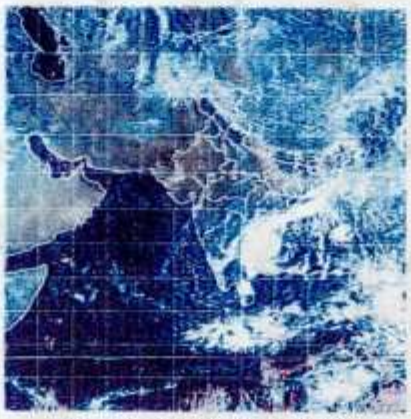
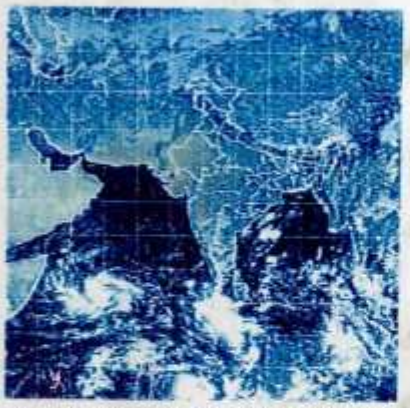
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

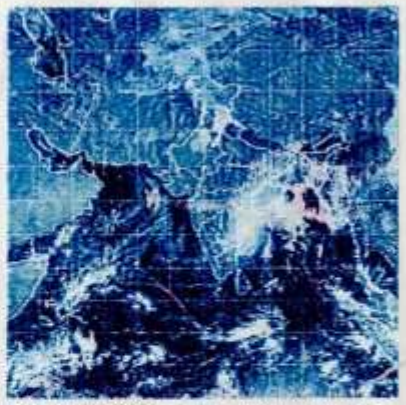
REPORT ON CYCLONIC DISTURBANCES OVER NORTH INDIAN OCEAN DURING 2003



INSAT imagery of May cyclone
(0600 UTC on 14th May 2003)



INSAT imagery of November cyclone
(0600UTC on 12th November ,2003)



INSAT imagery of December cyclone
(0600 UTC on 15th December,2003)

RSMC-TROPICAL CYCLONES NEW DELHI

JANUARY, 2004

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CONTENTS

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INTRODUCTION

Regional Meteorological Centre (RMC) New Delhi was re-designated as Regional Specialized Meteorological Centre (RSMC) - Tropical Cyclones New Delhi with effect from July 1988 and was assigned the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the WMO/ESCAP Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Maldives, Myanmar, Sultanate of Oman, Pakistan, Sri Lanka and Thailand.

Cyclone warning Division

As per the recommendations of the Cyclone Review Committee (CRC) a Cyclone Warning Directorate co-located with RSMC Tropical Cyclones - New Delhi, was established in 1990 in the India Meteorological Department's (IMD) HQ, New Delhi to co-ordinate and supervise the cyclone warning work in the country.

Functions

The broad functions of the Cyclone Warning Division and RSMC Tropical Cyclones New Delhi are as follows:

1) Round the clock watch over weather situations over the entire North Indian Ocean.
2) Analysis and processing of global meteorological data for diagnostic and prediction purposes.
3) Detection, tracking and prediction of cyclonic storms in the Bay of Bengal and the Arabian Sea.
4) Running of numerical models for tropical track prediction.
5) Interaction with Disaster Management Agencies to provide timely information and warnings for emergency support services.
6) Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel.
7) Issue of Tropical Weather Outlook to the Panel countries once daily (at 0600 UTC), an additional outlook at 1700 UTC in the event of a depression which is likely to intensify into a cyclonic storm and cyclone advisories to the Panel countries at 3 - hourly intervals .
8) Issue of Tropical cyclone Advisories for International Aviation at 6 - hourly intervals.
9) Exchange of composite data and bulletins pertaining to cyclonic storms with Panel countries.
10) Collection, processing and archival of all data pertaining to cyclonic storms viz. wind, storm surge, pressure, rainfall, satellite information etc.

11) Preparation of comprehensive annual reports on cyclonic storms and tropical depressions over North Indian Ocean every year.
12) Research on storm surge, track and intensity prediction techniques.

CHAPTER 1

Activities of Regional Specialized Meteorological Centre – Tropical Cyclones New Delhi

Area of responsibility

The area of responsibility of RSMC Tropical cyclones New Delhi (hereafter referred to as RSMC New Delhi) covers sea areas of North Indian Ocean north of equator between 45^0 E to 100^0 E and includes the member countries of WMO/ESCAP Panel on Tropical Cyclones viz, Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman and Thailand as shown in fig. 1.1. The Centre issues Tropical Weather Outlook daily at 0600 UTC and Cyclone Advisories on tropical cyclones (at three hourly interval) when they develop over the north Indian Ocean. Recently RSMC New Delhi has commenced the practice of issuing Tropical cyclone Advisories for Aviation as per ICAO requirements.

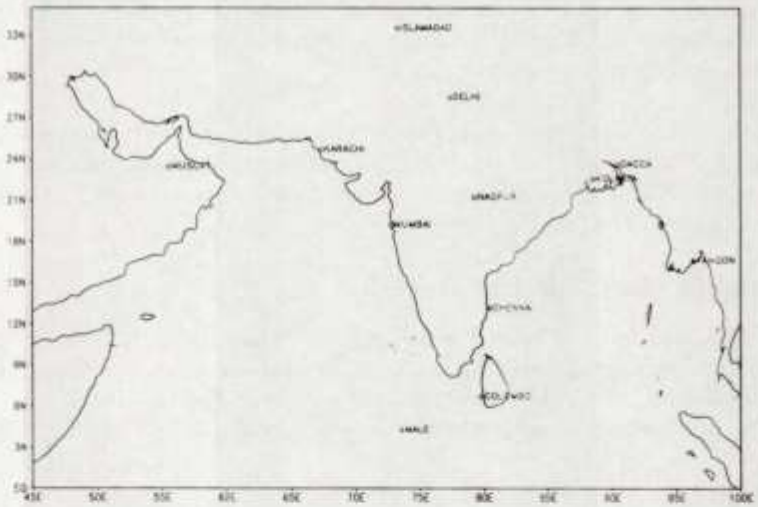


Figure 1.1 Area of responsibility of RSMC New Delhi

Analysis

Surface analysis of tropical disturbances is performed five times daily at 00, 03, 06, 12, and 18 UTC. During cyclone period synoptic charts are being prepared every three hour and analysed to monitor the tropical cyclonic storms that form over the North Indian Ocean within the area of responsibility of RSMC New Delhi.

Cloud images from Geostationary Meteorological Satellites INSAT - 3A and METSAT (Kalpana-1) are the main source of information for the analysis of tropical cyclones over the data-sparse region of North Indian Ocean. The direction and speed of the movement of a tropical cyclone are determined primarily from the three hourly displacement vectors of the centre position and inputs from various numerical models. When the system comes closer to the coastline, the system location and intensity are determined based on radar observations at hourly intervals.

Forecast

Limited Area Model (LAM)

A Quasi-Lagrangian Model (QLM) for cyclone track prediction has been in operational use at RSMC New Delhi. The QLM is a multilevel primitive equation fine-mesh model cast in the sigma coordinate system (σ = p/ps; pressure divided by surface pressure). The model has a limited area domain using a Cartesian grid. The horizontal grid spacing is 40 km and the integration domain covers an area of 4400x4400 km^2 which is centred on the initial position of the cyclone. The QLM uses 16 layers in the vertical. The model incorporates physical processes. Radiation and turbulent processes, which have only marginal impact in the development of Tropical Cyclones have been excluded to minimise computational time. The numerical integration of the model is carried out by using the so called Quasi-Lagrangian Model.

The model provides track forecasts upto 36 hours at present. The initial analysis and lateral boundary conditions are generated from operational analysis and forecasts produced by the global spectral model of National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi.

Global and Regional Spectral Model

A Regional Spectral Model based on the Florida State University has been installed in the computer system Origin-200. Successful test runs are conducted up to 72 hours forecast with European Centre for Medium Range Forecast (ECMWF) analysis data. Further test runs are being conducted with the analysis field of NCMRWF, New Delhi.

Storm Surge Modelling

For the operational storm surge prediction, India Meteorological Department (IMD) has been using nomograms developed by IMD. The nomograms are based on the numerical solution to the hydrodynamical equation s governing motion of the sea. The nomograms are prepared relating peak surge with various parameters such as pressure drop, radius of maximum winds, vector motion of the cyclone and offshore bathymetry. The performance of these techniques as seen operationally over the years has been reasonably good.

IMD also uses PC based storm surge model developed by IIT Delhi . The model is fully non-linear and is forced by wind stress and quadratic bottom friction following the method of numerical solution of the vertically integrated mass continuity and momentum equations. The method uses a conditionally stable semi-implicit finite difference scheme with staggered grid for numerical solution of the model equations. The bottom stress is computed from the depth-integrated current using conditional quadratic equation. The bathymetry of the model is derived from Naval Hydrographic charts applying cubic spline technique.

Meteorological inputs for the model are pressure drop, radius of maximum winds, forecast landfall, speed and vector motion of the storm. The coastal boundaries are taken as vertical side walls across which the normal transport vanishes. The normal current across the open sea boundaries is prescribed by a radiation type of boundary condition. It is assumed that the motion in the sea area is generated from initial state of rest.

Products generated by RSMC New Delhi

RSMC New Delhi prepares and disseminates the following RSMC bulletins via GTS and AFTN.

Tropical Weather Outlook

Tropical Weather Outlook is issued daily at 0600 UTC for use by the member Countries of WMO/ESCAP Panel. This contains description of synoptic systems over North Indian Ocean along with information on major cloud systems as seen in satellite imageries. In addition, a special weather outlook is also Issued at 17 UTC during situations when a tropical depression is expected to intensify and attain the cyclone intensity. These bulletins are transmitted through the Global Telecommunication System (GTS).

Global Maritime Distress Safety System

Under Global Maritime Distress Safety System (GMDSS) scheme, India has been designated as one of the 16 services in the world for Issuing sea area bulletins for broadcast through GMDSS for MET AREA VIII (N), which covers a large portion of North Indian Ocean. As a routine two GMDSS bulletins are issued at 0900 and 1800 UTC. During cyclone situation additional bulletins (up to 4) are being issued for GMDSS broadcast. In addition, coastal weather and warning bulletins are also issued for broadcast through NAVTEX transmitting stations located at Mumbai and Chennai.

Tropical Cyclone Advisories

Tropical cyclone advisories are issued at 3 hourly Interval. These bulletins contain the current position of the cyclone, expected direction and speed of movement, estimated central pressure and forecast of winds, squally weather and state of the sea in and around the system.

Tropical Cyclone Advisories for Aviation

The practice of issuing Tropical Cyclone Advisories for Aviation was introduced very recently. These bulletins are issued for Aviation as soon as any disturbance over the north Indian Ocean attains or likely to attain the intensity of Cyclonic Storm within next six hours (sustained Wind speed $\geq$ 34 knots). These bulletins are issued at six hourly intervals based on 00, 06, 12, 18 UTC synoptic charts and the time of issue will be H+O3 hrs. Tropical cyclone advisories are also made available on real time basis through internet at IMD's website: http://www.imd.emet.in

Satellite Activities

India has launched an exclusive Meteorological Geo-stationary Satellite METSAT, now named KALPANA-I, in September 2002 over the Indian Ocean purely for meteorological purposes. It provides satellite imageries in VIS, IR, and WV channels. In addition another Geo-stationary satellite under INSAT series (INSAT-3A) was launched in April, 2003 with the meteorological payloads identical to those of INSAT-2E. The INSAT-3A was made operational in May, 2003.

CHAPTER 2

1. Cyclonic Activities over North Indian Ocean during 2003

The North Indian Ocean witnessed development of seven disturbances (Table 1.1) out of which three systems attained the intensity of Cyclonic Storms viz., one Very Severe Cyclonic Storm and two Severe Cyclonic Storms. Remaining four systems were depressions out of which two became deep depressions. Tracks of the systems are given in fig. 1.2.

During this year, out of three cyclones, two developed in the Bay of Bengal and only one in the Arabian Sea. All the four depressions developed in the Bay of Bengal.

The first cyclone formed over southeast Bay of Bengal on 10 May. Moving initially in a northwesterly direction it subsequently recurved towards Myanmar coast and weakened into a deep depression. It re-intensified into a cyclonic storm and finally crossed Myanmar coast on 19 May. No damage occurred over the Indian Sub-continent because of this cyclone.

The Second system formed over the South West Arabian Sea at very low latitude (around 6^0 N) on 11 November. It attained the intensity of a Severe Cyclonic Storm on 13 November. This system moved westwards throughout its lifespan and dissipated over the sea itself off Somalia coast.

The third system formed over the Southeast Bay of Bengal during the period 11-16 December. This system attained the intensity of a Severe Cyclonic Storm on 14^{th}. Moving in a northwesterly direction it crossed the North Andhra Pradesh coast close to Machilipatnam (43185) as a Severe Cyclonic Storm. It caused extensive damage to life and property over central parts of costal Andhra Pradesh. The system weakened rapidly over north coastal Andhra Pradesh and adjoining Orissa.

One of the notable features is that the frequency of depressions is higher this year compared to the last three years though the total number of disturbances is much lower than the normal frequency of about 15 per year. Comprehensive information on Tropical Cyclone activity over the North Indian Ocean for last three years is given in table 1.2.

Table-1.1

List of cyclonic disturbances during 2003

1.	Very Severe Cyclonic Storm over Bay of Bengal, May 10-19
2.	Deep Depression over the Bay of Bengal, July 25-28
3.	Depression over the Bay of Bengal, August 27-28
4.	Depression over the Bay of Bengal, October 6-9
5.	Deep Depression over the Bay of Bengal, October 26-28
6.	Severe Cyclonic Storm over the Arabian Sea, November 12-15
7.	Severe Cyclonic Storm over the Bay of Bengal, December 11-16

Table 1.2

Year		D	DD	CS	SCS	VSCS	Total
2000	BOB	1		3		2	6
	ARB	--	--	--	--	--	-
2001	BOB	2	--	1	--	--	3
	ARB	--	--	2	--	1	3
2002	BOB	1	1	2	1	--	5
	ARB	--	--	1	--	--	1
2003	BOB	2	2	--	1	1	6
	ARB	--	--	--	1	--	1

Some of the characteristic features of these seven cyclonic disturbances are given in Table 1.3. The statistical data pertaining to the monthly frequencies, total life time (days), frequency distribution (intensity-wise and basin-wise) are given in Table 1.4.

RSMC New Delhi mobilized all its resources, both technical and human, to track the tropical disturbances that formed over the North Indian Ocean and issued advisories to WMO / ESCAP Panel countries.

Table 1.3

Some Characteristic features of cyclonic disturbance during 2003 given in Table 1.1

Cyclonic Storm / Depression	Date, Time (UTC) & lat. (N) / long. (E) of genesis	Date, Time (UTC) & point of landfall	Estimated lowest central pressure, Date & Time (UTC).	Estimated Maximum wind speed (kt), Date & Time	Maximum T. No. attained
Very Severe Cyclonic Storm over the Bay of Bengal May, 10-19	May 10 at 0300 UTC near 6.0° N / 90.5° E	Crossed Myanmar coast north of Kyaukpyu around midnight of May, 19	980 hPa at 0600 UTC on May, 13	75 kt on May, 13 at 0600 UTC	4.5
Deep Depression over Bay of Bengal July, 25-28	July 25 at 0300 UTC near 21.0° N / 89.0° E	Crossed Orissa coast north of Balasore during the evening of July 25	988 hPa at 1200 UTC on July 25	30 kt on July ,25 at 1200 UTC	2.0
Depression over Bay of Bengal August, 27-28	August 27 at 1200 UTC near20.5° N/ 88.5° E	Crossed Orissa coast near Chandbali in the early morning of August, 28	996 hPa at 1200 UTC on August ,27	25 kt on August, 27 at 1200 UTC	1.5
Depression over Bay of Bengal October, 6-9	October 6 at 0300 UTC near 16.5° N/ 84.0° E	Crossed Orissa coast south of Kaligapatnam around 2100 UTC on October, 6	998 hPa at 0300 UTC on October, 6	25 kt on October, 6 at 0300 UTC	1.5
Deep Depression over Bay of Bengal October, 26-28	October 26 at 1200 UTC near 13.5° N/ 93.5° E	Crossed the coast north of Visakhapatnam around 1000 UTC on October, 28	1004 hPa at 0300 UTC on October, 27	30 kt on 27October, at 0300 UTC	2.0
Severe Cyclonic Storm over Arabian Sea, November , 12-15	November 12 at 0900 UTC near 6.5° N/ 61.0° E	Dissipated over south west Arabian Sea off Somalia in the morning of November, 16	990 hPa at 0900 UTC on November, 13	55 kt on November, 13 at 0900 UTC	3.5
Severe Cyclonic Storm over Bay of Bengal December, 11-16	December 11 at 1200 UTC near 4.5° N/ 90.5° E	Crossed the coast near Machilipatnam around 1800 UTC on December, 15	990 at 1200 UTC on December, 15	55 kt on December, 15 at 1200 UTC	3.5

Table -1.4

Statistical data relating to cyclonic disturbances in the North Indian Ocean during 2003

a) Monthly frequencies and total lifetime of cyclonic disturbances (CI ≥ 1.5)

S.No	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Life Time in (Days)
1.	D								↔		↔			1.0 & 3.4
2.	DD							↔			↔			3.0 & 1.8
3.	CS													
4.	SCS											↔	↔	3.4 & 4.8
5.	VSCS					↔								9.6
6.	SuCS													

Average Lifetime	**3.50 (days)**

b) Frequency distribution of Cyclonic disturbances of different intensities based on satellite assessment.

CI No.	≥2.0	≥2.5	≥3.0	≥4.0	≥5.0	≥6.0	≥7.0
No. Of Disturbances	5	3	3	1	-	-	-
No. of days with Cyclone Intensity	3.56	3.34	1.97	1.38	-	-	-

c) Basin-wise distribution of cyclonic disturbances

Bay of Bengal	**6**
Arabian Sea	**1**

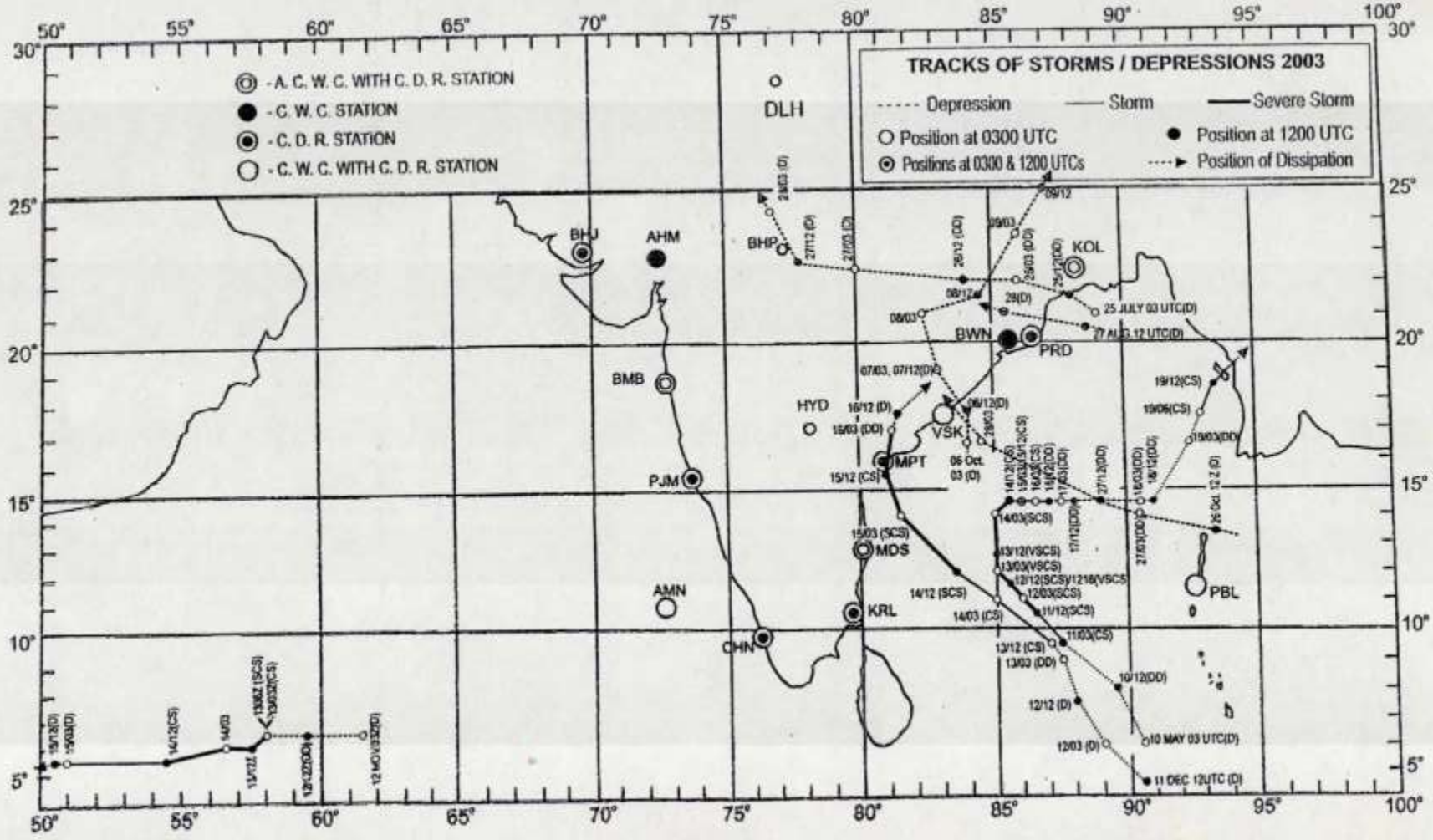

TRACKS OF STORMS / DEPRESSIONS 2003
Depression
Storm
Severe Storm
Position at 0300 UTC
Position at 1200 UTC
Positions at 0300 & 1200 UTCs
Position of Dissipation
- A. C. W. C. WITH C. D. R. STATION
- C. W. C. STATION
- C. D. R. STATION
- C. W. C. WITH C. D. R. STATION
DLH
BHJ
AHM
BHP
KOL
BWN
PRD
BMB
HYD
VSK
MPT
PJM
MDS
AMN
KRL
CHN
PBL
25 JULY 03 UTC(D)
10 MAY 03 UTC(D)
11 DEC 12UTC (D)
50°
55°
60°
65°
70°
75°
80°
85°
90°
95°
100°
30°
25°
20°
15°
10°
5°

Fig. 1-2

2. Brief Description of the Systems

2. 1 Very Severe Cyclonic Storm over the Bay of Bengal May 10-19, 2003

During the first week of May 2003 the equatorial trough in the North Indian Ocean was active between the equator and 5^0N latitude. It showed progressive northward movement. In this active equatorial trough a low pressure area developed over the southeast Bay of Bengal on 8 May that concentrated into a depression on 10^{th} morning when it lay centred near lat. 6.0^0 E / long. 90.5^0 E at 100300 UTC about 1400 km southeast of Chennai.

Moving northwestwards, it intensified into a Deep Depression near lat. 8.0^0 N/ long. 89.5^0 E at 101200 UTC. While continuing to move in the same direction the system further intensified into a Cyclonic Storm at 110000 UTC and lay centred near lat.9.0^0 N/long. 88.5^0 E. It attained the intensity of a Severe Cyclonic Storm when it was located near lat. 10.5^0 N / long. 86.5^0 E at 111200 UTC. The system continued to move northwestwards till 120900 UTC when it was located near lat. 11.0^0 N / long. 86.0^0 E.

The movement of the Severe Cyclonic Storm slowed down due to the influence of the middle tropospheric ridge line close to the system centre. In the process, the system further intensified into a Very Severe Cyclonic Storm and lay centred near lat. 11.5^0 N /long. 85.5^0 E. Thereafter, it started moving in a northerly direction and had the lowest estimated central pressure of 980 hPa at 132100 UTC. The system remained practically stationary but weakened into a Cyclonic Storm rather fast on 14^{th} when it lay centred near lat. 14.0^0 N / long. 85.5^0 E at 1200 UTC. Moving slowly eastwards it became a deep depression at 161200 UTC near lat. 14.5^0 N/ long.87.0° E. It maintained eastward course until 181200 UTC. It started moving in a northeasterly direction from 190300UTC and re-intensified into a Cyclonic Storm near lat. 17.5^0 N / long 93.0^0E at 190600 UTC. Under the influence of a mid- tropospheric anticyclone located to the east, the system subsequently moved northeastwards and was located at 191200 UTC near lat. 18.5^0 N/ long. 93.5^0 E. Maintaining the same direction of movement, the system crossed Myanmar coast north of Kyaukpyu (480711) around midnight of 19 May. After landfall, the system gradually weakened into a Deep Depression and further into a depression over Myanmar the next day.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.1.1. A few INSAT cloud images of the system are given in fig. 2.1.1

Weather realized

No adverse weather was experienced over the Indian sub-continent as the system moved far away from the Indian coastline. However some significant rainfall in association with the system occurred over Andaman & Nicobar Islands on 11th.

Damage

As the system moved far away from the Indian coast line, no damage was reported to the Indian coastline. Report from Myanmar is awaited.

Table 2.1.1
Best track positions and other parameters for the Bay of Bengal Very Severe Cyclonic Storm May 10-19, 2003

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
10.5.2003	03	6.0/90.5	1.5	1002	25	-	**D**
	06	6.0/ 90.5	1.5	1002	25	-	D
	09	7.0/90.5	1.5	1002	25	-	D
	12	8.0/89.5	2.0	1002	30	4	**DD**
	15	8.0/89.5	2.0	1000	30	4	DD
	18	8.5/89.0	2.0	1000	30	4	DD
	21	8.5/89.0	2.0	1000	30	4	DD
11.5.2003	00	9.0/88.5	2.5	1000	35	6	**CS**
	03	9.5/87.5	2.5	998	35	6	CS
	06	10.0/87.0	2.5	998	35	6	CS
	09	10.0/87.0	3.0	998	45	10	CS
	12	10.5/86.5	3.5	990	55	14	**SCS**
	15	10.5/86.5	3.5	990	55	14	SCS
	18	11.0/86.0	3.5	990	55	14	SCS
	21	11.0/86.0	3.5	986	55	16	SCS
12.5.2003	00	11.0/86.0	3.5	986	55	16	SCS
	03	11.0/86.0	3.5	986	55	16	SCS
	06	11.0/86.0	3.5	986	55	16	SCS
	09	11.0/86.0	3.5	986	55	16	SCS
	12	11.5/85.5	3.5	986	55	16	SCS
	15	11.5/85.5	3.5	986	55	16	SCS
	18	11.5/85.5	4.0	982	65	20	**VSCS**
	21	11.5/85.5	4.0	982	65	20	VSCS
13.5.2003	00	11.5/85.5	4.0	982	65	20	VSCS
	03	12.0/85.0	4.0	982	65	20	VSCS
	06	12.5/85.0	4.5	980	75	28	VSCS
	09	12.5/85.0	4.5	980	75	28	VSCS
	12	12.5/85.0	4.0	982	65	20	VSCS
	15	12.5/85.0	4.0	982	65	20	VSCS
	18	13.0/85.0	4.0	982	65	20	VSCS
	21	13.0/85.0	4.0	982	65	20	VSCS
14.5.2003	00	13.5/85.0	4.0	980	65	22	VSCS
	03	14.0/85.0	4.0	982	65	20	**SCS**
	06	14.0/85.0	3.5	986	55	16	SCS
	09	14.5/85.5	3.5	986	55	14	SCS
	12	14.5/85.5	3.0	990	45	10	**CS**
	15	14.5/85.5	2.5	990	35	6	CS

Table 2.1.1 (Contd)

Best track positions and other parameters for the Bay of Bengal Very Severe Cyclonic Storm May 10-19, 2003

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
14.5.2003	18	14.5/85.5	2.5	994	35	6	CS
	21	14.5/86.0	2.5	994	35	6	CS
15.5.2003	00	14.5/86.0	2.5	992	35	6	CS
	03	14.5/86.0	2.5	994	35	6	CS
	06	14.5/86.0	2.5	994	35	6	CS
	09	14.5/86.0	2.5	994	35	6	CS
	12	14.5/86.0	2.5	994	35	6	CS
	15	14.5/86.0	2.5	994	35	6	CS
	18	14.5/86.0	2.5	994	35	6	CS
	21	14.5/86.0	2.5	994	35	6	CS
16.5.2003	00	14.5/86.0	2.5	994	35	6	CS
	03	14.5/86.5	2.5	996	35	6	CS
	06	14.5/86.5	2.5	996	35	6	CS
	09	14.5/86.5	2.5	996	35	6	CS
	12	14.5/87.0	2.0	996	30	4	DD
	15	14.5/87.0	2.0	996	30	4	DD
	18	14.5/87.0	2.0	996	30	4	DD
	21	14.5/87.0	2.0	996	30	4	DD
17.5.2003	00	14.5/87.0	2.0	996	30	4	DD
	03	14.5/87.5	2.0	998	30	4	DD
	06	14.5/87.5	2.0	998	30	4	DD
	09	14.5/87.5	2.0	998	30	4	DD
	12	14.5/88.0	2.0	998	30	4	DD
	15	14.5/88.5	2.0	998	30	4	DD
	18	14.5/89.0	2.0	998	30	4	DD
	21	14.5/89.5	2.0	998	30	4	DD
18.5.2003	00	14.5/90.0	2.0	1000	30	4	DD
	03	14.5/90.5	2.0	1000	30	4	DD
	06	14.5/90.5	2.0	1000	30	4	DD

12
66

Table 2.1.1 (Contd)

Best track positions and other parameters for the Bay of Bengal Very Severe Cyclonic Storm May 10-19, 2003

Date	Time (UTC)	Centre Lat. °N / Long. °E	C. I NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the centre (hPa)	Grade
18.5.2003	09	14.5/90.5	2.0	1000	30	4	DD
	12	14.5/91.0	2.0	998	30	4	DD
	15	14.5/91.0	2.0	998	30	4	DD
	18	15.0/91.5	2.0	998	30	4	DD
	21	15.5/91.5	2.0	998	30	4	DD
19.5.2003	00	16.0/92.0	2.0	998	30	4	DD
	03	16.5/92.5	2.0	998	30	4	DD,
	06	17.5/93.0	2.5	996	35	6	CS
	09	18.0/93.0	2.5	994	35	6	CS
	12	18.5/93.5	2.5	994	35	6	CS
	15	19.0/93.5	2.5	994	35	6	CS
	18	19.5/94.0	2.5	994	45	6	CS
	21	20.0/94.5	-	-	-	-	CS

Crossed Myanmar coast north of KYAUKPYU (48071) around midnight of 19 May, 2003.

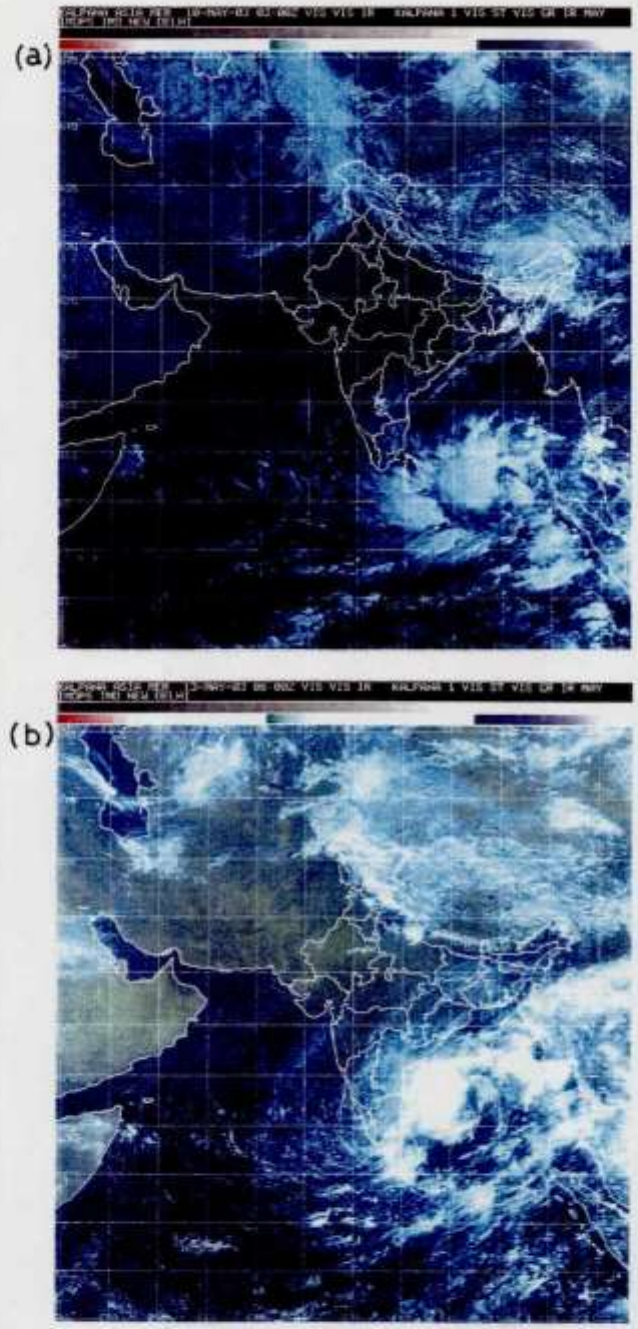
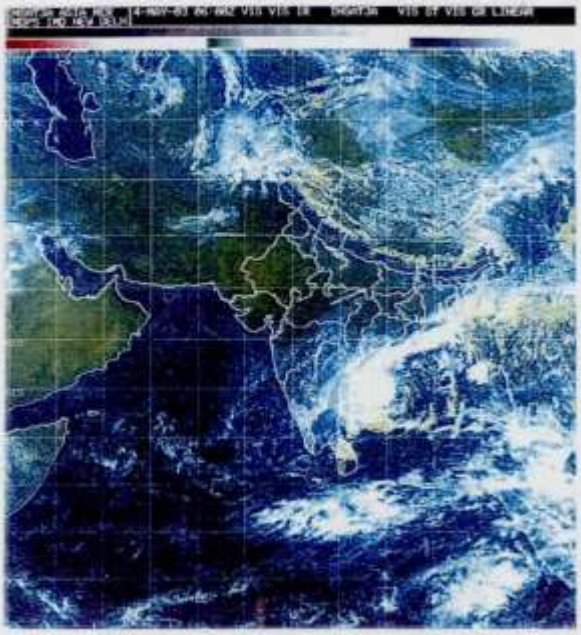


Fig. 2.1.1 Satellite picture showing cloudiness (a) in association with the Depression over southeast Bay of Bengal on May 10, 2003 and (b) a well developed spiral band cloud in the eastern sector when the system had intensified into a Very Severe Cyclonic Storm on 13 May, 2003.

(c)



(d)

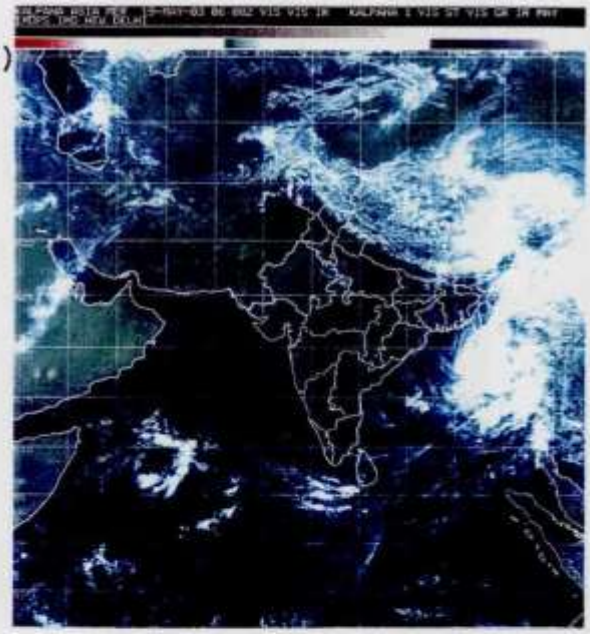


Fig. 2.1.1 (Cont) Satellite picture showing cloudiness associated with (c) the Very Severe Cyclone on 14 May, 2003 and (d) the re-intensification of the Deep Depression into a Cyclonic Storm on 19 May, 2003 when the system was heading for Myanmar coast.

2.2 Deep Depression over the Bay of Bengal 25-28 July, 2003

A low pressure area formed over Northwest Bay of Bengal on 24 July close to the south-eastern end of the monsoon trough. It concentrated into a Depression next day and lay centred near lat. 21.0^0 N / long. 89.0^0 E at 250300 UTC. Moving in a north-westerly direction along the monsoon trough it further intensified into a Deep Depression at 251200 UTC near lat.21.5° N / long. 88.0^0 E about 100 km east of Balasore (42895). It crossed Orissa coast north of Balasore in the evening of 25th and was centred near Keonjhargarh (42891) at 260300 UTC. While moving north-westwards the system weakened gradually into a low pressure area over south Rajasthan in the evening of 28th.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.2.1. A few INSAT cloud images of the system are given in fig. 2.2.1.

Weather realised

Under the Influence of the system widespread rainfall occurred over central parts of India. Isohyetal analysis of the cumulative rainfall (in cm) for the period 25-28 July is given in Fig 2.2.2.

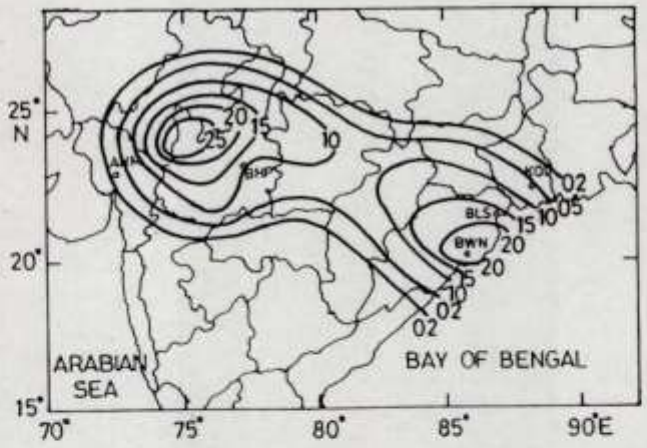


Fig 2.2.2.

Damage

No damage to life and property was reported.

Table 2.2.1

Best track positions and other parameters for the Bay of Bengal Deep Depression July, 25-28 2003

Date	Time (UTC)	Center 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
25.07.2003	0300	21.0 / 89.0	1.5	992	25	2	**D**
	1200	21.5 / 88.0	2.0	988	30	4	**DD**
		Crossed Orissa coast north of Balasore as a Deep Depression in the evening of July 25, 2003 .					
26.07.2003	0300	22.0 / 86.0	--	990	30	4	DD
	1200	22.0/ 84.0	--	988	30	4	DD
27.07.2003	0300	22.5 / 80.0	--	992	25	2	**D**
	1200	23.0 / 77.5	--	992	25	2	D
28.07.2003	0300	24.0 / 76.5	--	994	25	2	D

The system weakened into a low pressure area over south Rajasthan in the evening of July 28.

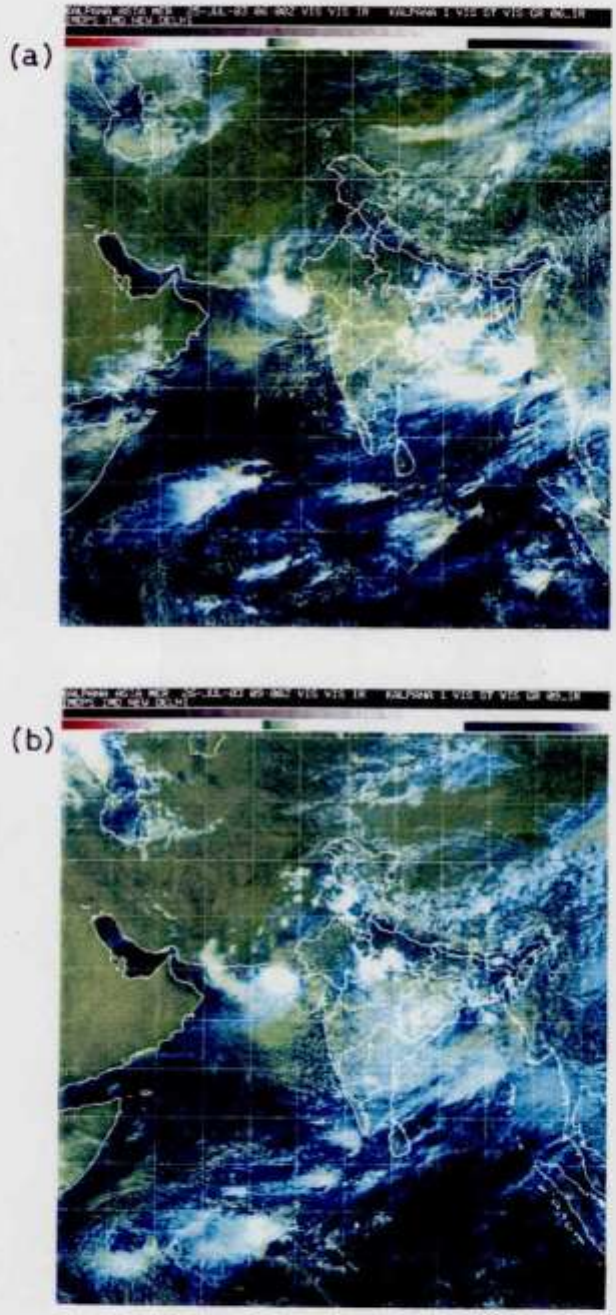
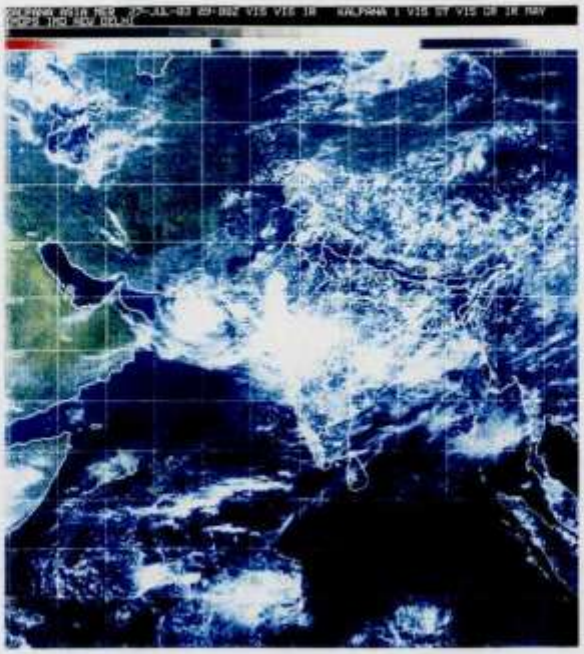


Fig. 2.2.1 Satellite picture showing (a) cloudiness in association with Depression over North Bay of Bengal on 25 July, 2003 (b) cloudiness with Deep Depression over east-central India on 26 July, 2003.

(c)



(d)

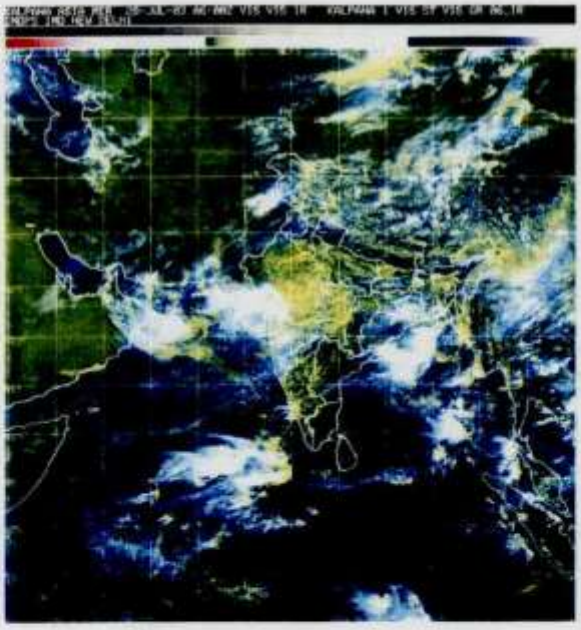


Fig. 2.2.1 (contd) Satellite picture showing (c) cloudiness over West Madhya Pradesh in association with Depression and also over north Bay of Bengal and north Arabian Sea in association of an active monsoon trough on 27 July, 2003 and (b) over western India and north Arabian Sea when the depression was located over Rajasthan on 28 July, 2003.

2.3 Depression over the Bay of Bengal 27-28 August, 2003

A low pressure area formed over Northwest Bay of Bengal coast near the southeastern end of the monsoon trough on 27 August. It concentrated into a Depression same day evening and lay centred near lat. 20.5 N/ long. 88.5 E at 271200 UTC about 150 km east of Chandbali (42973). The system moved in a west-north-westerly direction and crossed Orissa coast near Chandbali (43973) in the early morning hours of 28th and lay centred near Keonjhargarh (42891) in North Orissa at 280300 UTC. The system continued to move in a west-north-westerly direction and weakened into a low pressure area over east Madhya Pradesh and adjoining Chattisgarh on 29th morning.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.3.1. A few INSAT cloud images of the system are given in fig. 2.3.1.

Weather realised:

Under the influence of this system widespread rainfall occurred over Orissa and West Bengal. Isohyetal analysis of Cumulative Rainfall for the period 27-28 August is given in Fig 2.3.2.

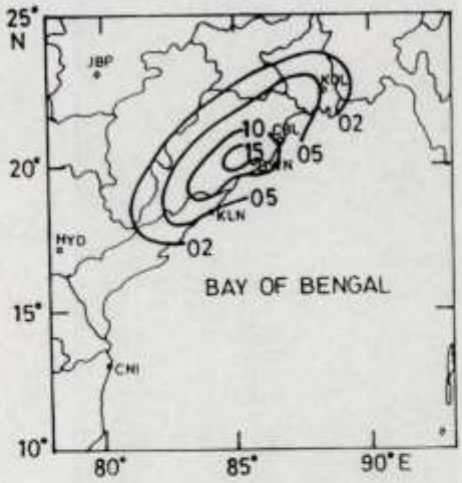


Fig. 2.3.2

Damage:

No damage was reported.

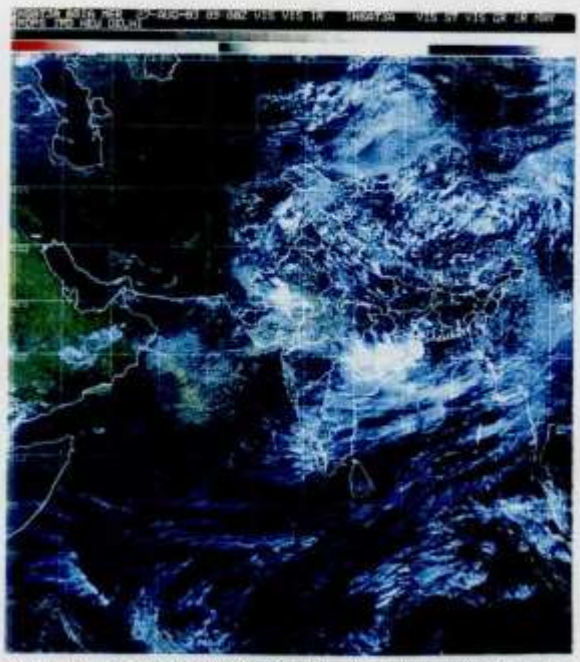
Table 2.3.1

Best track positions and other parameters for the Depression over Bay of Bengal from August 27-28, 2003

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
27.08.2003	1200	20.5/88.5	1.5	996	25	4	**D**
28.08.2003	0300	21.0/85.5	---	996	25	4	D
	1200	21.0/85.5	---	996	25	4	D

The System crossed Orissa coast near Chandbali during early morning of 28th August.

(a)



(b)

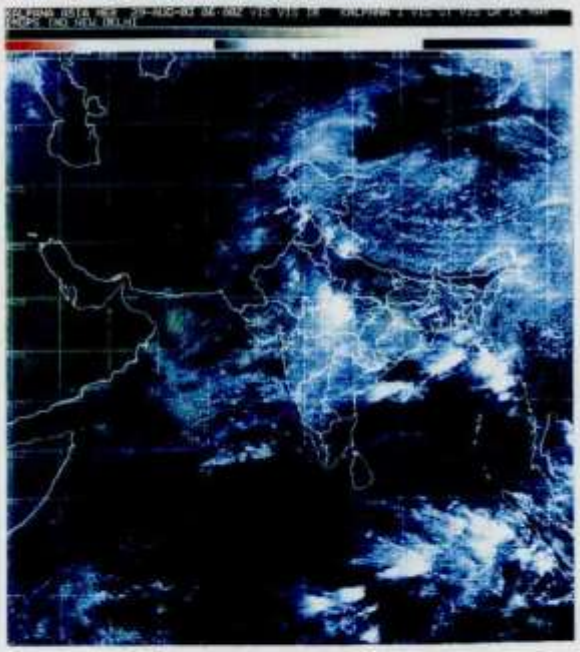


Fig. 2.3.1 Satellite picture showing Cloudiness in association with a Depression (a) near Paradip (43976) on August 27, 2003 and (b) near Ambikapur (42693) on August 29, 2003.

2.4 Depression over the Bay of Bengal 6-9 October, 2003

A low pressure area formed over west central Bay of Bengal on 4 October. It moved in a north-westerly direction and concentrated into a Depression near lat. 16.5^0 N/ long 84.0^0 E at 060300 UTC. It moved in a northerly direction and lay centred near lat. 17.5^0 N/ long. 84.0^0 E at 061200 UTC. The system then moved north-westwards and crossed north Andhra Pradesh coast near Kalingapatnam around 062100 UTC. The system maintained the intensity of Depression and lay centred at 070300 UTC and 071200 UTC about 100 km east of Jagdalpur (43041) and remained practically stationary the same day evening. It moved in a north-north-westerly direction and was centred at 080300 UTC near lat. 21.0^0 N/ long. 82.5^0 E about 100 km southeast of Raipur (42875). Maintaining the same intensity the system re-curved and moved into a north-northeasterly direction and was centred near Jharsuguda (42798) at 081200 UTC, subsequently moved northeastwards and was close to Dhanbad (42703) at 090300 UTC and near Bhagalpur (42498) at 091200 UTC. The system weakened gradually into a low pressure area over Sub-Himalayan West Bengal & Sikkim and neighbourhood in the morning of 10th.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.4.1. A few INSAT cloud images of the system are given in fig. 2.4.1.

Weather realised:

The system caused widespread heavy rainfall over Orissa and Gangetic West Bengal. Isohytal analysis of the cumulative Rainfall (in cm) for the period 6-9 October is given in Fig. 2.4.2.

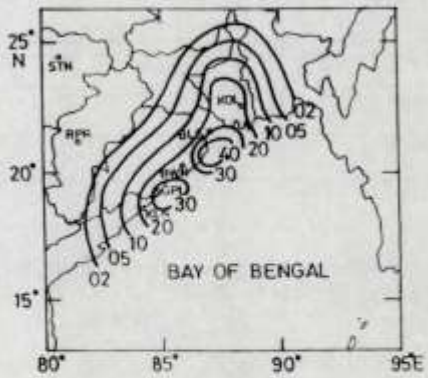


Fig. 2.4.2

Damages:

As per media reports and information available from Govt. sources, 13 people died in Kolkata and neighbouring districts and thousands of people were affected due to heavy rains on 9 October. A feeble tornado injured 11 persons and damaged houses and agricultural crops over 6 acres of land.

Table 2.4.1

Best track positions and other parameters for the Depression over Bay of Bengal from October 06-09, 2003

Date	Time (UTC)	Centre Lat. 0^0 N / Long $.0^0$ E	C. I NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the centre (hPa)	Grade
06.10.2003	0300	16.5/84.0	1.5	998	25	4	D
	0900	17.0/84.0	1.5	998	25	4	D
	1200	17.5/84.0	1.5	998	25	4	D
07.10.2003	0300	19.0/83.0	---	998	25	4	D
	1200	19.0/83.0	---	998	25	4	D
08.10.2003	0300	21.0/82.5	---	998	25	4	D
	1200	21.5/84.5	---	1000	25	4	D
09.10.2003	0300	23.5/86.0	---	1000	25	4	D
	1200	25.0/87.0	---	1000	25	4	D

The system weakened into a Low pressure area over Sub- Himalayan West Bengal & Sikkim and neighbourhood in the morning of October 10, 2003.

(a)

(b)

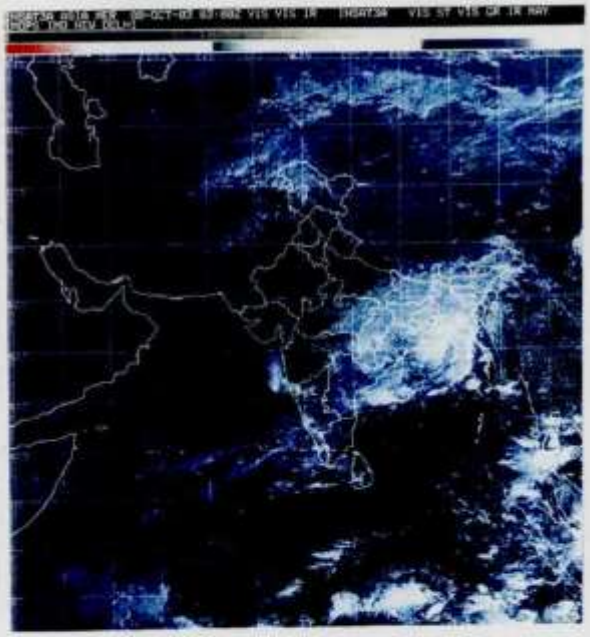


Fig. 2.4.1 Satellite picture showing cloudiness in association with a Depression near (a) Kalingapatnam (43105) on October 6, and near (b) Raipur (43875) on October 8, 2003.

2.5 Deep Depression over the Bay of Bengal 26-28October, 2003

Under the influence of a remnant of a tropical Depression of the west Pacific a low pressure area formed over the Andaman Sea in the forenoon of 26 October. It concentrated into a Depression over east central Bay of Bengal on 26th evening near lat. 13.5^0 N/ long. 93.5^0 E. As the sub-tropical ridge in the upper levels was to the north of the system, it moved in a west-north- westerly direction and further Intensified into a Deep Depression near lat. 14.0^0 N /long.90.5^0 E at 270300 UTC.

It continued to move in the same direction and weakened in the afternoon of 28th October into a Depression due to strong vertical wind shear. It lay centred at 280900 UTC close to Visakhapatnam (43149). The system crossed the coast north of Visakhapatnam around 281000 UTC and weakened gradually into a low pressure area over North Andhra Pradesh and neighbourhood by 28th evening.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.5.1. A few INSAT cloud images of the system are given in fig. 2.5.1.

Weather realised

Under the Influence of this system isolated heavy rainfall occurred over north coastal Andhra Pradesh on 29 October.

Damge

No significant damage were reported due to this system.

Table 2.5.1

Best track positions and other parameters for the Deep Depression over Bay of Bengal from October 26-28, 2003

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
26.10.2003	1200	13.5/93.5	1.5	1004	25	-	D
27.10.2003	0300	14.0/90.5	2.0	1004	30	4	DD
	1200	14.5/89.0	2.0	1006	30	4	DD
28.10.2003	0300	16.5/84.5	2.0	1004	30	4	DD
	0900	17.8/83.5	1.5	1006	25	-	D

1200Z

The Deep Depression Weakened into a Low pressure area over north Andhra Pradesh and Chhatisgarh in the evening of October 28, 2003.

(a)

(b)

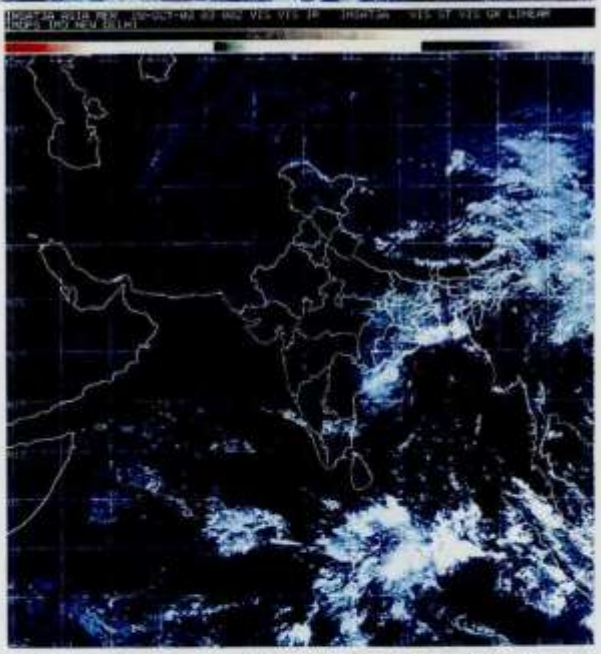


Fig. 2.5.1 Satellite picture showing cloudiness in association (a) with Deep Depression over central Bay of Bengal on 27 October and (b) when the depression was close to Andhra Pradesh coast on 28 October, 2003.

2. 6 Severe Cyclonic Storm over the Arabian Sea 12-15November, 2003

After the withdrawal of southwest monsoon, the north-east monsoon set in over peninsular India in the last week of the October. The ITCZ was seen predominantly active during this time and sea surface temperature anomaly maxima was located over southeast Arabian Sea. During this period a disturbance formed close to the equator and moved westwards throughout its lifespan as it was embedded in the easterly wind regime and dissipated over the seas off Somalia coast.

On the morning of 12 November convective cloud clusters were seen in satellite imagery near lat. 6.5^0 N /long.62.0^0 E indicating formation of a low pressure area. By 120300 UTC, it concentrated into a Depression and lay centred near lat.6.5^0 N / long. 61.5^0 E. By evening of 12^{th} the system further intensified into a Deep Depression centred near lat 6.5 N / long 59.5 E. The system then moved in a westerly direction and further intensified into a Cyclonic Storm at 130000 UTC and was centred near lat. 6.5^0 N / long. 58.0^0 E. The system remained practically stationary and further concentrated into a Severe Cyclonic Storm at 130600 UTC. The system continued to move slowly in a westerly direction. As the system entered the colder region of south- west Arabian sea, it slowly dissipated over the sea off Somalia in the morning of 16 November.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.6.1. A few INSAT cloud images of the system are given in fig. 2.6.1.

Weather Realised

Nil

Damage

No damage was caused as the system dissipated over the sea itself.

Table 2.6.1

Best track positions and other parameters for the Severe Cyclonic Storm over the Arabian Sea from November 12-15, 2003

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
12.11.2003	0300	6.5/61.5	1.5	1002	25	2	**D**
	1200	6.5 /59.5	2.0	1000	30	4	**DD**
	1800	6.5/59.0	2.0	998	35	6	**CS**
13.11.2003	0000	6.5/58.0	2.5	998	35	6	CS
	0300	6.5/58.0	2.5	998	35	6	CS
	0600	6.5/58.0	3.5	994	55	14	**SCS**
	0900	6.2/57.7	3.5	990	55	14	SCS
	1200	6.0/57.5	3.5	990	55	14	SCS
	1500	6.0/57.0	3.5	990	55	14	SCS
	1800	6.0/57.0	3.5	990	55	14	SCS
	2100	6.0/57.0	3.5	990	55	14	SCS
14.11.2003	0000	6.0/56.5	3.5	990	55	14	SCS
	0300	6.0/56.5	3.5	990	55	14	SCS
	0600	5.5/55.5	3.5	990	55	14	SCS
	0900	5.5/55.0	3.5	990	55	14	SCS
	1200	5.5/54.5	2.5/3.0	994	45	6	**CS**
	1500	5.5/54.5	2.5/3.0	994	35	6	CS
	1800	5.5/52.0	2.5/3.0	996	30	4	**DD**
	2100	5.5/51.5	2.5/3.0	996	30	4	DD
15.11.2003	0000	5.5/51.0	2.0	998	30	4	DD
	0300	5.5/51.0	1.5	1000	25	2	**D**
	1200	5.5/50.5	1.5	1000	25	2	D
	The system weakened into a low pressure area on 16th morning and subsequently dissipated over the sea off Somalia coast. between 0300 to 0400 UTC .						

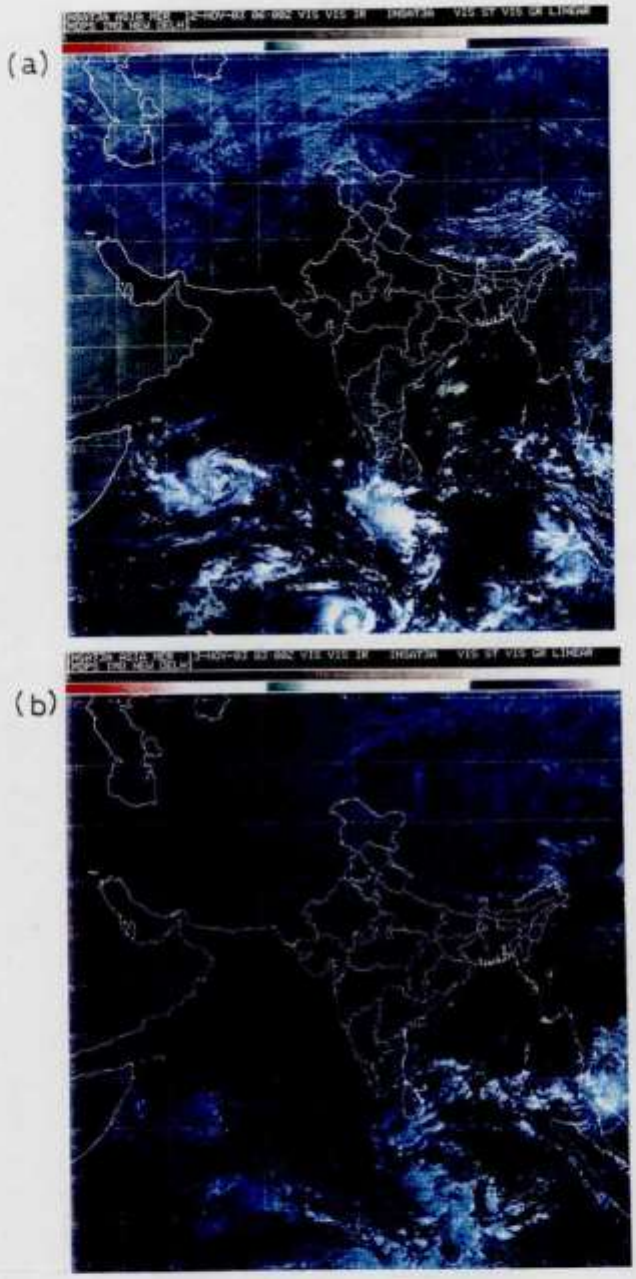
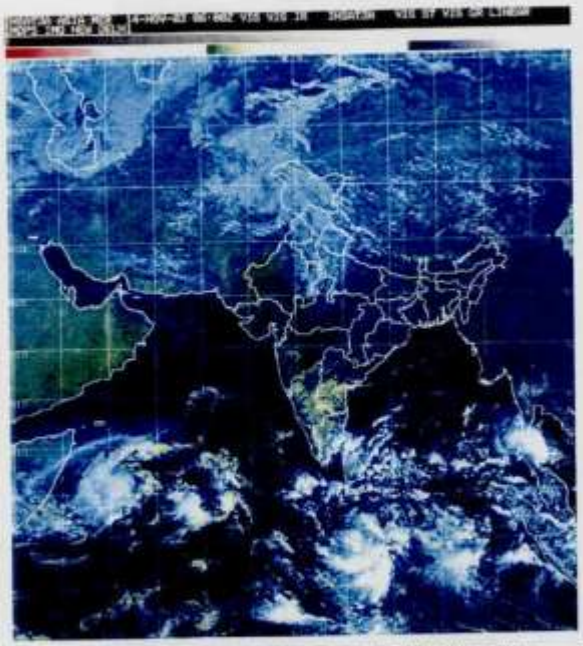


Fig. 2.6.1 Satellite picture showing comma shaped cumulus cloudiness entering into the central region of a depression near (a) lat. 6.5^0 N/ long. 59.5^0 E on November 12, 2003 and (b) when the system had intensified in a cyclonic storm near lat. 6.5^0 N/ long. 58.0^0 E.

(c)



(d)

Fig. 2.6.1 (Cont) Satellite picture showing (c) developing of CDO on November 14, 2003 and (d) curved cumulus lines in the central region of the system on November 15, 2003 when the system had weakened into a well marked low pressure area.

2. 7 Severe Cyclonic Storm over the Bay of Bengal 11-16 December, 2003

A low pressure area formed over the southeast Bay of Bengal and adjoining Indian Ocean on 8 December. This system persisted for two days over the same area. It Developed into a well-marked low pressure area by 11th morning and concentrated into a depression near lat. 4.5^0 N / long. 90.5^0 E at 111200 UTC. The system initially moved in a north-westerly direction and further intensified into a Deep Depression at 130300 UTC when it was near lat. 9.0^0 N/ long. 87.5^0 E. It attained the intensity of a Cyclonic Storm at 131200 UTC when it was centred near lat. 9.5^0N / long. 87.0^0 E.

Moving in a north-westerly direction the system further intensified into a Severe Cyclonic Storm at 141200 UTC near lat. 12.0^0 N/ long. 83.5^0 E. The coastal observations of Machilipatnam, Kavali and Chennai recorded pressure fall of the order 3 hPa indicating that the system was moving towards north Tamilnadu –south Andhra Pradesh coast. During the night of 14 December the system came under the range of Doppler Weather Radar (DWR) Chennai. The system was constantly monitored by DWR Chennai till 150600UTC and then by CDR Machilipatnam upto 151100UTC.Spiral bands started appearing from 141056 UTC. "Eye" was fairly defined at 150208 UTC { fig 2.7.4 (d)}.

Upper level wind analysis of 200 hPa on 14 & 15 December 1200 UTC (Fig. 2.7.1) favoured the system movement towards Andhra Pradesh coast. The coastal observations 151200 UTC suggested the system centre close to Machilipatnam as the pressure departure was 13.4 hPa with north-easterly winds of 40 kt. While the system was crossing the coast, south of Machilipatnam around 151900 UTC), the pressure departure at Machilipatnam was 15.5 hPa with southeasterly winds of 35 kt. The hourly observations recorded at Kakinada (43189), Machilipatnam (43185) and Bapatla (43220) are given in Table 2.7.1 indicating that the system crossed the coast around 151800 UTC a little south of Machilipatnam. After landfall the system weakened into a Cyclonic Storm and further into a Deep Depression by 1603000 UTC about 100 km north of Machilipatnam. The system weakened rapidly thereafter into a Depression over the same area on 16^{th} evening and into a low pressure area over south Orissa and adjoining over north Andhra Pradesh on 17^{th} morning.

As observed by DWR Chennai, the system as a whole moved with an average speed of 15 kmph during the period of radar surveillance. Initially it was heading towards northwest and subsequently changed to north-northwest. Overall intensity of radar echoes was of moderate to strong and the vertical extent of the significant echoes were within 10-12 km. The maximum sustained wind speed measured DWR Chennai was 30 mps (108 kmph) at a height of 1.8 km at about 150 km to the northeast of the station. Occasional wind maximum of about 34 mps (122kmph) was also observed.

The track of the system is given in Fig. 1.2. The best track positions and other parameters have been included in Table 2.7.2.. A few INSAT cloud images of the system are given in fig. 2.7.2.

The track of the Severe Cyclonic Storm observed by DWR Chennai & CDR Machlipatnam is given in figure 2.7.3. Products of DWR Chennai & CDR Machilipatnam are given in fig. 2.7.4 & 2.7.5 respectively.

Table 2.7.1

Hourly Observations from 151200 UTC to 152100UTC suggesting landfall time around 151800 UTC close to Machilipatnam.

Stations/ Time → UTC	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100
Kakinada (43189)										
Machili Patnam (43185)										
Baptla (43220)										

Weather Realised

Under the Influence of this system heavy to very heavy rainfall occurred over Andaman & Nicobar Islands during the initial stages and over north Andhra Pradesh during the time of landfall.

Damage

No. of deaths	81
Building destroy completely	1637
Building partially damaged	7453
Agricultural area affected	61898.5 hectares
No. of villages suffered electric failure	2,000
No. of villages affected by Telecommunication disruptions	41
Loss of property (total)	Rs. 23903.13 lakhs

A ship by name MV.NANDKAWAS of Essar Shipping Company got damaged and was on the verge of sinking near Machilipatnam coast. Crew members were rescued by Indian Coast Guards.

Table 2.7.2
Best track positions and other parameters for the Bay of Bengal Severe Cyclonic Storm December 11-16, 2003

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
11.12.2003	1200	4.5/90.5	1.5	1004	25	2	**D**
12.12.2003	0300	6.0/89.0	1.5	1006	25	2	D
	1200	7.5/88.0	1.5	1004	25	2	D
13.12.2003	0300	9.0/87.5	2.0	1004	30	4	**DD**
	1200	9.5/87.0	2.5	1002	35	6	**CS**
	1500	10.0/87.0	2.5	1002	35	6	CS
	1800	10.0/87.0	2.5	1002	35	6	CS
	2100	10.5/86.5	2.5	1000	35	6	CS
14.12.2003	0000	10.5/86.0	2.5	998	35	6	CS
	0300	11.0/85.0	3.0	998	45	10	CS
	0600	11.0/85.0	3.0	996	45	10	CS
	0900	11.5/84.5	3.0	994	45	10	CS
	1200	12.0/83.5	3.5	992	55	14	**SCS**
	1500	12.5/83.0	3.5	992	55	14	SCS
	1800	12.8/82.5	3.5	992	55	14	SCS
	2100	13.4/82.2	3.5	992	55	14	SCS
15.12.2003	0000	13.8/81.7	3.5	992	55	14	SCS
	0300	14.0/81.5	3.5	992	55	14	SCS
	0600	14.3/81.5	3.5	992	55	14	SCS
	0900	15.0/81.0	3.5	992	55	14	SCS
	1200	15.5/81.0	3.5	990	55	14	SCS
	1500	15.8/81.0	3.5	992	55	14	SCS
	1800	16.0/81.0	3.5	992	55	14	SCS
	Crossed coast near to Machilipatnam around mid-night on Decmber 15						
	2100	16.5/81.0	---	---	---	---	**Cs**
16.12.2003	0000	17.0/81.0	---	---	---	---	CS
	0300	17.0/81.0	---	---	---	---	**DD**
	0600	17.5/81.5	---	---	---	---	**D**
	1200	17.5/81.5	---	---	---	---	D

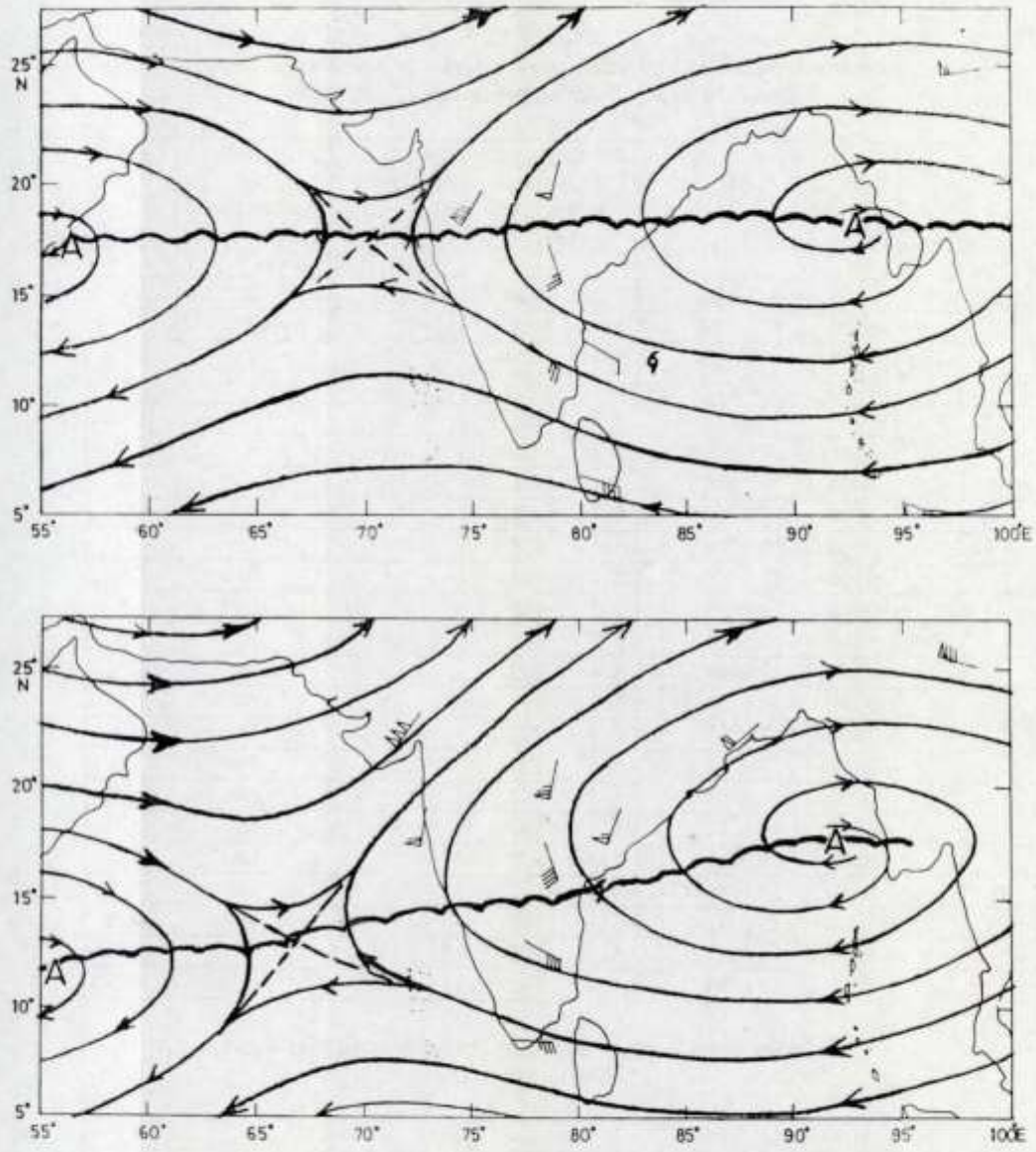
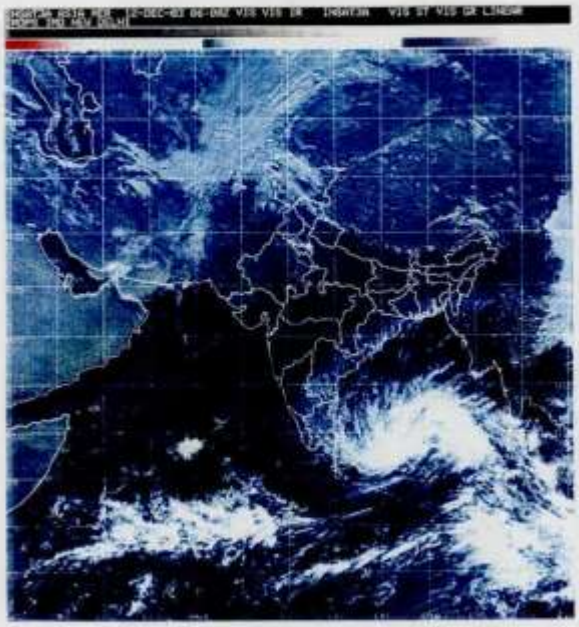


Fig.2.7.1 200 hPa streamline analysis at 1200UTC on 14 and 15 December,2003 along with system centre.

(a)



(b)

Fig. 2.7.2 Satellite picture showing convection over south Bay of Bengal in association with a Depression (a) near lat. 6.5^0 N/ long. 88.5^0 E on 12 December, 2003 and (b) when the system had become a Deep Depression near lat. 9.0^0 N/ long. 87.5^0 E on December 13, 2003.

(c)

(d)

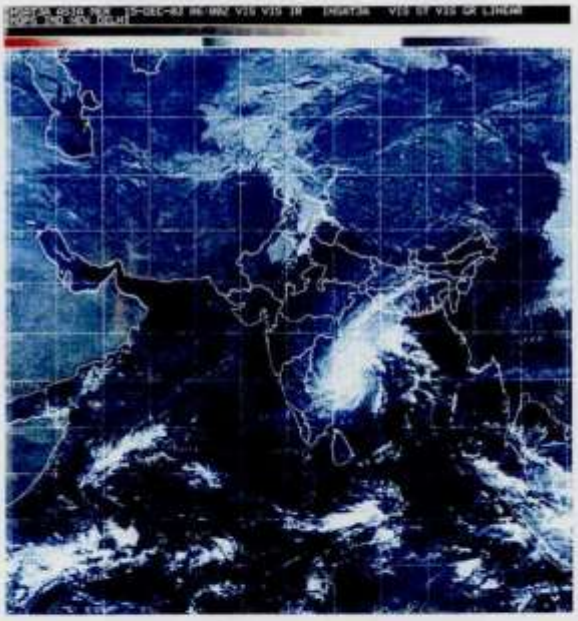


Fig. 2.7.2 (Cont) Satellite picture showing (c) dense convection in the south west sector of the system on December 14, 2003 and (d) when the system was very close to the coast on December 15, 2003.

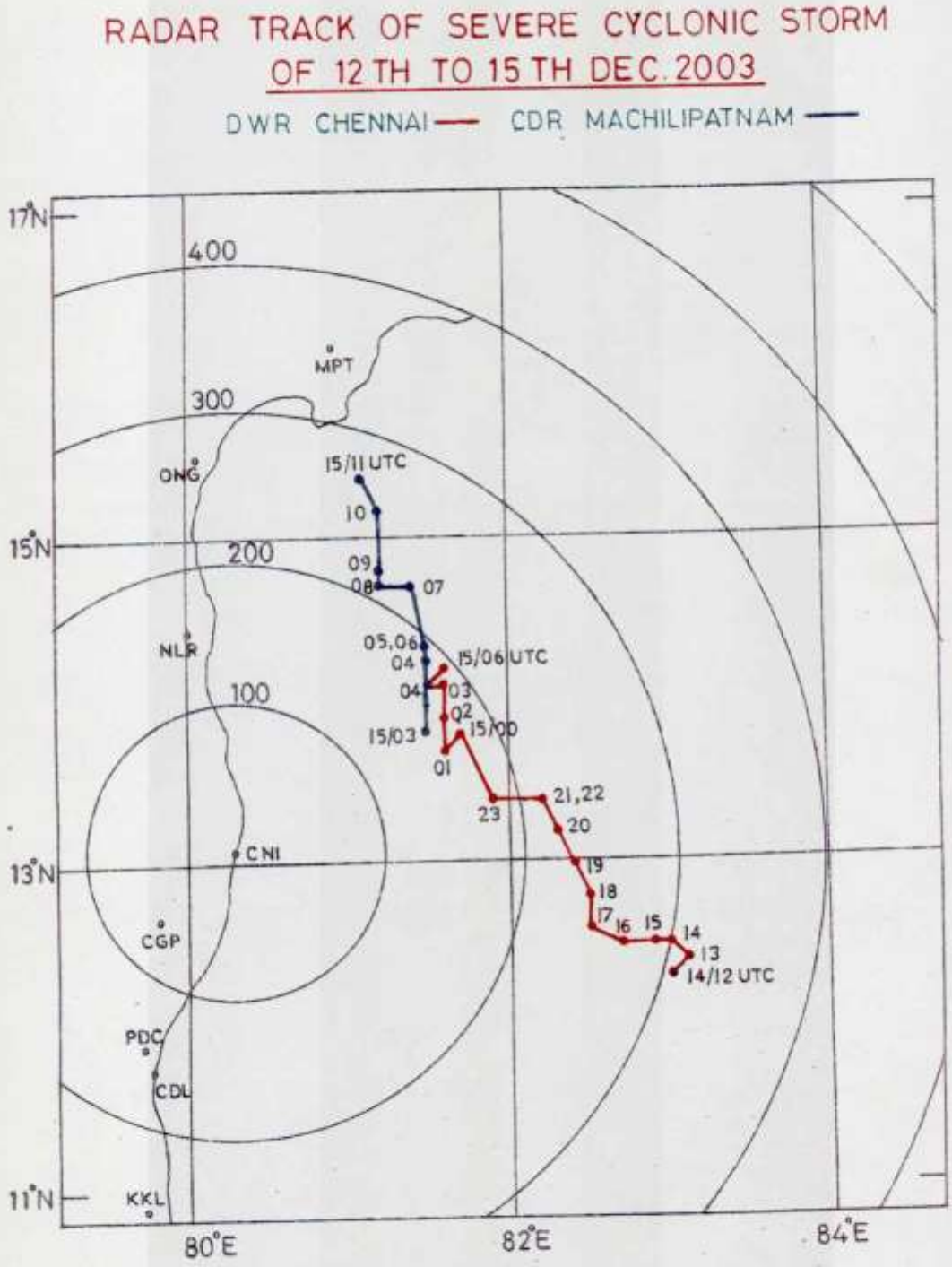
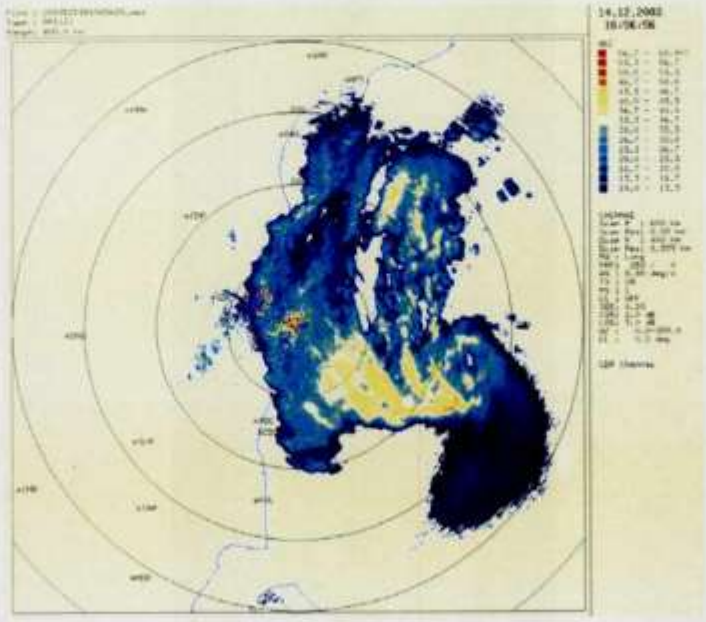


Fig. 2.7.3 Radar track of the Severe Cyclonic Storm 12-15 December, 2003.

(a)



(b)

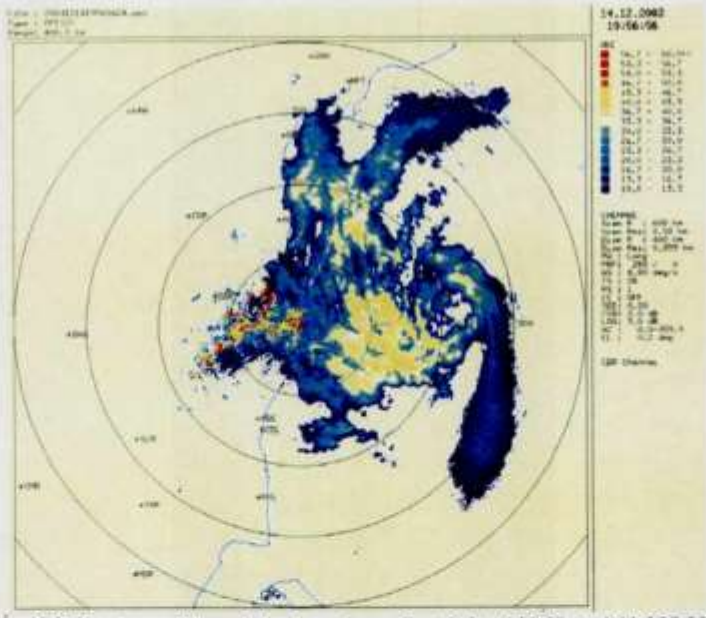


Fig 2.7.4 (a) PPI display of logarithmic radar reflectivity (dBZ) at 141657 UTC (b) display of logarithmic radar reflectivity at 141957 UTC.

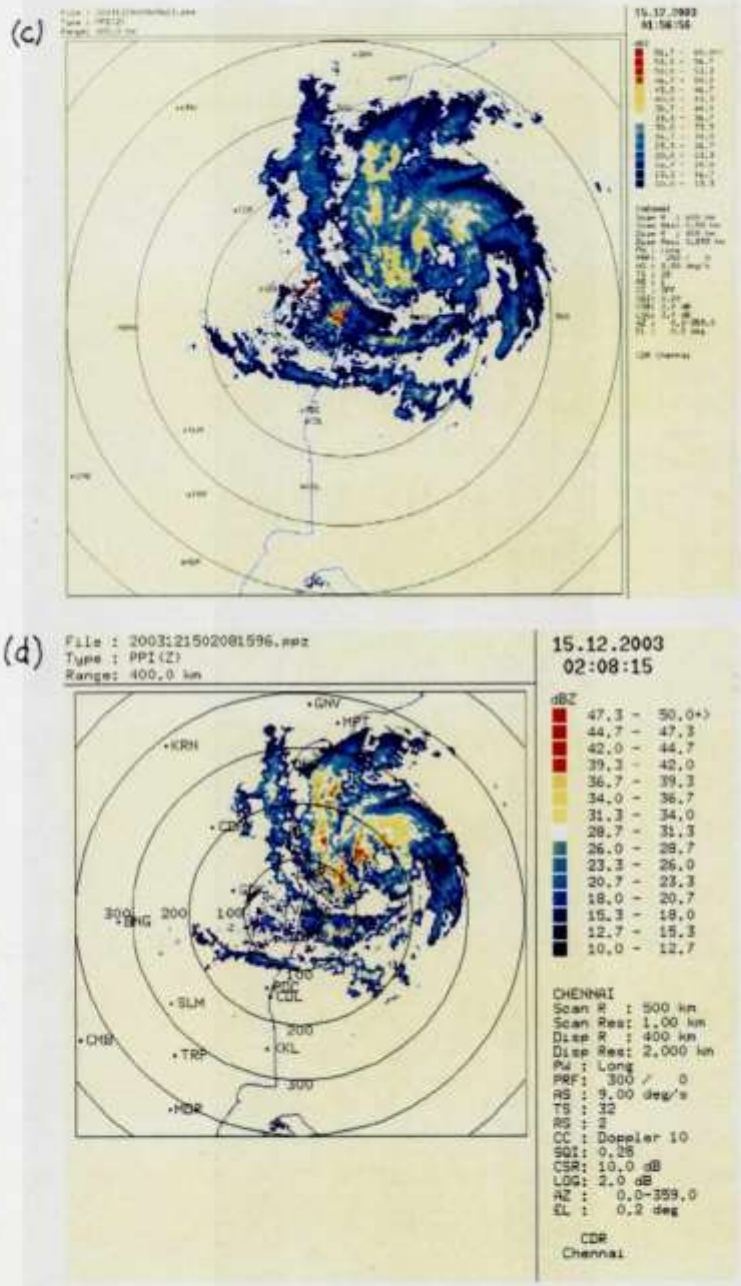
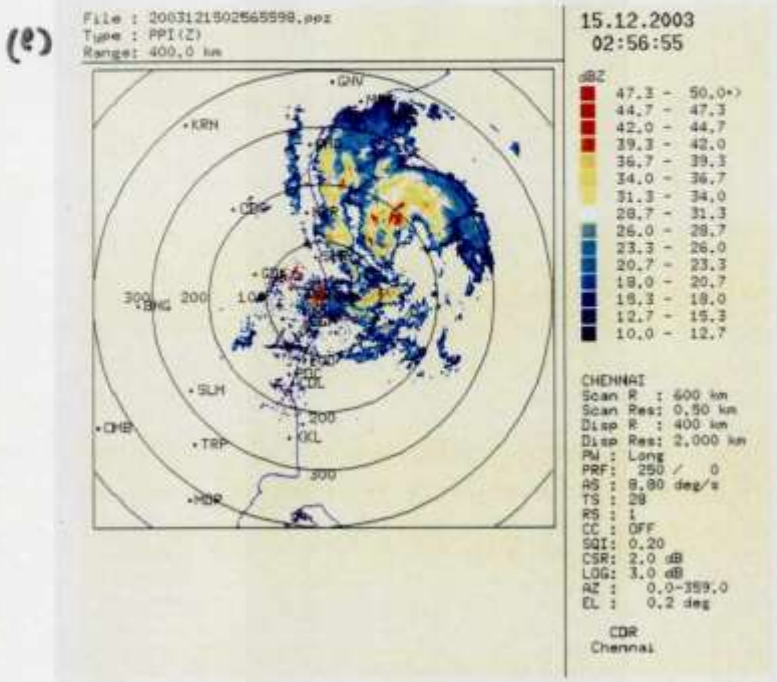


Fig. 2.7.4 (cont) (c) PPI display of logarithmic radar reflectivity (dBZ) at 150157 UTC
(d) PPI display of logarithmic radar reflectivity (dBZ) at 150208 UTC



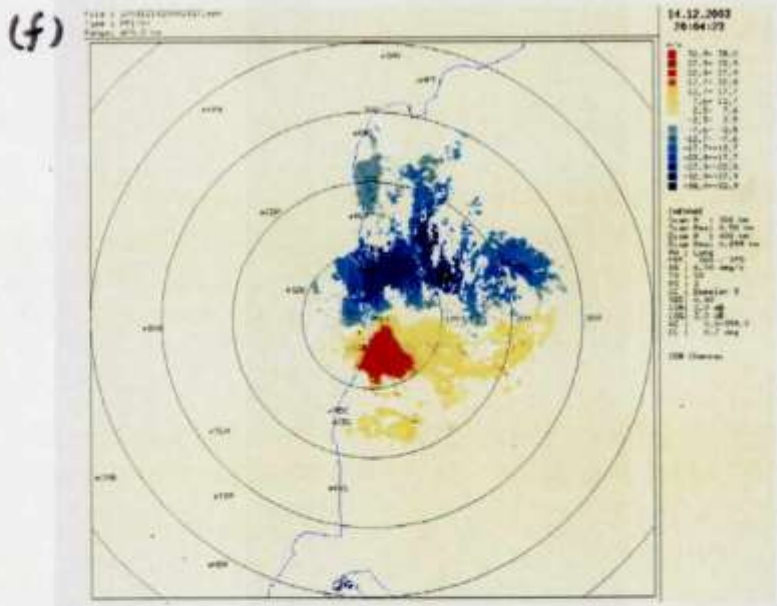
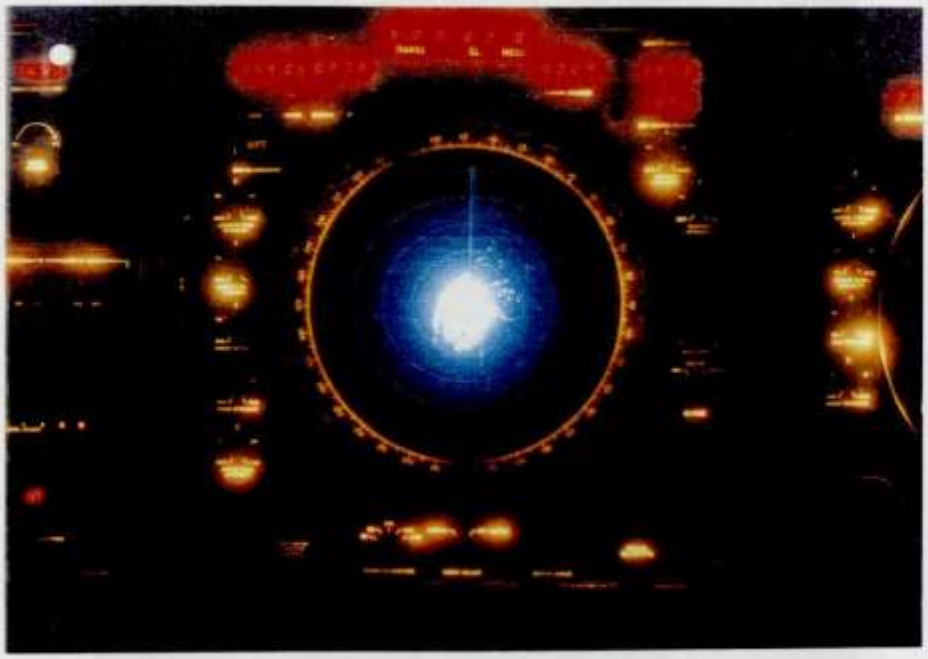


Fig. 2.7.4 (cont) (e) PPI display of logarithmic radar reflectivity (dBZ) at 150256 UTC
(f) PPI display of radial velocity at 142004 UTC

(a)



(b)

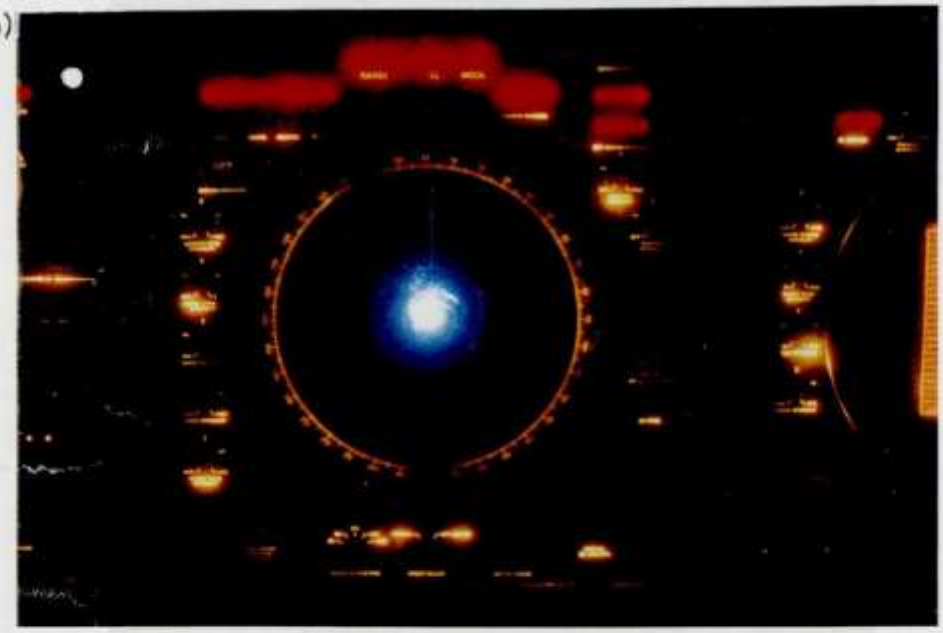


Fig 2.7.5 Machilipatnam Radar picture when the Severe Cyclonic Storm was very near to the coast of Andhra Pradesh at (a) 0600 UTC on December 15, 2003 (b) 1800 UTC on December 15, 2003 showing good spiral features.