainfall at isolated places would occur over **sub-Himalayan West Bengal**, **Sikkim, Mizoram, Tripura, Meghalaya and south Assam** during next 24 hrs.	
01.08.2015 1200 UTC	Heavy to very heavy rainfall at a few places would occur over the **Gangetic West Bengal** during next 24 hrs and isolated heavy to very heavy rainfall during subsequent 24 hrs. Heavy to very heavy rainfall at a few places would occur over **north Odisha** and **Jharkhand** during next 24 hrs and heavy to very heavy rainfall at isolated places in subsequent 24 hrs. Isolated heavy to very heavy rainfall would occur over **south Odisha** during same period. Heavy to very heavy rainfall at isolated places would occur over **Chhattisgarh** on 01 August and heavy to very heavy rainfall at few places with isolated extremely heavy falls on 02 and 03 August. Isolated heavy to very heavy rainfall would occur over **east Madhya Pradesh** on 03 and 04 August. Heavy to very heavy rainfall at isolated places would occur over **sub-Himalayan West Bengal**, **Bihar, Sikkim, Mizoram, Tripura, Meghalaya and south Assam** during next 24 hrs.	
02.08.2015 0300 UTC	Heavy to very heavy rainfall at isolated places would occur over the **Gangetic West Bengal** during next 24 hrs and isolated heavy rainfall during subsequent 24 hrs. Heavy to very heavy rainfall at isolated places would occur over **Jharkhand, Odisha** and **Chhattisgarh** during next 48 hrs. Heavy to very heavy rainfall would occur over **east Madhya Pradesh** on 03 and 04 August. Heavy rainfall at isolated places would occur over **sub-Himalayan West Bengal**, **Bihar and Sikkim** during next 24 hrs.	

Based on the Table 12(a), skill scores are calculated and the same are presented in Table 12 (b) and (c) for 24 and 48 hr forecasts respectively.

Table - 12(b): Contingency Table for verification of 24 hr Heavy Rainfall Forecast

24 HOUR HEAVY RAINFALL FORECAST VERIFICATION			
Observed	**Forecast**		
	YES	NO	TOTAL
YES	21	3	24
NO	12	3	15
TOTAL	33	6	39

48 HOUR HEAVY RAINFALL FORECAST VERIFICATION			
Observed	**Forecast**		
	YES	NO	TOTAL
YES	20	3	23
NO	6	14	20
TOTAL	26	17	43

Table - 12(c): Skill scores for 24 and 48 hr heavy rainfall forecast

Skill Parameter	24 hr forecast	48 hr forecast
Probability of detection(POD)	0.9	0.9
False alarm rate (FAR)	0.4	0.2
Missing rate (MR)	0.1	0.1
Correct non-occurrence (C-NON)	0.2	0.7
Critical success index (CSI)	0.6	0.7
Bias for occurrence	1.4	1.1
Percentage correct (PC)	61.5	79.1
Heidke skill score (HSS)	0.1	0.6

Table 13. Verification of Gale Wind Forecast

Date/ Time(IST)	**Gale wind Forecast**	**Recorded wind speed**
30.07.15 0530	Squally wind speed reaching 50-60 kmph gusting to 70 kmph would prevail along and off **West Bengal & north Odisha coasts** during next 48 hours. Squally wind speed reaching 40-50 kmph gusting to 60 kmph would prevail over **Mizoram and Tripura** commencing from today evening for next 24 hours and over **Gangetic West Bengal** from tomorrow morning.	60-70 kmph at the time of landfall. Chittagong reported 44 kmph at 1735 UTC of 30th July.
30.07.15 1730	Squally wind speed reaching 50-60 kmph gusting to 70 kmph would prevail along and off West Bengal & north Odisha coasts during next 48	30 - 40 kmph around the

	hours. Squally wind speed reaching 40-50 kmph gusting to 60 kmph would prevail over Mizoram and Tripura commencing from today evening for next 24 hours and over Gangetic West Bengal from tomorrow morning.	system centre reported at the inland stations over West Bengal, Odisha and Jharkhand
31.07.15 0530	Squally wind speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off West Bengal & north Odisha coasts during next 24 hours. Squally wind speed reaching 40-50 kmph gusting to 60 kmph would prevail over Mizoram and Tripura during next 12 hours and over Gangetic West Bengal during next 24 hours.	
31.07.15 1730	Squally wind speed reaching 35-45 kmph gusting to 55 kmph would prevail along and off West Bengal & north Odisha coasts during next 24 hours. Strong wind speed reaching 30-40 kmph gusting to 50 kmph would prevail over Mizoram, Tripura and Gangetic West Bengal during next 12 hours	
01.08.15 0530	Squally wind speed reaching 35-45 kmph gusting to 55 kmph would prevail along and off West Bengal & north Odisha coasts during next 24 hours. Strong wind speed reaching 30-40 kmph gusting to 50 kmph would prevail over Gangetic West Bengal during next 12 hours.	
01.08.15 1730	Strong wind speed reaching 30-40 kmph gusting to 50 kmph would prevail over Gangetic West Bengal around the Depression centre during next 24 hours.	
02.08.15 0530	Strong wind speed reaching 30-40 kmph gusting to 50 kmph would prevail around the Depression centre over Jharkhand and adjoining West Bengal during next 24 hours.	

Table 14. Verification of Storm Surge Forecast issued by IMD

Forecast Storm surge above astronomical tide and area to be affected	**Actual Storm Surge**
30.08.15-0830/1130/1430 IST Tidal Wave (storm surge + astronomical tide) of about 2 meters would inundate low lying areas of Bangladesh coast around the time of landfall. of landfall (12 Oct 2014/ Around noon)	Chittagong (Bangladesh) reported Storm Surge of 1-2 metre

12. Summary and Conclusion:

The cyclonic storm (CS), KOMEN over the Bay of Bengal (BoB) developed from a low pressure area over northeast BoB and adjoining Bangladesh & Gangetic West Bengal on 25th July evening and concentrated into a depression over the same area in the morning of 26th July. Following a semi-circular track over northeast BoB, it crossed Bangladesh coast between Hatia and Sandwip near lat. 22.5^{0}N and long. 91.4^{0}E during 1400 and 1500 UTC of 30th July.

IMD utilised all its resources to monitor and predict the genesis, track and intensification of CS Komen. The forecast of its genesis (formation of Depression) on 26th July, its track, intensity, point & time of landfall, as well as associated adverse weather like heavy rain, gale wind & storm surge were predicted well with sufficient lead time, thereby helping the disaster managers to effectively manage the cyclone and minimize the damage.

For 24 and 36 hrs lead period, the operational landfall point & time error was 41 km & 10hrs, track forecast error was 76.7 & 94.1 km and intensity forecast error based on absolute error was 2.9 kts. The lead period for the system was limited due to shorter life period of the cyclone.

Following lessons were learnt on the monitoring and prediction of the system:

- Though rare, the cyclonic storms can develop during July. It was the fourth cyclone after one cyclone each in 1972, 1973 and 1989 that developed during the month of July in last 54 years (1961-2015). The physical and dynamical characteristics leading to cyclogenesis in July need further investigation. A continuous watch should be maintained for possible cyclogenesis during the month of July like the pre and post monsoon season.
- The track of CS Komen was unique in nature with a semicircular path over northeast BoB. The process behind such tracks needs further investigation.
- The possible interaction between the two monsoonal disturbances occurring at the same time needs further investigation. Considering the present scenario, the observations indicate, the interaction between the deep depression over Rajasthan (which occurred during 27th July to 1st August) and CS Komen (during 26th July to 2nd August).
- The performance of NWP models w.r.t. genesis, intensity and especially track showed large variations. The models could not simulate the semicircular track. Therefore, there is a need for detailed investigation on the performance of NWP models for such small scale shorter duration TCs developing during monsoon season.
- The genesis of the depression over northeast BoB was mainly based on the coastal surface observations. Dvorak technique failed to estimate the intensity of the system during genesis days. Of course intensity estimation of monsoonal systems over Head Bay of Bengal is a limitation as mentioned in the Dvorak technique. And hence there was large difference between the centre of the system estimated by satellite and the DWR/ coastal observations. While CS Komen moved over land at 0600 UTC of 30th near Chittagong, it actually crossed the coast between Hatia and Sandwip near 22.5^{0} N/ 91.4^{0}E during 1400-1500

UTC of 30th July. There was some difference of between the centre fixed by Satellite and RADAR. The difference was more during the depression stage (around 120 km). The difference decreased as the system intensified into CS (around 50 km). At the time of landfall the difference was around 30 km.

Damage to houses at North-24 Parganas and West Myanmar

Damage due to flood at National Highway 60 and marooning of villages at Balasore, Odisha

13. Acknowledgements:

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