GOVERNMENT OF INDIA

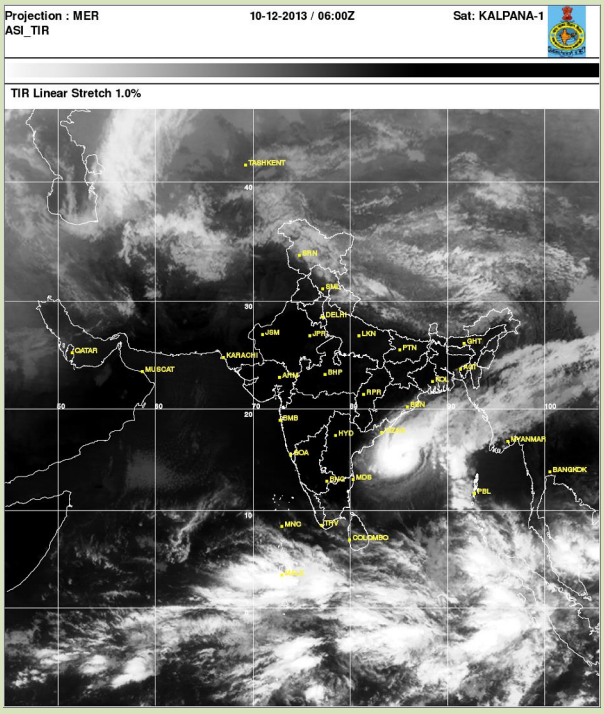
MINISTRY OF EARTH SCIENCES

EARTH SYSTEM SCIENCE ORGANIZATION

INDIA METEOROLOGICAL DEPARTMENT

A Preliminary Report on Very Severe Cyclonic Storm 'MADI' over Bay of Bengal

(06-13 December 2013)



CYCLONE WARNING DIVISION, NEW DELHI

FEBRUARY, 2014

Very Severe Cyclonic Storm 'MADI'

(06-13 December 2013)

1. Introduction :

A cyclonic storm 'MADI' formed over southwest Bay of Bengal on 7th December. It initially moved northwards intensified upto very severe cyclonic storm. After crossing Lat. 15^0 N it wekened due to unfavourable conditions and recurved southwestwards. It crossed Tamil Nadu coast near Vedaranyam around 1330 UTC of 12th Dec., emerged into Palk strait around 1500 UTC and again crossed Tamil Nadu coast near Tondi around 1700 UTC of 12th December 2013. It then emerged into southeast Arabian Sea as a well marked low pressure area in the early morning of 13th Oct. 2013. Salient features of the system are given below:

i. It has a unique track with near northerly movement till 15.7^0N and then recurving southwestwards to Tamil Nadu coast.

ii. It moved very slowly during its northward journey and speed peaked up gradually after the recurvature to southwest.

iii. The genesis, track, intensification and weakening of the system was well predicted by IMD.

iv. Most of the numerical weather prediction (NWP) models could predict genesis, track, intensification and weakening of the system. However there was large divergence about the place and time of recurvature from the northerly to southwesterly movement.

2. Monitoring and Prediction

The very severe cyclonic storm, MADI was monitored mainly with satellite supported by meteorological buoys, coastal and Island observations. It was monitored by Doppler Weather Radar (DWR), Chennai, Visakhapatnam and Machilipatnam. The half hourly INSAT/ Kalpana imageries, hourly coastal observations and every 10 minutes DWR imageries and products were used for monitoring of cyclone.

Various NWP models and dynamical-statistical models including IMD's global and meso-scale models were utilized to predict the track and intensity of the storm.

The Tropical Cyclone Module in the digitized forecasting system of IMD was utilized for analysis and comparison of various NWP models and decision making process.

3. Genesis:

A low pressure area from south China Sea moved across Malay peninsula and emerged into south Andaman Sea on 01st December, morning. Moving westwards it lay over southeast Bay of Bengal on 02nd December. Continuing its westwards movement, it lay over southwest Bay of Bengal off Sri Lanka coast on 03rd December, 2013. It persisted over the same region and became well marked on 04th December. It further concentrated into a depression in the morning of 06th December over southwest Bay of Bengal and lay centered near latitude 10.0°N and longitude 84.0°E, about 350 km northeast of Tricomalee (Sri Lanka). The genesis was declared using the sea surface wind observations based on ASCAT and OceanSat-II. Also the ship and buoy observations near the centre supported the genesis. A ship near latitude 11.9°N and Longitude 85.4°E reported wind speed of 080/23 knots. The sea surface temperature during genesis was about 26-28°C and ocean thermal energy was about 60-80 KJ/$cm^{2.}$ The vertical wind shear was moderate (10-20 knots). The lower level convergence and relative vorticity increased from 05th to 06th December, 2013, along with increase in upper tropospheric divergence. The Madden Julian Oscillation (MJO) index lay over the phase-3 i.e. equatorial Indian Ocean adjoining Bay of Bengal with amplitude less than1. Past studies indicate that phase 3 is favourable for genesis of the system.

4. Intensification and movement:

As the system lay over the warmer sea surface region alongwith higher ocean thermal energy and low to moderate vertical wind shear, it gradually intensified into a deep depression at 1800 UTC of 06th December while remaining practically stationary over the region. The depression remained practically stationary, as it lay close to the upper troposphere ridge which ran along 10°N. It led to very slow northward movement afterwards. The deep depression further intensified into a cyclonic storm ñMADIôwith centre near latitude 10.5°N and longitude 84.0°E at 0000 UTC of 07th December, 2013. It intensified into a severe cyclonic storm over the same region at 0900 UTC of 07th December, 2013. As it lay slightly to the north of

the ridge, the severe cyclonic storm then moved slightly north-northeastwards and intensified into a very severe cyclonic storm at 0600 UTC of 08th December, 2013 near latitude 12.3°N and longitude 84.7°E.

As the very severe cyclonic storm moved to the north of 13.0°N i.e. to west central Bay of Bengal, it experienced colder sea surface temperature and low Ocean thermal energy (< 50 KJ/cm^2). Also the vertical wind shear of horizontal gradually increased and became high (20-30 knots). As a result, the very severe cyclonic storm weakened into a severe cyclonic storm at 1200 UTC of 09th December and lay centered near latitude14.6°N and longitude 84.7°E. It continued to move slowly north-northeastwards till 0900 UTC of 10th December as a severe cyclonic storm upto latitude 15.7°N and longitude 85.3°E under the influence of the upper tropospheric steering ridge which moved northward alongwith northward movement of system. However, due to gradual weakening of system, the steering level changed from upper troposphere to lower and middle troposphere. The influence of the upper tropospheric anticyclonic circulation to the east of system centre decreased and that of lower and middle level anticyclonic circulation lying to the west of the system centre (over central India) increased. As a result, the severe cyclonic storm re-curved westwards initially and then southwestwards commencing from 0900 UTC of 10th December.

At the same time, the animation of Total Precipitated Water (TPW) imageries indicated that the dry and cold air penetrated into the southwestern periphery of the cyclone. It gradually penetrated further towards the centre of the cyclone from the southern side. As a result, it isolated the core of the cyclone from the warm and moist air from the southeast sector. Hence due to combined impact of colder sea surface temperature, low Ocean thermal energy, high vertical wind shear and incursion of cold and dry air into the core of the cyclone, it gradually weakened into a cyclonic storm near latitude 14.6°N and longitude 84.6°E at 2100 UTC of 10th December 2013, further into a deep depression near latitude14.0°N and longitude 83.8°E at 0300 UTC of 11th December and into a depression near latitude 12.9°N and longitude 82.7°E at 1800 UTC of 11th December.

The depression crossed Tamil Nadu coast close to Vedaranyam around 1330 UTC of 12th December. It then emerged into Palk strait at 1500 UTC, moved west-

southwards and again crossed Tamil Nadu coast near Tondi around 1700 UTC of 12th December. It continued to move west-southwestwards across south peninsula and weakened further into a well-marked low pressure area over southeast Andaman Sea and adjoining Kerala at 0000 UTC of 13th December, 2013. It may be mentioned that due to increased convection and organization as per Dvorak estimate the system showed temporary increase in intensity upto very severe cyclonic storm stage during the weakening phase on 10th December (0300-0900 UTC). The best track position and other parameters of the very severe cyclonic Storm 'MADI' over the Bay of Bengal is given in Table 1 and the track is given in Fig. 1. The DWR imageries are shown in Fig.2. The satellite imageries are shown in fig.3. The IMD GFS model analyses are shown in Fig.4.

Table.1 Best track positions and other parameters of the Very Cyclonic Storm 'MADI' over the Bay of Bengal during 06-13 Dec 2013

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
06-12-2013	0300	10.0/84.0	1.5	1004	25	3	D
	0600	10.0/84.0	1.5	1004	25	3	D
	1200	10.2/84.0	1.5	1004	25	3	D
	1800	10.4/84.0	2.0	1002	30	5	DD
07-12-2013	0000	10.5/84.1	2.5	998	35	7	CS
	0300	10.5/84.1	2.5	998	35	7	CS
	0600	10.7/84.2	3.0	996	45	10	CS
	0900	10.8/84.3	3.5	992	55	14	SCS
	1200	11.0/84.4	3.5	992	55	14	SCS
	1500	11.0/84.5	3.5	992	55	14	SCS
	1800	11.2/84.5	3.5	990	55	16	SCS
	2100	11.5/84.6	3.5	990	55	16	SCS
08-12-2013	0000	11.8/84.6	3.5	988	60	18	SCS
	0300	12.0/84.6	3.5	988	60	18	SCS
	0600	12.3/84.7	4.0	986	65	20	VSCS
	0900	12.6/84.7	4.0	986	65	20	VSCS
	1200	13.0/84.7	4.0	986	65	20	VSCS
	1500	13.2/84.7	4.0	986	65	20	VSCS
	1800	13.4/84.7	4.0	986	65	20	VSCS
	2100	13.6/84.7	4.0	986	65	20	VSCS
09-12-2013	0000	13.8/84.7	4.0	986	65	20	VSCS
	0300	14.0/84.7	4.0	986	65	20	VSCS
	0600	14.3/84.7	4.0	986	65	20	VSCS

	0900	14.4/84.7	4.0	986	65	20	VSCS
	1200	14.6/84.7	3.5	988	60	18	SCS
	1500	14.7/84.7	3.5	988	60	18	SCS
	1800	14.8/84.8	3.5	988	60	18	SCS
	2100	14.8/84.8	3.5	988	60	16	SCS
10-12-2013	0000	15.0/85.0	3.5	988	60	16	SCS
	0300	15.3/85.3	4.0	988	65	16	VSCS
	0600	15.4/85.3	4.0	988	65	16	VSCS
	0900	15.7/85.3	4.0	988	65	16	VSCS
	1200	15.4/85.0	3.5	990	55	14	SCS
	1500	15.1/84.8	3.5	990	55	14	SCS
	1800	14.9/84.7	3.5	992	50	12	SCS
	2100	14.6/84.6	3.0	994	45	10	CS
11-12-2013	0000	14.3/84.2	3.0	996	40	8	CS
	0300	14.0/83.8	2.0	998	30	6	DD
	0600	13.7/83.5	2.0	998	30	6	DD
	0900	13.5/83.4	2.0	1000	30	5	DD
	1200	13.3/83.3	2.0	1000	30	5	DD
	1800	12.9/82.7	1.5	1000	25	4	D
12-12-2013	0000	12.5/82.0	1.5	1000	25	3	D
	0300	12.0/81.5	1.5	1000	25	3	D
	0600	11.5/81.2	1.5	1000	25	3	D
	0900	11.0/80.7	1.5	1000	25	3	D
	1200	10.5/80.0	1.5	1000	25	3	D
	The system crossed Tamil Nadu coast near Vedaranyam aound 1330 UTC and emerge into Palk straight and again crossed Tamil Nadu coast near Tondi around 1700 UTC						
	1800	10.0/78.8	-	1004	20	3	D
13-12-2013	0000	Weakened into a Well marked low pressure area over southeast Arabian Sea and adjoining Kerala.					

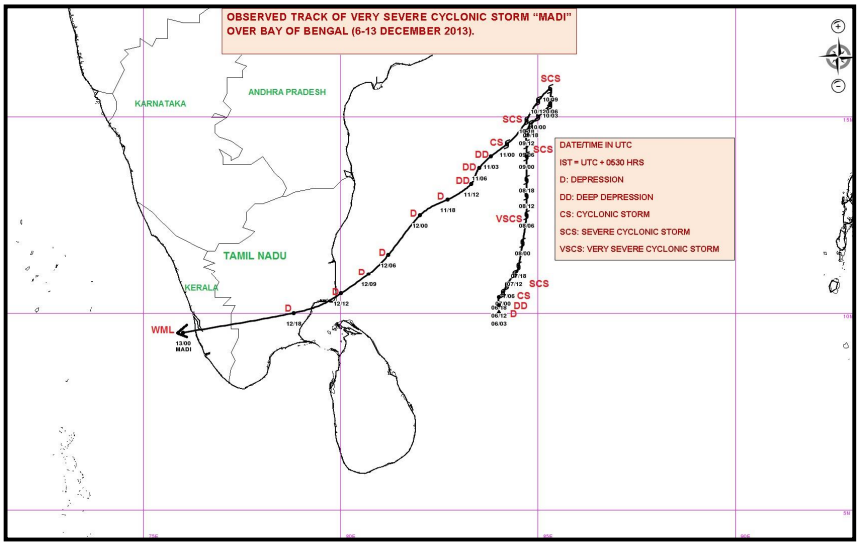


Fig.1. Track of Very Severe cyclonic storm 'Madi' over the Bay of Bengal (06-13 Dec., 2013)

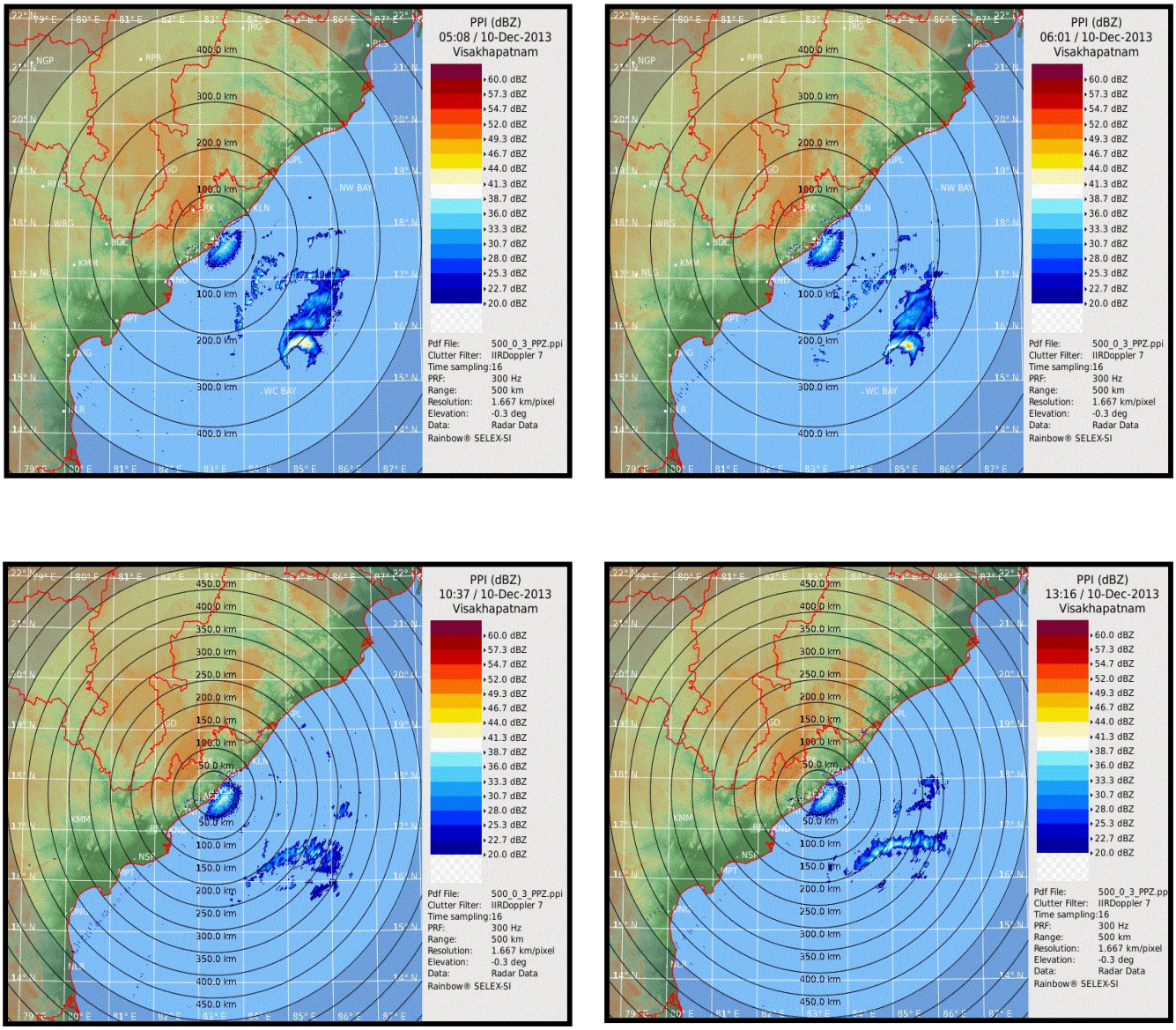


Fig. 2 Visakhapatnam RADAR imageries based on 0510, 0600, 1040 & 1320 UTC of 10th December, 2013

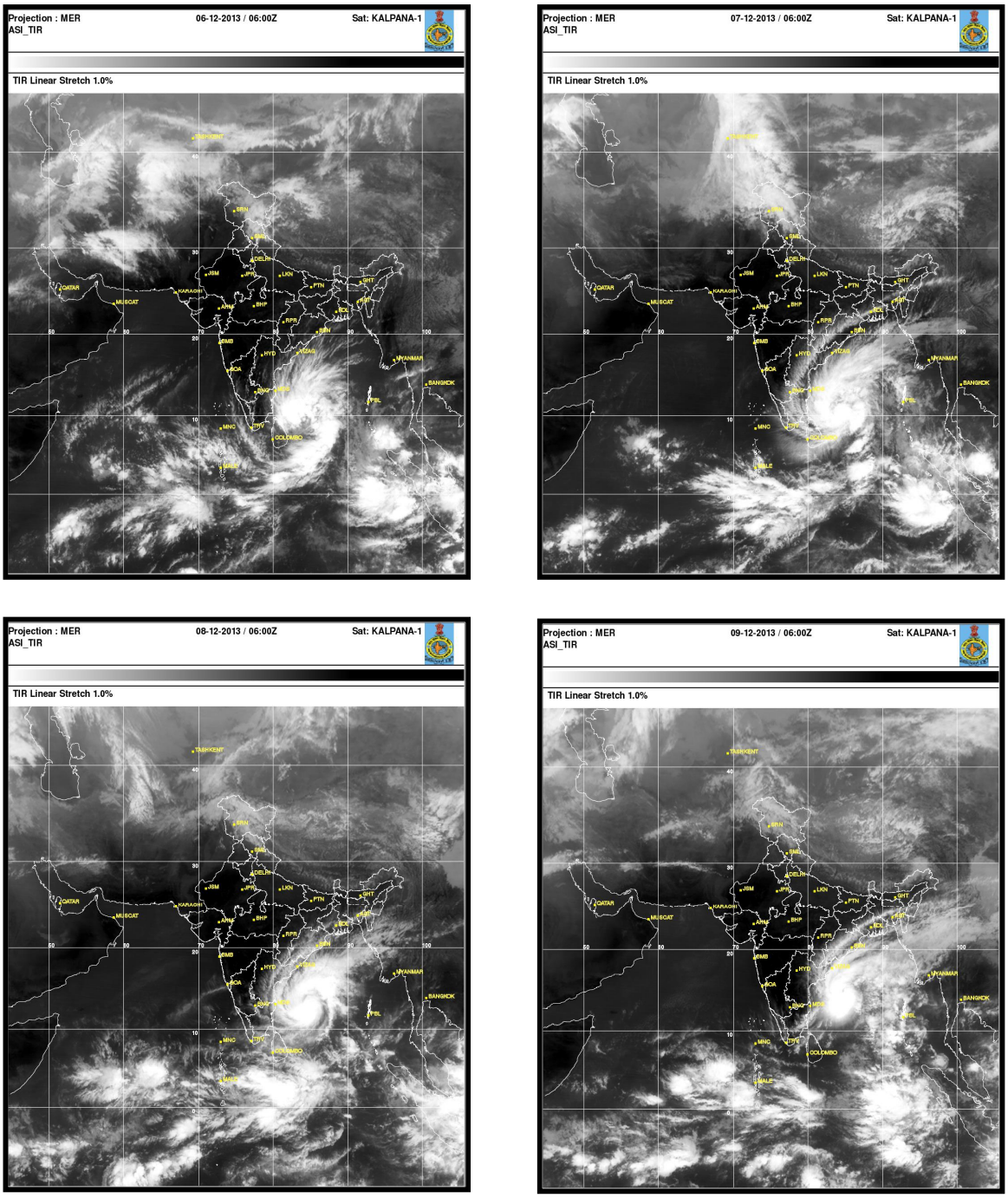


Fig. 3 (a) Typical Kalpana-1 Satellite imageries of very severe cyclonic storm ‘MADI’ at 0600 UTC of 06th, 07th, 08th and 09th December 2013.

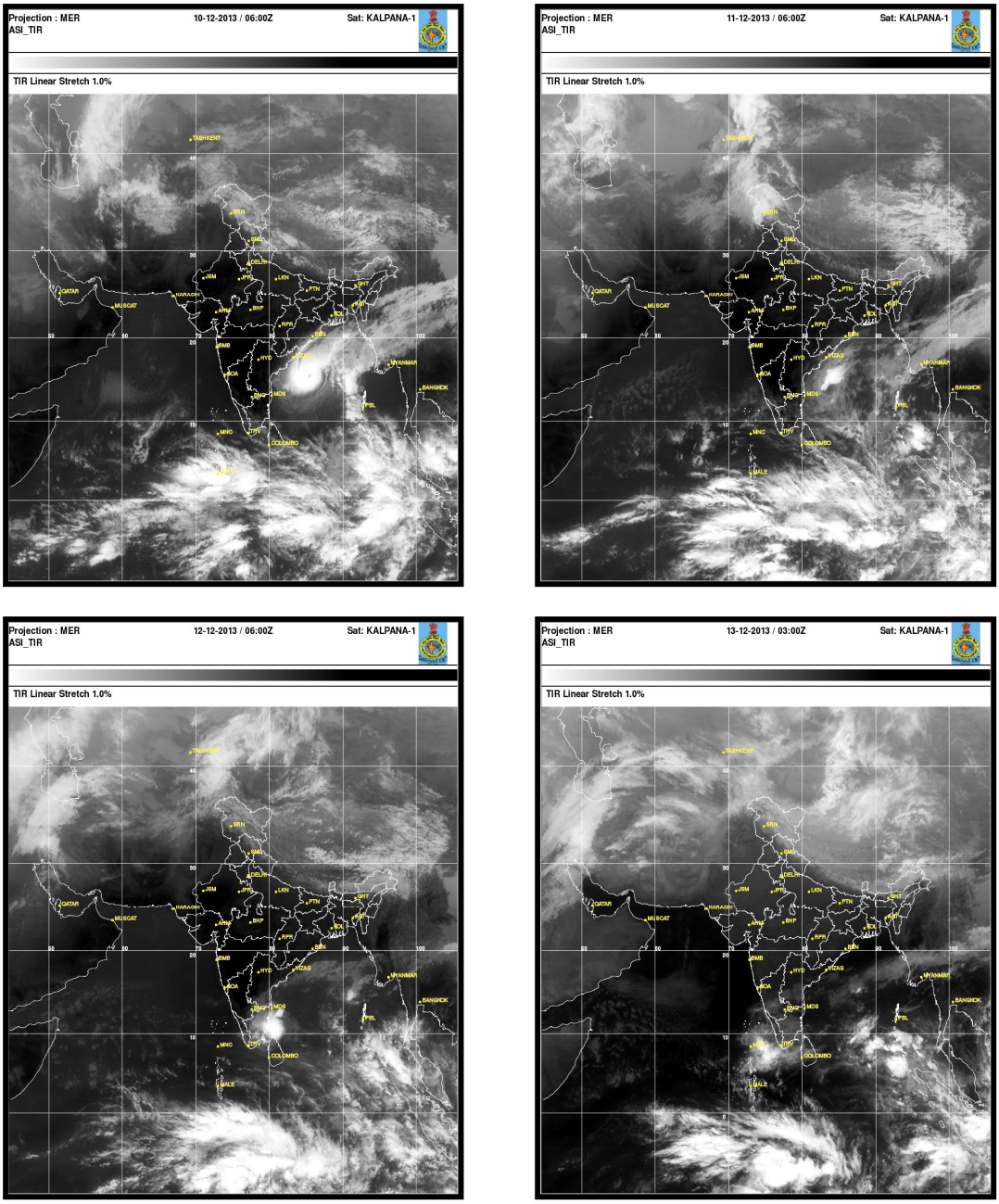
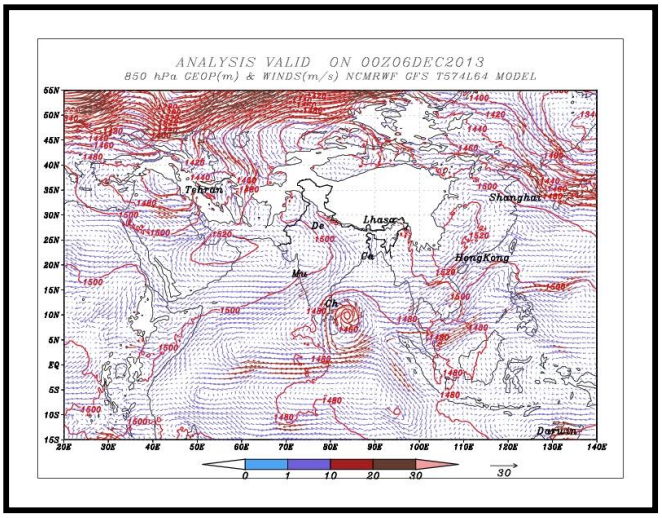
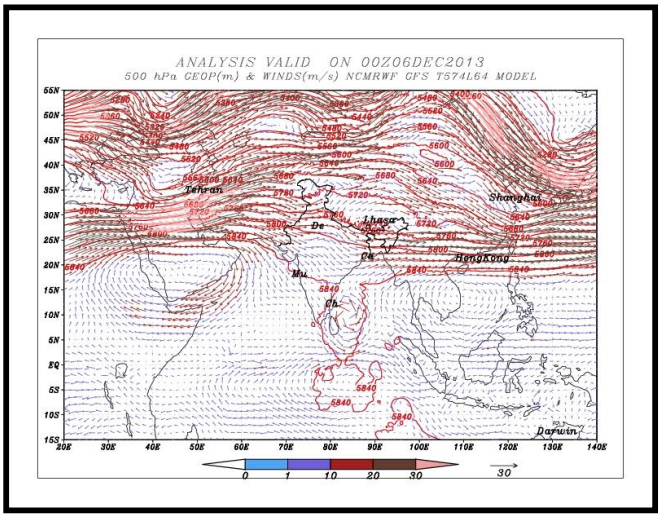


Fig.3 (b) Typical Kalpana-1 Satellite imageries of very severe cyclonic storm ôMADIô at 0600 UTC of 10th, 11th, 12th and 0300 UTC of 13th December 2013.





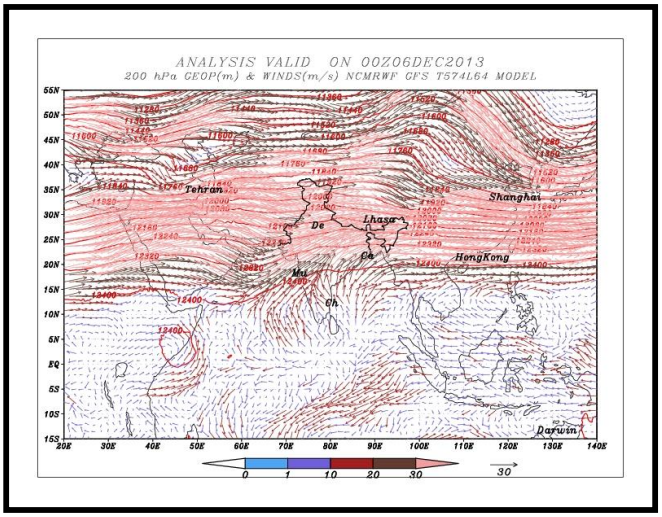
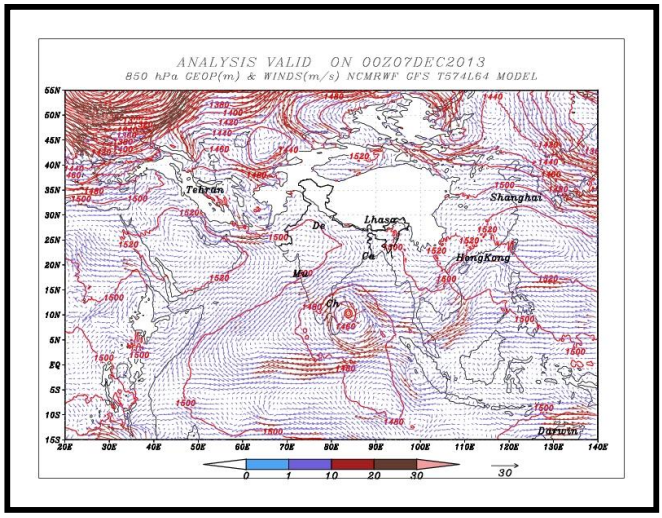
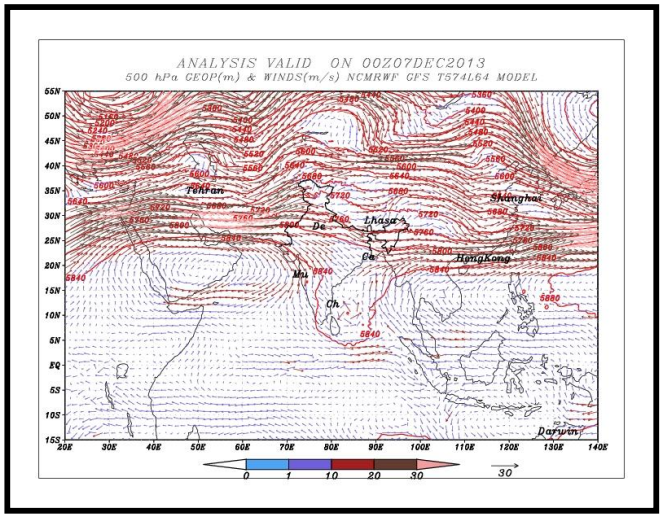


Fig. 4(a): NCMRWF GFS Analysis based on 00 UTC of 6th Dec. 2013 in association with VSCS MAADI





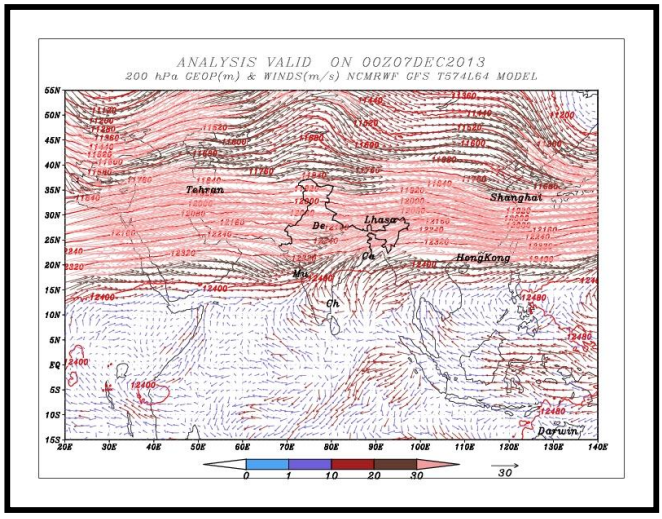
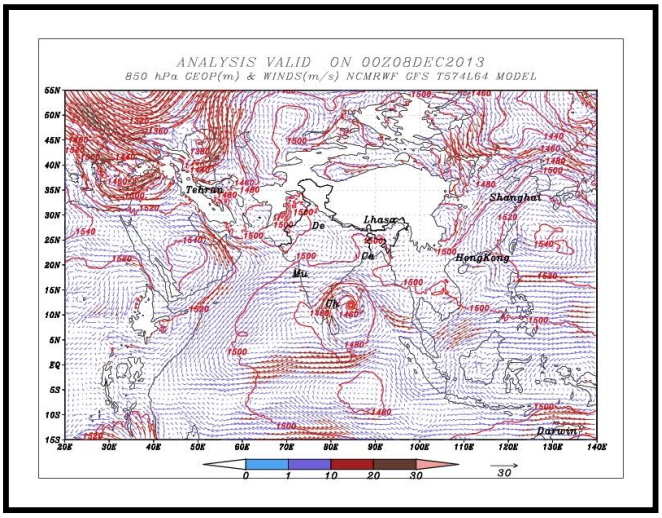
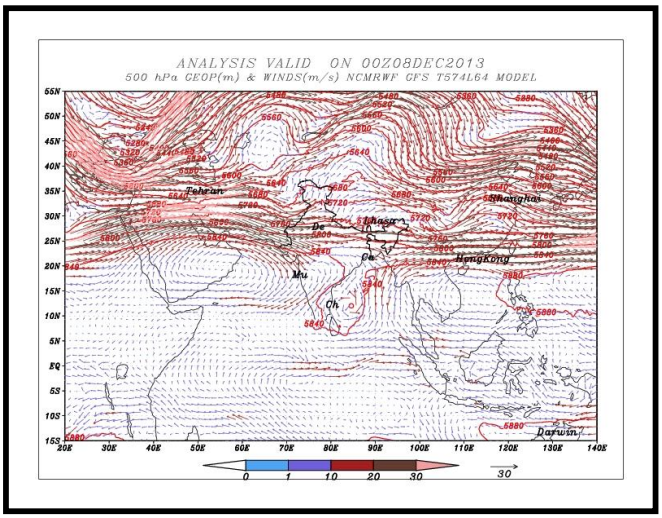


Fig 4(b): NCMRWF GFS Analysis based on 00 UTC of 7th Dec. 2013 in association with VSCS MAADI





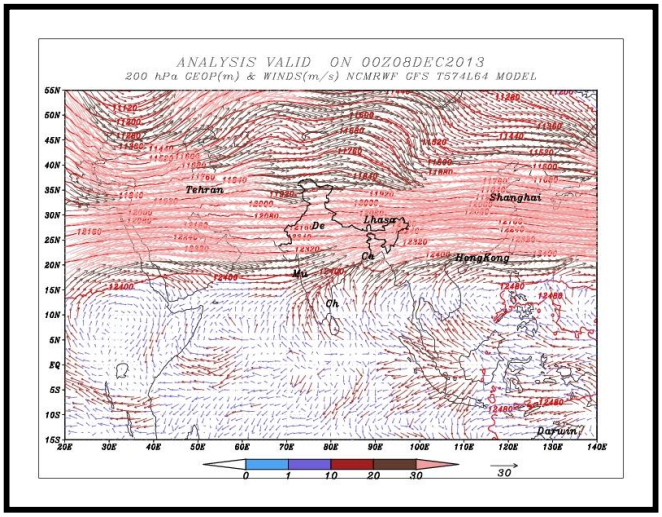
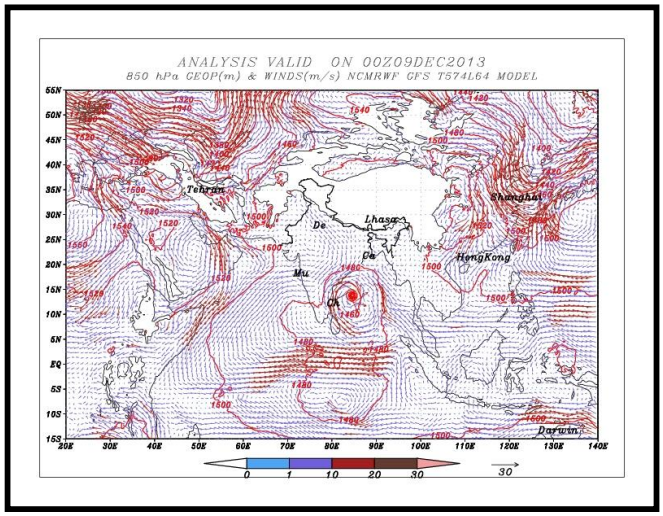
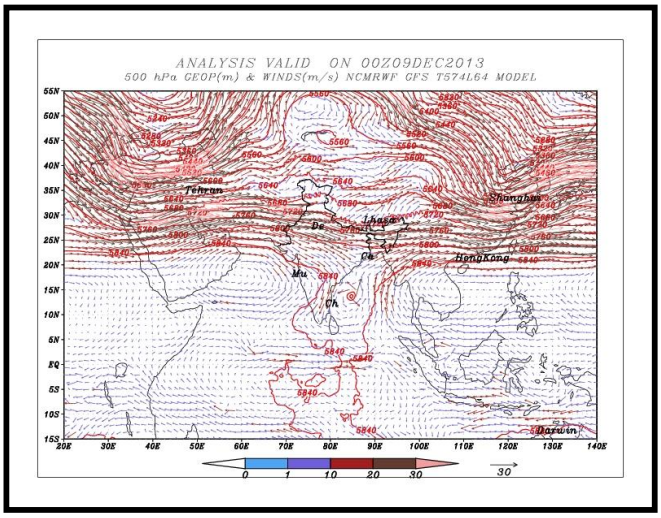


Fig 4(c): NCMRWF GFS Analysis based on 00 UTC of 8th Dec. 2013 in association with VSCS MAADI





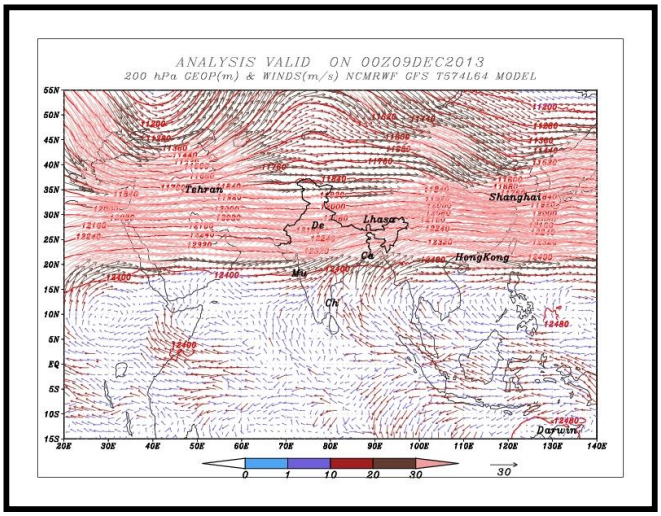
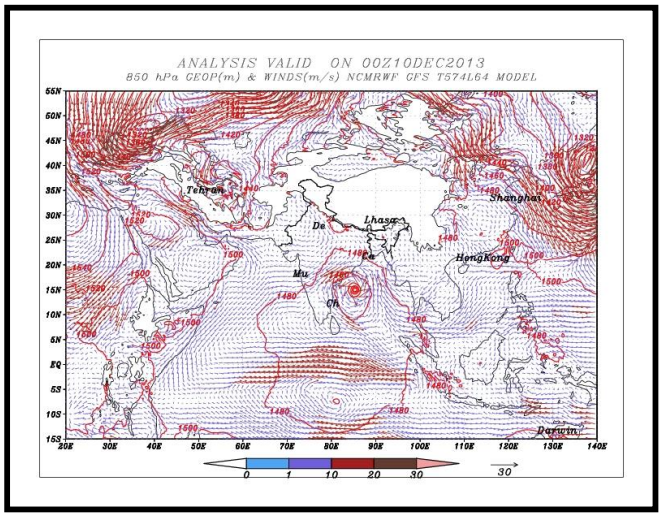
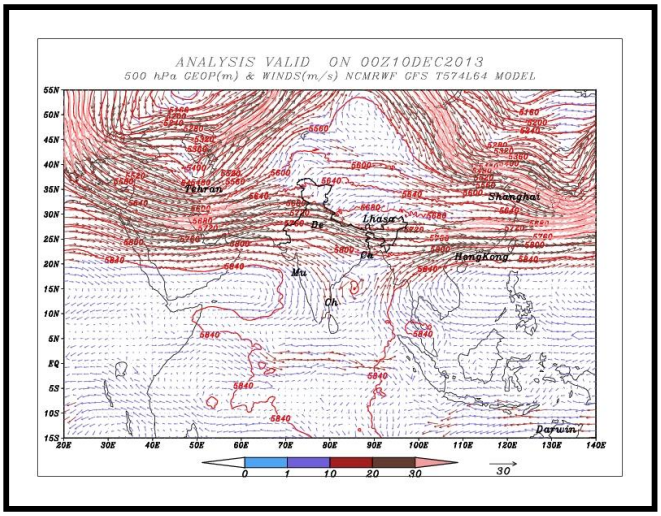


Fig 4(d): NCMRWF GFS Analysis based on 00 UTC of 9th Dec. 2013 in association with VSCS MAADI





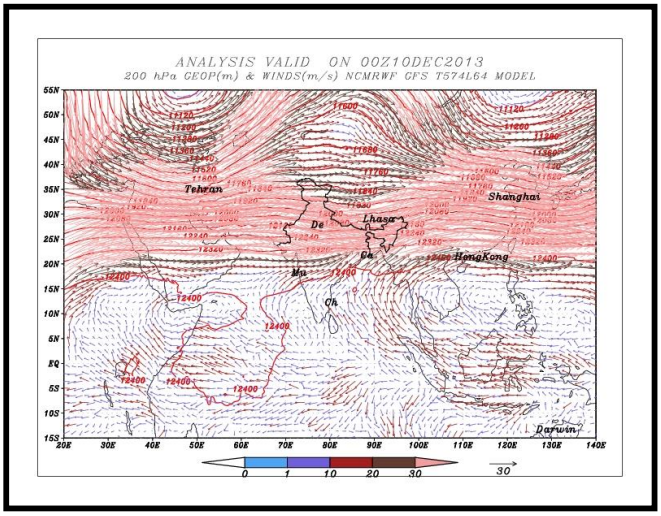
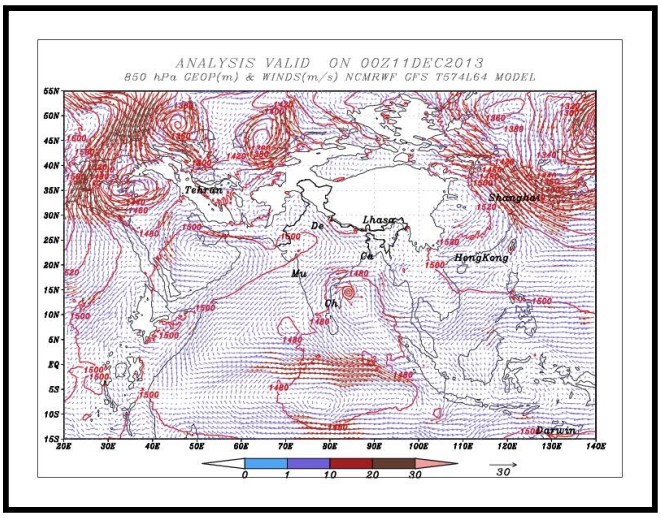
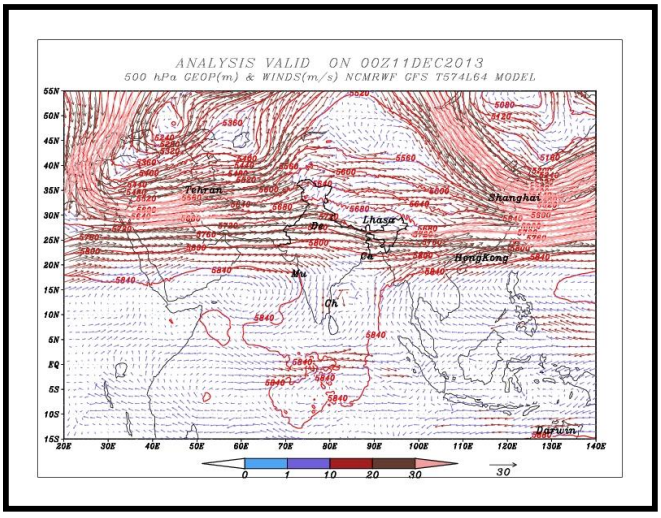


Fig 4(e): NCMRWF GFS Analysis based on 00 UTC of 10th Dec. 2013 in association with VSCS MAADI





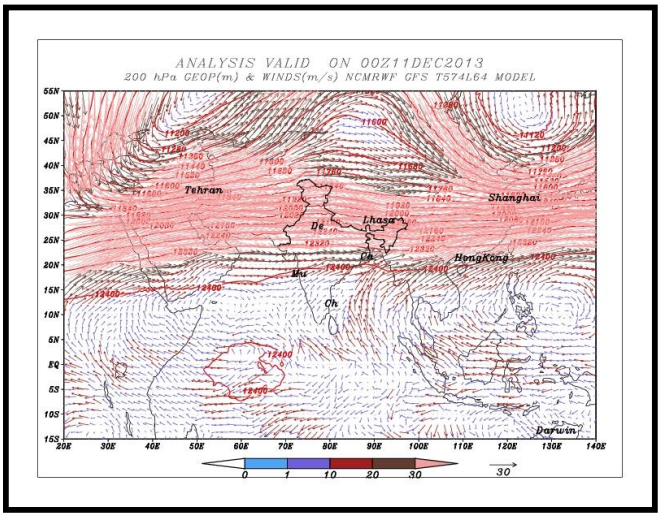
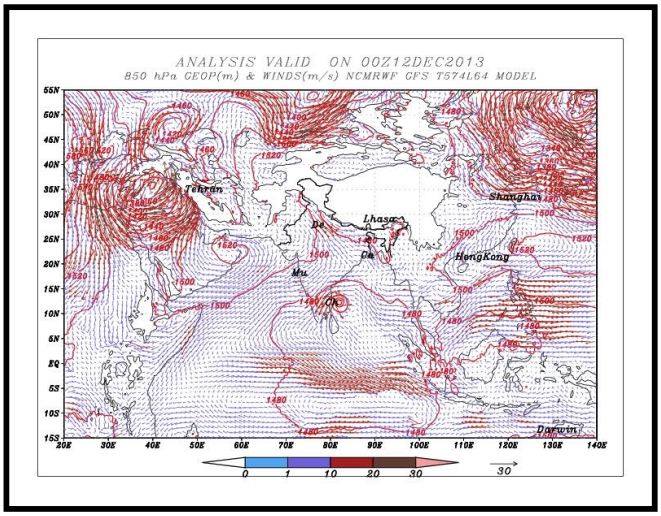
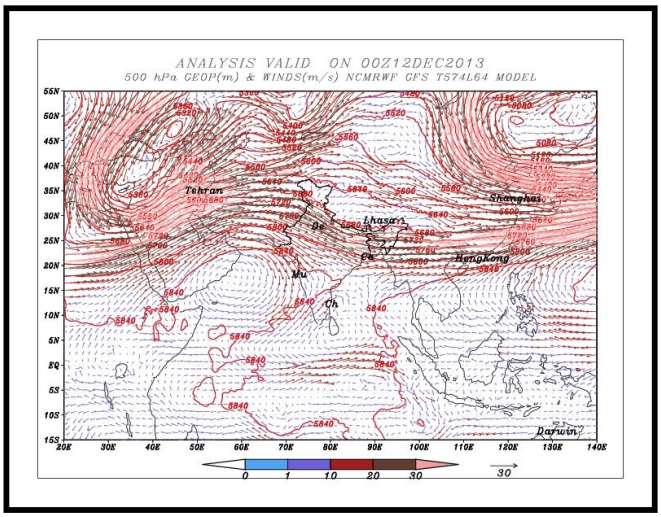


Fig 4(f): NCMRWF GFS Analysis based on 00 UTC of 11th Dec. 2013 in association with VSCS MAADI





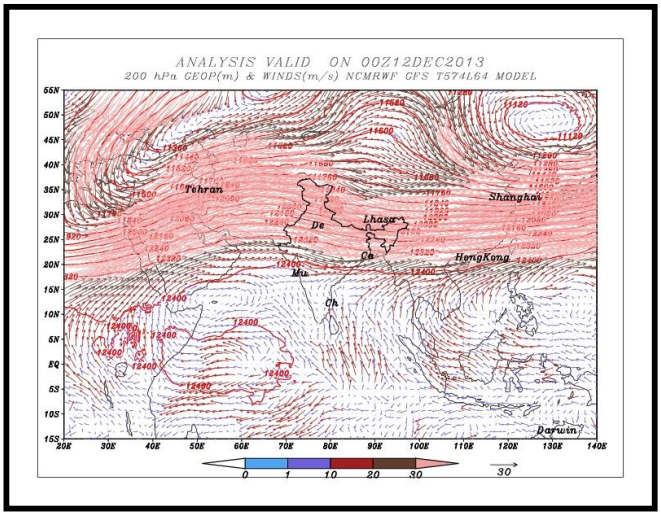
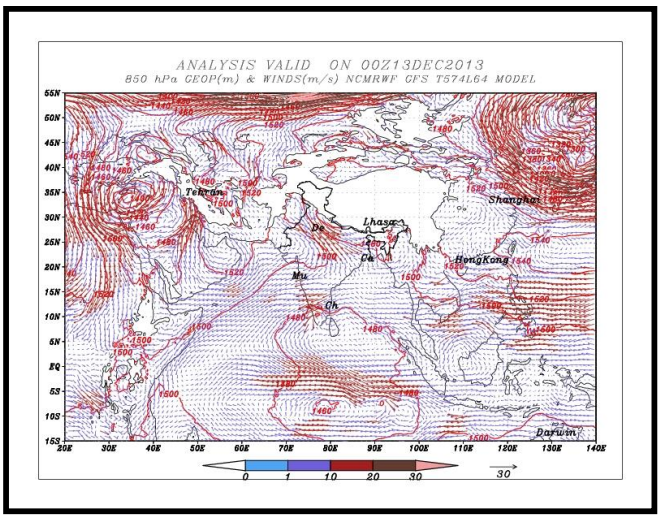
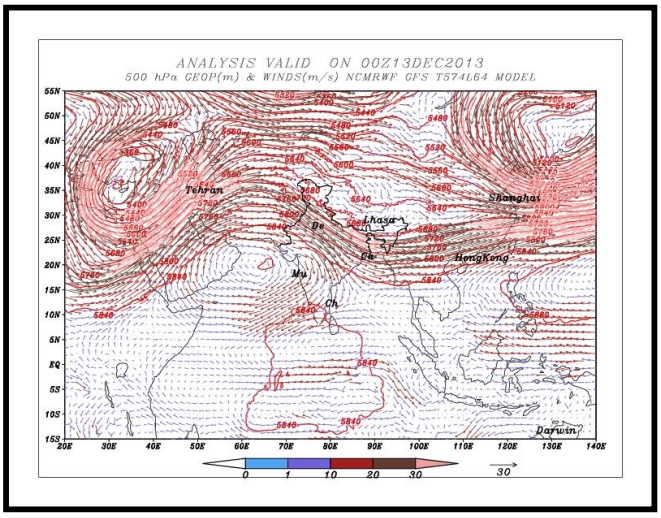


Fig 4(g): NCMRWF GFS Analysis based on 00 UTC of 12th Dec. 2013 in association with VSCS MAADI





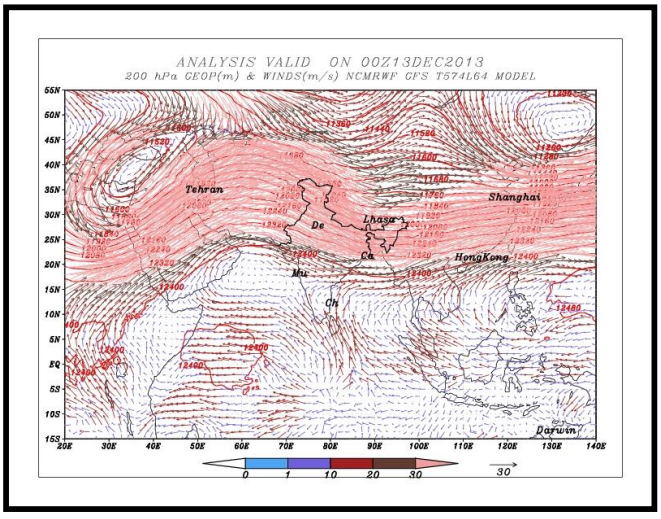


Fig 4(h): NCMRWF GFS Analysis based on 00 UTC of 13th Dec. 2013 in association with VSCS MAADI

5. Warning services

The Cyclone Warning Division/ Regional Specialised Meteorological Centre (RSMC)-Tropical Cyclone, IMD, New Delhi mobilised all its resources for monitoring and prediction of cyclonic storm, **MADI**. It issued 3/6 hourly warning/advisory bulletins to national disaster management agencies. It issued forecast and warning bulletins to various national and international disaster management agencies including National Disaster Management (NDM), Ministry of Home Affairs (MHA), National Disaster Management Authority, concerned state Govts. and other users in regular intervals. It also issued advisories to World Meteorological Organisation (WMO)/Economic and Social Cooperation for Asia and the Pacific (ESCAP) Panel member countries including Bangladesh, Myanmar, Thailand, Pakistan, Oman, Sri Lanka and Maldives. As Tropical Cyclone Advisory Centre (TCAC), it also issued tropical cyclone advisories with effect from the stage of deep depression for international civil aviation purpose as per the requirement of International Civil Aviation Organization (ICAO). The TCAC bulletin was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong like previous year.

The cone of uncertainty in the track forecast was given. The radius of maximum wind and radius of Ó34 knots, Ó50 knots and Ó64 knots wind in four quadrants of cyclone was issued 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 IMD's website regularly. The prognostics and diagnostics of the systems were described in the special tropical weather outlook and tropical cyclone advisory bulletins. Tropical cyclone vitals were prepared every six hourly from deep depression stage onwards and provided to various NWP modeling groups in India for synthetic vortex generation in NWP models.

The numbered warning bulletins were issued by Cyclone Warning division, IMD, New Delhi since 06th December, 2013. The bulletins were issued every three hourly since the cyclonic storm stage, i.e. from early morning of 07th December,2013. The number of bulletins issued by the Regional Specialised Meteorological Centre and Cyclone Warning Division, New Delhi, are given below:

Table 2. Statistics of bulletins issued during VSCS, MADI

S.N.	Bulletins	No. of Bulletins
1	Press Release	6
2	National Bulletin	47
3	RSMC Bulletin	44
4	TCAC Bulletin (Text & Graphics)	19
5	ADRR Bulletin to Hong Kong	19
6	TC Vitals	18
7	Quadrant Wind forecast	18
8	Frequency of SMS to senior Govt. officials at national and state level	8 times

In addition, special e-mails about the cyclone were also sent to all concerned offices. The warning bulletins were issued to various disaster management agencies in the national level and to Govt. of Andaman & Nicobar Islands, Andhra Pradesh, Odisha and Tamil Nadu states. Bulletins issued by CWCs and ACWCs are given in Table 3.

Table.3 (a). No. of bulletins issued during VSCS 'MADI' by CWC Bhubaneswar

S. No.	Name of the Bulletin	Number of bulletins
1	Number of Informatory message issued	32
2	Number of Port Warning issued	31
3	Fishermen Warning	20
4	Press/AIR/Doordarshan/other TV Channel Bulletin issued	32

Table.3 (b). No. of bulletins issued during VSCS 'MADI' by CWC, Visakhapatnam		
S. No.	Name of Bulletin	No. of Bulletins
1.	Port warnings	9
2.	Fishermen Warning	24
3.	Coastal Bulletins (in addition to regular bulletins)	6
4.	Press Bulletins	1

6. Realised Weather:

Chief amounts of 24 hrs. Rainfall (7 cm or more) ending at 0300 UTC from 06th December to 14th December, 2013 are given below:

7th December - Nil

8th DECEMBER 2013

ANDAMAN & NICOBAR ISLANDS: Hut Bay-9,

9th DECEMBER 2013

ANDAMAN & NICOBAR ISLANDS: Port Blair-10,

10th DECEMBER 2013-Nil

11TH DECMBER 2013-NIL

12TH DECEMBER 2013-NIL

13th DECEMBER 2013

TAMILNADU & PUDUCHERRY: Colachel-11, Tindivanam-11, Kallakurichi-11, Eraniel-11, Cheyyur-11, Pondicherry-10, Ulundurpet-9, Virudhunagar-9, Attur-8, Airport Madurai-7, Tirumangalam-7, Vilupuram-7,

14TH DECEMBER 2013-NIL

7. Forecast verification

(a) Track forecast error and skill

In the first bulletin issued in the 06th December, 2013, when the system was a depression over Southwest Bay of Bengal, it was predicted that the system would intensify into a cyclonic storm and move nearly northward and then recurve north-northeastwards. In the 05th bulletin issued in the early morning of 07th December 2013, it was predicted that the system would intensify into a very severe cyclonic storm.

In the bulletin issued at 1130 UTC based on 0900 UTC observation of 08th December, 2013, it was predicted that the cyclone would recurve southwestwards from 10th night. Whereas the cyclone actually started recurving from 1200 UTC of 10th December, 2013.

Similarly the gradual weakening of the system over the sea after attaining the maximum intensity was predicted at 1930 UTC based on 1800 UTC observation maintaining weakening from 1800 UTC of 09th December, 2013. The cyclone actually started weakening from 1200 UTC of 09th December, 2013.

The average track forecast error is shown in Table 4. It was 89, 150 and 239 respectively for 24, 48 and 72 hrs. forecast against the long period average of 133, 254 and 376 km based on the *per*iod of 2008-2012 respectively.

Table.4. Operational track forecast error of 'MADI'

Lead Period (hrs)	Track Forecast Error in km	Long period average (2008-2012)
12	49.5 (21)	75.4
24	88.5 (19)	132.6
36	115.4 (17)	190.2
48	150.0 (17)	253.6
60	196.4 (15)	308.9
72	231.2 (13)	376.1
84	272.2 (11)	-
96	313.4 (9)	-
108	438.0 (7)	-
120	462.6 (4)	-

Table 5. Operational Track Forecast Skill (%)

Lead period (hrs)	Track forecast skill	Long period skill (2008-2012)
12	56.1	23.1
24	57.7	34.8
36	64.6	35.1
48	69.5	41.8
60	67.0	47.4
72	65.0	50.0
84	61.1	-

96	54.9	-
108	28.1	-
120	12.3	-

The track forecast skill was about 58%, 69% and 65% for 24, 48 and 72 hrs forecast respectively. They were significantly higher than long period average (Table 5).

(b) Intensity forecast error

The intensity forecast error (average absolute error (AAE) and root mean square error (RMSE)) of IMD for very severe cyclonic storm, MADI are shown in Table 6. The AAE was about 07, 09 & 07 knots against the long period average of 10,13 and 19 knots based on the period of 2008-2012. The RMSE was about 08, 10 and 10 knots against the long period average of 13, 18 and 24 knots. Hence, both the AAE and RMSE are below the long period average. The skill of intensity forecast compared to persistence forecast is shown in Table 7. The skill varied from 23% for 12 hrs to 89% for 120 hrs forecast.

Table 6. Operational average intensity forecast error of 'MADI'

Lead Period	Intensity Forecast Error (knots)		Long period Average (2008-2012):Absolute Error (knots)	Long period Average (2008-2012): RMS Error (knots)
	Absolute error	Root mean square error		
12	5.0 (23)	6.5 (23)	7.3	9.9
24	6.6 (21)	8.1 (21)	10.4	13.5
36	8.8 (19)	10.6 (19)	12.7	16.1
48	8.7 (17)	9.9 (17)	13.4	17.8
60	7.5 (15)	8.9 (15)	13.4	15.3
72	7.3 (13)	9.8 (13)	19.0	24.0
84	9.0 (11)	11.8 (11)	-	-
96	11.3 (09)	13.0 (09)	-	-
108	14.8 (07)	15.2 (07)	-	-
120	14.2 (05)	14.4 (05)	-	-

Table 7. Operational Intensity Forecast skill (%)

Lead period (hrs)	Skill in term of Absolute Error (%)	Skill in term of RMS Error (%)
12	23.1	16.5
24	45.5	44.9
36	53.2	53.3
48	67.9	68.9
60	80.8	80.1
72	84.9	83.7
84	87.3	85.5
96	88.0	87.6
108	87.7	88.3
120	89.1	89.7

(c) Rainfall forecast

The heavy rainfall warning issued by IMD along with the actual heavy rainfall is given in Table 8.

Table 8. Verification of heavy rainfall warning issued by IMD

Date & time	Warning issued	24 hr heavy rainfall realised at 0300UTC of date
06th December 0300 UTC	Isolated heavy falls r Andaman and Nicobar Island during next 72 hours.	**07th December- Nil** **08TH December, 2013 Isolated Heavy rainfall**- Andaman & Nicobar **09TH December, 2013 Isolated Heavy rainfall**- Andaman & Nicobar **10th , 11th & 12th December – Nil** **13th December, 2013** **Isolated heavy rainfall -** Tamil Nadu & Puducherry **14th December – Nil**
07th December 0300 UTC	NIL	
08th December 0300 UTC	NIL	
09th December 0300 UTC	NIL	
10th December 0300 UTC	NIL	
11th December 0300 UTC	Isolated places over coastal Tamil Nadu and Puducherry during next 48 hours.	
12th December 0000 UTC	Isolated places over coastal Tamil Nadu and Puducherry during next 48 hours.	
13th December 0000 UTC	Isolated places over Lakshadweep during next 24 hours.	

(d) Squally wind forecast

The Squally wind forecast issued by IMD along with the actual Squally wind is given in Table 9

Table 9. Verification of Squally windl warning issued by IMD		
Date & time	Warning issued	Realised wind (kmph)
12th December 0900 UTC	Squally wind speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Tamil Nadu and Puducherry coasts during next 24 hrs.	South coastal Tamil Nadu experienced squally wind of 40 ï 50 kmph at the time of landfall. Tondi: 46 kmph
12th December 1200 UTC	Squally wind speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Tamil Nadu and Puducherry coasts during next 24 hrs.	
12th December 1800 UTC	Squally wind speed reaching 45-55 kmph gusting to 65 kmph would prevail along and off Tamil Nadu and Puducherry coasts during next 12 hrs.	
13th December 0000 UTC	Strong surface wind speed reaching 40-50 kmph gusting to 60 kmph would prevail over Lakshadweep area and along off Kerala coast during next 24 hrs.	

(e) Storm surge forecast

No storm surge was predicted due to this system and no surge was also reported along the Tamil Nadu and Puducherry coast.

8. Damage: No damage has been reported due to this system

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