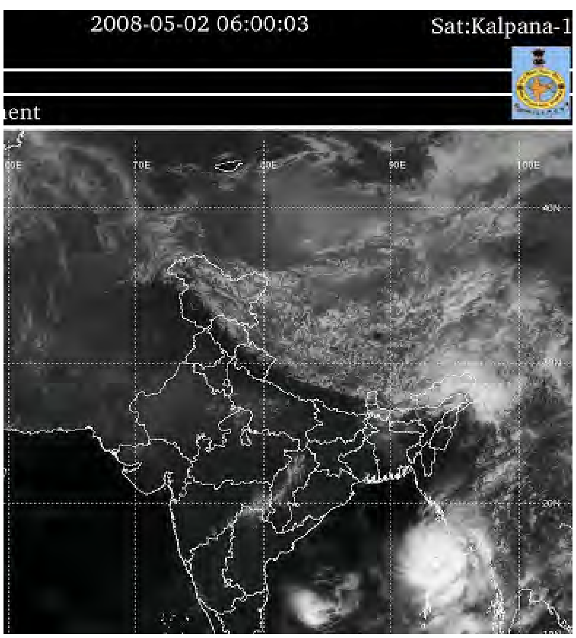
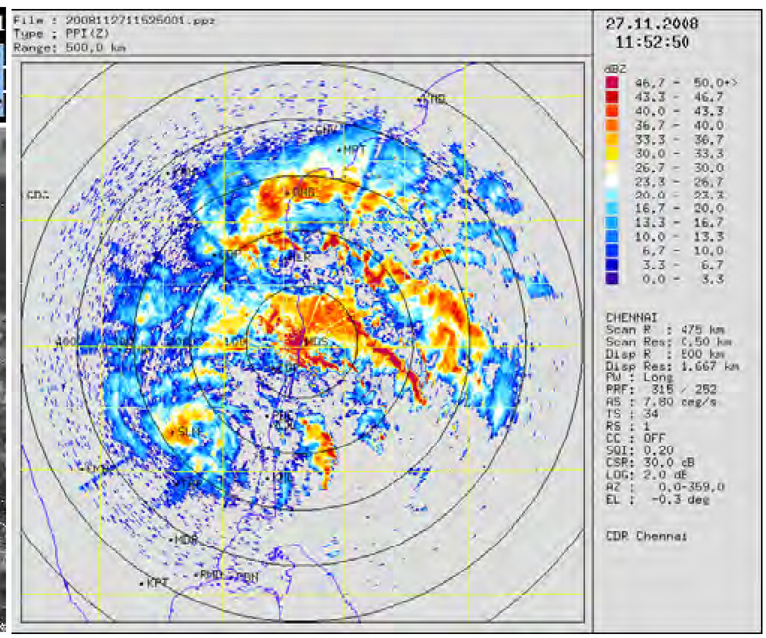
भारत मौसम विज्ञान विभाग

INDIA METEOROLOGICAL DEPARTMENT

REPORT ON CYCLONIC DISTURBANCES OVER NORTH INDIAN OCEAN

DURING 2008





Kalpana-1 imagery of NARGIS: May 2, 2008 DWR imagery of NISHA : November 27, 2008

RSMC-TROPICAL CYCLONES, NEW DELHI

JANUARY 2009

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INTRODUCTION

Regional Specialized Meteorological Centre (RSMC) - Tropical Cyclones, New Delhi has the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the World Meteorological Organisation (WMO)/ Economic and Social Co-operation for Asia and the Pacific (ESCAP) Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Pakistan, Maldives, Myanmar, Sultanate of Oman, Sri Lanka and Thailand. It has also the responsibilities as a Tropical Cyclone Advisory Centre (TCAC) to provide Tropical Cyclone Advisories to the designated International Airports as per requirement of International Civil Aviation Organization (ICAO).

As per the recommendations of the Cyclone Review Committee (CRC) set up by the Government of India, a Cyclone Warning Directorate, co-located with RSMC Tropical Cyclones - New Delhi, was established in 1990 in Northern Hemisphere Analysis Centre (NHAC) of India Meteorological Department (IMD), New Delhi to co-ordinate and supervise the cyclone warning in the country.

The broad functions of RSMC- Tropical Cyclones, New Delhi are as follows:

- Round the clock watch on weather situations over the entire north Indian Ocean.
- Analysis and processing of global meteorological data for diagnostic and prediction purposes.
- Detection, tracking and prediction of cyclonic disturbances in the Bay of Bengal and the Arabian Sea.
- Running of numerical weather prediction models for tropical cyclone track and storm surge predictions.
- Interaction with National Disaster Management Authority and National Disaster Management, Ministry of Home Affairs, Govt. of India to provide timely information and warnings for emergency support services. RSMC-New Delhi also coordinates with national Institute of Disaster Management (NIDM) for sharing the information related to cyclone warning.
- Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel.
- Issue of Tropical Weather Outlook and Tropical Cyclone Advisories to the Panel countries in general.
- Issue of Tropical Cyclone advisories to International airports in the neighbouring countries for International aviation.
- Collection, processing and archival of all data pertaining to cyclonic disturbances viz. wind, storm surge, pressure, rainfall, damage report, satellite and Radar derived information etc. and their exchange with Panel member countries.
- Preparation of comprehensive annual reports on cyclonic disturbances formed over North Indian Ocean every year.
- Preparation of annual review report on various activities including meteorological, hydrological and disaster preparedness and prevention activities of panel member countries.
- ReSearch on storm surge, track and intensity prediction techniques.

CHAPTER- I

ACTIVITIES OF REGIONAL SPECIALIZED METEOROLOGICAL CENTRE – TROPICAL CYCLONES, NEW DELHI

1.1 AREA OF RESPONSIBILITY

The area of responsibility of RSMC- New Delhi covers Sea areas of north Indian Ocean north of equator between 45^0 E and 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 in normal weather. If a depression forms over north Indian Ocean a Special Tropical Weather Outlook is issued additionally at 1700 UTC. The Tropical Cyclone Advisories are issued on tropical cyclones at three hourly intervals when they develop over the north Indian Ocean. RSMC-New Delhi has also been issuing Tropical Cyclone Advisories for Aviation as per requirements of ICAO.

RSMC New Delhiis continuing the naming of Tropical Cyclones formed over North Indian Ocean since October 2004.

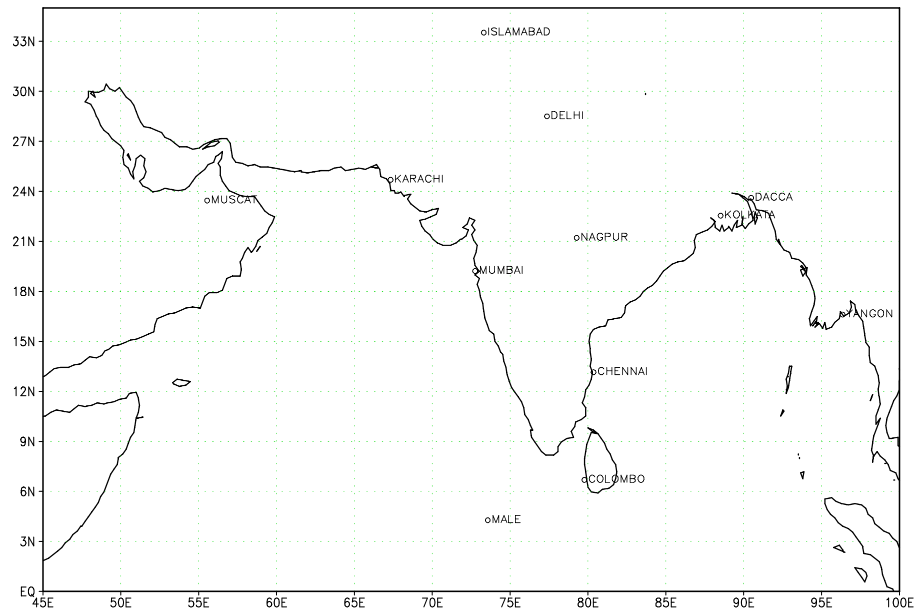

Fig. 1.1 Area of responsibility of RSMC- Tropical Cyclone, New Delhi

1.2 OBSERVATIONAL SYSTEM

A brief description of different types of observational network of IMD and observations collected from networks are given below.

1.2.1 Surface Observatories

IMD has a good network of surface observatories satisfying the requirement of World Meteorological Organization. There are 559 surface observatories in IMD. The data from these stations are used on real time basis for operational forecasting. Recently a number of moored ocean buoys including Meteorological Buoy (MB), Shallow Water (SW), Deep Sea (DS) and Ocean Thermal (OT) buoys have been deployed over the Indian Sea, under the National Data Buoy Programme (NDBP) of the Department of Ocean Development (DOD), Government of India. The existing buoy network is shown in fig 1.2. A number of Automated Weather Stations (AWS) are also in operation along the coast and provide surface observations on hourly basis which are utilised in cyclone monitoring and forecasting. The AWS network of India is shown in Fig. 1.3

Fig.1.2. Existing buoys network over north Indian Ocean

1.2.2 Upper Air Observatories

There are at present 62 Pilot Balloon Observatories, 39 Radiosonde/ Radiowind observatories and 01 Radiosonde Observatory. The upper air meteorological data thus collected all over the country are used on real time basis for operational forecasting. The short period averages of Radiosonde data and normal of Radiowind data have been published.

A Wind Profiler/Radio Acoustics Sounding System has been installed at DCP Complex, Pashan, Pune in collaboration with M/S SAMEER, Mumbai and IITM, Pune. The instrument is capable of recording upper air temperature up to 3 Km and upper wind up to 9 km above Sea level. The performance of the instrument is being monitored.

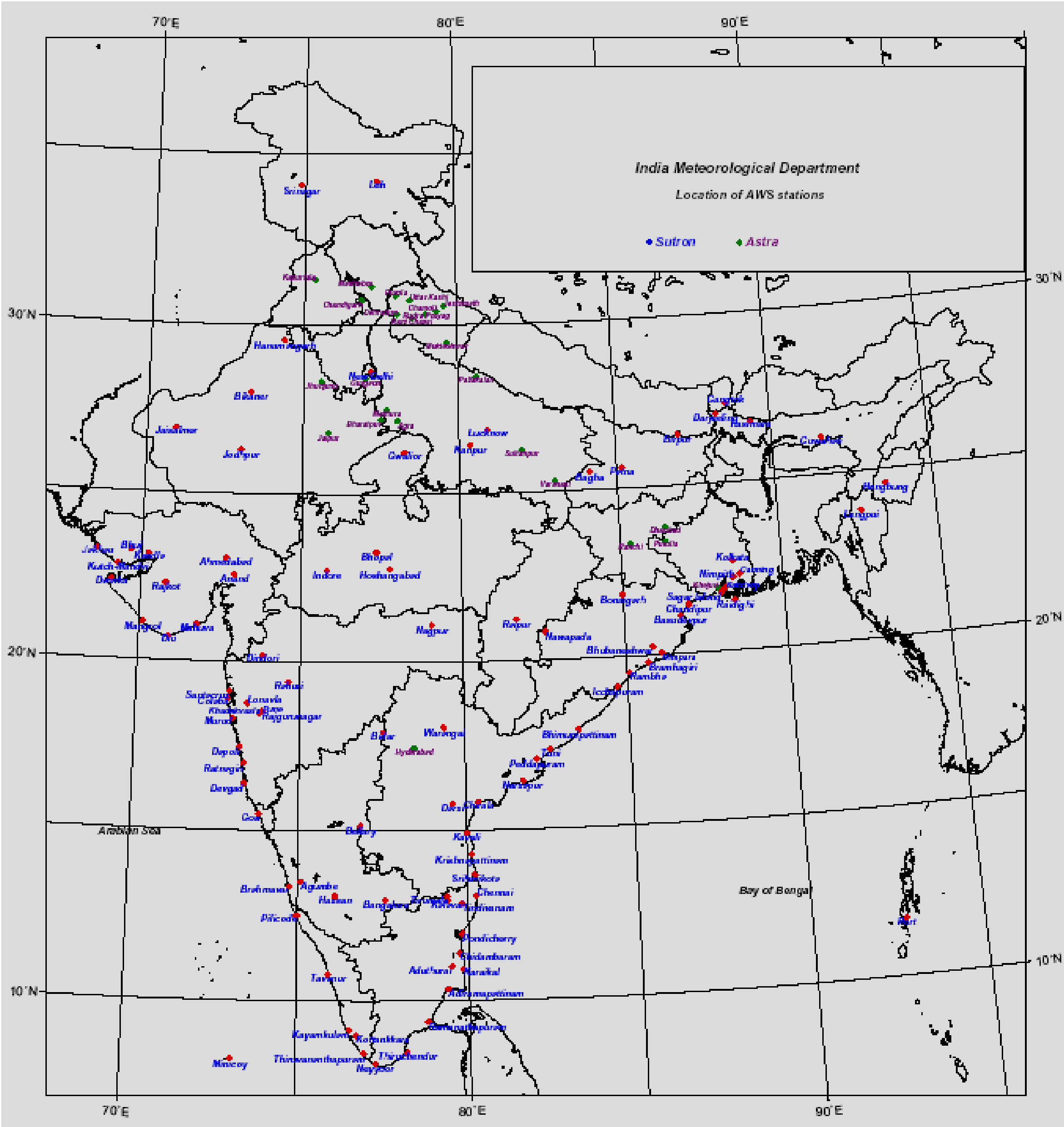

Fig 1.3 Automatic Weather Stations network

1.2.3. Radar

(i) Cyclone Detection Radars

There are 11 S-band Radars for Cyclone Detection located at Kolkata, Paradip, Visakhapatnam, Machilipatnam, Chennai, Sriharikota, Karaikal, Kochi, Goa, Mumbai, and Bhuj, (Fig. 1.4). Out of these 11 stations, 6 stations (except Chennai, Kolkata, Sriharikota, Visakhapatnam and Machilipatnam) are using conventional S-band radars. Four number of S-Band Doppler Weather Radars (Meteor 1500S) imported from MIS Gematronik, Germany have been installed, commissioned and made operational at Chennai, Kolkata, Machilipatnam and Visakhapatnam respectively with effect from 22.2.2002, 29.1.2003, 8.12.2004 and 27.7.2006 respectively. One indigenous Doppler Weather Radar developed by Indian Space ReSearch Organization (ISRO) under IMD-ISRO collaboration has been installed and made operational at SHAR Centre, Sriharikota (Andhra Pradesh) with effect from 9 April, 2004.

Doppler Weather Radars (DWRs) provide vital information on radial velocity within tropical cyclone which is not available in conventional radars. Conventional radar provides information on reflectivity and range only, whereas a DWR provides velocity and spectral width data along with various meteorological, hydrological and aviation products which are very useful for forecasters in estimating the storm's center, its intensity and predicting its future movement. The DWR generates these products through a variety of software algorithms. S-band conventional radars and DWR network in India is shown in Fig. 1.4.

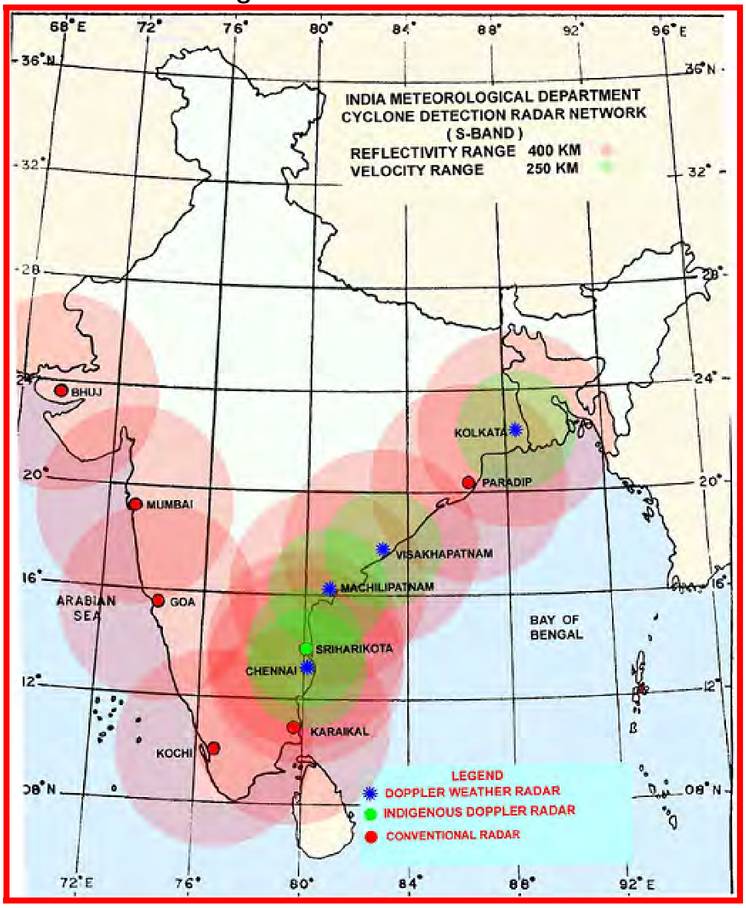

Fig. 1.4. S-band Cyclone Detection Radar Network

(ii) Storm Detection Radars

There are at present 9 X-band radars working on 3 cm wavelength for the purpose of storm detection. These are located at Kolkata, Chennai, Guwahati, Ranchi, Delhi, Lucknow, Mumbai, Nagpur and Agartala airports (Fig. 1.5). Two radars located at Sriganganagar which operate in S-band of frequency are also used for storm detection and warning. One conventional S-band radar installed at Mausam Bhawan, New Delhi is used for testing and training purposes.

(iii) Multi-Met Radars

17 X-band radars of IMD's radar network which operate in 3 cm frequency range are used for both storm detection and wind finding purposes (Fig. 1.5). 7 X-band radars installed at Ahmedabad, Goa, Mangalore, Visakhapatnam, Bhubaneswar, Mohanbari and Bangalore are latest digital technology based EEC radars. These radars have the facility of computer controlled operation with presentation of wind profile and display of reflectivity of clouds. The remaining 10 radars located at Patna, Bhopal, Patiala, Machilipatnam, Karaikal, Hyderabad, Chennai, Thiruvanthapuram, Delhi and Srinagar are conventional analog radars.

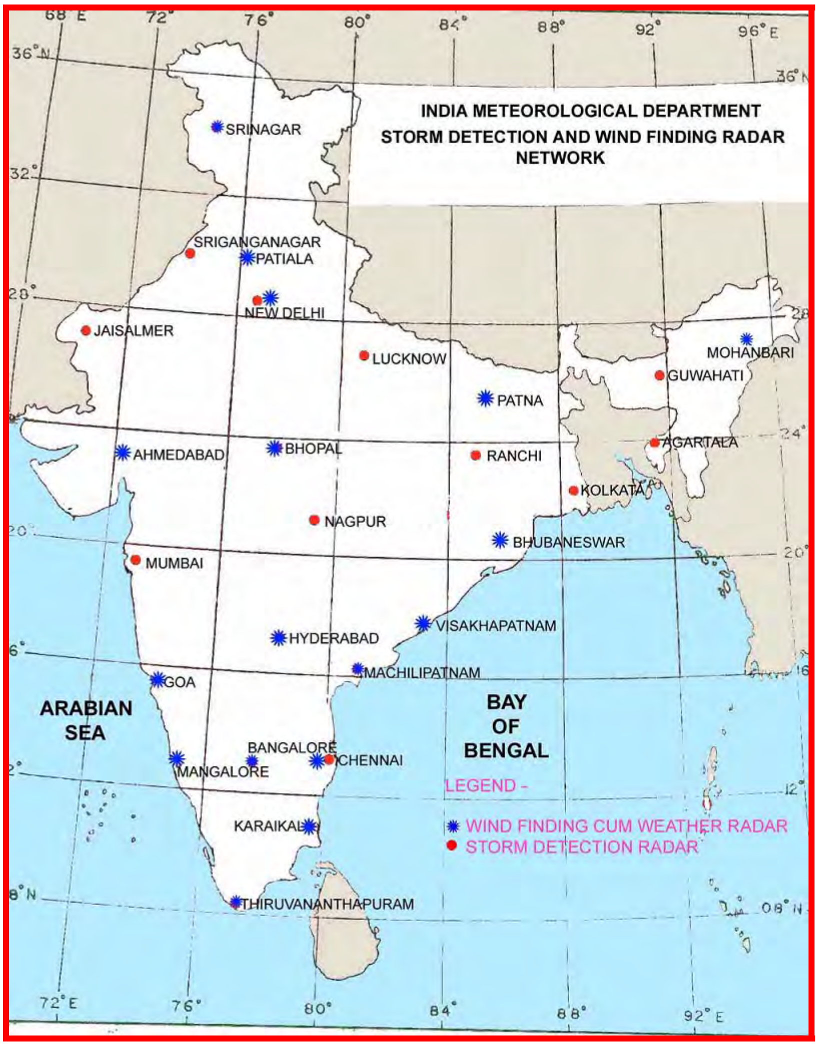

Fig. 1.5. Storm Detection and Multi-Met Radar network

Future Plan

IMD is modernizing its observational network in the phased manner. In the first phase, 12 DWRs are being procured from M/s Beijing Metstar China. Four of these radars will replace the existing old conventional CDRs located at Paradip, Karaikal, Goa, and Mumbai by the end of 2009. The other six radars will replace X-band radars located at Delhi, Patiala, Lucknow, Nagpur, Bhopal, Mohanbari, Agartala and Patna.

IMD is also procuring 2 S-band DWRs from M/s BEL, Bangalore which will replace cyclone detection radars at Bhuj and Kochi. Two C-band polarimetric DWRs will also be installed at Jaipur and Delhi for Commonwealth Games to be held in 2010.

IMD plans to install 8 C-band DWRs at Guwahati, Kolkata, Mumbai, Chennai, Mussoorie, Nainital, Srinagar, Shimla and 15 S-band DWRs at Jaisalmer, Akola, Gwalior, Hyderabad, Amini Devi, Ahmedabad, Sri Ganganagar, Jabalpur, Jagdalpur, Ranchi, Raipur, Ramanathapuram, Thiruvananthapuram, Mangalore, and Veraval in the 2nd phase of modernization.

1.2.4 Satellite Monitoring

Under INSAT-3D program, a new Geostationary Meteorological Satellite INSAT-3D is being designed by ISRO. It will have an advanced imager with six imagery channels (VIS, SWIR, MIR, TIR-1, TIR-2, & WV) and a nineteen channel sounder (18 IR &1 Visible) for derivation of atmospheric temperature and moisture profiles. It will provide 1 km. resolution imagery in visible band, 4 km resolution in IR band and 8 km in water vapour channel. This new satellite is scheduled for launch in 2009 and will provide much improved capabilities to the meteorological community and users. In preparation for the reception and processing of this data, SAC-ISRO has installed a data reception and processing system to process the data from the INSAT 3A and Kalpana 1 satellites. After full commissioning, the system will be able to receive and process the data from all the above three satellites on real time mode and produce the following products:

1. Outgoing Long wave Radiation (OLR)
2. Quantitative Precipitation Estimation (QPE)
3. Sea Surface Temperature (SST)
4. Snow Cover
5. Snow Depth
6. Fire
7. Smoke
8. Aerosol
9. Cloud Motion Vector (CMV)
10. Water Vapor Wind (WVW)
11. Upper Tropospheric Humidity (UTH)
12. Temperature, Humidity profile & Total ozone
13. Value added parameters from sounder products

a) Geo-potential Height
b) Layer Perceptible Water
c) Total Perceptible Water
d) Lifted Index
e) Dry Microburst Index
f) Maximum Vertical Theta-E Differential
g) Wind Index

14. Fog
15. Normalized Difference Vegetation Index
16. Flash Flood Analyzer
17. Himalayan Snow Cover Analysis System (HSCAS)
18. Tropical Cyclone-intensity /position

Web Products:

The Satellite Meteorology Division updates twelve images on the IMD website every half hour from the VHRR payload. It also updates images of various geophysical products as and when available. The division has also commenced maintaining an archive of of all products in the website which is available to all users.

1.2.4.1. Meteorological Data Dissemination

IMD transmits processed imagery, meteorological and facsimile weather charts to field forecasting offices distributed over the country using the Meteorological Data Dissemination (MDD) facility, through INSAT in broadcast mode. The bulletins providing description of the cloud organization and coverage are also sent as advisory to forecasting offices every synoptic hour. When cyclones are detected in satellite imagery, these bulletins are sent every hour. Such advisories are also transmitted to the neighbouring countries.

Processed satellite imagery, analyzed weather charts and conventional synoptic data are up-linked to the satellite in C-band. Satellite broadcasts these data to MDD receiving stations in S-band. MDD receiving stations analyse weather imagery and other data to generate required forecast. The processing system is also being used for generating analogue type of cloud imagery data which are transmitted through INSAT-3C to field stations using S-band broadcast capability of the satellite alongwith other conventional meteorological data and fax charts. There are about 33 MDD receiving stations in the country being operated by different agencies. Two MDD receiving stations are also operating in neighbouring countries at Sri Lanka and Maldives. These stations are receiving direct broadcast of cloud imagery, weather facsimile charts and meteorological data on an operational basis. The frequency of transmission from ground to satellite (uplink) is 5899.225 MHz and that of downlink is 2599.225 MHz.

1.3. ANALYSIS

The analysis of synoptic observations is performed four times daily at 00, 06, 12, and 18 UTC. During cyclone period, synoptic charts are prepared and analysed every three hour to monitor the tropical cyclones over the north Indian Ocean.

Cloud imageries from Geostationary Meteorological Satellites INSAT-3A and METSAT (KALPANA-1) are the main sources of information for the analysis of tropical cyclones over the data-sparse region of north Indian Ocean. Data from Ocean buoys also provide vital information. Ship observations are also used critically during the cyclonic disturbance period.

The direction and speed of the movement of a tropical cyclone are determined primarily from the three hourly displacement vectors of the centre of the system and by analyzing satellite imageries. When the system comes closer to the coastline, the system location and intensity are determined based on hourly observations from CDR and DWR stations as well as coastal observatories. The AWS stations along coast are also very useful as they provide hourly observations on real time basis. The water vapour derived wind vector and cloud motion vectors in addition to the conventional wind vectors observed by Radio Wind (RW) instruments are very useful for monitoring and prediction of cyclonic disturbances especially over the Sea region.

1.4 PREDICTION SYSTEM IN OPERATIONAL USE DURING THE YEAR 2007

1.4.1. Quasi-Lagrangian Model (QLM)

The QLM, a multilevel fine-mesh primitive equation model with a horizontal resolution of 40 km and 16 sigma levels in the vertical, is being used for tropical cyclone track prediction in IMD. The integration domain consists of 111x111 grid points centred over the initial position of the cyclone. The model includes parameterization of basic physical and dynamical processes associated with the development and movement of a tropical cyclone. The two special attributes of the QLM are: (i) merging of an idealized vortex into the initial analysis to represent a storm in the QLM initial state and (ii) imposition of a steering current over the vortex area with the use of a dipole. The initial fields and lateral boundary conditions are derived based on global model (T-80 and T254) forecasts obtained online from the National Centre for Medium Range Weather Forecasting (NCMRWF), India. The model is run twice a day based on 00 UTC and 12 UTC initial conditions to provide 6 hourly track forecasts valid up to 72 hours. The track forecast products are disseminated as a World Weather Watch (WWW) activity of RSMC, New Delhi.

1.4.2. Limited Area Model (LAM)

The operational forecasting system known as Limited Area Forecast System (LAFS), is a complete system consisting of data decoding and quality control procedures, 3-D multivariate optimum interpolation scheme for objective analysis and a semi-implicit semi-Lagrangian multi-layer primitive equation model. The model is run twice a day based on 00 UTC and 12 UTC observations. The horizontal resolution of the model is 0.75^0x0.75^0 lat. / long. With 16 sigma levels in the vertical. First guess and boundary conditions for running the LAFS are obtained online from global forecast model being operated by the NCMRWF. During cyclone situation, the model is run by including Holland vortex scheme. The forecast products are disseminated as a WWW activity of RSMC, New Delhi.

1.4.3. Non-hydrostatic Meso-scale Model MM-5 (Version 3.6)

The non-hydrostatic model MM-5 is being run on operational basis daily once based on 00 UTC initial conditions for the forecast upto 72 hours. The horizontal resolution of the model is 45 km with 23 sigma levels in the vertical. The domain of integration covers the area between lat. 25.0^o S to 45.0^o N and long. 30^o E to 120.0^o E. National Centre for Environmental Prediction (NCEP) analysis and six hourly forecasts are used as initial and boundary conditions to run the model. During cyclone situations, the model is run by including Holland vortex scheme. The forecast products are disseminated as a WWW activity of RSMC, New Delhi.

1.4.4. Non-hydrostatic mesoscale model WRF

Weather ReSearch and Forecast (WRF) model has been implemented based on 00 UTC initial and boundary conditions from NCEP model outputs for the forecast up to 72 hours. The model is run with a single forecast domain covering Indian subcontinent at the horizontal resolution of 27 km. The performance of the model is found to be reasonably skilful for cyclone genesis and track prediction.

1.4.5. Statistical Dynamical model for Cyclone genesis and intensity Prediction

A statistical-dynamical model has been implemented for real time forecasting of cyclone genesis and intensity. The approach consists of (a) Analysis of Genesis Potential Parameter (GPP) and (b) 12 hourly Intensity Prediction for forecasts up to 72 hours. The model parameters are calibrated based on model analysis fields of past cyclones. For the real-time forecasting, model parameters are derived based on the forecast fields of MM5 model. The method is found to be promising for the operational use.

1.4.6. Storm Surge Model

For the operational storm surge prediction, IMD uses both nomograms developed by IMD and Dynamical Storm Surge Model developed by Indian Institute of Technology (IIT), Delhi. The nomograms are based on the numerical solution to the hydrodynamical equations governing motion of the Sea. The nomograms are prepared relating peak surge with various parameters such as pressure drop, radius of maximum wind, vector motion of the cyclone and offshore bathymetry. The dynamical model of IIT Delhi is fully non-linear and is forced by wind stress and quadratic bottom friction following the method of numerical solution to the vertically integrated mass continuity and momentum equations. The updated version of the model currently in operational use covers an analysis area lying between lat. 2.0^0 N and 22.25^0 N and long. 65.0^0 E & 100.0^0 E. The method uses a conditionally sTable semi-implicit finite difference stair step scheme with staggered grid for numerical solution of the model equation. The bottom stress is computed from the depth-integrated current using conventional quadratic equation. The bathymetry of the model is derived from Naval Hydrographic charts applying cubic spline technique.

1.5 PRODUCTS GENERATED BY RSMC, NEW DELHI

RSMC, New Delhi prepares and disseminates the following RSMC bulletins.

(i) Tropical Weather Outlook

Tropical Weather Outlook is issued daily at 0600 UTC in normal weather for use of the member countries of WMO/ESCAP Panel. This contains description of synoptic systems over north Indian Ocean along with information on significant cloud systems as seen in satellite imageries and ridge line at 200 hPa level over Indian region. In addition, a special weather outlook is issued at 1700 UTC when a tropical depression lies over north Indian Ocean.

(ii) Tropical Cyclone Advisories

Tropical cyclone advisories are issued at 3 hourly intervals based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC observations. The time of issue is HH+03 hrs. These bulletins contain the current position and intensity, central pressure of the cyclone, description of satellite cloud imagery, expected direction and speed of movement, forecast of winds, squally weather and state of the Sea in and around the system. Tropical cyclone advisories are transmitted to panel member Countries through global telecommunication system (GTS) and are also made available on real time basis through internet at IMD's website: http://www.imd.ernet.in and http://www.imd.gov.in. RSMC, New Delhi can also be contacted through e-mail (cwdhq@imdmail.gov.in) or cwdhq2008@gmail.com) for any real time information on cyclonic disturbances over north India Ocean.

(iii) Global Maritime Distress Safety System (GMDSS)

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 cyclonic situations, additional bulletins (up to 4) are 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.

(iv) Tropical Cyclone Advisories for Aviation

Tropical Cyclone Advisories for aviation are issued for international aviation as soon as any disturbance over the north Indian Ocean attains or likely to attain the intensity of cyclonic storm (sustained surface wind speed ≥ 34 knots) within next six hours. These bulletins are issued at six hourly intervals based on 00, 06, 12, 18 UTC synoptic charts and the time of issue is HH+03 hrs. These bulletins contains present location of cyclone in lat./long., max sustained surface wind (in knots), direction of past movement and estimated central pressure, forecast position in Lat./Long and forecast winds in knots valid at HH+12, HH+18 and HH+24 hrs in coded form. The tropical cyclone advisories are transmitted on real time basis through GTS and AFTN channels to designated International Airports of the region prescribed by ICAO.

(V) Bulletin for Indian coasts

These bulletins are issued on every three hourly interval based on the standard 8 synoptic observations at 00, 03, 06, 09, 12, 15, 18 and 21 UTC when the system intensifies into a cyclonic storm over north Indian Ocean. This bulletin contains present status of the cyclone i.e. location, intensity; past movement and forecast intensity & movement, likely landfall point and time and likely adverse weather including heavy rain, gale wind & storm surge. Expected damage and action suggested are also included in the bulletins. This bulletin is completely meant for national users and these are disseminated through various modes of communication including All India Radio, Telephone/Fax, Print and electronic media. It is also posted on cyclone page of IMD website.

1.6 Cyclone Warning Dissemination

In addition to the conventional network**,** for quick dissemination of warning against impending disaster from approaching cyclones, IMD has installed specially designed receivers within the vulnerable coastal areas for transmission of warnings to the concerned officials and people using broadcast capacity of INSAT satellite. This is a direct broadcast service of cyclone warning in the regional languages meant for the areas affected or likely to be affected by the cyclone. There are 352 cyclone warning dissemination system (CWDS) stations along the Indian coast; out of these 100 digital CWDS are located along Andhra coast. The IMD's Area Cyclone Warning Centres (ACWCs) at Chennai, Mumbai & Kolkata and Cyclone Warning Centre (CWCs) at Bhubaneswar, Visakhapatnam & Ahmedabad are responsible for originating and disseminating the cyclone warnings through CWDS. The bulletins are generated and transmitted every hour. The cyclone warning bulletin is up-linked to the INSAT in C band. For this service, the frequency of transmission from ground to satellite (uplink) is 5859.225 MHz and downlink is at 2559.225 MHz. The warning is selective and will be received only by the affected or likely to be affected stations. The service is unique in the world and helps the public in general and the administration, in particular, during the cyclone Season. It is a very useful system and has saved millions of lives and enormous amount of property from the fury of cyclones. The digital CWDS have shown good results and working satisfactorily.

1.7. Forecast Demonstration Project (FDP) on Landfalling Tropical Cyclones over the Bay of Bengal

A Forecast Demonstration Project (FDP) on landfalling tropical cyclones over the Bay of Bengal has been taken up. It will help us in minimizing the error in prediction of tropical cyclone track and intensity forecasts. The programme has been divided into three phases

(i) Pre- pilot phase : Oct-Nov. 2008
(ii) Pilot phase : Oct-Nov. 2009, 2010
(iii) Final phase : Oct-Nov 2011

During pre-pilot phase **(15 Oct-30 Nov 2008),** several national institutions participated for joint observational, communicational & NWP activities.

1.8. Cyclone Manual Review

Cyclone warning is one of the most important functions of the IMD and it was the first service undertaken by the Department as early as in 1865 and thus the service started before the establishment of the department in 1875. The historical development of the cyclone warning system leading to the organization as it is today is well known to you. In view of the developments in observational tools, analysis and prediction techniques, the monitoring and prediction methodology w.r.t cyclones over north Indian Ocean has undergone several changes. All these above facts have been documented as forecasting manual or cyclone manual. These manuals have undergone several changes in the past considering the requirements of forecasters and disaster managers. The last review of the cyclone manual was carried out and published by IMD during 2003.

In the recent years, there have been many developments in observational and prediction aspects including deployment of DWR. (AWS), meteorological satellites and development of prediction models including QLM, WRF, HWRF models etc. in addition to various synoptic and statistical methods. Hence, the review of the cyclone manual has been taken up with special emphasis on forecasting aspects.

1.9. Modernisation Programme of IMD

During the past 133 years, IMD has undergone several instances of modernization helping it to harmonize with emerging technologies and societal demands. Present phase of modernization is driven by :-

- Demand for high resolution data and forecasts in all time scales with higher accuracies
- 24x7 weather surveillance and dedicated telecom systems for issuing early warnings of disastrous weather
- District specific data, forecasts and Agro advisories
- Specialized Met information to various sectors
- Delivery of Weather Information to Public

Modernization refers to adoption of technologies enabling

- Observational Upgradation
  - Insat-3D, Megha-Tropique, Ocean Sat 2
  - Doppler Weather Radars
  - Automatic Rain Gauges
  - Automatic Weather Stations
  - Upper Air Systems
  - Envirnment Monitoring
  - Seismic Network
- Advanced data communication and processing Technology
- Advanced Computing Systems
- Installation of specific purpose Numerical Prediction Models
  - Cyclone Warning
  - Now casting
  - General Weather Prediction
  - Climate Simulation
  - Environmental Predictions
- Human Resource Development
  - Agro Met Services
  - Aviation Met Services
  - Web Enabled Services
- Weather Channel

The ongoing modernization programme aims at the following:

1. Establishing connectivity (network) for various kinds of instruments across the country to Atmospheric Data Centre at Delhi.
2. The data management software for managing huge quantity (25 Terabytes) of data on continuous basis for 20000 odd sensors including Doppler Weather Radar. This software will enable the scientists of IMD to access relevant data from the data repository;

3. Software tools for various meteorology, climatology and public weather service applications relating to forecasting like nowcasting using DWR and other sensor data, short range forecasting using numerical models and synoptic observation, medium and long range forecasts, specialized services like agro-met advisories and aviation service, climatological software for managing 130 years of observational data of IMD and automatic public weather warning (TV, radio, newspaper, mobile) preparation and dissemination software;
4. Setting up a forecasting environment as an integrated fully automated facility in which manual synoptic weather forecasting will be replaced by hybrid systems in which synoptic method is overlaid on numerical models supported by modern graphical and GIS applications to produce (i) high quality analyses (ii) Ensemble of forecasts from numerical models at different scales - global, regional and mesoscale (iii) nowcasting with radar mosaics for severe thunderstorms and tornadoes (iv) Prediction of intensity and track of tropical cyclone and storm surge (v) Aviation forecasts (vi) Forecasts and warning for shipping (vii) High quality Agro-met Advisory Services (viii) High quality extension of the forecast upto district and village levels. The proposed forecasting network to be established during phase I of modernisation programme is shown in Fig.1.6

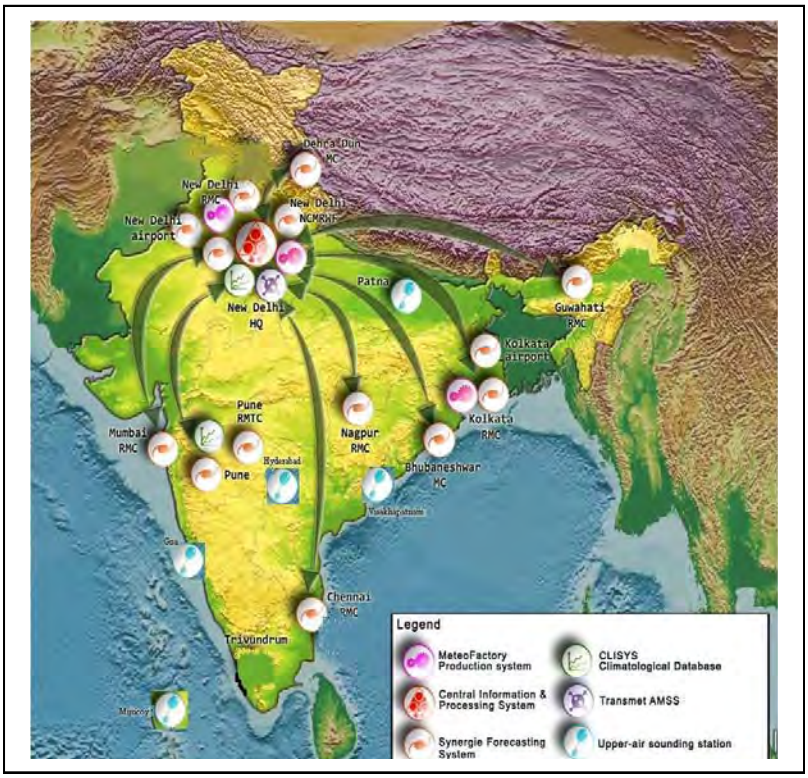

Fig.1.6. Proposed network of forecasting system during phase I of modernization programme

The expected outcomes of the modernization programme are as follows.

- ❖ Improved Weather and Climate Monitoring
- ❖ Real time data availability with rapid updation of data, quicker response time for management, easy accessibility, opportunities for value addition.

- Improved Weather Forecasting for Nowcasting, Short, Medium and Long-range scales (months to Seasons),
- Reduction in loss of life and property from weather hazards
- Understanding, assessment and prediction of climate variability and change for mitigation and adaptation measures,
- Support sustainable agriculture and horticulture and provide inputs for managing rising agricultural risks,
- Meet increasing requirements of civil aviation,
- Understand the effect of environmental factors on human well being, human health and ecology to make more informed decisions
- Monitor and manage Water and Energy Resources of the country.

CHAPTER –II

CYCLONIC ACTIVITIES OVER NORTH INDIAN OCEAN DURING 2008

The north Indian Ocean witnessed the formation of ten cyclonic disturbances (Table 2.1) during the year, 2008 against a normal of fifteen. Out of ten disturbances, six intensified upto the intensity of depression/deep depressions, three into cyclonic storms and one into very severe cyclonic storm. Tracks of the cyclonic disturbances formed over the north Indian Ocean during 2008 are shown in Fig. 2.1.

One deep depression and one depression formed over the Arabian Sea. However, both the system dissipated over the Sea itself. The Bay of Bengal witnessed the formation of one very severe cyclonic storm, three cyclonic storms, two deep depressions, one depression and one land depression during the year.

Salient features of cyclonic disturbances during 2008

- The north Indian Ocean witnessed the formation of ten cyclonic disturbances including one very cyclonic storm and three cyclonic storms (Table 2.1) during the year, 2008 against a normal of fifteen.
- The Arabian Sea was devoid of any cyclone during the year 2008.
- The very severe cyclonic storm, '**NARGIS**' was the most devastating cyclone over the Bay of Bengal after Bangladesh cyclone of 1991 in term of loss of life and property as about 1,40,000 people died in Myanmar due to this cyclone.
- The month of July was devoid of any monsoon depression like the previous July of 1995, 1998, 2000, 2001, 2002 and 2004.

The brief synopses of the cyclonic storms during 2008 are given below:

(a) Very severe cyclonic storm "NARGIS" over the Bay of Bengal during 27 April to 3 May, 2008

A depression formed over the southeast Bay of Bengal at 0300 UTC of 27 April, 2008. Under favourable conditions like warmer Sea surface temperature, low to moderate vertical wind shear and upper level divergence, it intensified into a cyclonic storm **"NARGIS"** at 0300 UTC of 28 and into a very severe cyclonic storm at 0300 UTC of 29 April. The system initially moved in a northwesterly direction and then recurved northeastwards and crossed southwest coast of Myanmar near Lat. 16.0^0 N between 1200 and 1400 UTC of 2 May, 2008. The special features of the very severe cyclonic storm **"NARGIS"** are given below:

(I) The system continued to intensify even after the recurvature.

(II) The system moved almost in easterly direction from 0600 UTC of 1 May till 1500 UTC of 2 May.

(III) The system maintained the intensity of cyclonic storm for about 12 hrs after the landfall causing extensive loss of life and property.

(b) Cyclonic Storm "RASHMI" over the Bay of Bengal during 25-27 October, 2008

A low pressure area developed over the westcentral Bay of Bengal on 24 October 2008. It concentrated into a depression at 0300 UTC of 25 October over the same region. It moved into a north-northeasterly direction and intensified into a cyclonic storm **'RASHMI'** at 1200 UTC of 26 October over the northwest Bay of Bengal. It further moved in a north-northeasterly direction and crossed Bangladesh coast near long.89.5^{0}E about 50 kms west of Khepupara between 2200-2300 UTC of 26 October, 2008. It caused loss of life and property in Bangladesh and northeastern states, due to heavy rainfall and gale/squally winds. The special features of the storm are as follows.

(i) The system intensified with increase in sustained wind speed reaching upto 45 knots just before the landfall.

(ii) System rapidly weakened over land into a low pressure area (within 12 hrs)

(iii) System moved northeastwards skirting the coast causing rainfall over coastal Andhra Pradesh, Orissa, West Bengal and Bangladesh.

Comparing with the past data three cyclonic storm (one each during 1905, 1967, 1988) out of nine cyclonic storms with genesis over the region between 15-20^{0}N or and 85-90^0 E have crossed Bangladesh coast during the period 1891-2007.

(c) Cyclonic Storm 'KHAI MUK' over the Arabian Sea during 13-16 November 2008

A trough of low pressure area over the southeast Bay of Bengal organized into a low pressure area on 12 November. It intensified into a depression at 1200 UTC of 13 November over the southeast Bay of Bengal. Moving northwestwards, it intensified into a cyclonic storm **'KHAI MUK'** at 1200 UTC of 14 November over the westcentral and adjoining southwest Bay of Bengal. Subsequently, it weakened into a deep depression at 0600 UTC of 15 November over the westcentral Bay of Bengal. It continued to move in west-northwesterly direction and crossed south Andhra Pradesh coast to the north of kavali (43243) as a deep depression between 2200 & 2300 UTC of 15 November. The special feature of the storm was that it weakened into a deep depression within the Sea.

(d) Cyclonic Storm "NISHA" over the Bay of Bengal during 25-27 November, 2008

A low pressure area formed over Sri Lanka and neighbourhood on 24 November. It concentrated into a depression over Sri Lanka and lay centred close to the southwest of Trincomalee(43418) at 0900 UTC of 25 November. It intensified into a cyclonic storm **'NISHA'** at 0300 UTC of 26 November over the southwest Bay of Bengal close to Vedaranniyam(43349). It then moved very slowly and crossed Tamil Nadu and Puducherry coast near Karaikal between 0100 and 0200 UTC of 27 November, 2008. It caused widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy falls over coastal Tamil Nadu and Puducherry. Exceptionally heavy rainfall occurred over districts of Cauvery delta. It led to flood over coastal areas of Tamil Nadu and Puducherry. There was loss of 78 human lives and huge crop loss. The salient features of cyclone, **NISHA** are as follows:

(i) The cyclogenesis took place over the land region(north Sri Lanka).

(ii) System remained quasi-stationary for about 24 hours very close to the coast causing exceptionally heavy rainfall.

Cyclonic disturbances during monsoon Season (June-September), 2008

Four cyclonic disturbances developed during the monsoon Season (June-September), 2008. These included one depression over the Arabian Sea and another over the Bay of Bengal during June, one land depression over coastal Orissa during August and one deep depression over the Bay of Bengal during September. The tracks of these systems are shown in Fig. 2.1. The salient features of the monsoon disturbances during 2008 are as follows:

(i) Frequency of disturbances over the Indian region was significantly less compared to long period average of about 7 disturbances. However, it was comparable considering recent years, as the average frequency of the disturbances during monsoon Season was about 3.5 based on data of 1991-2007.

(ii) No system developed as remnant of the systems from south China Sea.

(iii) The month of July was devoid of any monsoon depression like the previous July of 1995, 1998, 2000, 2001, 2002 and 2004.

(iv) The first ever land depression developed in August 2008 after 1987.

(v) The movement of the systems was climatological, as the depressions developing over the Bay of Bengal and coastal Orissa moved west-northwestwards/ northwestwards. No system had a longer track, as no system moved to the left of 80.0^0 E.

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

Table 2.1: Cyclonic disturbances formed over north Indian Ocean and adjoining land areas during 2008

1.	Very severe cyclonic storm “**NARGIS**” over the Bay of Bengal during 27 April- 3 May, 2008
2.	Depression over the Arabian Sea during 5-7 June, 2008
3.	Depression over the Bay of Bengal during 16-18 June, 2008
4.	Land depression over Orissa coast during 9-10 August, 2008
5.	Deep depression over the Bay of Bengal during 15-19 September, 2008
6.	Deep depression over the Arabian Sea during 19-23 October, 2008
7.	Cyclonic storm “**RASHMI**” over the Bay of Bengal during 25-27 October, 2008
8.	Cyclonic storm “**KHAI MUK**” over the Bay of Bengal during 13-16 November, 2008
9.	Cyclonic storm “**NISHA**” over the Bay of Bengal during 25-27 November, 2008
10.	Deep depression over the Bay of Bengal during 4-7 December, 2008

Table 2.2: Some Characteristic features of cyclonic disturbances formed over north Indian Ocean and adjoining region during 2008

Cyclonic Storm / Depression	Date, Time & Lat.(⁰N)/ Long. (⁰E) of genesis	Date, Time (UTC) place of landfall/ dissipation	Estimated lowest central pressure, Date &Time (UTC) & lat.⁰N / long.⁰E	Estimated Maximum wind speed (kt), Date & Time	Max. T. No. Attained
Very Severe Cyclonic Storm "NARGIS" over the Bay of Bengal during 27 April- 3 May.	27 April 0300 UTC near 12.0/87.0	Crossed Myanmar Coast near 16.0⁰N between 1200 & 1400 UTC of 02 May	962 hPa at 0600 UTC of 02 May near 16.0/93.5	90 kt at 0600 UTC of 02 May	T 5.0
Depression over the Arabian Sea during 5-7 June.	5 June, 0000 UTC near 15.5/66.0	Dissipated over the west central and adjoining northwest Arabian Sea at 0000 UTC of 7th June	996 hPa at 1200 UTC of 5th June near 17.0/65.0	25 kt at 0000 UTC of 5 June	T 1.5
Depression over the Bay of Bengal during 16-18 June.	16 June, 0300 UTC near 21.5 /90.0	Crossed Bangladesh coast near 89.5⁰E between 1100-1200 UTC of 16 June	988 hPa at 0900 UTC of 16 June near 21.5/89.5	25 kt at 0300 UTC of 16 June	T 1.5
Land Depression over Orissa during 9-10 August.	9 August, 1200 UTC near 20.0/86.0	Weakened into a well marked low pressure area over north Orissa	988 hPa at 1200 UTC of 9 August near 20.0/86.0	25 kt at 1200 UTC of 9 August	-
Deep Depression over the Bay of Bengal during 15-19 September.	15 September 1200 UTC near 19.5/88.5	Crossed Orissa coast near Chandbali between 1600-1700 UTC of 16 September.	988 hPa at 1800 UTC of 16 September near 21.0/86.5	30 kt at 0300 UTC of 16 September	T 2.0
Deep Depression over the Arabian Sea during 19-23 October.	19 October, 0900 UTC near 9.0/60.0	Dissipated over the west central Arabian Sea and adjoining Gulf of Aden at 0300 UTC of 23 October	1000 hPa at 0300 UTC of 21 October, near 10.5/54.5	30 kt at 0300 UTC of 21 October.	T 2.0
Cyclonic Storm "RASHMI" over the Bay of Bengal during 25-27	25 October 0300 UTC near 16.5 / 86.5	Crossed Bangladesh coast between 2200-2300 UTC of 26 October	984 hPa at 2100 UTC of 26 October Near 21.0/89.0	45 kt at 2100 UTC of 26 October.	T 3.0

October.		near Long. 89.5^0 E			
Cyclonic Storm "KHAI MUK" over the Bay of Bengal during 13-16 November.	13 November, 1200 UTC near 11.5/85.5	Crossed South Andhra Pradesh coast close to the north of Kavali between 2200 and 2300 UTC of 15 November.	994 hPa at 2100 UTC of 14 November Near 14.5/83.0	40 kt at 2100 UTC of 14 November	T 2.5
Cyclonic Storm "NISHA" over the Bay of Bengal during 25-27 November.	25 November 0900 UTC near 8.5/81.0	Crossed Tamil Nadu coast north of Karaikal near lat 11.3/79.8 between 0000 & 0100 UTC 27 November	996 hPa at 2100 UTC of 26 November near 11.0/80.0	45 kt at 0900 UTC of 26 November.	T 3.0
Deep Depression over the Bay of Bengal during 4-7 December.	4 December 0300 UTC near 6.5/90.0	Weakened into a well marked low pressure area over Sri Lanka and adjoining south west Bay of Bengal at 1500 UTC of 7 December	1004 hPa at 0000 UTC of 5 December, Near 7.5/88.5	30 kt at 0000 UTC of 5 December.	T 2.0

Table 2.3: Statistical data relating to cyclonic disturbances over the north Indian Ocean during 2008

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

S.N	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	D						↔ ↔						
2.	DD									↔	↔		↔
3.	CS										↔	↔ ↔	
4.	SCS												
5.	VSCS				↔								
6.	SuCS												

↔ Peak intensity of the system

B) Life time of cyclonic disturbances during 2008

S.No	Type	Life Time in (Days)
1.	D	13.5
2.	DD	8.5
3.	CS	3.0
4.	SCS	1.0
5.	VSCS	4.0
6.	SuCS	-
Total Life Time in (Days)		**30.0**

c) Frequency distribution of cyclonic disturbances with different intensities based on satellite assessment.

CI No.	**≥1.5**	**≥2.0**	**≥2.5**	**≥3.0**	**≥4.0**	**≥5.0**	**≥6.0**	**≥7.0**
No. of disturbances	**9**	**7**	**4**	**3**	**1**	**1**	**-**	**-**

D) Basin-wise distribution of cyclonic disturbances

Basin	**Number of cyclonic disturbances**
Bay of Bengal	**7**
Arabian Sea	**2**
Land depression	**1**

Table 2.4
Cyclonic disturbances formed over the north Indian Ocean and land areas of India during 1997-2008

Year	Basin	D	DD	CS	SCS	VSCS	SuCS	Total
1997	BOB	1	4	1	1	1	--	8
	ARB	1	--	--	--	--	--	1
	Total							**9**
1998	BOB	--	3	--	1	2	--	6
	ARB	--	1	1	1	1	--	4
	Total							**10**
1999	BOB	1	3	1	--	1	1	7
	ARB	--	--	--	--	1	--	1
	Total							**8**
2000	BOB	1	--	3	--	2	--	6
	ARB	--	--	--	--	--	--	-
	Total							**6**
2001	BOB	2	--	1	--	--	--	3
	ARB	--	--	2	--	1	--	3
	Total							**6**
2002	BOB	1	1	2	1	--	--	5
	ARB	--	--	1	--	--	--	1
	Total							**6**
2003	BOB	2	2	--	1	1	--	6
	ARB	--	--	--	1	--	--	1
	Total							**7**
2004	BOB	2	--	--	--	1	--	3
	ARB	--	2	--	3	--	--	5
	LAND	2	--	--	--	--	--	2
	Total							**10**
2005	BOB	2	3	4	--	--	--	9
	ARB	2	--	--	--	--	--	2
	LAND	1	--	--	--	--	--	1
	Total							**12**
2006	BOB	5	2	1	--	1	--	9
	ARB	--	1	--	1	--	--	2
	LAND	1	--	--	--	--	--	1
	Total							**12**
2007	BOB	3	4	1	--	1	--	9
	ARB	--	1	1	--	--	1	3
	Total							**12**
2008	BOB	1	2	3		1		7
	ARB	1	1	--	--	--	--	2
	LAND	1	--	--	--	--	--	1
	Total							**10**

D: Depression **DD:** Deep Depression, **CS:** Cyclonic Storm, **SCS:** Severe Cyclonic Storm, **VSCS:** Very Severe Cyclonic Storm, **SuCS:** super Cyclonic Storm
BOB: Bay of Bengal **ARB:** Arabian Sea

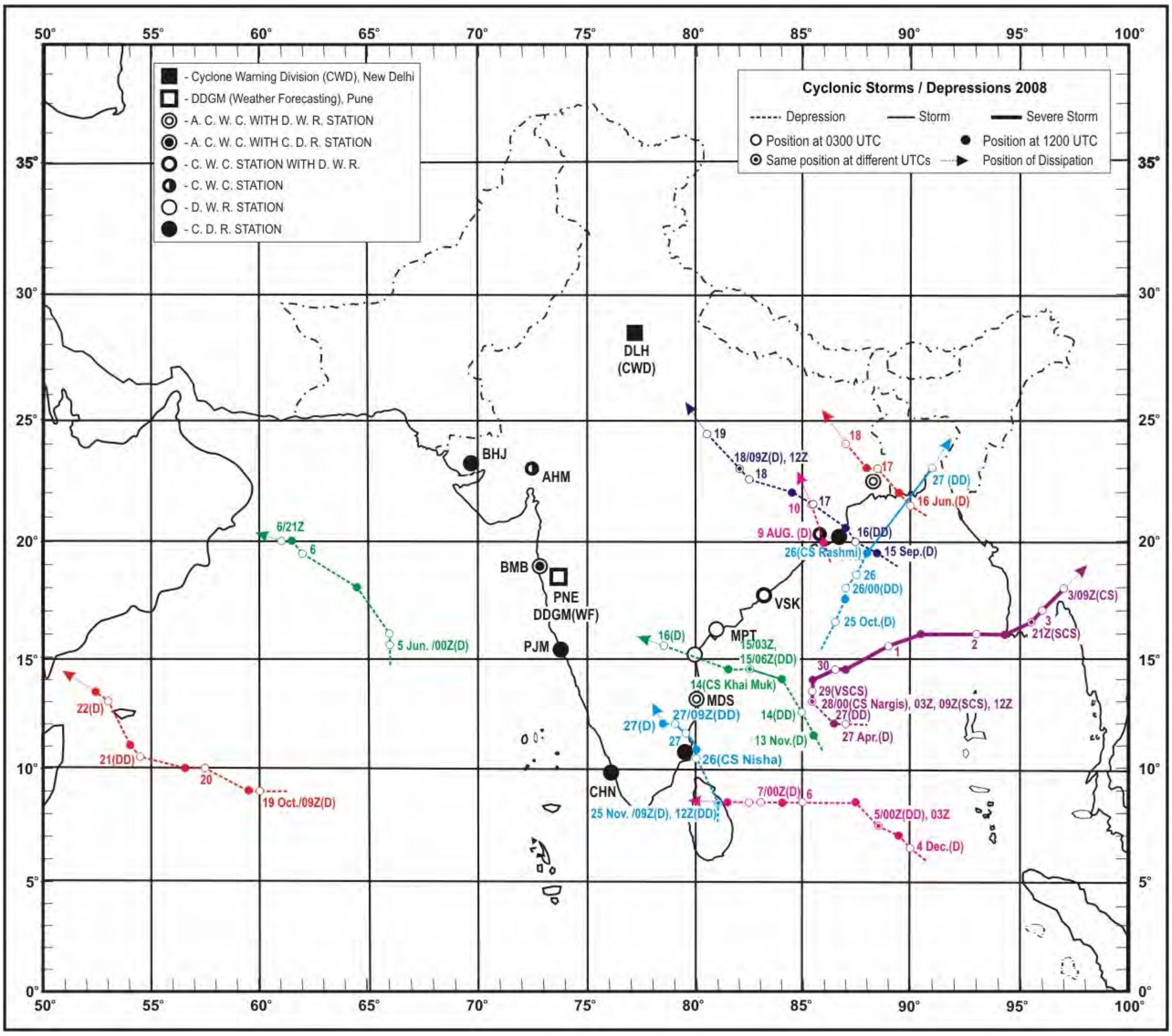

Fig. 2.1.Tracks of the systems formed over the north Indian Ocean during 2008.

2.1. Very Severe Cyclonic Storm “NARGIS” over Bay of Bengal during 27 April to 3 May, 2008

2.1.1 Introduction

A depression formed over the southeast Bay of Bengal in the morning of 27 April, 2008. Under favourable conditions, it intensified into a cyclonic storm **“NARGIS”** at 0000 UTC of 28 and into a very severe cyclonic storm at 0300 UTC of 29. The system initially moved in a northwesterly direction and then recurved northeastwards and crossed southwest coast of Myanmar near Lat. 16.0^0 N between 1200 and 1400 UTC of 2 May, 2008. It was the most devastating cyclonic storm over the north Indian Ocean in recent years in terms of loss of life and property.

The special features of the very severe cyclonic storm **“NARGIS”** are given below:

(i) The system continued to intensify even after the recurvature.

(ii) The system moved almost in easterly direction from 0600 UTC of 1 May till 1500 UTC of 2May.

(iii) The system maintained the intensity of very severe cyclonic storm for about 12 hrs after the landfall.

The genesis of the system is presented in sec. 2.1.2; intensification & movement are presented and discussed in sec. 2.1.3. The maximum wind & estimated central pressure (ECP) are presented and discussed in sec 2.1.4. The main features observed in Satellite imageries are described in section 2.1.5. The realized weather and damage due to the system are given in section 2.1.6 and 2.1.7 respectively.

2.1.2. Genesis

During last week of April, Inter-Tropical Convergence Zone (ITCZ) was very active. Under its influence, a cyclonic circulation developed and the associated cloud clusters persisted for 3-4 days over southeast Bay of Bengal. As a result of increasing convection under the influence of cyclonic circulation, a low-pressure area formed over the southeast Bay of Bengal in the morning of 26 April. Under the favourable conditions like warmer Sea surface temperature, low vertical wind shear and poleward outflow, it concentrated into a depression over the same area and lay centred at 0300 UTC of 27 near lat. 12.0^0 N and long. 87.0^0 E.

2.1.3 Intensification and movement

Initially, the depression moved westwards, intensified into a deep depression and lay centered at 1200 UTC of 27 near lat. 12.0^0 N and long. 86.5^0 E. At this time, upper air ridge was running roughly along 15.0^0 N over the region. There was an anticyclonic circulation, located to the east and centered near lat. 15^0 N and long. 95^0 E. Due to this, strong steering flow from the southeast prevailed and the system started to move in a northwesterly direction. It intensified into a cyclonic storm and lay centred at 0000 UTC of 28 near lat. 13.0^0 N and long. 85.5^0 E. The upper tropospheric ridge over the storm region ran roughly along 14^0 N. However, anticyclonic circulation lay to the east-southeast of the system centre and became the primary steering influence to cause nearly northerly but slow movement of the system. A trough in extra tropical westerlies roughly ran along 60^0 E to the north of 15^0 N. It provided the added upper air divergence to the system. The system intensified into a severe cyclonic storm at 0900 UTC of 28 and into a very severe cyclonic storm at 0300 UTC of 29. As the system lay very close to the upper tropospheric ridge, its movement in northerly direction slowed down till 29. Thereafter, the system lay to the north of ridge and came under the joint influence of upper air anticyclone lying to the southeast and mid-latitude upper tropospheric westerlies. Due to above reason, the system started to move in a east-northeasterly direction till 1200 UTC of 1 May. The system then moved in easterly direction while intensifying further and crossed southwest coast of Myanmar between 1200 to 1400 UTC of 2 May near lat. 16.0^0 N**.** From 1500 UTC of 2 May, it took northeasterly course and started to move in a northeasterly direction. After crossing the coast, the system gradually weakened and it lay as a severe cyclonic storm, centred at 0300 UTC of 3 May over Myanmar near lat. 17.0^0 N and long. 96.0^0 E, close to Yangon. The system weakened into a low pressure area over northeast Myanmar and adjoining Thailand in the evening of 3rd May, 2008. The best track position and other parameters are given in the Table 2.1.1. The track of the system is shown in Fig.2.1. A few satellite imageries of the system are given in Fig.2.1.1. The upper air wind pattern at 200 hPa are shown in fig 2.1.2. The vertical wind shear of horizontal wind is shown in fig. 2.1.3.

2.1.4. Sustained maximum wind and ECP

The maximum sustained wind speed of 90 knots prevailed around system centre during 0600 to 1800 UTC of 2 May. As per the news paper reports, the maximum wind speed of 190 kmph prevailed over the delta region. As the system moved eastwards close to the coast, the system maintained cyclone intensity even after 20 hours of landfall.

The lowest ECP of the system was 962 hPa recorded at 0600 UTC of 2 May with a pressure drop of about 40 hPa.

Throughout the life of cyclone, the Sea surface temperature over the Bay of Bengal was $29\text{-}32^0$C, which was favourable for both cyclogenesis and intensification. The vertical wind shear of horizontal winds between 200 and 850 hPa levels was also favourable as it was less than 20 knots around the system centre throughout the period except a few hours on 29 April, when satellite imagery showed slight weakening of the system. The upper level divergence, lower level convergence, lower level relative vorticity were also favourable for intensification of the system.

2.1.5. Main features observed in satellite imageries

The very severe cyclonic storm **“NARGIS”** was mostly tracked by satellite. Satellite imageries showed banding features with arc length of 0.5^0 and intensity T 2.5 (cyclonic storm) at 0000 UTC of 28 April. It showed CDO pattern with banding features at 0200 UTC of 29 April with T 4.0. At 1200 UTC of same day, due to increase in shearing, system showed slight disorganization. However, the system again intensified and the eye of the cyclone was visible from 0400 UTC of 1 May to 1200 UTC of 2 May. The eye temperature was -57^0C. and the intensity of the system increased to T 5.0 at 0500 UTC of 2 May and the same intensity continued till the landfall of the system. The daily outgoing longwave radiation as observed at 0000 UTC by INSAT-Kalpana-1 satellite during 27 April to 3 May are shown in Fig.2.1.2. It clearly indicated the eastward propagation of convection in association with the system.

2.1.6. Realised Weather

India

Fairly widespread rainfall occurred over Andaman and Nicobar Islands during the cyclone period. The significant amount of rainfall (in cm) recorded over Andaman and Nicobar Island are given below:

27 APRIL 2008:
Nancowry-4, Port Blair-1, Carnicobar-1
28 APRIL 2008:
Port Blair-5, Hut Bay-5, Carnicobar-4, Nancowry-2, Mayabandar-2
29 APRIL 2008:
Port Blair-8, Mayabandar-7, Long Island-6, Hut Bay-4, Carnicobar-2
30 APRIL 2008:
Carnicobar-2, Hut Bay-2, Mayabandar-2, Long Island-1, Port Blair-1
01 MAY 2008:
Carnicobar-7, Hut Bay-2
02 MAY 2008:
Long Island-11, Mayabandar-6

03 MAY 2008:
Mayabandar-2, Port Blair-1, Long Island-1

Myanmar

As per news paper report, widespread rainfall caused flood over Ayeyarwady river delta and Yangon city. The storm surge of about 3-5 meters over the Ayeyarwady delta region of Myanmar has been reported in the media. The storm surge as estimated by Department of Meteorology and Hydrology, Myanmar is shown in Fig. 2.1.5.

Maximum estimated wind speed of 190 kmph has been reported over delta region during landfall

2.1.7. DAMAGE:

Details of the damage are given below:

Affected population	11 millions
Houses Damaged	745764
Deaths (human)	84000
Missing (human)	54000
Injured people	20000
Death of cattle, bulls, buffaloes, household animals	155248 above
Area covered by salty Sea water	72798 acres
National Sector Loss	3.3547 trillion kyats

A few photographs showing damage caused by very severe cyclonic storm, '**NARGIS'** are given in fig.2.1.6.

Table 2.1.1. Best track positions and other parameters for Bay of Bengal very severe cyclonic storm, "NARGIS" (27 April to 3 May, 2008)

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
27-04-2008	0300	12.0/87.0	1.5	1000	25	3	D
	0600	12.0/87.0	1.5	998	25	3	D
	0900	12.0/86.5	1.5	998	25	3	D
	1200	12.0/86.5	2.0	998	30	4	DD
	1500	12.0/86.5	2.0	994	30	4	DD
	1800	12.5/86.0	2.0	994	30	4	DD
	2100	13.0/85.5	2.0	994	30	4	DD
28-04-2008	0000	13.0/85.5	2.5	994	35	6	CS
	0300	13.0/85.5	2.5	994	40	8	CS
	0600	13.0/85.5	3.0	990	45	10	CS
	0900	13.0/85.5	3.5	986	55	14	SCS
	1200	13.0/85.5	3.5	986	55	14	SCS
	1500	13.0/85.5	3.5	986	55	14	SCS
	1800	13.0/85.5	3.5	986	55	14	SCS
	2100	13.0/85.5	3.5	986	55	14	SCS
29-04-2008	0000	13.0/85.5	3.5	986	55	14	SCS
	0300	13.5/85.5	4.0	980	65	20	VSCS
	0600	13.5/85.5	4.0	980	65	20	VSCS
	0900	13.5/85.5	4.0	980	65	20	VSCS
	1200	14.0/85.5	4.0	980	65	20	VSCS
	1500	14.0/85.5	4.0	980	65	20	VSCS
	1800	14.0/85.5	4.0	980	65	20	VSCS
	2100	14.0/86.0	4.0	980	65	20	VSCS
30-04-2008	0000	14.0/86.0	4.0	980	65	20	VSCS
	0300	14.5/86.5	4.0	980	65	20	VSCS
	0600	14.5/86.5	4.0	980	65	20	VSCS
	0900	14.5/87.0	4.0	980	65	20	VSCS
	1200	14.5/87.0	4.0	980	65	20	VSCS
	1500	15.0/87.5	4.0	980	65	20	VSCS
	1800	15.0/87.5	4.0	980	65	20	VSCS
	2100	15.0/87.5	4.0	980	65	20	VSCS
01-05-2008	0000	15.5/88.0	4.0	980	65	20	VSCS
	0300	15.5/89.0	4.0	980	65	20	VSCS
	0600	16.0/89.5	4.0	980	65	20	VSCS
	0900	16.0/90.0	4.0	980	65	20	VSCS
	1200	16.0/90.5	4.0	980	65	20	VSCS
	1500	16.0/91.0	4.0	980	65	20	VSCS
	1800	16.0/91.5	4.0	980	65	20	VSCS
	2100	16.0/92.0	4.0	980	65	20	VSCS
	0000	16.0/92.5	4.5	972	77	28	VSCS
	0300	16.0/93.0	4.5	972	77	28	VSCS

<table>
<tr><td rowspan="7">02-05-2008</td><td>0600</td><td>16.0/93.5</td><td>5.0</td><td>962</td><td>90</td><td>40</td><td>VSCS</td></tr>
<tr><td>0900</td><td>16.0/94.0</td><td>5.0</td><td>962</td><td>90</td><td>40</td><td>VSCS</td></tr>
<tr><td>1200</td><td>16.0/94.3</td><td>5.0</td><td>962</td><td>90</td><td>40</td><td>VSCS</td></tr>
<tr><td colspan="7">Very severe cyclonic storm crossed southwest coast of Myanmar near 16.0^0 N between 1200-1400 UTC.</td></tr>
<tr><td>1500</td><td>16.0/95.0</td><td>-</td><td>964</td><td>90</td><td>40</td><td>VSCS</td></tr>
<tr><td>1800</td><td>16.5/95.5</td><td>-</td><td>974</td><td>80</td><td>30</td><td>VSCS</td></tr>
<tr><td>2100</td><td>16.5/95.5</td><td>-</td><td>986</td><td>60</td><td>18</td><td>SCS</td></tr>
<tr><td rowspan="5">03-05-2008</td><td>0000</td><td>16.5/95.5</td><td>-</td><td>990</td><td>50</td><td>14</td><td>SCS</td></tr>
<tr><td>0300</td><td>17.0/96.0</td><td>-</td><td>992</td><td>50</td><td>12</td><td>SCS</td></tr>
<tr><td>0600</td><td>17.5/96.5</td><td>-</td><td>994</td><td>45</td><td>10</td><td>CS</td></tr>
<tr><td>0900</td><td>18.0/97.0</td><td>-</td><td>998</td><td>35</td><td>6</td><td>CS</td></tr>
<tr><td>1200</td><td colspan="6">Weakened into a well marked low pressure area over eastcentral Myanmar.</td></tr>
</table>

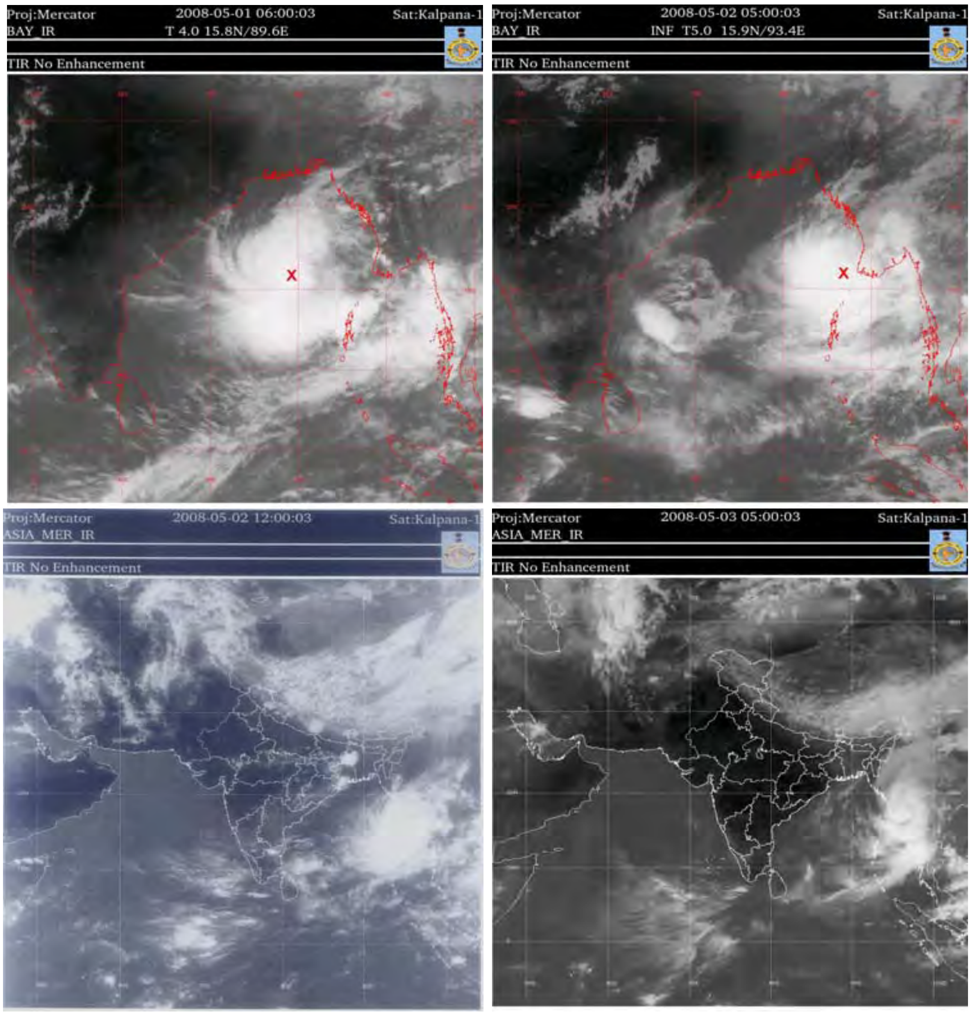

Fig. 2.1.1. (a-d) KALPANA-I Satellite imageries of the very severe cyclonic storm, 'NARGIS'

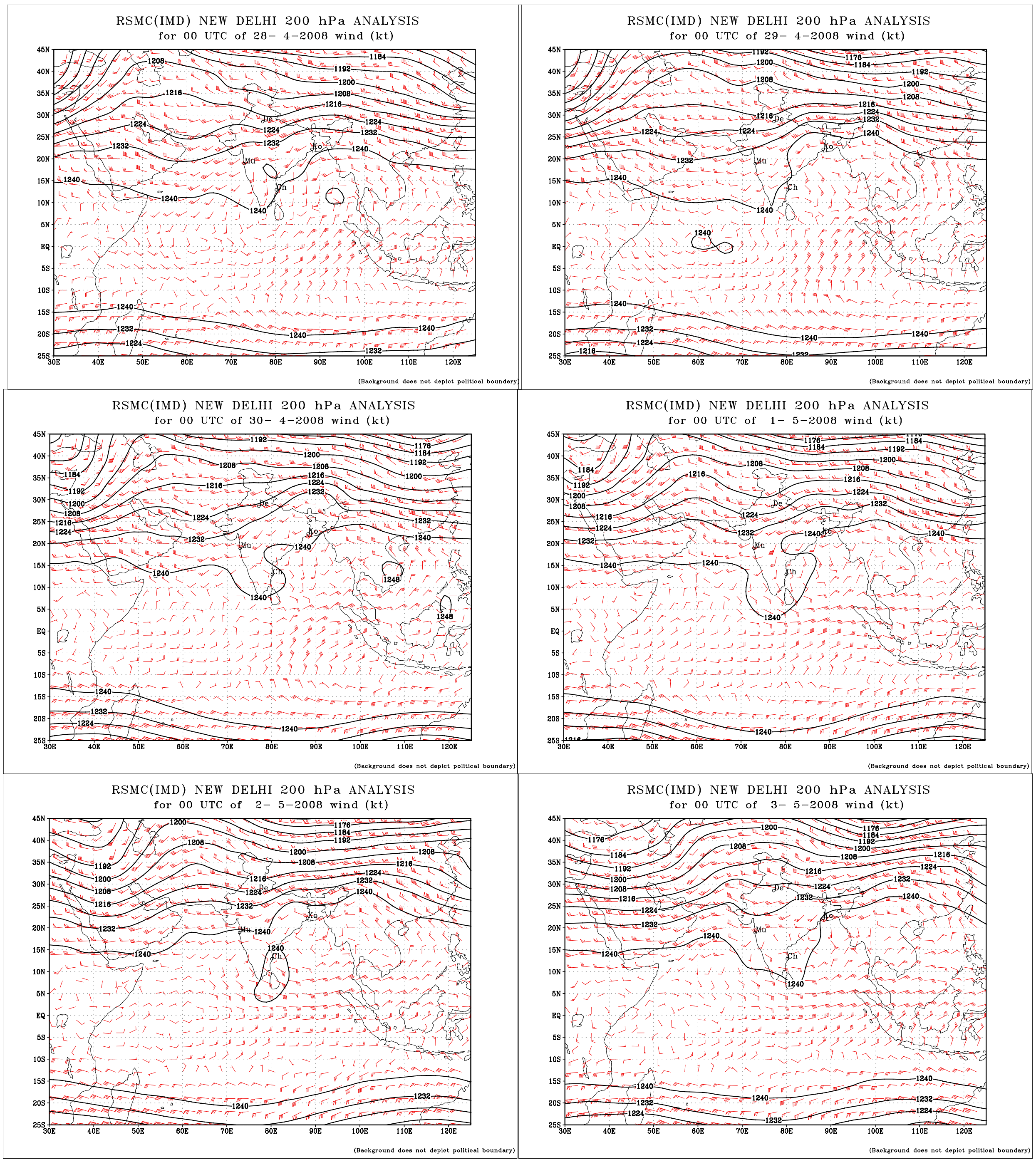

Fig.2.1.2. Upper air wind pattern at 0000 UTC of 200 hPa during 27 April – 3 May, 2008

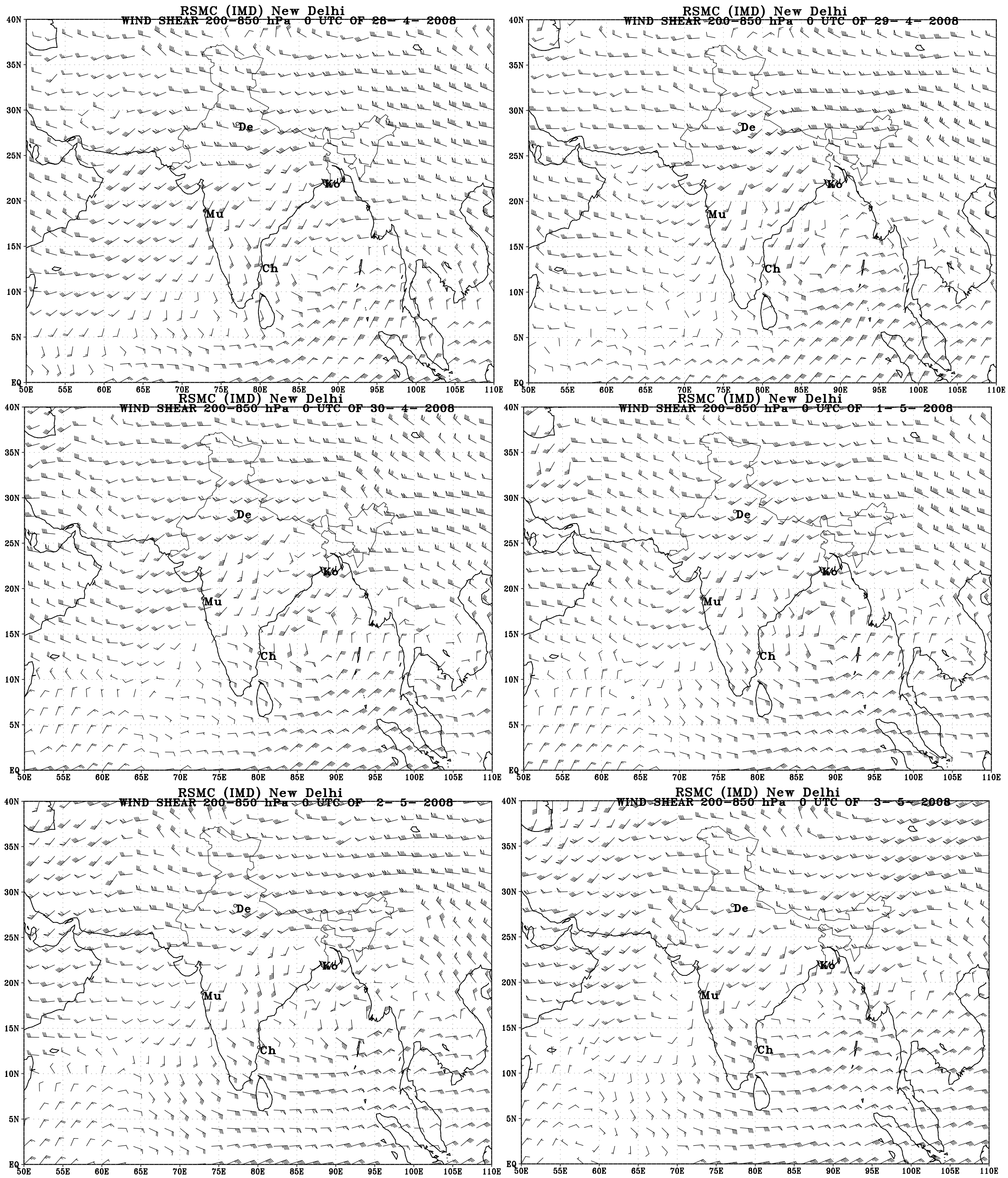

Fig. 2.1.3 Vertical wind shear at 0000 UTC during 27 April – 3 May, 2008

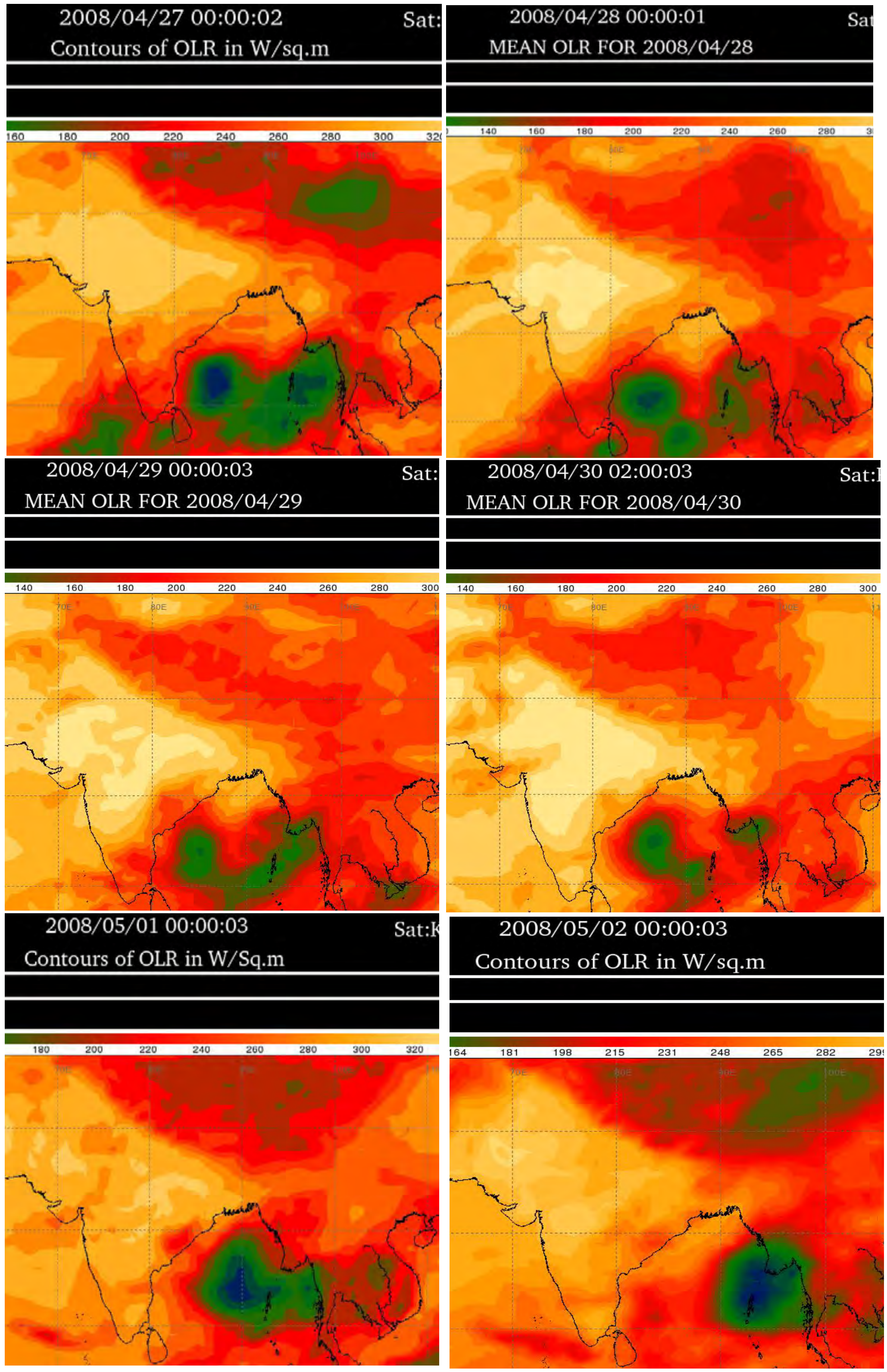

Fig. 2.1.4. Daily OLR distribution as observed at 0000 UTC during 27 April- 3 May 2008

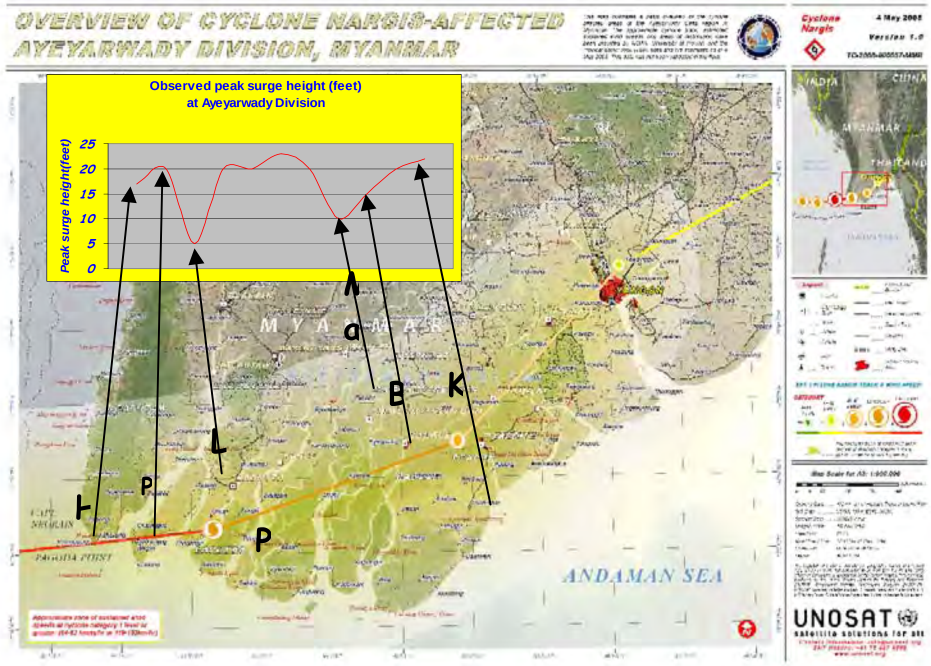

Fig.2.1.5. The storm surge as estimated by Department of Meteorology and Hydrology, Myanmar

Fig. 2.1.6. Photographs showing damage in Myanmar caused by Very Severe Cyclonic Storm "NARGIS"

2.2 Depression over the Arabian Sea (5-7 June, 2008)

2.2.1 Introduction:

A depression formed over the eastcentral Arabian Sea on 5 June during onset phase of monsoon. It moved in a northwesterly direction and weakened into a low pressure area over northwest and adjoining westcentral Arabian Sea and coastal Oman on 7 June. It caused heavy rainfall over coastal Oman. The genesis of the system is discussed in sec. 2.2.2, intensification and movement in sec. 2.2.3 and realised weather and damge in sec 2.2.4.

2.2.2 Genesis:

During the onset phase of monsoon, the southwesterly monsoon current over the Arabian Sea strengthened in the beginning of June and an off shore trough ran along Karnataka and Kerala coast with increase in pressure gradient. An east-west shear zone ran across south peninsula with embedded cyclonic circulation over southeast Arabian Sea during 1-3 June. Under the influence of the above systems, a low pressure area developed over eastcentral Arabian Sea on 4 June morning. The associated cyclonic circulation extended upto mid-tropospheric level. It concentrated into a depression over eastcentral Arabian Sea at 0000 UTC of 5 June, under the favourable conditions of low to moderate vertical wind shear, upper level westward divergent flow and stronger low level convergence to the south of the system. It lay centred at 0000 UTC of 5 June over eastcentral Arabian Sea near Lat. 15.5^0 N and long. 66.0^0 E, about 800 km southwest of Mumbai.

2.2.3 Intensification and movement:

The system moved in a northerly direction initially and lay centred at 0300 UTC of same day near Lat. 16.0^0 N and long. 66.0^{0}E, the system further moved in a north-northwesterly direction and lay centred at 1800 UTC of 5 June near Lat. 19.0^0 N and long. 64.0^{0}E. Thereafter the system moved in a northwesterly direction till 2100 UTC of 6 June and lay centred near Lat. 20.5^0 N and long. 60.5^{0}E. At this time, with strong low level westerly flow on the southern side of the system and westward divergent flow at the upper troposphere with ridge line roughly running along Lat. 21.0^0 N, the system lay in a region of moderate easterly vertical wind shear. The system also came under the effect of interaction with land surface. As a result, the system weakened into a well marked low pressure area at 0000 UTC of 7 June over northwest and adjoining westcentral Arabian Sea and adjoining coastal Oman. The best track parameters of the system are shown in Table 2.2.1 The INSAT imageries and outgoing long wave radiation (OLR) distribution in association with the system are shown in Fig.2.2.1.

Table 2.2.1: Best track positions and other parameters for depression over the Arabian Sea (05-07 June, 2008)

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
05-6-2008	0000	15.5/66.0	1.5	1000	25	4	D
	0300	16.0/66.0	1.5	1000	25	4	D
	0600	16.5/65.5	1.5	1000	25	4	D
	0900	17.0/65.0	1.5	1000	25	4	D
	1200	18.0/64.5	1.5	996	25	4	D
	1500	18.5/64.5	1.5	996	25	4	D
	1800	19.0/64.0	1.5	996	25	4	D
	2100	19.5/63.5	1.5	996	25	4	D
06-6-2008	0000	19.5/63.0	1.5	996	25	4	D
	0300	19.5/62.0	1.5	995	25	4	D
	0600	20.0/62.0	1.5	995	25	4	D
	0900	20.0/61.5	1.5	995	25	4	D
	1200	20.0/61.5	1.5	994	25	4	D
	1500	20.0/61.5	1.5	996	25	4	D
	1800	20.0/61.0	1.5	996	25	4	D
	2100	20.0/61.0	1.5	996	25	4	D
07-6-2008	0000	Weakened into a well marked low pressure area over northwest & adjoining westcentral Arabian Sea and adjoining coastal Oman.					

2.2.4 Realised Weather and Damage:

As this system moved northwestwards away from Indian coast, it did not cause any severe weather over the country. However, it caused fairly widespread rainfall over Lakshadweep Islands during its genesis period. The system caused fairly widespread rainfall with isolated heavy falls over coastal Oman as per the News Paper report.

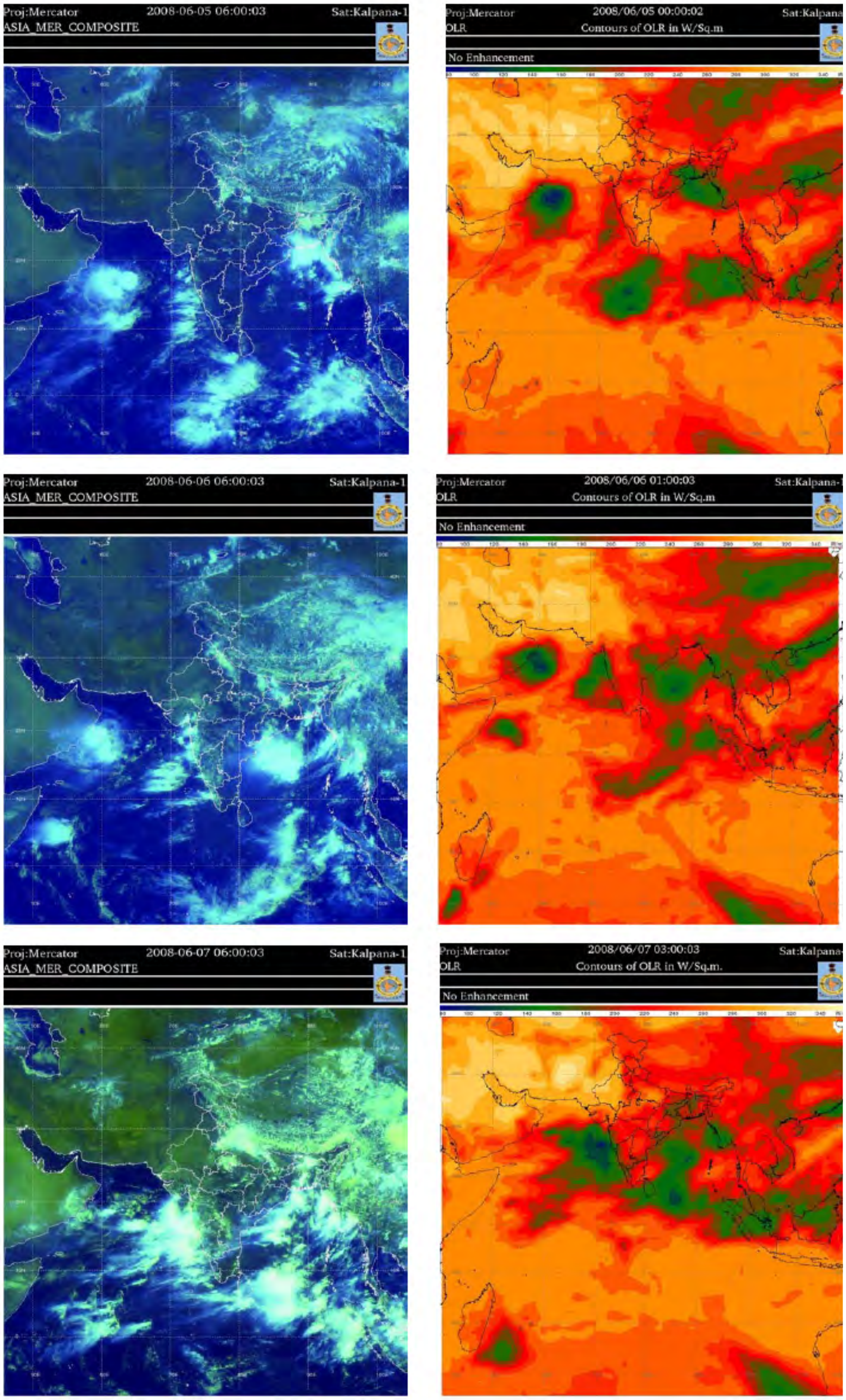

Fig.2.2.1. INSAT imageries at 0600 UTC and OLR at 0000 UTC over Indian region during 5-7 June 2008

2.3 Depression over the Bay of Bengal (16-18 June, 2008)

2.3.1 Introduction:

A depression developed over the north Bay of Bengal during onset phase of monsoon at 0300 UTC of 16th June. Moving in a north-northwesterly direction, it crossed Bangladesh coast near long 89.5^{0} E between 1100 and 1200 UTC of 16 June. Under its influence widespread rainfall with scattered heavy to very falls and isolated extremely heavy falls occurred over Gangetic West Bengal, Jharkhand and north Orissa leading to flood over these regions. The genesis of the system is discussed in sec. 2.3.2, intensification and movement in sec. 2.3.3, and realized weather and damage in sec. 2.3.4.

2.3.2 Genesis:

A convective cloud cluster developed over central and adjoining Bay of Bengal on 13 June. It slowly organized with persistence of the convection over the region. The southwesterly winds over the Bay of Bengal increased in intensity leading to development of a lower level cyclonic circulation embedded with the monsoon trough over the north Bay of Bengal on 14 June. Under its influence, a low pressure area formed over the north Bay of Bengal at 0300 UTC of 15 June. The mean Sea level pressure fell by about 2 hPa along West Bengal and Orissa coasts at 1200 UTC of 15 June. The adequate upper level divergence continued to support the deep convection over the region. Under the influence of the above favourable conditions, the low pressure area over the north Bay of Bengal concentrated into a depression and lay centred at 0300 UTC of 16 June 2008 over the north Bay of Bengal near lat. 21.5^{0}N and long. 90.0^{0} E, about 220 km southwest of Kolkata.

2.3.3 Intensification and movement:

The upper tropospheric ridge ran roughly along 25^{0}N at this time. The southeasterly winds prevailed at 200 hPa level over the north Bay of Bengal and adjoining areas favouring northwestward movement of the system. Hence, the depression moved in a northwesterly direction and crossed Bangladesh coast near long. 89.5^{0}E between 1100 and 1200 UTC of 16 June. The system did not intensify further due to moderate to high vertical wind shear over the region. The winds over Kolkata at 0000 and 1200 UTC of 16 June were about 090/10knots at 850 hPa level. However, on 17 and 18 June, the lower tropospheric winds became very strong varying between 30 and 40 knots around the system centre. The maximum pressure departure was about 02-08 hPa in association with the system during16-18 June. It continued to move in a northwesterly direction and lay centred at 0300 UTC of 17 June over Gangetic west Bengal and adjoining Bangladesh near Krishna Nagar (42711) in west Bengal. It then moved slightly west-northwestwards and lay centred at 1200 UTC of 17 June near Burdwan (42709) in Gangetic West Bengal. It further moved northwestwards and lay centred at 0300 UTC of 18 June over Jharkhand, about 50 km southwest of Dumka (42599). It weakened into a well marked low pressure area over Jharkhand and neighborhood at 0900 UTC of 18 June and into a low pressure over northeast Madhya Pradesh and adjoining areas at 0300 UTC of 19 June.

The best track parameters of the system are shown in Table 2.3.1. The INSAT imageries along with OLR distribution are shown in Fig.2.3.1. DWR, Kolkata imageries at 1200 UTC of 16 June and 0300 UTC of 17 June 2008 are shown in Fig.2.3.2.

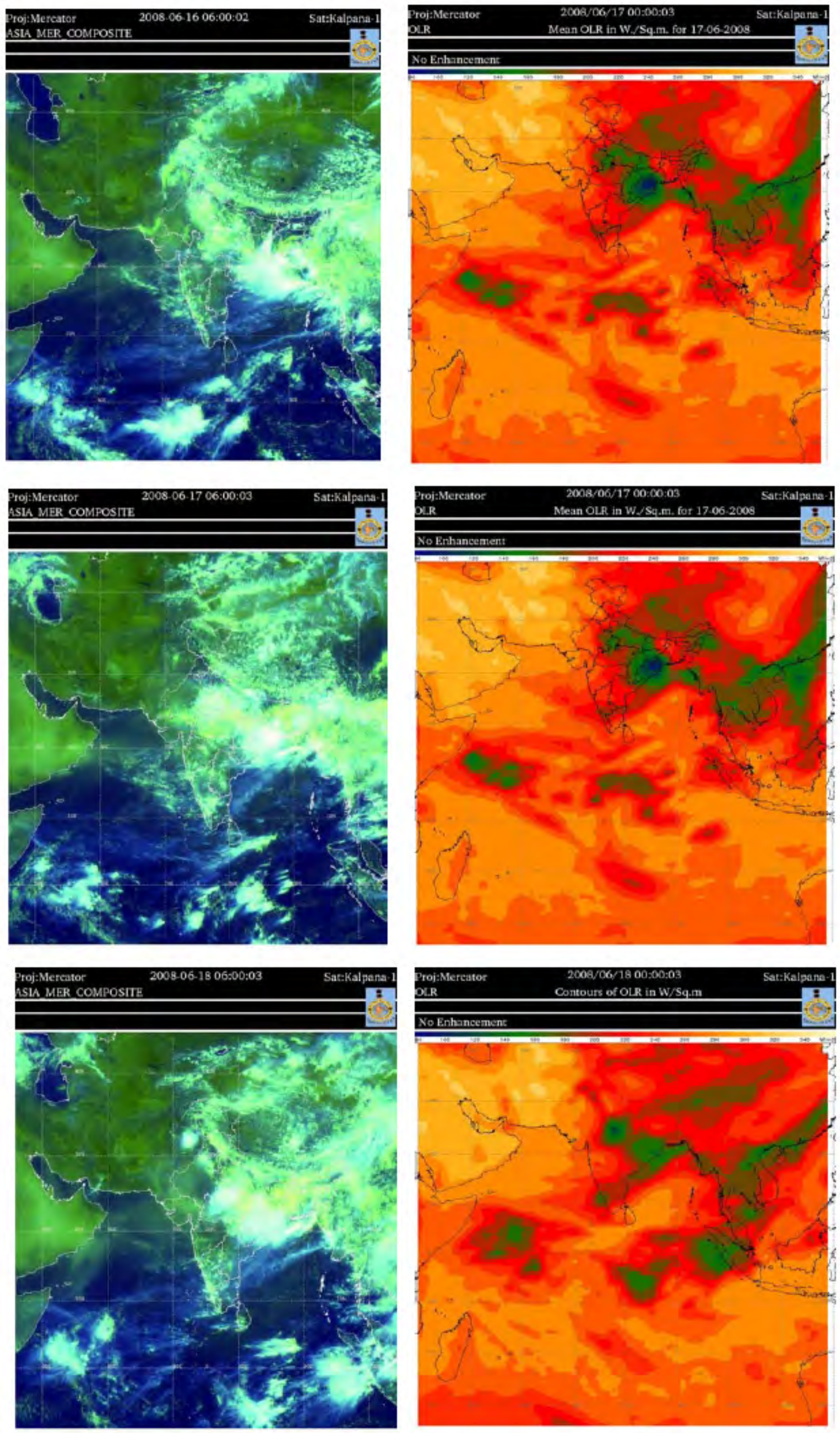

Fig.2.3.1. INSAT imageries at 0600 UTC and OLR at 0000 UTC over Indian region during 16- 18 June 2008

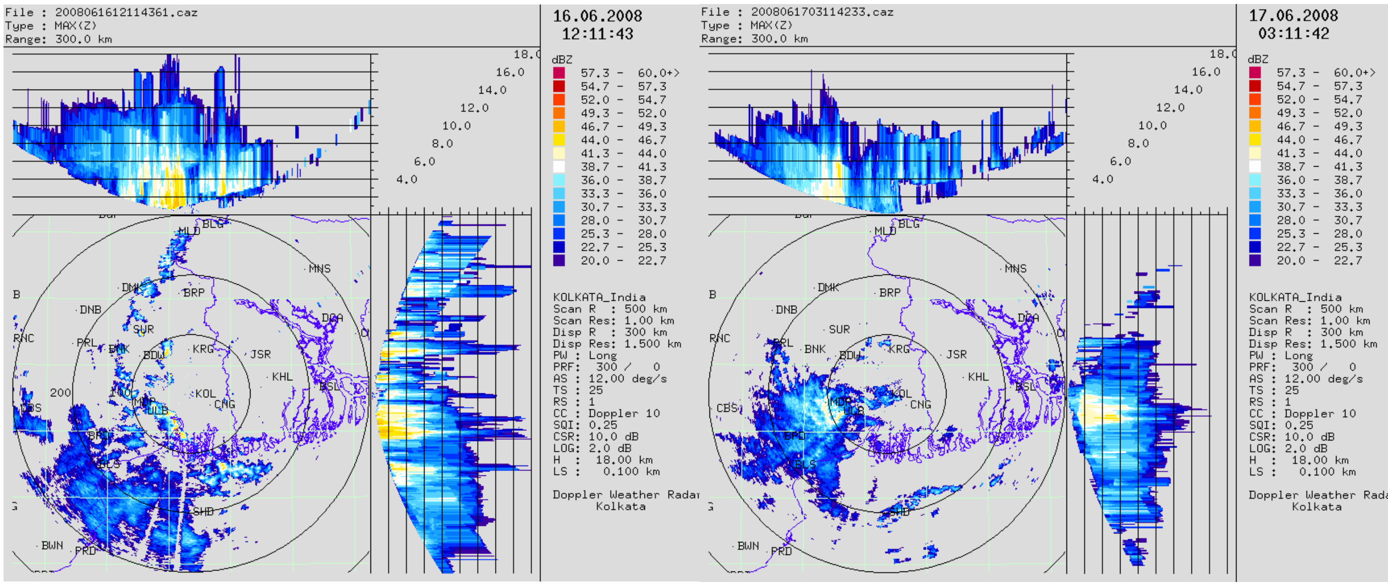

Fig.2.3.2. DWR, Kolkata imageries at 1200 UTC of 16 June and 0300 UTC of 17 June, 2008

Table 2.3.1: Best track positions and other parameters for depression over the Bay of Bengal depression (June 16-18, 2008)

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
16-06-2008	0300	21.5/90.0	1.5	992	25	4	D
	0900	21.5/89.5	1.5	988	25	4	D
	The system crossed Bangladesh coast between 1100 UTC & 1200 UTC near 89.5^0 E.						
	1200	22.0/89.5	1.5	988	25	4	D
17-06-2008	0300	23.0/88.5	1.5	990	25	4	D
	0900	23.0/88.0	1.5	990	25	4	D
	1200	23.0/88.0	1.5	990	25	4	D
18-06-2008	0300	24.0/87.0	1.5	992	20	3	D
	0900	Well marked low pressure area over Jharkhand and neighbourhood.					

2.3.4 Realised Weather and Damage:

The depression during 16-18 June caused widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy falls (>25 cm) over Gangetic West Bengal, north Orissa and Jharkhand during 16-18 June. The 24 hours exceptionally heavy rainfall of 53 cm was recorded over Kolaikunda in West Bengal at 0300 UTC of 18 June. As a result, It caused severe flood over Gangetic West Bengal, north Orissa and adjoining Jharkhand. The heavy rainfall occurred mostly in the left forward sector of the depression. However, northern sector of the system covering sub-Himalayan West Bengal and Sikkim could get heavy rainfall on 18 and 19 June. It may be due to the interaction of the mid-latitude westerly trough over the region with the system. There was also the distant effect of this depression causing good rainfall upto Himachal Pradesh and Uttarakhand in the northwest and Arunachal Pradesh in the northeast. The chief amount of rainfall (>7 cm) due to the depression recorded at 0300 UTC of date are given below.

16-06-2008
ORISSA:
Chandbali 17, NH-5 15, Jaipur & Nilgiri 12 each, Telkoi, Harabhanga & Baripada 11 each, Balasore 10, Balimundali 9, Rajghat & Bangiriposhi each, Athamalik, Rajkishore Nagar & Jamsolaghat 7 each

GANGETIC WEST BENGAL
Kolkata (Alipore) 7

17-06-2008
ORISSA
Jaleswar & Rajghat 25 each,Bhogari 19, Joshipur 17, NH-5, Balasore, Nilgiri, Baripada & Jamsolaghat 14 each, Tiring & Khandpada 13 each, Jaipur & Balimundali 12 each, Ghatagaon, Bangiriposh, Karanjia & Thakurmunda 11 each, Soro, Sukinda, Aandpur, Telkoi & Pallahara 9 each, Champua 8 Jhumpura, Keonjhargarh, Athamalik, Bijepur,Paikmal & Lahunipara 7 each.

GANGETIC WEST BENGAL
Contai 26, Uluberia & Kharagpur (IIT) 24 each, Midnapore 21, Kalaikunda 19, Canning 18, Digha 17, Durgachak 14, Kolkata (Alipore) 11, Harinkhola 8, Dengarparaghat 7.

18-06-2008
GANGETIC WEST BENGAL
Kalaikunda 53, Midnapore 37, Mohanpur 31, Phulberia 17, Kharidwar 15, Simulia 12, Kansabati Dam & Dengarparaghat 10 each, Harinkhola 8, Tusuma & Digha 7 each.

ORISSA
Rairangpur 32, Jaleswar 29, Rajghat 28, Baripada 25, Bangiriposhi 20, Joshipur & Karanhia 19 each, Jhumpura & Chandanpur 17 each, Champua 16, Balimundali & Thakumunda 15 each Ghatagaon 14, Swampatna 13, Telkoi & Pallahara 12 each, Bhogari 11 Balasore, Jaipur & Udala 10 each, Nilgiri, Baragaon & Lhunjpara 9 each, Anandpur 8, Rengali, Deogarh & Panposh 7 each.

JHARKHAND
Jamshedpur (AP) 34, Jamshedpur (City) 28, Ranchi 14, Chaibasa 13, Tenughat 9, Konner & Pupunki 8 each, Ramgarh 7.

2.4. Land Depression over Orissa (August 09-10, 2008)

2.4.1 Introduction:

A land depression formed over coastal Orissa at 1200 UTC of 9 August. Moving in a north-northwesterly direction it weakened into a low pressure area at 1200 UTC of 10 August. It was short lived system with life time of less than 24 hours. The genesis of the system is discussed in sec. 2.4.2, intensification and movement in sec. 2.4.3 and realised weather in sec. 2.4.4.

2.4.2 Genesis:

The depression moved northwestwards and lay centred over north Orissa near lat. 21.5^0E/long. 85.5^0E, close to Keonjhargarh (42891) at 0300 UTC of 10 August. Moving in a northwesterly direction, it weakened into a well marked low pressure area over north Orissa and neighbourhood at 1200 UTC of the same day and lay as a low pressure area over East Madhya Pradesh and neighbourhood on 11 August. It became less marked on 12 August. However, the associated upper air cyclonic circulation lay over northwest Madhya Pradesh and adjoining East Rajasthan extending upto mid-tropospheric level on 12 August. The cyclonic circulation lay over East Rajasthan and neighbourhood extending upto 2.1 Km above mean Sea level on 13 August and merged with the monsoon trough on 14 August. The best track parameters of the system are shown in Table 2.4.1 The INSAT imageries of the system are shown in Fig.2.4.1.

2.4.3 Intensification and movement:

An upper air cyclonic circulation lay over northwest Bay of Bengal and adjoining coastal areas of north Orissa and West Bengal on 7 August. Under its influence, a low pressure area formed over northwest and adjoining westcentral Bay of Bengal off Orissa-West Bengal coast at 0300 UTC of 8 August. It became well marked low pressure area over the same region at 0300 UTC of 9 August. It concentrated into a depression and lay centred at 1200 UTC of 9 August over coastal Orissa near lat. 20.0^0N/long. 86.0^0E close to Puri (43053).

Table 2.4.1:Best track positions and other parameters for Land Depression over Orissa (09-10 August, 2008)

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
09-08-2008	1200	20.0/86.0	-	988	25	-	D
10-08-2008	0300	21.5/85.5	-	990	25	-	D
	0900	22.5/85.2	-	990	25	-	D
	1200	The depression weakened into a well marked low pressure area over north Orissa					

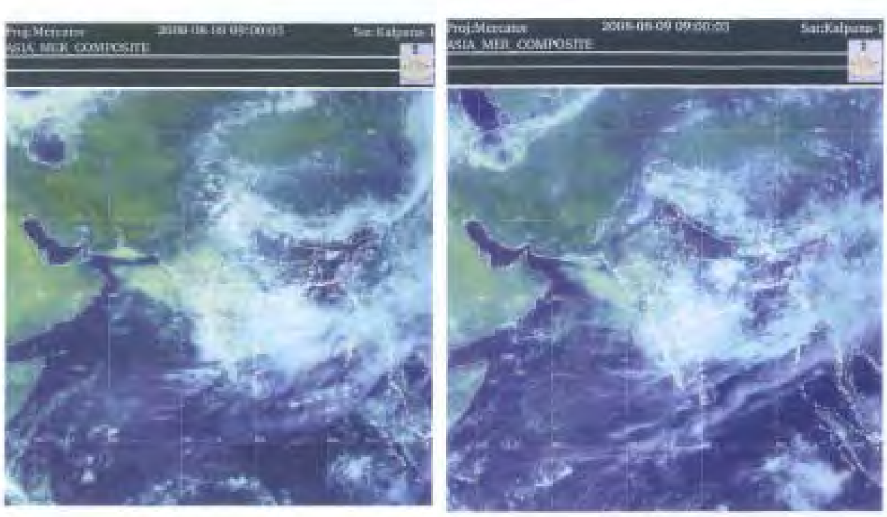

Fig.2.4.1. INSAT imageries at 0900 UTC over the Indian region on 9 and 11 August, 2008

2.4.4 Realised Weather and Damage:

As the system was short lived, it did not cause much adverse weather and there was no damage reported due to this system. However, it caused widespread rainfall with scattered heavy to very heavy rainfall over Orissa. The heavy rainfall occurred mostly in the left forward sector of the depression (Rajamani and Rao, 1981). However, northern sector of the system covering West Bengal and Sikkim and northeastern states could also get heavy rainfall. Active/vigorous monsoon condition prevailed upto west coast in the southwest and northeastern states in the northeast unlike the previous system when it extended only in west to northwest direction. The chief amounts of rainfall (7 cm or more) recorded at 0300 UTC of date are given below.

09 AUGUST 2008
ORISSA
Madanpur-rampur-22, Lanjigarh-15, Bhawanipatna-13, Bolangir-13, Paradeep-12, Baliguda-12, Kotraguda-10, Khairamal-9, Sambalpur-8, Gopalpur-8, Titilagarh-8, Bissam- cuttack-8, Chandbali-7, Berhampur-7, Boudhgarh-7, Kakatpur-7,

10 AUGUST 2008
ORISSA : Nawarangpur-15, Koraput-12, Gunpur-12, Junagarh-11, Kosagumda-11, Parlakhemundi -9, Jaipatna-9, Mohana-7, Phulbani-7.

CHHATTISGARH: Narayanpur-12, Devbhog-10, Keshkal-9, Dhamtari-8, Nagari-8, Dondilohara-7.

11 AUGUST 2008
WEST BENGAL : Kalaikunda-8.
ORISSA : Jaleswar-13, Rengali-12, Bhubaneswar-11, Deogaon-9, Reamal-7, Paikmal-7, Tureikela-7.
MADHYA PRADESH
Chicholi-9, Guna-9, Ratlam and Jabalpur-8 each.

2.5 Deep Depression over the Bay of Bengal (15-19 September, 2008)

2.5.1 Introduction:

A depression formed over the northwest Bay of Bengal at 1200 UTC of 15 September. Moving in a west-northwesterly direction, it intensified into a deep depression at 0300 UTC of 16 September and crossed Orissa coast near Chandbali between 1600 and 1700 UTC of 16 September. It moved then northwestwards upto central Uttar Pradesh and came under the influence of mid-latitude westerly trough. Under its influence, flood condition prevailed in Orissa and Yamuna catchments areas. The genesis of the system is discussed in sec. 2.5.2, intensification and movement of the system in sec. 2.5.3 and realised weather and damage in sec. 2.5.4

2.5.2 Genesis:

An upper air cyclonic circulation extending upto mid-tropospheric level lay over North Bay of Bengal on 14 September. Under its influence, a low pressure area formed over northwest Bay of Bengal off Orissa-West Bengal coasts on 15 September morning and it became well marked in same afternoon. Due to strong divergence, moderate vertical wind shear and easterly flow over the region, the system further concentrated into a depression and lay centered at 1200 UTC of 15 September over northwest Bay of Bengal near Lat. 19.5^0 N and Long. 88.5^0 E, about 230 kms east-southeast of Paradip.

2.5.3 Intensification and movement:

The system was located to the south of the upper level anticyclone with strong divergent easterly flow over the region and moderate vertical wind shear. Under this scenario, it moved west-northwestwards and further intensified into a deep depression and lay centered at 0300 UTC of 16 September over northwest Bay of Bengal near Lat. 20.0^0 N and Long. 87.5^0 E, about 130 kms southeast of Chandbali. Moving northwestwards, the system crossed Orissa coast near Chandbali between 1600 and 1700 UTC of 16 September (Fig. 2.5.1) and lay centered at 0300 UTC of 17 September over north Orissa near Keonjhargarh. It lay centred at 0300 UTC of 18 September over north Chhatishgarh, about 50 km north of Champa. It further moved northwestwards, weakened into a depression and lay centred at 1730 IST hours over north Chatishgarh near Pendra.

The depression lay centred at 0300 UTC of 19 September over northeast Madhya Pradesh close to Satna. The system came under the influence of the mid-latitude westerly trough (Fig.2.5.1) and moved northward and weakened into a well marked low pressure area central Uttar Pradesh & neighbourhood at 1200 UTC of 19 September. Best track positions and other parameters for deep depression are shown in Table 2.5.1. The maximum 24 hours pressure fall of 15.3 hPa was recorded over Chandbali at 1700 UTC of 16 September. The lowest pressure of 982.9 hPa was also recorded over Chandbali at 1700 UTC of 16 September (Fig.2.5.2). The maximum surface wind of 40 knots was reported by Chandbali at 1700 UTC of 16 September. The 24 hrs pressure change in association with the system could very well indicate well in advance the likely movement of the system. A few INSAT imageries of the system are shown in Fig.2.5.1

Table 2.5.1:Best track positions and other parameters for Deep Depression over the Bay of Bengal (15-19 September, 2008)

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
15-09-2008	1200	19.5/88.5	1.5	996	25	4	D
	1500	19.5/88.5	1.5	996	25	4	D
	1800	19.5/88.0	1.5	986	25	4	D
16-09-2008	0000	19.5/88.0	1.5	994	25	4	D
	0300	20.0/87.5	2.0	994	30	5	DD
	0900	20.5/87.0	2.0	990	30	5	DD
	1200	20.5/87.0	2.0	986	30	5	DD
	1500	21.0/87.0	2.0	986	30	5	DD
	The system cross the Orissa coast near Chandbali between 16 &17 UTC						
	1800	21.0/86.5	-	988	30	5	DD
17-09-2008	0000	21.0/86.0	-	992	30	5	DD
	0300	21.5/85.5	-	992	30	5	DD
	0900	22.0/84.5	-	992	30	5	DD
	1200	22.0/84.5	-	992	30	5	DD
18-09-2008	0300	22.5/82.5	-	996	30	5	DD
	0900	23.0/82.0	-	996	25	4	D
	1200	23.0/82.0	-	996	25	4	D
19-09-2008	0300	24.5/80.5	-	996	25	4	D
	0900	26.0/80.0	-	996	25	4	D
	1200	The system weakened into a well marked low pressure area over central Uttar Pradesh and neighbourhood					

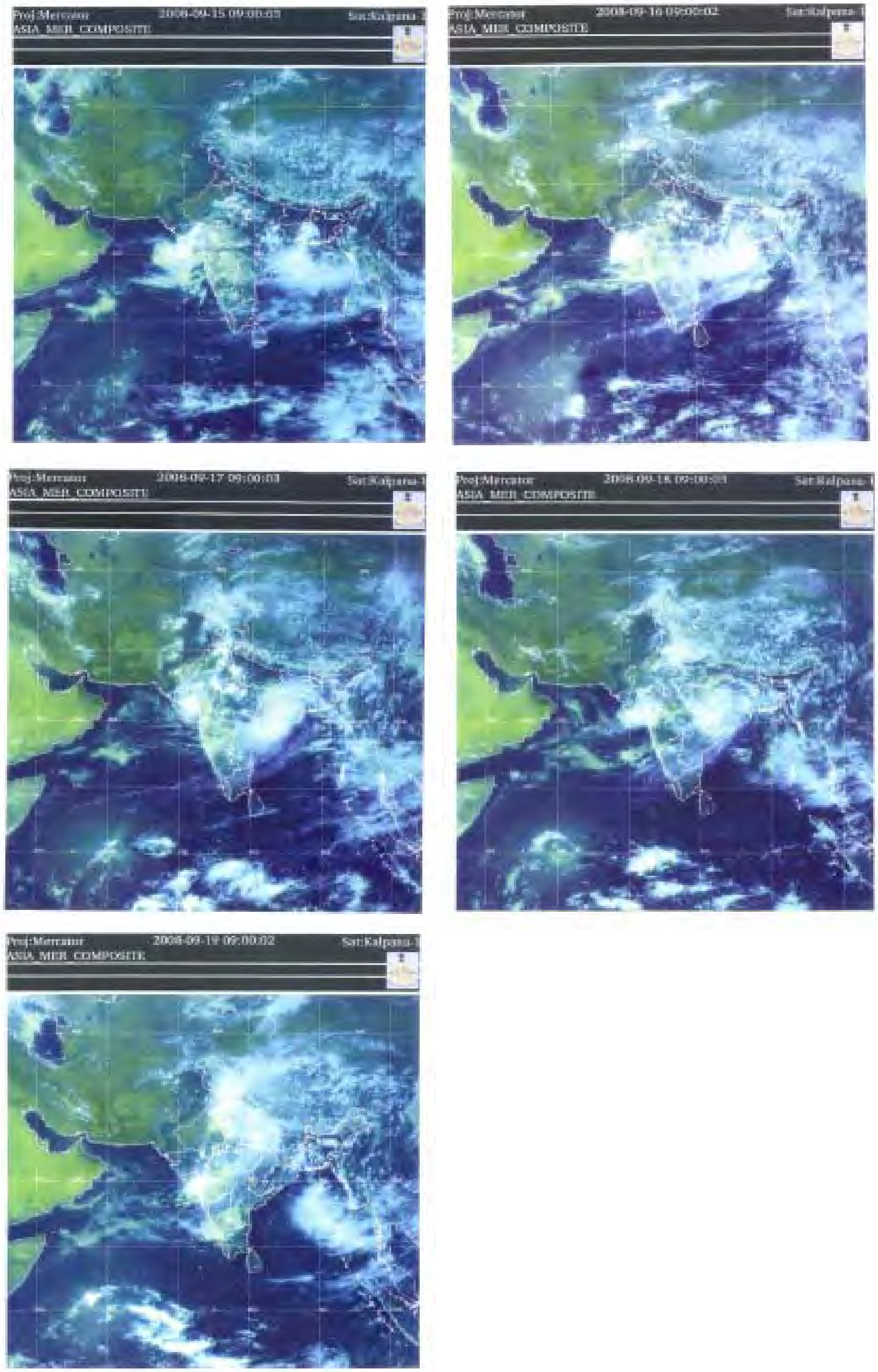

Fig.2.5.1. INSAT imageries of deep depression over the Bay of Bengal at 0600 UTC of 15-19 September, 2008

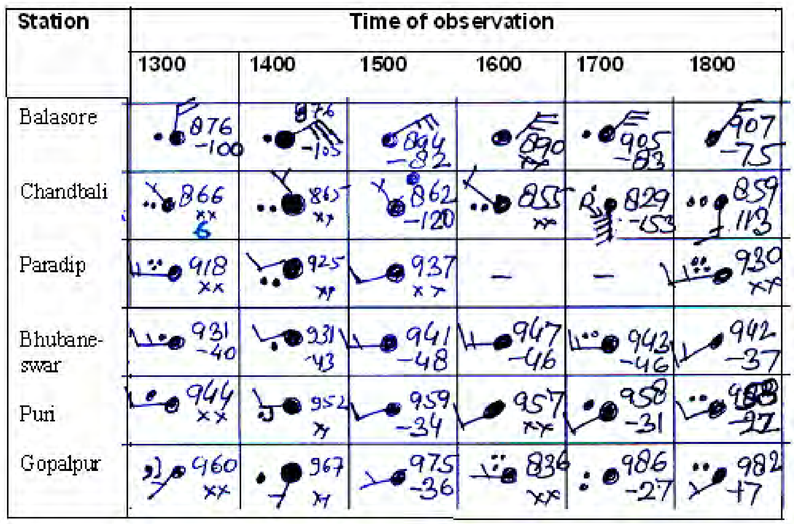

Fig. 2.5.2. Coastal observations from 1300 to 1800 UTC of 16-09-2008

2.5.4 Realised Weather and Damage:

Widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy fall was recorded over Orissa at 0300 UTC of 17 and 18 September 2008. Scattered heavy to very heavy falls also occurred over Chhattisgarh on 19 September. As a result, flood conditions prevailed over Orissa, especially over the Mahanadi, Brahmani and Baitarani river basins due to this system. The chief amounts of rainfall (7 cm or more) recorded at 0300 UTC of date over Orissa and Chhattisgarh are given below.

ORISSA:

15. 09. 2008:

Chandbali, Angul and Jharsuguda 7 each.

16. 09. 2008:

Paradip 16, Madanpur-Rampur and Lanjigarh 11 each, Telkoi and Komna 10 each, Patamundai 9, Bissam-cuttack 8, Keonjhargarh, Athagarh, Kendrapada, Rajkanika, Rengali, Kakatpur Khandapada and Kotraguda 7 each.

17. 09. 2008:

Akhuapada 31, Jenapur 30, Baliguda 24, Rajkanika 23, Mundali and Patamundai22 each, Tikabali 21, Madanpur-rampur, Nawana 20 each, Belgaon, Bolangir, Binika, Daringibadi 19 each Chandbali, Kendrapada, and Bhawanipatna 17 each, Ghatagaon and Athagarh 16 each, Paradeep and Kotagarh 15 each, Alipingal, Lanjigarh and Kalinga 14 each, Jajpur, Tikarpada and Titlagarh 13 each, Khairamal, Cuttack, Naraj, Patnagarh, Sonepur and Phulbani 12 each, Bonth, Thakurmunda and Bhubaneswar 11 each, Rajghat, Athamalik, Bargarh, Khariar and Kantamal 10 each, Bhogari, Altuma, Bijepu, Paikmal, Bhanjanagar, Junagarh and Barmul 9 each, Keonjhargarh, Aska, Madhabarida, Khandapada and Dunguripalli 8 each, Anandpur, Jhumpura, Swampatna, Dhenkanal, Kamakhya, Nagar Narsinghpur, Jaipatna**,** Komna, Kakatpur, Nimapara, Pipili, Dashpalla and Kotraguda 7 each

18. 09. 2008 :
Patnagarh 27 Kantamal 26 Titlagarh 25 Rairakhol 24 Kotagarh 23 Sambalpur 22 Batagaon, Madanpur-Rampur and Bolangir 20 each, Hirakud, Jharsuguda, Laikera and Baliguda 19 each Tikabali 18, Kuchinda,Rajkishore Nagar, Junagarh and Belgaon 17 each Khairamal, Hemgiri and Sonepur 16 each Deogaon and Boudhgarh15 each, Jamankira, Deogarh and Lanjigarh 14 each, Rajghat, Naktideul, Pallahara, Reamal, Ambabhona, Paikmal, Bhawanipatna, Dunguripalli and Phulbani 13 each, Bargarh Tensa and Jaipatna 12 each, Athamalik, Bijepur, Sohela, Daringibadi and Kotraguda 11 each, Telkoi and Padampur 10 each, Chhendipada, Rengali,Baragaon, Binika and Kalinga 9 each, Lahunipara 8 Rajgangapur, Harabhanga, Nawarangpur, Bissam-Cuttack and Gudari 7

19. 09. 2008 :
Patnagarh 7

CHHATTISGARH:

19. 09. 2008:

Katghora 17, Durg 16, Bilaigarh 14, Pithora and Basna 13 each, Pamgarh, Baloda, Saja and Pendra Road 12 each, Chhura, Gariaband and Mahasamund 11 each Pali, Uproad, Masturi Dabhra, Dhramjaigarh, Raipur, Arang, Rajim and Akaltara 10 each, Rajnandgaon, Dongargarh, Kurud, Mana, Kharsia, Lailunga and , Saraipali 9 each, Takhatpur, Marwahi, Malkharoda, Bemetara and Bilaspu 8 each, Dongargaon, Korba, Kartala, Abhanpur, Tilda, Gurur, Bilha, Pusor, Palari Baghbahra, Simga, Berla, Pandaria, Sakti and Jaijaipur 7 each

There was distant effect of the system (Mukherjee and Shyamala, 1978), influencing the rainfall over western part of the country. Also there was interaction with mid-latitude westerlies leading to increase in rainfall over western Himalayan region and adjoining plains (Ananthakrishnan and Bhatia, 1960). It has caused flood over Yamuna river basin affecting Haryana, Delhi and Uttar Pradesh.

From Fig.2.5.2, maximum sustained surface wind of 40 knots was recorded over Chandbali around the time of landfall in association with the thundersquall. As a result, there was breaking of tree branches and uprooting of small trees over coastal Orissa.

2.6 Deep depression over the Arabian Sea (19-23 October, 2008)

2.6.1 Introduction:

In association with an active easterly wave a depression formed over southwest Arabian Sea on 19 October, 2008. It moved in west-northwesterly direction initially and then moved northwestwards towards Yemen coast. It intensified into a deep depression for a short period during 0300 UTC of 21 to 0300 UTC of 22 October. However, the system dissipated over the Gulf of Aden off Yemen coast on 23 October. The genesis of the system is discussed in sec. 2.6.2, intensification and movement of the system in sec. 2.6.3 and realised weather and damage in sec. 2.6.4.

2.6.2 Genesis:

A low pressure area formed over Comorin area on 16 October in association with a active easterly wave. It lay centred over southeast Arabian Sea on 17 and over southeast and adjoining southwest Arabian Sea on 18 October. In association with favorable environmental conditions like low to moderate vertical wind shear (10-20 knots), negative wind shear tendency (-5 to-10 knots), upper tropospheric divergence due to the ridge roughly running along 15^0N and warmer SST (27-$28\ ^0$C) the low pressure area concentrated into a depression and lay centred at 1200 UTC of 19 October over southwest Arabian Sea near lat. 9.0^0N and long. 59.0^0E, about 1050 KM east-southeast of Alula (63200) of Somalia and 1100 Km southeast of Salalah (43316) of Oman. Satellite imageries indicated improvement in cloud organization and satellite estimated intensity was T1.5. The deep convection due to the system was sheared to the west of the system centre. The lowest cloud top temperature was about -75^0C.

2.6.3 Intensification and movement:

As the above favorable conditions continued and the system lay to the south of upper tropospheric ridge. The depression moved in a west-northwesterly direction and intensified into a deep depression lay centred at 0300 UTC of 21^{st} over southwest Arabian Sea near lat. 10.5^0N and long. 54.5^0E about 450 KM southeast of Alula 700 KM southeast of Riyan (41443) of Yemen and 700 KM south of Salalah. The lowest cloud top temperature was about -75^0C to -80^0C, vertical wind shear was about 10 to 20 knots around the system, wind shear tendency was -10 to -20 knots in the northwest of the system and SST was about 27-28^0C to the west of the centre . The upper tropospheric ridge runs about 17^0N.

As the deep depression moved north-westwards it entered into a relatively cold water. It also interacted with land surface. The convection due to the system was sheared to the west. As a result the system weakened into a depression and lay centred at 0300 UTC of 22^{nd} over westcentral Arabian Sea near lat. 13.0^0N and long. 53.0^0E about 300 KM east-northeast of Alula, 450 KM east-southeast of Riyan amd 450 KM of south-southwest of Salalah. At that time cloud top temperature was about -60^0C, wind shear was slightly higher (15-20 knots). Continuing its northwestwards movement it further weakened into a well marked low pressure area at 0300 UTC of 23 October over westcentral Arabian Sea and adjoining Gulf of Aden. A few INSAT imageries of the system are shown in Fig. 2.6.1.

Table-2.6.1: Best track Positions and other parameters for deep depression over the Arabian Sea (19-23 October, 2008)

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
19-10-2008	0900	09.0/60.0	1.5	1004	25	4	D
	1200	09.0/59.5	1.5	1004	25	4	D
20-10-2008	0300	10.0/57.5	1.5	1004	25	4	D
	1200	10.0/56.5	1.5	1002	25	4	D
21-10-2008	0300	10.5/54.5	2.0	1000	30	5	DD
	1200	11.0/54.0	2.0	1000	30	5	DD
22-10-2008	0300	13.0/53.0	1.5	1002	25	4	D
	1200	13.5/52.5	1.5	1002	25	4	D
23-10-2008	0300	Weakened into a well marked low pressure lay over westcentral Arabian Sea and adjoining Gulf of Aden					

2.6.4. Realised weather and damage:

As this system moved west-northwestwards away from Indian coast, it did not cause any severe weather over the country. However, according to news paper report, the system caused flood over Yemen due to heavy rainfall.

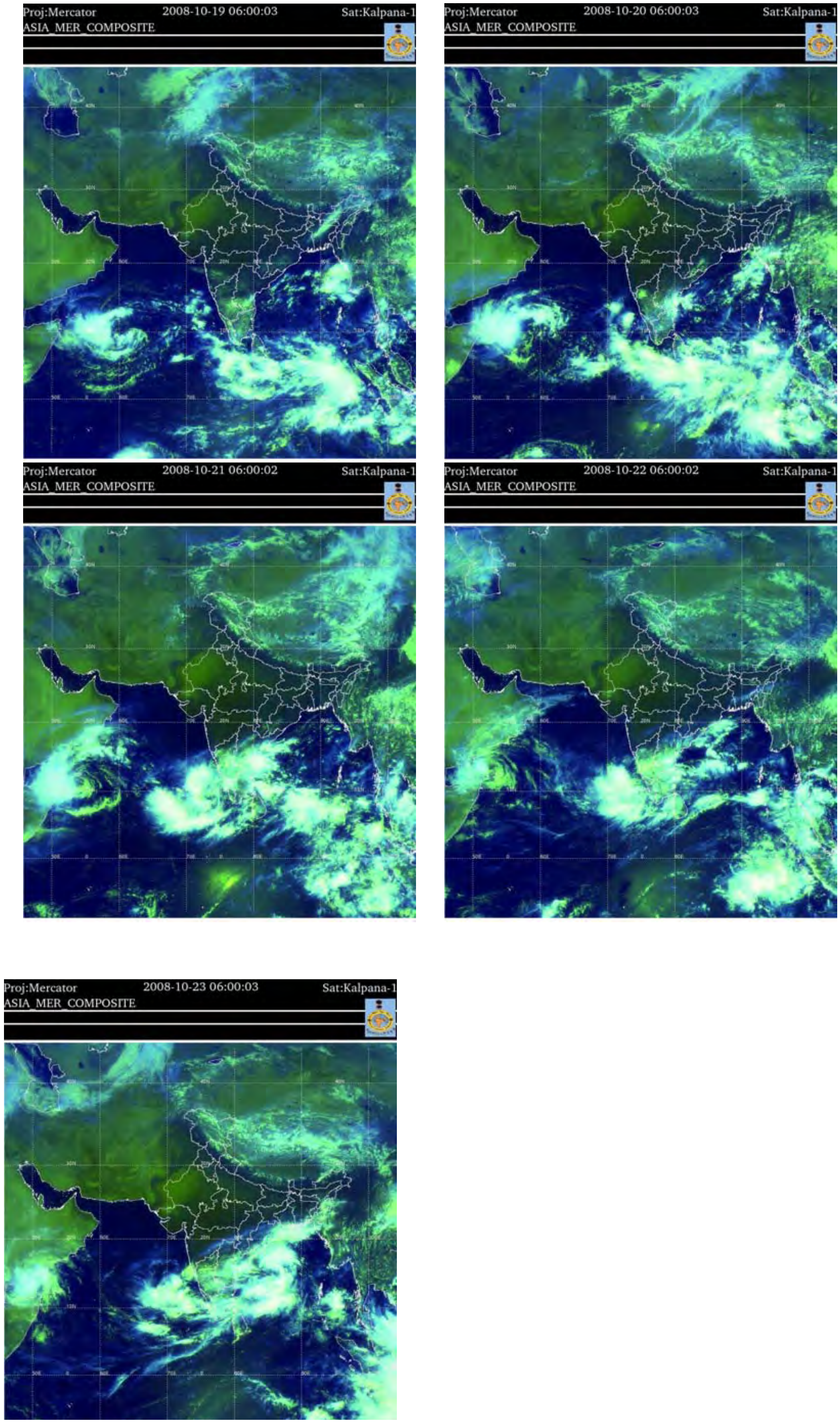

Fig. 2.6.1. INSAT imageries of the deep depression during 19-23 October, 2008.

2.7 Cyclonic storm "RASHMI" over the Bay of Bengal 25-27 October, 2008

2.7.1 Introduction

The cyclonic storm **'RASHMI'** crossed Bangladesh coast near long.89.5^{0}E about 50 kms west of Khepupara between 2200 and 2300 UTC of 26 Oct. 2008. It caused loss of life and property in Bangladesh and northeastern states of India, due to heavy rainfall and gale/squally winds. The special features of the storm are as follows.

(i) The system intensified with sustained wind speed reaching upto 45 knots just before the landfall.
(ii) System rapidly weakened over land into a low pressure area (within 12 hrs).
(iii) System moved northeastwards skirting the coast causing rainfall over coastal Andhra Pradesh, Orissa, West Bengal and Bangladesh.

Such recurving systems in the month of October over the Bay of Bengal is very rare as only 3 cyclonic storm (during 1905,1967,1988) out of 9 storms with genesis over the region between lat. 15-20^{0}N or and long. 85-90^0 E have crossed Bangladesh coast during the period 1891- 2007. The genesis of the system is discussed in section 2.7.2, intensification and movement in sec. 2.7.3 and realized weather and damage in sec. 2.7.4.

2.7.2 Genesis:

Southwest monsoon withdrew from the entire country, Bay of Bengal and Arabian Sea on 15 October. Simultaneously, the northeast monsoon set in over peninsular India and adjoining Bay of Bengal and Arabian Sea. The ITCZ over Indian region was active trough on equatorial easterlies in lower levels roughly ran along 100^0 E upto 10^0 N on 16, along 95^0 E upto 15^0 N on 17, along 92^0 E upto 15^0 N on 18 and along 88^0 E upto 15^0 N on 19 October. It was seen as trough of low pressure extending from southwest Bay of Bengal to north Bay of Bengal on 20 and from southwest Bay of Bengal to westcentral Bay of Bengal off Tamilnadu and Andhra Pradesh coast during 21 and 23 October. The associated cyclonic circulation extended upto mid-troposperic level on 23 October.

Under its influence, a low pressure area formed over the westcentral Bay of Bengal off Andhra Pradesh coast on 24 October. A trough from this system extended upto coastal Bangladesh across north Bay of Bengal. A trough in westerlies at 500 hpa level roughly ran along 86^0 N to the north of 20^0 N. A vortex was seen in the satellite imagery of 0600 UTC of 24 with centre near 16.0^0 N and 85.0^0 E.

A convective cloud cluster was seen over westcentral Bay of Bengal on 23rd which subsequently led to the development of low level cyclonic circulation over the same area at 1200 UTC of 23 October in satellite imagery. The environmental conditions continued to be favourable for the cyclogenesis over the Bay of Bengal region from the beginning of the second fortnight with warmer SST (29-30^0 C) over central Bay of Bengal and adjoining areas, low to moderate vertical wind shear (10-20 knots) and depth of moisture extending upto mid-troposperic level.

Under the influence of all the above, the low pressure area concentrated into a depression and lay centred at 0300 UTC of 25 October near lat.16.5^0 N and long.86.5^0 E. The satellite imageries at 0300 UTC 25 October suggested organised convections and curved band pattern is association with the system. The intensity was estimated to be T 1.5 with sustained maximum wind speed of 25 knots and estimated central pressure of 1004 hpa.The lowest cloud top temperature was about -60^0 C.

2.7.3 Intensification and movement:

The intense convection due to the system was sheared to the west of the system centre. The 24 hours wind shear tendency was about -5 to -10 knots. The lower level vorticity and upper level divergence increased during past 24 hours. The system lay close to the south of the upper troposperic ridge which roughly ran along 18^0 N. Under the influence of the above, the depression moved north-northwestwards and further intensified into a deep depression and lay centred at 0000 UTC of 26 October over westcentral and adjoining northwest Bay of Bengal near 18.0^0 N and long. 87.0^0 E. The sustained maximum wind speed was estimated to be about 30 knots. The convection according to satellite imagery further organized and curved band pattern of the system continued with T 2.0. The lowest cloud top temperature due to convection was about -80^{0}C at 0000 UTC of 26 October. The low level vorticity and upper level divergence increased further. The vertical wind shear continued to be low to moderate (10-20 knots). The wind shear tendency was negative (-5 to –10 knots) to the north of the system. The intense convection was sheared to the southwest of the system centre. The system lay close to the upper tropospheric ridge and at the periphery of the anticyclonic circulation centred over Myanmar. With the continuance of similar favourable environment conditions, the system further moved in a north-northeasterly direction, intensified into a cyclonic storm **'RASHMI'** and lay centred at 1200 UTC of 26 October over the northwest Bay of Bengal near Lat. 19.5^{0}N and long. 88.0^{0}E about 350 km south of Kolkata. The satellite estimate intensity of the system was T 2.5 and sustained maximum wind speed was about 35 knots. The system lay to the north of the upper tropospheric ridge. The organized convection changed from curved band pattern to central dense over cast (CDO) pattern. The lowest cloud top temperature was about -80^0 C. The vertical wind shear continued to be low to moderate (10-20 knots) around the system centre and wind shear tendency was –5 to –10 knots to the north and northeast of the system centre. As the system lay to the north of the system centre, it started to move rapidly in a north-northeasterly direction after 1200UTC of 26 October towards Bangladesh coast. However due to favourable environmental condition as discussed earlier, the system further intensified with estimated intensity of 3.0 and sustained maximum wind speed of about 45 knots at 2100 UTC of 26 October The cyclonic storm, **'RASHMI'** lay centred at 2100 UTC of 26 October over north Bay of Bengal near lat. 21.5^0 N and long. 89.5^{0}E, very close to the coast. The lowest cloud top temperature continued to be -80^{0}C.

The system crossed Bangladesh coast near long. 89.5^{0}E (about 50 km west khepupara) between 2200 and 2300 UTC of 26th. Due to the land interaction and increase in vertical wind shear and entrainment of cold air the cyclonic storm **'RASHMI'** weakened into a deep depression at 0300 UTC of 27 October over Bangladesh and lay centred near 23.5^{0}N and 91.0^{0}E close to Maijdicourt(41953). It further weakened into a well marked low pressure area over Meghalaya and neighborhood at 0900 UTC of 27 and become less marked on 28 October.

The westward propagation of the trough in easterlies and its intensification leading to the formation of cyclonic storm was also reflected in the 24 hours mean Sea level pressure (MSLP) change and pressure departure.. The MSLP fell by about 2 hPa over Andhra Pradesh (AP) coast on 23 October and was below normal by about 2 hPa along north Tamil Nadu(TN) and AP coast. It further fell slightly over north coastal AP, Orissa and West Bengal on 24 October and increased over TN coast by 1-2 hPa on 24 October. It was below normal by about 2-4 hpa along north coastal AP and south Orissa coast on 24 October. The MSLP fell by 2-3 hpa over coastal Orissa and fell slightly elsewhere along the east coast on 25th and were below normal by 4-5 hPa along north AP and Orissa coast. It fell by 2-4 hpa over Orissa, West Bengal and Bangladesh coasts at 0300 UTC of 26 October and was below normal by 4-6 hpa along these coasts. The maximum pressure fall of 20.7 hpa was reported over Khepupara (Bangladesh) at 2100 UTC of 26 October just before the landfall.

2.7.4 Estimated central pressure and sustained maximum wind

The lowest pressure (984.5 hPa) was reported by Khepupara at 2100 UTC of 26 October. Hence, the surface observations indicated the maximum pressure drop of about 18 hpa at the system center with inner most closed isobar of 984 hpa and outer most closed isobar of 1002 hpa. The estimated central pressure of the system fell from 1004 hpa at 0300 UTC of 25 to 984 hpa at 2100 UTC of 26 October. The MSLP along Orissa, West Bengal and Bangladesh coast increased from 27 October and became above normal gradually.

The shape of the closed isobars in association with the system remained elliptical since genesis of the system till 261200 UTC. At 261200 UTC it changed into circular shape when the system intensified into a cyclonic storm. The major axis of the ellipse was oriented from southwest to northeast. The size of the system, considering the size of the outermost closed isobar varied from 6^0x4^0 long./lat. At 0300 UTC of 25 to 6^0x6^0 at 0300 UTC of 27 October. A few INSAT imageries of the system are shown in Fig. 2.7.1.

2.7.5 Radar analysis

The system was tracked by conventional cyclone detection radar at Paradip and Doppler Weather Radar (DWR), Kolkata. The brief reports on the characteristics of the system as observed in these radars are discussed in sec.2.7.5.1 and 2.7.5.2 respectively.

2.7.5.1 Radar observations from CDR, Paradip

Special Radar observations were taken from 250000 UTC to 270300 UTC. Special hourly Radar observations were taken and reported during 1300-2000 UTC of 26 October. The centre of the system was reported from 260000 UTC (with poor confidence) based on the curved line features. Curved lines with some banding features could be seen at 261200 UTC when the system was along the station latitude. Centre was reported at Lat. 20.4^0 North and Long. 88.4^0. East. Similarly, the centre locations were reported upto 1500 UTC of 261500 UTC. Thereafter the echo strength reduced gradually and no centre could be defined with confidence due to absence of prominent features.

Table 2.7.1:Best track Positions and other parameters for cyclonic storm RASHMI over the Bay of Bengal (25-27 October 2008)

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
25.10.2008	0300	16.5/86.5	1.5	1004	25	3	D
	0900	17.0/87.0	1.5	1002	25	3	D
	1200	17.5/87.0	1.5	1002	25	3	D
	1800	18.0/87.0	1.5	1002	25	3	D
26.10.2008	0000	18.0/87.0	2.0	1000	30	5	DD
	0300	18.5/87.5	2.0	1000	30	5	DD
	0900	18.5/87.5	2.0	1000	30	5	DD
	1200	19.5/88.0	2.5	996	35	6	CS
	1500	20.5/88.5	2.5	996	40	8	CS
	1800	21.0/89.0	2.5	994	40	10	CS
	2100	21.5/89.5	3.0	984	45	14	CS
	The cyclonic storm crossed Bangladesh coast near 89.5^{0}E (about 50 km west of Khepupara) between 2200 and 2300 UTC.						
27.10.2008	0000	22.5/90.0	Over land	992	35	6	CS
	0300	23.0/91.0	Over land	1002	30	5	DD
	0900	Weakened into a well marked low pressure area lay over Meghalaya and neighborhood.					

2.7.5.2 DWR observations from CDR Kolkata

DWR, Kolkata was observing the system round the clock since 0000 UTC of 26.oCTOBER. The signatures of the depression were first observed at 0844 UTC. Spiral bands could be seen at a distance of 250-280 km south-southwest of Kolkata. However, better organized spiral bands were observed at 0934 UTC. At 1209 UTC when the system became cyclone storm, a clear circular eye was seen at a distance 280 km south-southeast of DWR, Kolkata. Lot of convective clouds could also be seen associated with the system. The estimated diameter was about 20-22 km. The shape of the circular eye was maintained till 1239 UTC. The eye was seen till 1400 UTC but the shape got disorganized. No eye was visible at 1500 UTC and it appeared that system got weakened. The movement of the system was found to be north-northeasterly. The system further advanced to northeasterly direction but got weakened gradually. From DWR pictures it appeared that system entered Bangladesh coast at around 1800 UTC. The system advance towards Bangladesh and weakened gradually. A DWR imagery are shown in Fig. 2.7.2

The maximum radial wind recorded by DWR Kolkata from PPI_V pictures was about 24 m/s(70 km/h) at 1239 UTC at a distance of 240 km from DWR.

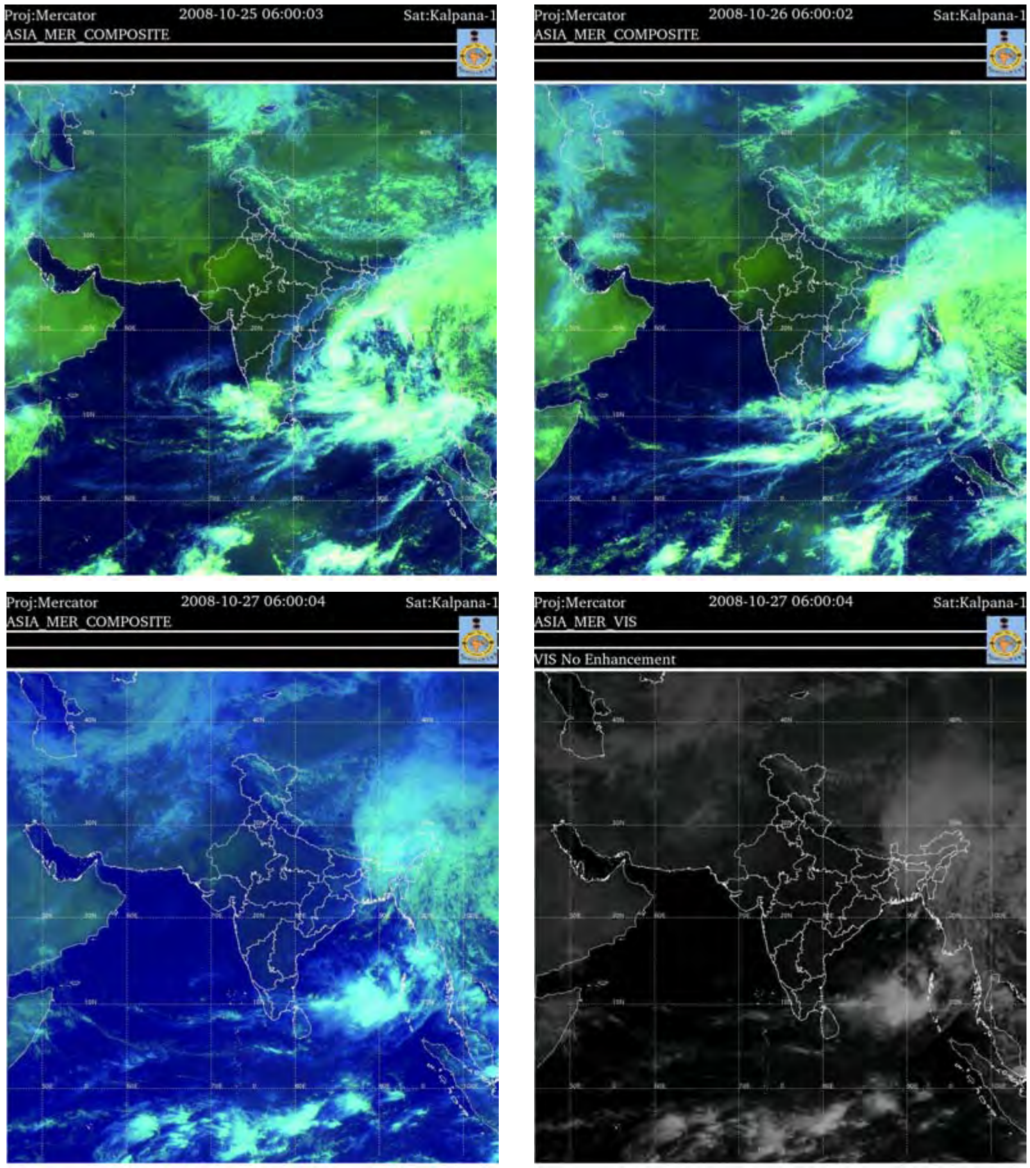

Fig. 2.7.1. INSAT imageries of the cyclonic storm, 'RASHMI' during 25-27 October, 2008.

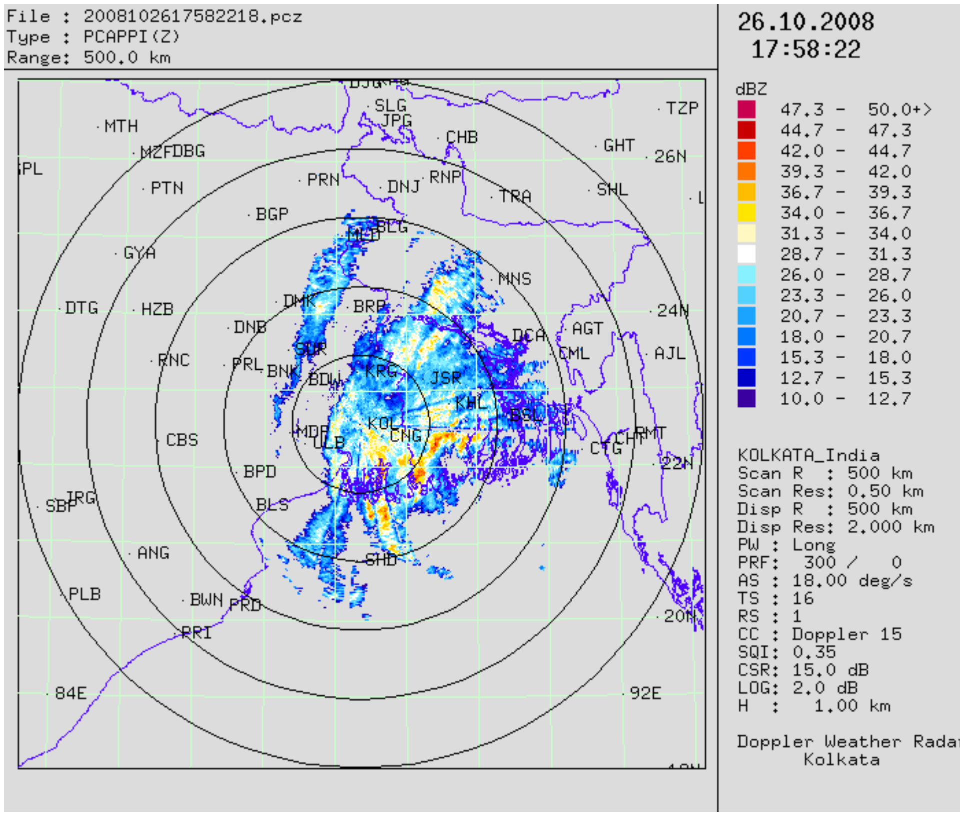

Fig.2.7.2. DWR imagery of 'RASHMI' at 1800 UTC of 26th October 2008.

2.7.6 Realised weather

Under the influence of the system the weather realized over different states of India and Bangladesh are as follows.

2.7.6.1. Rainfall

India

Fairly widespread rainfall occurred over coastal Andhra Pradesh on 24 and 25, coastal Orissa on 24-26 and Nagaland, Manipur, Mizoram & Tripura during 25-28 October. Widespread/ fairly widespread rainfall occurred over Gangetic West Bengal on 27th. Sub Himalayan West Bengal on 28, Arunachal Pradesh, Assam and Meghalaya on 28 & 29 October. The chief amounts of rainfall (≥ 7 cm) are given below

West Bengal

27-10-2008: Canning- 14, Haldia- 9, Alipore and Diamond Habour- 8 each.

Northeastern states

26-10-2008: Sabroom and Dharmanagar 12 each, Agartala and Belonia 10 each, Kailashahar, Arundhatnagar and Gharmura 9 each, Sillchar and Sonamura 8 each, Dholai 7,

27-10-2008: Williamnagar 15, Shillong C.S.O. 11 and Cherapunji 10

28-10-2008: Cherapunji 15, Basar 11, Bomdila 11, Melabazar 9, Shillong C.S.O. 8, Williamnagar 7, Golpara 7 and Manas NH Xing 7.

Bangladesh
Scattered heavy to very heavy falls occurred over Bangladesh due to the cyclonic storm

2.7.6.2. Wind
India
Maximum sustain surface wind of 10-15 knots have been reported from coastal stations of north Orissa and West Bengal in association with the system. The available data from northeastern states indicate that the sustained wind reported at Central Seismological Observatory(CSO), Shillong was the maximum and was 18 knots on 26 and 37 knots on 27 October.

Bangladesh
Maximum sustained surface wind of 40-50 knots prevailed over Bangladesh during the time of landfall. Dhaka reported maximum wind speed of about 40 knots and Chatgaon reported about 50 knots at the time of landfall.

2.7.6.3. Storm surge
According to media report, offshore islands and coastal areas of Bangladesh were swept by storm surge of about 6 feet above normal tide.

2.7.7 Damage

India
According to different media reports, the damage over the northeastern states includes the following.
Number of human deaths: 05 (Meghalaya)
: 08 (Arunachal Pradesh)
Incessant rains and wind uprooted most of the electric posts in Shillong. Storm damaged the power supply network at several places of Guwahati city. According to Assam electricity Board, the storm uprooted many trees and severed the branches of many others which snapped the power transmission lines. Under influence of "**RASHMI**", severe thundersquall and continuous heavy rain lashed vast areas of Tawang and Bomdila of west Arunachal Pradesh in the night hours of 27-28 October. The Road and other communication links with Bomdila and Tawang areas remained disrupted with other parts of the Country. A report says several road-bridges broke down and a number of dwelling houses weredevastated besides many persons being injured by the devastating thunder-squall.

Bangladesh
According to media reports, 15 persons died due to cyclonic storm, '**RASHMI**'. The low lying areas of coastal Bangladesh, especially of Barguna, Patuakhali, Khulna and Barisal districts were inundated due to tidal wave and heavy rain. The system caused damage to agricultural crops. The storm brought down electrical and telephone poles and uprooted trees; more than 40,000 people on 20 chars (river and offshore Islands) in coastal Barguna District were marooned due to flooding.

2.8. Cyclonic storm "KHAI MUK" over the Bay of Bengal 13-16 November, 2008

2.8.1. Introduction

The cyclonic storm **'KHAI MUK'** (13-16 November, 2008) developed over the southwest Bay of Bay Bengal, moved in a northwesterly direction, weakened before the landfall and crossed south Andhra Pradesh coast close to the north of Kavali between 2200-2300 UTC of 15 November 2008 as a deep depression. The special feature of the storm was that it weakened into a deep depression within the Sea. The (i) genesis, (ii) intensification and movement, (iii) landfall and dissipation and structure of the system are presented and discussed in section 2.8.2, 2.8.3, 2.8.4 and 2.8.5 respectively.

2.8.2. Genesis

An an upper air cyclonic circulation lay over Gulf of Thailand and neighbourhood during 6-9th. It lay over south Andaman Sea and neighbourhood on 10th and over southeast Bay of Bengal and adjoining south Andaman Sea on 11th. Under its influence, a low pressure area formed over southeast Bay of Bengal and adjoining areas on 12th. The environmental conditions continued to be favourable for the cyclogenesis over the Bay of Bengal region during this period with warmer SST (29-30^0 C) over central Bay of Bengal and adjoining areas, low to moderate vertical wind shear (10-20 knots) and depth of moisture extending upto mid tropospheric level. Hence, the low pressure area concentrated into a depression over southwest and adjoining southeast Bay of Bengal and lay centred at 1200 UTC of 13 November 2008 near lat. 11.5^0 N and long. 85.5^0 E, about 600 km east-southeast of Chennai (Fig.2.8.1). The satellite imageries at 1200 UTC of 13th November showed organized convections and curved band pattern of cloud in association with the system. The intensity was estimated to be T1.5 with sustained maximum wind speed of about 25 knots and central pressure of 1002 hPa. The lowest cloud top temperature was about -60^0 C.

2.8.3 Intensification and movement

On 13 and 14 November, the INSAT imagery indicated organised convection and curved band pattern in associated with the system centre. Vertical wind shear of horizontal wind over the region was 05 to 10 knots. The 24 hour shear tendency was -5 to -10 knots to northwest of the system. The system lay close to the south of the upper tropospheric ridge, which roughly ran along 14^{0}N. Under this scenario, the depression moved north-northwestwards, intensified into a deep depression and lay centred at 0300 UTC of 14 November over southwest and adjoining southeast Bay of Bengal near Lat. 12.5^0 N and Long. 85.0^0 E, about 520 km east-southeast of Chennai. Sustained maximum wind speed was estimated to be about 30 knots. The convection according to satellite imagery further organised with curved band pattern in association with the system with intensity becoming T 2.0. The lowest cloud top temperature due to convection fell further and was about -70^0 C. The system lay close to the south of the upper tropospheric ridge, which roughly runs along 16^0 N at 0300 UTC of 14 November. With the continuance of similar favourable environmental conditions, the system moved in a northwesterly direction, intensified into a cyclonic storm '**KHAI MUK**' and lay centred at 1200 UTC of 14 November over westcentral and adjoining southwest Bay of Bengal near Lat. 14.0^0 N and Long. 84.0^0 E, about 400 km east-northeast of Chennai.

The satellite estimated intensity of the system was T 2.5 with sustained maximum wind speed of 35 knots. Satellite imagery indicated further organization of convection with pattern changing from curved band to central dense over cast (CDO) (Fig.2.8.1). The lowest cloud top temperature was about -80^0 C. The vertical wind shear continued to be low to moderate (10-20 knots) around the system centre. The system lay to the south of the upper tropospheric ridge, which roughly ran along 18^0 N at 1200 UTC of 14 November. There was fall of mean Sea level pressure (MSLP) along the east coast and maximum fall was 3-4 hPa over coastal areas of north Tamil Nadu and south Andhra Pradesh. The MSLP was below normal by 5-6 hPa over coastal areas of north Tamil Nadu and south Andhra Pradesh. The cyclonic storm '**KHAI MUK**' maintained its intensity, while moving west-northwestwards till 0300 UTC of 15 November. Vertical wind shear of horizontal wind over the region increased gradually and was 15 to 20 knots and hence, the 24 hours wind shear tendency became positive (about 5 knots) at 0600 UTC of 15 November. Convective clouds got disorganized due to shearing of the system (Fig.2.8.1). The cloud pattern changed from CDO to shear pattern. The system weakened into a deep depression at 0600 UTC of 15 November and lay centred at Lat. 14.5^0 N and Long. 82.5^0 E, about 270 km northeast of Chennai. The sustained surface maximum winds speed was estimated to be about 30 knots. The system lay to the south of the upper tropospheric ridge, which roughly ran along 18.0^0 N at that time. The maximum 24 hour hour pressure fall of 9.8 hPa was recorded over Kavali (south coastal Andhra Pradesh) at 2000 UTC of 15 November. The deep depression moved in a west-northwesterly direction and crossed south Andhra Pradesh coast close to the north of Kavali (43243) between 2200 and 2300 UTC of 15 November.

Due to the land interaction, increase in vertical wind shear and entrainment of cold air, the associated convection disorganized further and the deep depression weakened into a depression which lay centred at 0300 UTC of the 16 November over Raylaseema, close to Nandyal (43212). It further weakened into a well marked low pressure area over Raylaseema and adjoining Telangana & interior Karnataka at 0900 UTC of 16 November. Hourly observations at the time of landfall is shown in Fig.2.8.2.

2.8.4 Maximum intensity and structure

The lowest MSLP of 995.2 hPa was reported at Kavali at 2200 UTC of 15 November. The maximum pressure fall of 9.8 hPa was also reported at Kavali at 2000 UTC of 15 November just before the landfall. The shape of the closed isobars in association with the system remained elliptical since genesis of the system till 0900 UTC of 14 November. The major axis of the ellipse was oriented from southeast to northwest. At 1200 UTC of 14 November, it changed into circular shape when the system intensified into a cyclonic storm with CDO pattern of cloud. The size of the system, considering the size of the outermost closed isobar varied from 6^{0}x4^0 long./lat. (Major axis / minor axis of the ellipse) at 0300 UTC of 14 to 6^{0}x6^0 at 0000 UTC of 15 November.

2.8.5 Radar Observations

The system was observed by DWR, Chennai and Machilipatnam. The DWR at Chennai was in continuous operation during the course of system. Neither the Eye nor any spiral Band could be seen in the Radar during the course of time.

Table 2.8.1: Best track Positions and other parameters for cyclonic storm KHAI MUK over the Bay of Bengal (13-16 November, 2008)

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
13-11-2008	1200	11.5/85.5	1.5	1002	25	3	D
	1800	12.0/85.0	1.5	1002	25	3	D
14-11-2008	0000	12.0/85.0	1.5	1002	25	3	D
	0300	12.5/85.0	2.0	1000	30	5	DD
	0600	13.0/85.0	2.0	1000	30	5	DD
	0900	13.5/84.5	2.0	1000	30	5	DD
	1200	14.0/84.0	2.5	998	35	6	CS
	1500	14.5/83.5	2.5	996	35	6	CS
	1800	14.5/83.5	2.5	996	35	6	CS
	2100	14.5/83.0	2.5	994	40	8	CS
15-11-2008	0000	14.5/83.0	2.5	994	40	8	CS
	0300	14.5/82.5	2.5	996	35	6	CS
	0600	14.5/82.5	2.0	996	30	5	DD
	0900	14.5/82.0	2.0	996	30	5	DD
	1200	14.5/81.5	2.0	996	30	5	DD
	1500	14.5/81.0	2.0	996	30	5	DD
	1800	15.0/80.5	2.0	996	30	5	DD
	2100	15.2/80.2	2.0	996	30	5	DD
	The system crossed the south Andhra Pradesh coast close to the north of Kavali (43243) between 2200 and 2300 UTC.						
16-11-2008	0000	15.5/79.5	-	998	30	5	DD
	0300	15.5/78.5	-	1004	25	3	D
	0900	Weakened into a well marked low pressure area over Raylaseema and adjoining Telangana and interior Karnataka.					

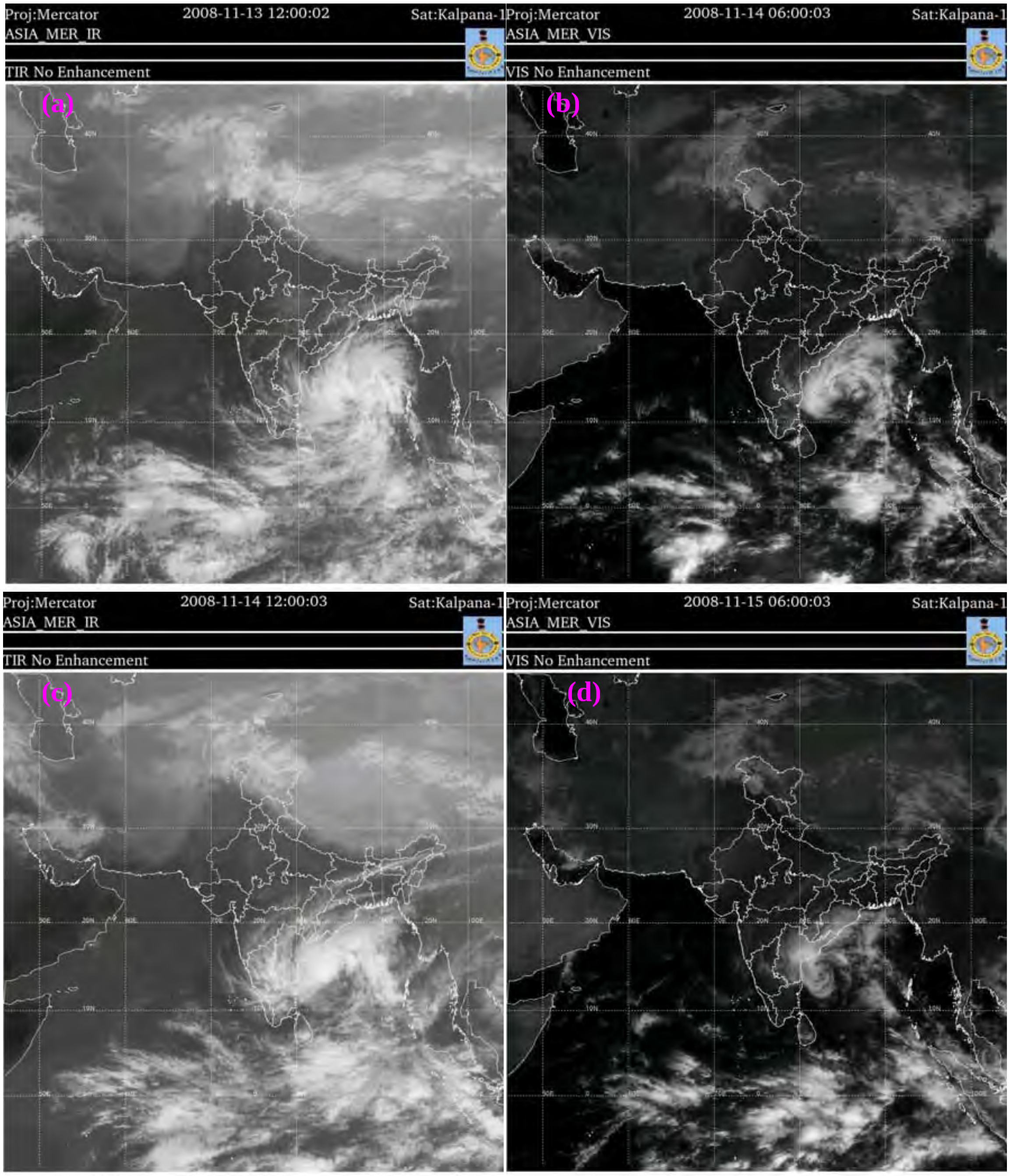

Fig. 2.8.1 INSAT imageries of the system at (a) 131200 UTC (b) 140600 UTC (c) 141200 UTC and (d) 150600 UTC.

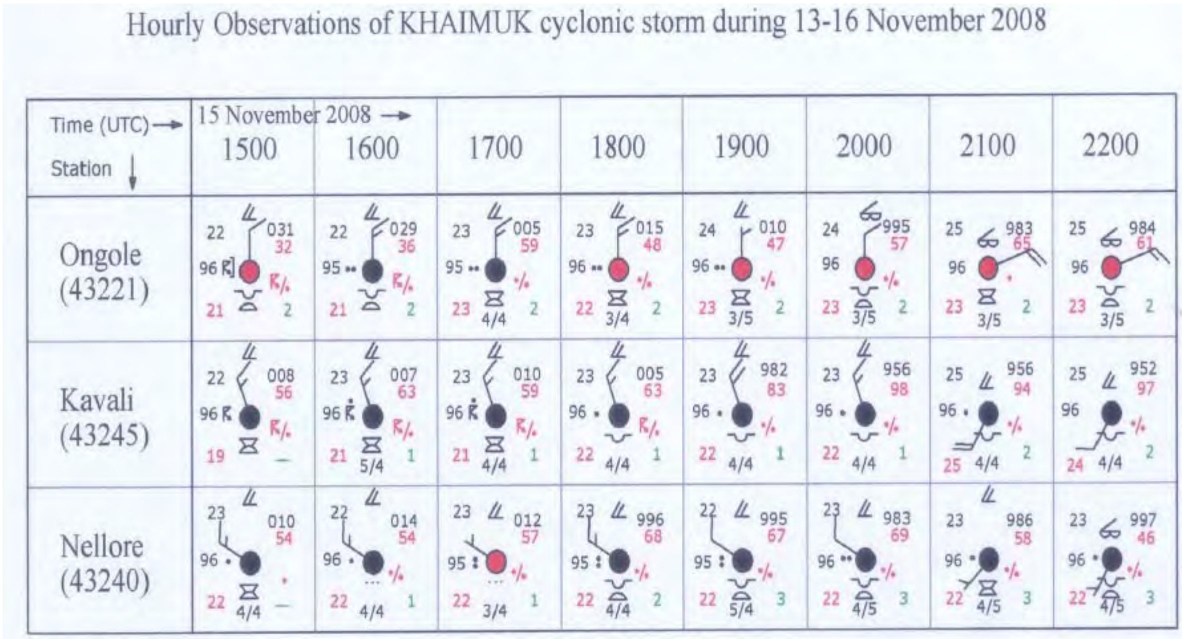

Fig. 2.8.2 Hourly observations at the time of landfall

2.8.5.1 DWR observations from CDR Machilipatnam

According to DWR Machilipatnam most of the Radar observations did not show any clear spiral bands to fix the centre. However, a vortex (in all ill defined eye) featuring maximum relativity of 54 dBZ, maximum velocity of 30 mps at 3.3 km height centred at 14.3^0 N and 81.2^{0}E was observed with very poor confidence level. Track of cyclone could not be drawn since centre could not be fixed confidently.

A few DWR imageries taken by DWR, Chennai and Machilipatnam are shown in Fig. 2.8.3

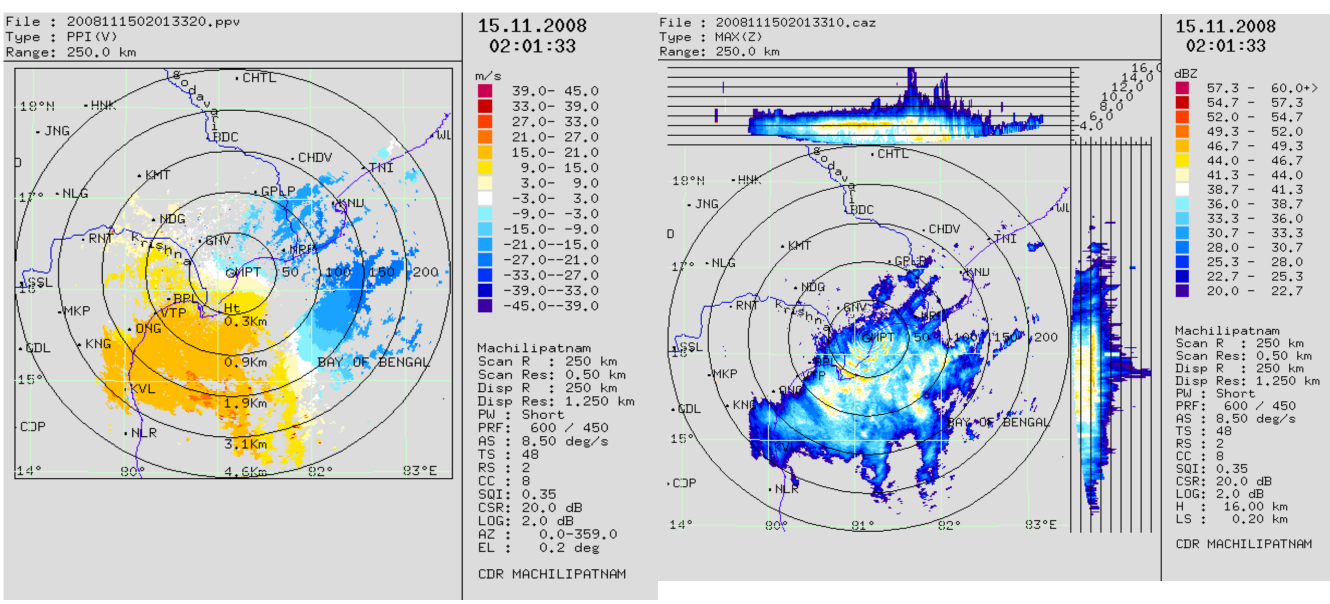

Fig. 2.8.3 (a) DWR imageries taken DWR, Machilipatnam

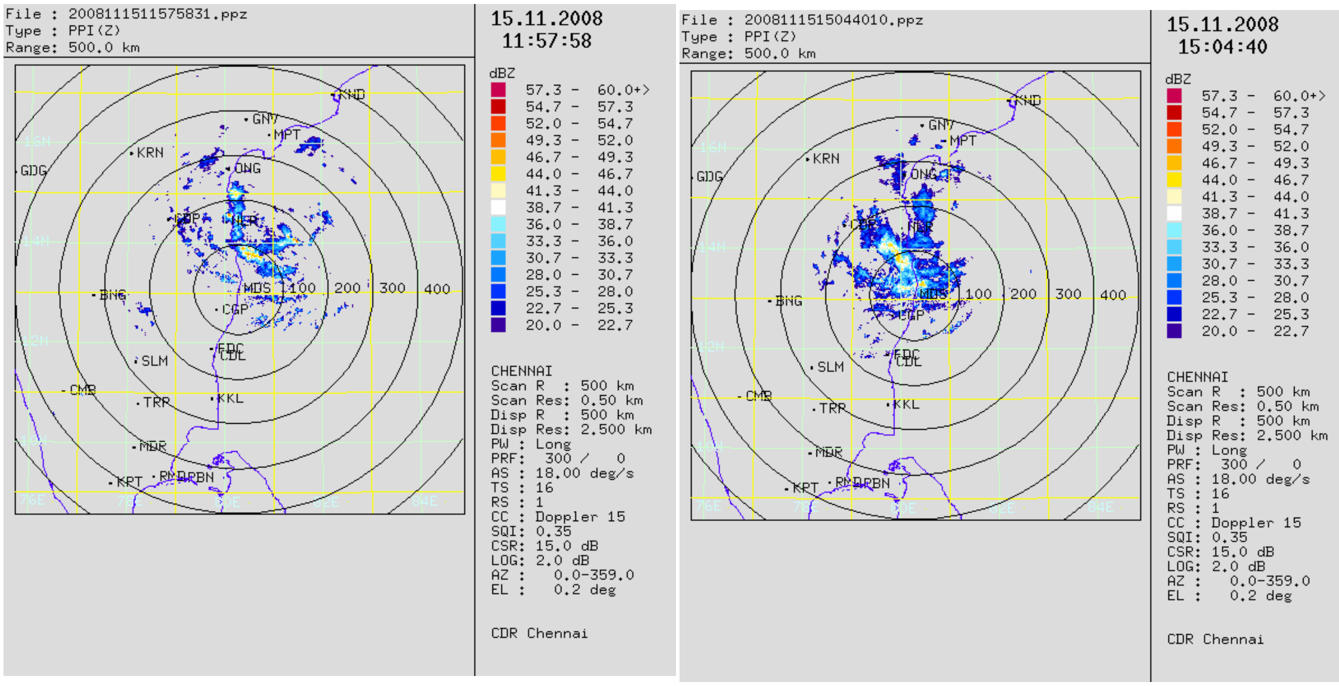

Fig. 2.8.3 (b)   DWR imageries taken DWR, Chennai

2.8.6 Realised weather

2.8.6.1 Rainfall:

Under the influence of the system, fairly widespread/ widespread rainfall with isolated heavy to very heavy falls occurred over coastal Andhra Pradesh and Rayalaseema. The significant amounts of rainfall (7 cm and above) are given below:

16.11.2008

Seetharampuram-13, Machilipatnam-13, Kaikalur-11, Narasapur-11, Kothapeta-11, Allavaram-11, P.Gannavaram-11, Sakinetipalli- 11, Palkol-10, Gudiwada-10, Koduru-10, Penumanthra-10, Penuganta-10, Achanta-9, Palakoderu-9, Pedapadu-9, Avanigedda-9, Rapur-9, Udayagiri-8, Bhimavaram-8, Bhimadole-8, Atmakur-8, Dendulur-8, Undrajayaram-8, Iragavaram-8, Undi-8, Akividu-8, Ravulupalem-8, Eluru-7, Tanuku-7, Repalle-7, Tpgudem-7, Gudur-7, Koyyalagudem-7, D.Tirumala-7, Ganapavaram- 7, Pentapadu-7, Veeravasaram-7, KPPuram-7, Rajole-7, Malikipuram-7, Uppalagutham-7, and Ainaville-7.

17.11.2008

Polavaram-23, Mogaltur-19, Pamarru-11, Kajuluru-10, Mummidibvaram-10, RC Puram-9, Eluru-9, Pedapadu-9, Bhimavaram-9, Kaikalur-9, Ambajipeta-9, Undi-8, Mandapeta-8 and Kalla-7.

2.8.6.2 Wind

The maximum surface wind observed at Kavali (43243) was 28 kmph and the direction was northerly to northeasterly during 0900-1400 UTC of 15 November.

2.8.7 Damage

There was no significant damage due to the system. According to different media reports, the damage over the Andhra Pradesh state includes the following:

1. Major erosion of coast seen at Uppada near Kakinada.
2. In many areas in East & West Godavari and Krishna districts, paddy fields got inundated.
3. Twenty country boats and one boat washed off in the Sea off Konapapapeta in Kothapalli Mandal of East Godavari.
4. A big ship was carried away by the waves along the Wakalapudi beach near Kakinada of East Godavari districts.
5. Many boats and fishing nets were swept off in the areas adjoining Wakadu, Alluru, Mypad, Gangapatnam in Nellore district.

A few photographs are indicating the damage due to the system shown in Fig. 2.8.4.

Fig. 2.8.4..Photographs showing damage caused by Cyclonic Storm "KHAI MUK"

2.9 Cyclonic storm "NISHA" over the Bay of Bengal (25-27 November, 2008)

2.9.1 Introduction

A cyclonic storm "**NISHA**" crossed Tamil Nadu and Puducherry coast near Karaikal (43346) between 0100 and 0200 UTC of 27 November, 2008. It caused widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy falls over coastal Tamil Nadu and Puducherry. Exceptionally heavy rainfall occurred over districts of cauvery delta. It led to flood over coastal areas of Tamil Nadu and Puducherry. There was loss of 78 human lives and huge crop loss. The salient features of cyclone, **NISHA** are as follows:

(1) The cyclogenesis took place over the land region (north Sri Lanka).

(2) System remained quasi stationary for about 24 hours very close to the coast causing exceptionally heavy rainfall.

The genesis of the system is presented in Sec. 2.9.2 and intensification. Movement of the system is presented in Sec. 2.9.3, pressure and wind characteristics are discussed in sec. 2.9.4, DWR characteristics are presented in Sec. 2.9.5 and the realized weather and damages are presented in Sec. 2.9.6 and 2.9.7 respectively.

2.9.2 Genesis

A trough of low pressure lay over southeast Bay of Bengal on 19. It ran from southwest Bay of Bengal to west central Bay of Bengal off Sri Lanka, Tamil Nadu and south Andhra Pradesh coasts during 20 to 22 November. The cloud motion vector estimated from INSAT observation also showed a trough in easterly over southeast Bay of Bengal between 800-600 hPa levels on 20 and over southwest Bay of Bengal on 21 & 22 November. Broken low medium clouds with embedded moderate to intense convection were observed over Tamil Nadu coast, Sri Lanka and adjoining southwest Bay of Bengal on 20 November. This convection persisted over the region along with a band of moderate to intense convection over the north Indian Ocean between equator and 5^0N and long. 70^0E to 90^0E on 21 November. The convection band moved northward and was seen between lat. 2^0 & 11^0N, east of long 72^0E on 22 November and to the east of 70^0E on 23 November. The convective clusters over southwest Bay of Bengal extended to westcentral Bay of Bengal on both the days. On 23 November, an embedded cyclonic circulation extending upto 3.1 km above mean Sea level (amsl) developed over the southwest Bay of Bengal. Under the influence of this cyclonic circulation, a low pressure area formed over north Sri Lanka and neighbourhood on 24 November with associated cyclonic circulation extending upto mid-tropospheric level. A trough from the system extended to westcentral Bay of Bengal off Tamil Nadu and south coastal Andhra Pradesh. The convective cloud mass over southwest Bay of Bengal and neighbour organized into a vortex at 0600 UTC of 24 November and lay centred within a half a degree of lat.8.0^0N and long 83.5^0NE. The intensity of the vortex according to Dvork's technique was estimated to be T1.0. Associated intense to very intense convection was observe red over southwest Bay of Bengal and adjoining Indian ocean and Sri Lanka between 4.0^0N and 7.5^0N and long 80.0^0E and 85.0^0E.The well marked low pressure area concentrated into a depression and lay centred at 0900 UTC of 25 November over north Sri Lanka near lat. 8.5^{0}N and long. 81.0^{0}E, close to southwest of Trincomalee.

Meteosat products showed vertical wind shear of horizontal wind between layers (150-300 hPa) and (700-925 hPa) to be about 10-15 knots on 20 and 21 November. It slightly increased on 22 November and became 20-25 knots on 23 November. However, it again decreased on 24 November and become 15-20 knots. The wind shear further decreased and become 10-15 knots at 0300 UTC of 25 November.

The Bay of Bengal was warmer during the period of cyclogenesis with average SST about 28-28.5^{0}C on 19 November. It was below normal by about 0.5^{0}C over central Bay of Bengal and near normal over south Bay of Bengal till 23November. It become about 29.0^{0}C on 24 and 25 November over the south Bay of Bengal.

The upper tropospheric ridge at 200 hPa level roughly ran along 18^{0}N on 16, 16^{0}N on17 and 15^{0}N during 18 to 20 November. It roughly ran along 14^{0}N from 21 November onwards. Hence the upper tropospheric flow pattern was favourable for cyclogenesis as it provided the required divergence.

2.9.3 Intensification and movement:

Remaining practically stationary, the depression intensified into a deep depression and lay centred at 1200 UTC of 25 November over north Sri Lanka, close to the southwest of Trincomalee due to further organization of convection. The CTT fell further to -70^{0}C and vertical wind shear continued to be 10-15 knots. The system lay to the south of the upper tropospheric ridge which roughly ran along 14^{0}N. Under the continued favourable environmental factor like warmer SST, low to moderate vertical wind shear, low level relative vorticity and upper level divergence, the system moved northwestwards and intensified into a cyclonic storm '**NISHA**' over the southwest Bay of Bengal and lay centred at 0300 UTC of 26 November near lat 10.5^{0}N and long. 80.0^{0}E, close to Vedaranniyam (43349). The lowest CTT was around -75^{0}C at 0300 UTC of 26 November. The system moved very slowly northwards thereafter and lay centred at 1200 UTC of 26 November near lat 10.8^{0}N and long 80.0^{0}E, close to Nagapattinam (43347). As the system lay close to the coast, the system did not intensify further. Rather, the lowest SST at 1200 UTC of 26 November increased to -70^{0}C. However, as the vertical wind shear continued to be low (about -05 to -10 knots) at 1200 UTC of 26 November, the system could maintain its intensity of cyclonic storm. It moved slightly northwards further and lay centred at 0000 UTC of 27 November over the southwest Bay of Bengal, close to the north of Karaikal. At this time the CTT further rose to -60^{0}C and vertical wind shear increased to 10-20 knots. As the system lay to south of the upper tropospheric ridge which roughly ran along 14^{0}N but in the periphery of the anticyclonic circulation over the southwest Bay of Bengal, it moved northwestwards initially and then north-northwestwards. It crossed Tamil Nadu and Puducherry coasts close to the north of Karaikal between 0100 and 0200 UTC of 27th November and lay centred at 0300 UTC of 27 November over coastal Tamil Nadu and Puducherry, about 50 km northwest of Karaikal. Due to land interaction, the system while moving northwestwards weakened into a deep depression over north interior Tamil Nadu with its centre located about 100 km east-southeast of Dharmapuri (43301) at 0900 UTC of 27 November. It further weakened into a depression and lay centred at 1200 UTC of same day over north interior Tamil Nadu, about 50 km southeast of Dharmapuri. It weakened into a well marked low pressure area at 0000 UTC of 28 over north interior Tamil Nadu and adjoining Rayalseema and south interior Karnataka. Moving westwards, it emerged into the Arabian Sea and lay as feeble low pressure area over southeast and adjoining eastcentral Arabian Sea at 0300 UTC of 28 and over eastcentral and adjoining southeast Arabian Sea off Karnataka coast during 29-30 November. The system became less marked 1 December 2008.

The best track parameters and other relevant information are given in Table 2.9.1. The track of system is shown in Fig. 2.1. A few INSAT imageries of the system area shown in Fig. 2.9.1. The hourly coastal observations are shown in Fig. 2.9.2.

Table 2.9.1:Best track Positions and other parameters for cyclonic storm "NISHA" over the Bay of Bengal (25-27 November, 2008)

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
25-11-2008	0900	8.5/81.0	1.5	1001	25	4	D
	1200	8.5/81.0	2.0	1001	30	5	DD
	1500	9.0/81.0	2.0	1001	30	5	DD
	1800	9.5/80.5	2.0	1002	30	5	DD
	2100	10.0/80.0	2.0	1002	30	5	DD
26-11-2008	0000	10.0/80.0	2.0	1000	30	6	DD
	0300	10.5/80.0	2.5	1000	40	8	CS
	0600	10.5/80.0	2.5	1000	40	8	CS
	0900	10.5/80.0	3.0	996	45	10	CS
	1200	10.8/80.0	3.0	996	45	10	CS
	1500	11.0/80.0	3.0	998	45	10	CS
	1800	11.0/80.0	3.0	998	45	10	CS
	2100	11.0/80.0	3.0	996	45	10	CS
27-11-2008	0000	11.3/79.9	3.0	996	45	10	CS
	The system crossed the Tamilnadu coast north of Karaikal (43346) near lat. 11.3^0 N and long.79.8^0 E between 0000 and 0100 UTC.						
	0300	11.5/79.5	-	1000	40	8	CS
	0900	12.0/79.0	-	1000	30	5	DD
	1200	12.0/78.5	-	1000	20	3	D
28.11.2008	0000	Weakened into a well marked low pressure area over north interior Tamil Nadu and adjoining areas of south interior Karnataka and Rayalaseema.					

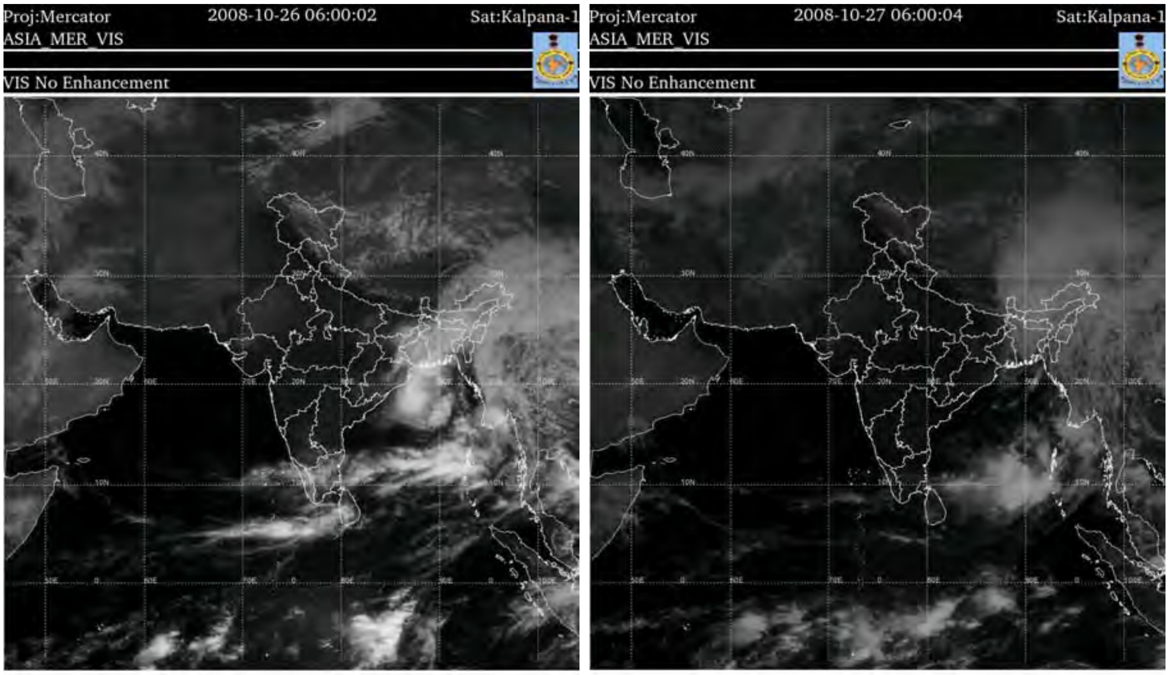

Fig. 2.9.1. INSAT imageries of the cyclonic storm NISHA

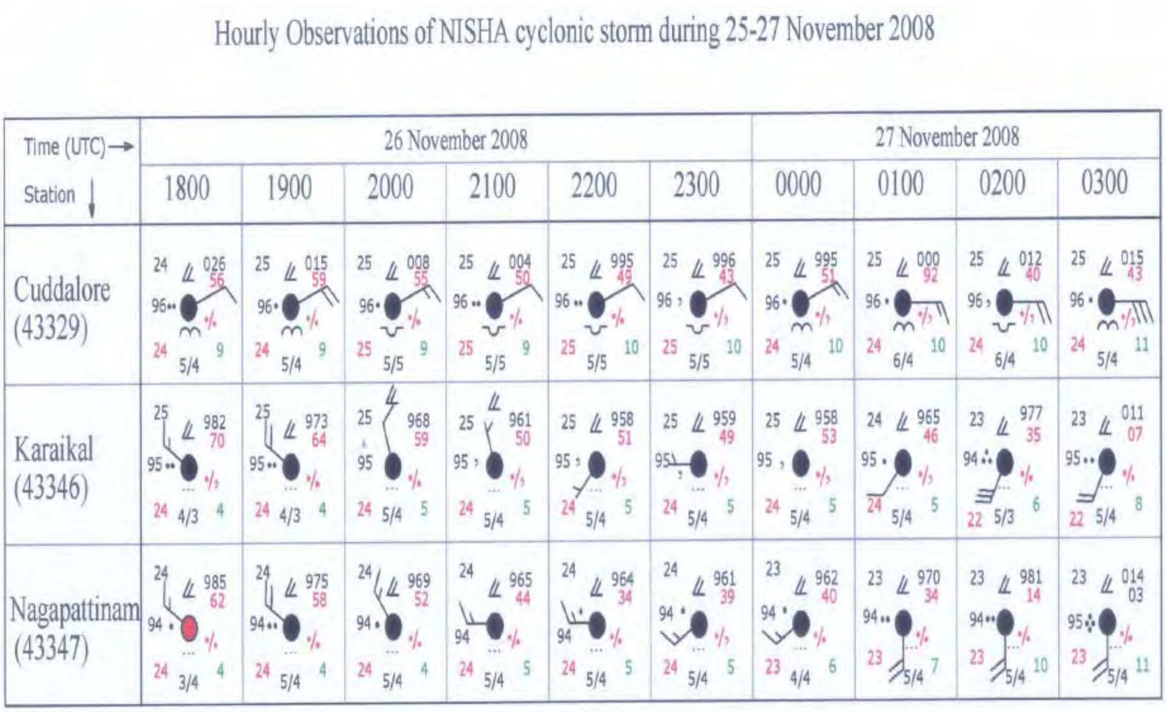

Fig. 2.9.2. Hourly coastal observations (260000 to 270300 UTC) in association with cyclonic storm, NISHA

2.9.4 Pressure and wind:

2.9.4.1 Estimated central pressure (ECP) and Sustained maximum wind:

The ECP and sustained surface maximum wind of the system are shown in Table 2.9.1. The maximum sustained wind was estimated to be 45 knots from 0900 UTC of 26 November till landfall. Karaikal reported lowest ECP of 995.8 hPa with calm wind condition at 0000 UTC of 27 November. The maximum wind of about 30-35 knots was reported by various stations in Tamil Nadu and Pudducherry coast in association with the system. Karaikal reported 35 knots at 0018 UTC of 27 November 2008.

2.9.4.2 Pressure Change in 24 hours:

The MSLP fell slightly by 1 hPa over the south peninsula on 23 November. It fell by about 2-3 hPa over Sri Lanka and about 1 hPa along the east coast of the peninsula on 24 November. The MSLP fell further over Tamil Nadu and Sri Lanka on 25 November by about 2-4 hPa. The maximum fall of -3.8 hPa was reported over Trincomalee at 0300 UTC of 25 November. Considering Tamil Nadu coast, Pamban (43363) reported maximum fall of 2.6 hPa at that time. The MSLP fall over Nagapattinam and Karaikal are show in Fig. 2.9.3

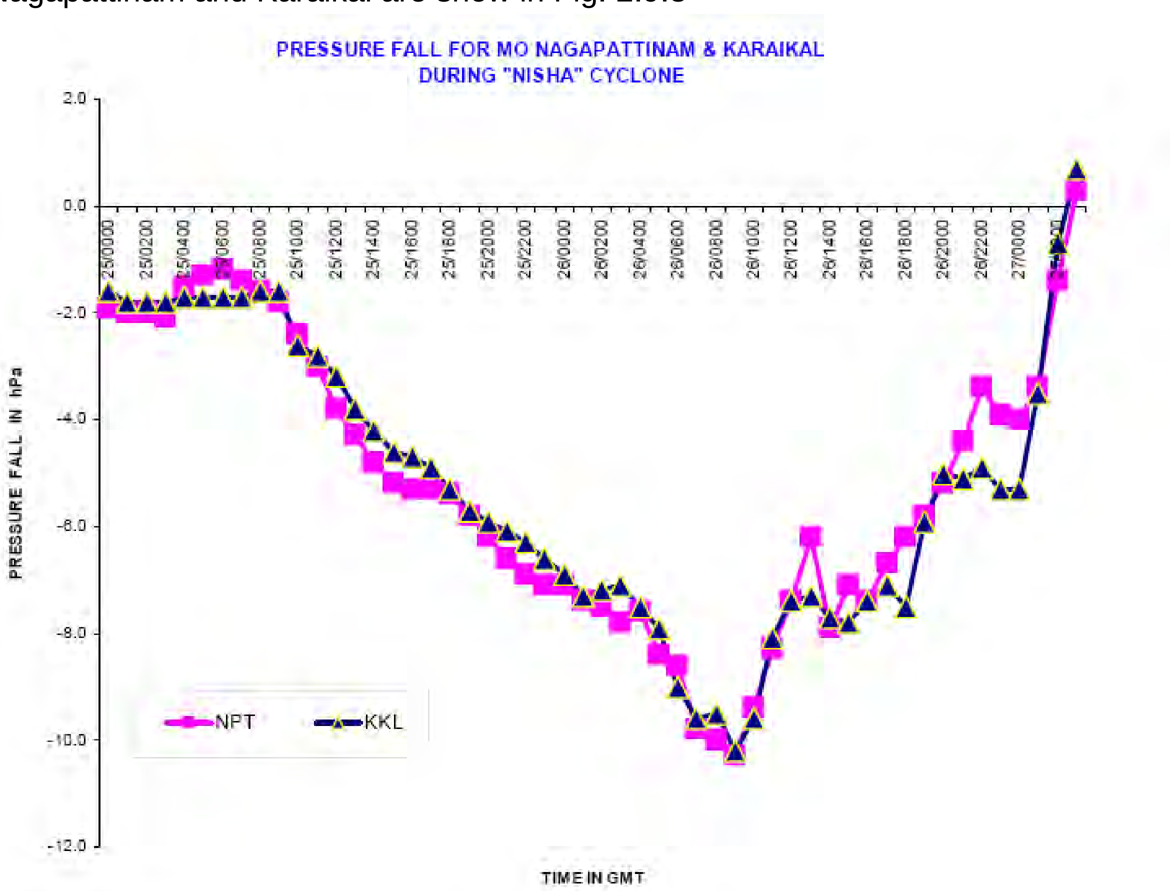

Fig. 2.9.3. MSLP fall over Nagapattinam and Karaikal

2.9.4.3 Pressure departure from normal:

The MSLP was near normal along east coast during 19-22 November. The MSLP became slightly below normal by about 1-2 hPa over Tamil Nadu and Sri Lanka on 23 November and by about 2 hPa over south Tamil Nadu on 24 November. The MSLP was below normal by 2-5 hPa along Tamil Nadu and Sri Lanka coasts and normal over remaining parts of east coast on 25 November. Tuticorin recorded maximum departure (5.2 hPa) from normal of at 0300 UTC of 25 November.

2.9.5 DWR Characteristic: The storm was traced by CDR Karaikal and DWR Chennai.

The observations reported by CDR Karaikal are given in Table 2.9.2 and radar imageries are show in Fig. 2.9.4

Table 2.9.2: Radar observation from CDR, Karaikal

Date and time (UTC)	Position
251200	8.5^0N/81.0^0E
260300	10.8^0N/80.4^0E
261200	10.9^0N/80.3^0E

The spiral band was reported by CDR Karaikal during 0300 of 26 to 0300 UTC of 27 November. Throughout the life period of the system over the Sea the features as seen by DWR Chennai were not sufficient to attempt centre fixing . However, after crossing the coast he system came closer to DWR Chennai, features grew prominent and centre could be fixed, based on a few spiral bands and in some cases with partial eye-wall. Confidence from poor to fair only could be assigned. Center was fixed during 0500 to 1300 UTC of 27 November. The details are shown in Table 2.9.3. A few imageries from DWR Chennai are shown in fig. 2.9.5. Maximum velocity observed in the cyclone field was not associated with the eye-wall region, but mostly associated with strong echoes in spiral bands. Maximum observed radial was arounds 28 mps.

On few occasions when eye in the form of Bounsws Weak Echo Region could be seen around the centre, the shape was irregular and reflectivity was much weaker.

Table 2.9.3: Radar observations from DWR, Chennai

Date	Time(UTC)	Position (lat/long)	AZ Deg.	Range	Confidence
27-11-2008	0500	11.5579.60	204	185	Fai
27-11-2008	0600	11.65/79.51	208	180	Fair
27-11-2008	0700	11.77/79.31	216	180	Poor
27-11-2008	0800	11.67/78.93	223	215	Poor
27-11-2008	0900	12.00/79.00	230	185	Poor
27-11-2008	1000	11.92/79.26	221	170	Poor
27-11-2008	1100	11.62/78.69	227	237	poor
27-11-2008	1200	11.52/78.69	225	245	Fair
27-11-2008	1300	11.48/78.52	227	262	Fair

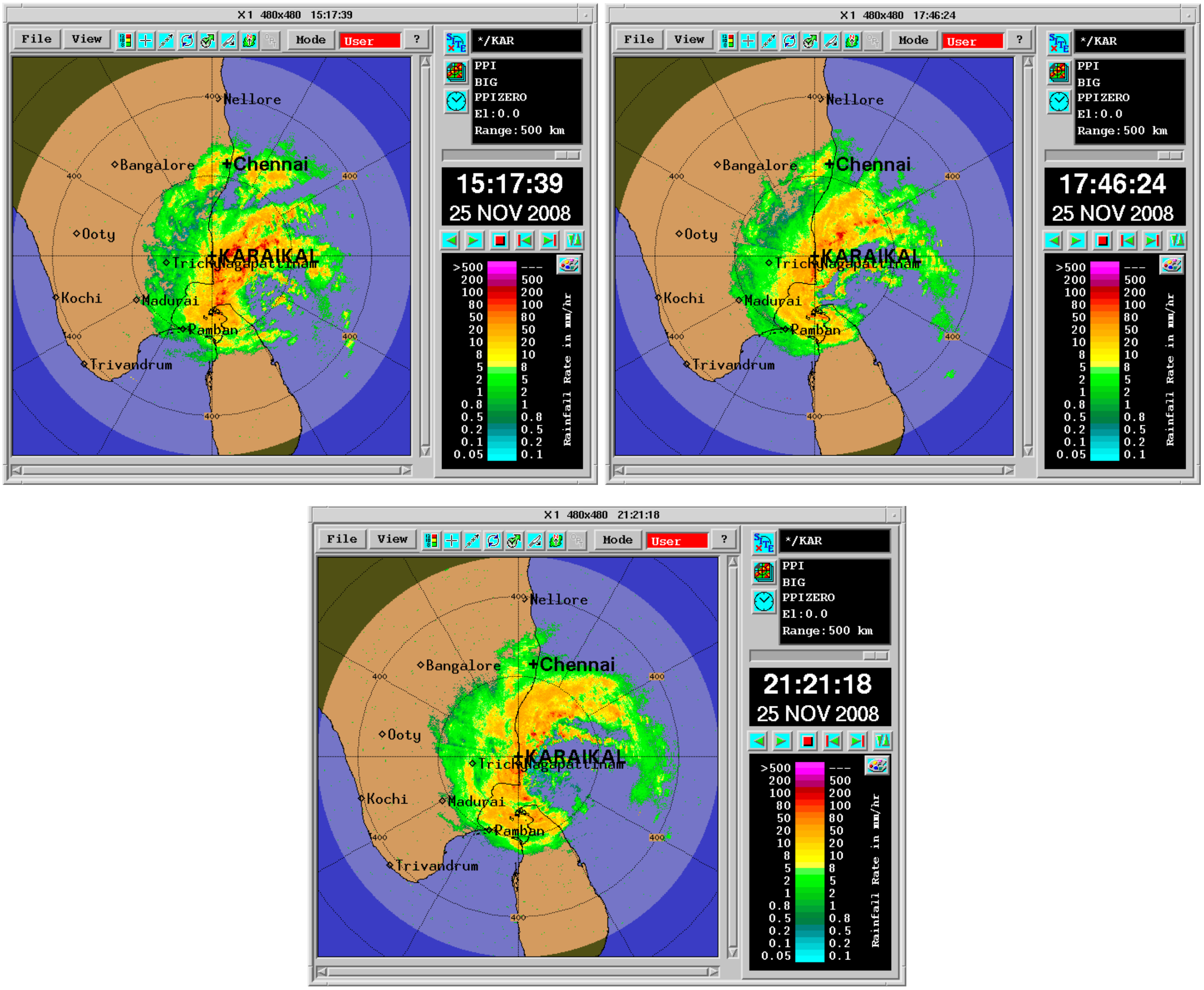

Fig. 2.9.4.Doppler Weather Radar (DWR) Karaikal imageries in association with cyclonic storm NISHA

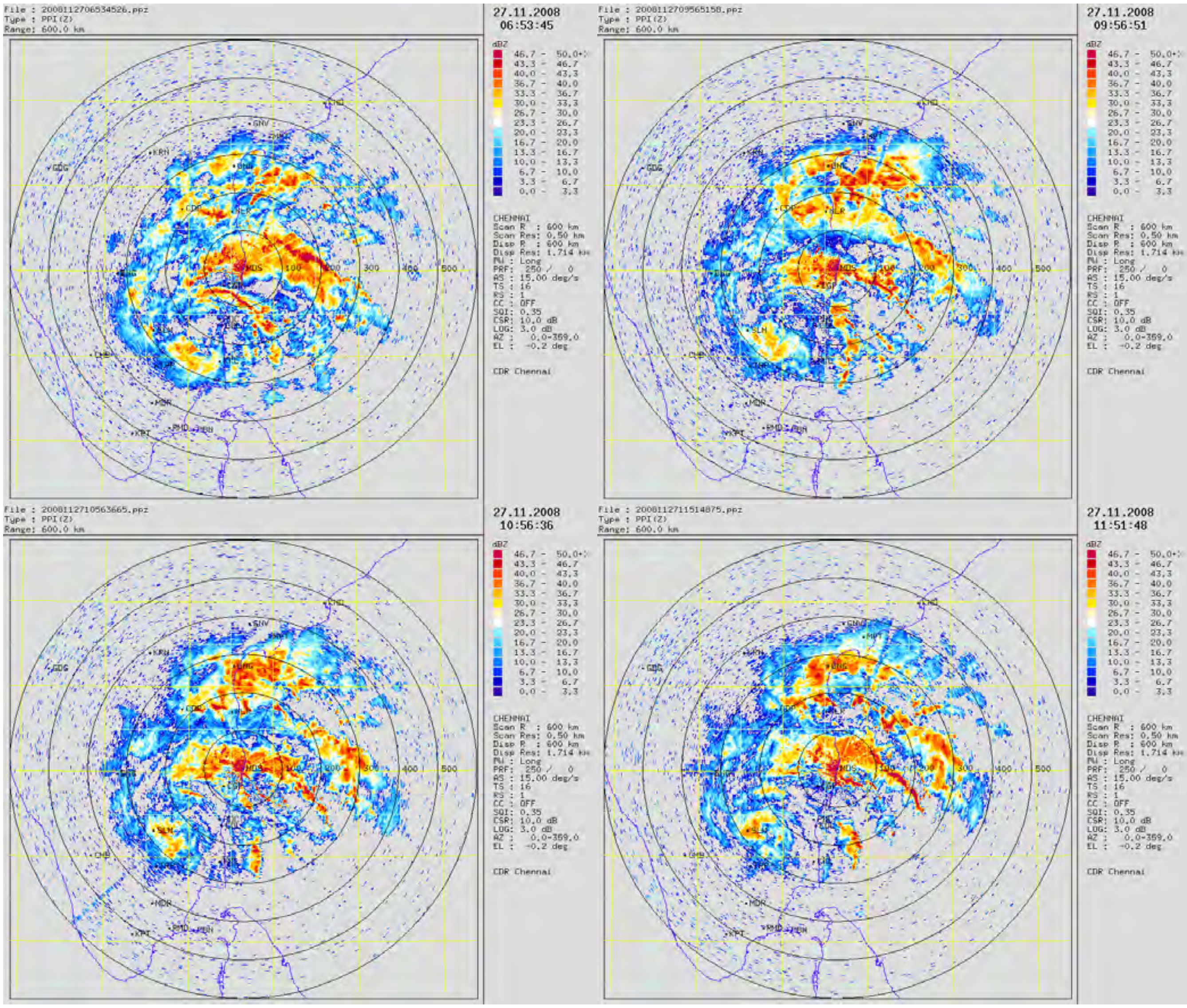

Fig. 2.9.5. Doppler weather Radar (DWR) Chennai imageries in association with cyclonic storm NISHA

2.9.6 Realized Weather and damage:

Due to the cyclonic storm, very heavy to extremely heavy rainfall occurred in Tamil Nadu and Pudducherry and heavy to very heavy rainfall occurred over south Andhra Pradesh. Chief amounts of rainfall(≥ 7 cm) are mentioned below.

25 November

TAMILNADU & PUDUCHERRY: Thiruvidalmarthu-30, Tanjavur-25, Rameswaram-23, Orathanadu-19, Mayiladuthurai-17, Tirukkattupalli, Pamban-15 each, Tiruvaiyaru-14, Sirkali, Kollidam-13 each, Papanasam, Ramanathapuram-12 each, Kumbhakonam-11, Sethiyathope Anicut, Chidabaram-10 each, Kattumannarkoil-11,Tiruchirapalli, R S Mangalam, Vedaranniyam-9 each, Tarangambadi, Karaikal-8 each, Tondi, Atirampattinam, Cuddalore, Nagapattinam, Puduchhery-7 Each.

26 November

TAMILNADU & PUDUCHERRY: Orathanadu, Vedaranniyam-33 each, Parangipettai, Chidambaram-28 each, Thiruvidalmarthu, Mayiladuthurai-26 each, Sirkali-25, Kattumannarkoil-24, Cuddalore-22, Sethiyathope Anicut, Kollidam-21 each, Tiruthuraipndi, Nagapattinam-20 each, Tiruvarur, Kodavasal-18 each, Karaikal-19, Puduchhery, Adirampattinam-18 each, Nannilam-17, Tanjavur-16, Valangiman, Kumbhakonam, Tarangambadi-15 each, Needamangalam-14, Rameswaram, Papansam, Pattukkottai, Mannargudi, Muthupet, Jayamkondam-13 each, Adiramapatnam, Srimushnam-12 each, Chryyur, Chennai (AP)-11 each, Anna University-10, Marina, Variddhachalam, Nungambakkam,Chennai (City)-9 each, Tambaram, Utheriramerur, Kancheepuram-8 each.

27 November

RAYALASEEMA: Tirupathi-10

TAMILNADU & PUDUCHERRY: Orathanadu (Thanjavur disrict) and Vedaranyam 33 each, Parangipettai and Chidambaram (Cuddalore disrict) 28, Thiruvidaimaruthur (Thanjavur disrict) and Mayiladuthurai (Nagapattinam disrict) 26 each, Sirkali (Nagapattinam disrict) 25. Panruti (Cuddalore disrict) 23, Sethiyathope (Cuddalore disrict) and Kollidam (Nagapattinam disrict) 21, Thiruthuraipoondi (Tiruvarur disrict) 20, Karaikal and Nagapattinam 19, Puducherry Airport 18, Kodavasal and Nannilam (both Tiruvarur disrict) and Tiruvarur 17, Kumbakonam (Thanjavur disrict) 16,Valangaiman (Thanjavur disrict) and Tarangambadi (Nagapattinam disrict) 15 each, Needamangalam (Tiruvarur disrict) 14, Papanasam and Pattukottai (both Thanjavur disrict), Mannargudi and Muthupet (both Tiruvarur disrict), Rameswaram (Ramanathapuram disrict) and Jayamkondam (Perambalur disrict) 13 each, Srimushnam (Cuddalore disrict) and Adiramapattinam 12 each, Chennai Airport, Anna University (Chennai disrict) and Cheyyur (Kanchipuram disrict) 11 each, Sriperumpudur (Kanchipuram disrict) and Thanjavur 10 each, Chennai, DGP Office (Chennai disrict), Virudhachalam (Villupuram disrict), Madukkur (Thanjavur disrict) and Karambakudi (Pudukottai disrict) 9 each, Tambaram, Kanchipuram, and Uthiramerur (Kanchipuram disrict) 8 each, Chengalpattu (Kanchipuram disrict),Poonamalle and Korattur (both Thiruvallur disrict),Gingee and Vannur (both Villupuram disrict),Villupuram, Manamelkudi and Ariyalur 7 each.

28 November

Coastal Andhra Pradesh:

Ongole-14, Kavali-12, Nellore-9, Bapatala-7

Rayalaseema: Tirupathi-13.

Tamilnadu & Puducherry: Chennai (AP)-28,Anna University-23, Cuddalore-22, Puduchhery-21, Tiruvallur-20, Chingleput, Ayiyalur, Tanjavur, Vellore-17 each, Pallipattu, Villupuram, Poonamallee, Muthupet, Poondi-16 each, Lalgudi, Chettykulam, Padallur, Red Hills, Tiruchchirapalli-15 each, Tozhudur, Nungambakkam, perumbalur, Parangipettai, Srimushnam, Tiruvaiyaru, Cholavaram, Ponneri, Vanur, Chennai (City)-14 each, Tambaram, Tirukkattupalli, Utheriramerur, Kodavasal, Gingee, Kancheepuram-13 each, kollidam, Grand Anicut, Arni, Polur, Tirutani, Vandavasi, TindivanamSriperumbudur-12 each, Thiruvidalmarthu, Chryyar, Samayapuram, Ulundurpet, Marina (DGP Office)-11 each, Tiruchi Town, Tiruvarur, Valangiman, Vembavur, Kumbhakonam, Orathanadu-10 each, Nannilam-9, Papanasam-8, Sendamangalam-7

2.9.7 Damage:

Tamil Nadu: According to Tamil Nadu Govt. loss of life is 100 over the state. As per media reports, 8 lakhs acres of Paddy in Nagapattinam, Thanjavur and Tiruvarur(delta) districts and 55,250 hectares of Paddy in Cuddalore district were submerged due to heavy rain. The areas affected by flood and wind are shown in fig. 2.9.6.

Andhra Pradesh:. As per News paper reports, 3.63 lakh hectors of crop were damaged in Chittur, Nellore and Prakassam districts of south coastal Andhra Pradesh.

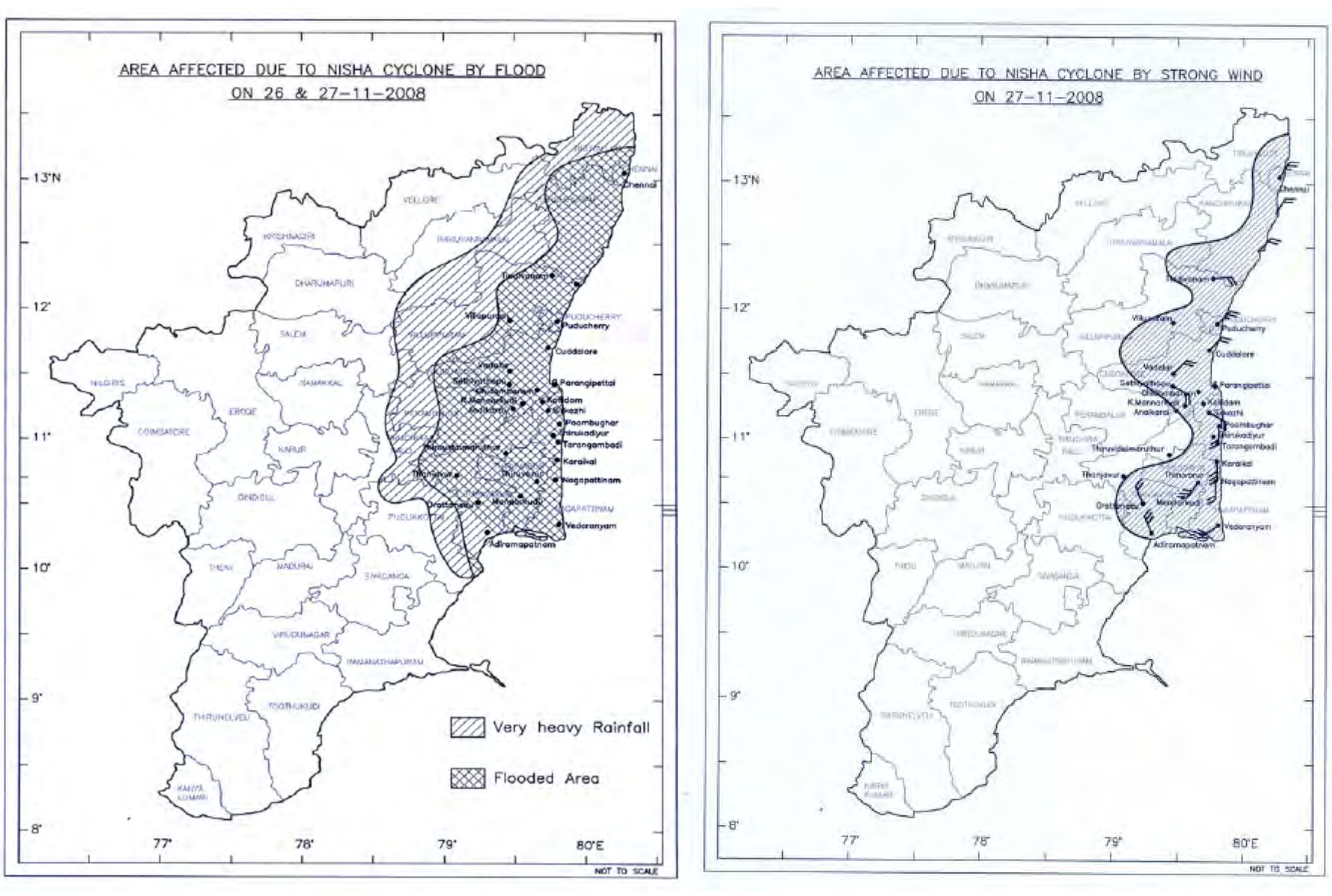

Fig. 2.9.6: The area affected by flood and strong wind due to cyclonic storm

Deep Depression over the Bay of Bengal (4-7 December, 2008)

2.10.1 Introduction:

A depression formed over the southeast Bay of Bengal at 0300 UTC of 4 December, 2008. It moved nearly in a northwesterly direction and intensified into a deep depression at 0000 UTC of 5 December. It moved in a nearly westerly direction from 1200 UTC of 5 December and towards Sri Lanka Coast and weakened gradually into a low pressure area over Sri Lanka at 1500 UTC of 7 December. The genesis of the system is presented in sec 2.10.2, intensification and movement in sec. 2.10.3 and realised weather in sec. 2.10.4.

2.10.2 Genesis:

The ITCZ was active during the first week of December. With the active ITCZ, a deep trough in easterlies developed over the south Andaman Sea. In its association, convective cloud clusters developed over south Andaman Sea on 1 December, 2008. With the persistence of convection, a low pressure area formed over the southeast Bay of Bengal and adjoining south Andaman Sea on 3 December. As per the INSAT imageries interpretations, the vortex formed on 3 December at 0600 UTC with intensity T1.0 and centre near lat 6.0^{0}N and long. 91.0^{0}E.The convection further organized and at 0300 UTC of 4 December, curved band pattern was observed. As per Dvork's technique, the intensity of the system increased to T1.5. Sustained maximum surface wind was estimated to be about 25 knots. The estimated central pressure of the system was 1006 hPa. The lowest cloud top temperature (CTT) was about -40 to -50^{0}C. vertical wind shear over the region was 15-20 knots. The 24 hours wind shear tendency showed no significant change. The system lay to the south of the upper tropospheric ridge, which roughly ran along lat. 12.0^{0}N. Hence, the system lay in a favourable upper level divergence, warmer Sea and moderate vertical wind shear. Under this scenario, the system was upgraded into a depression over the same area at 0300 UTC of 4 December, 2008 and lay centred near lat. 6.5^{0}N and long. 90.0^{0}E, about 630 km south-southwest of Port Blair (43333).

2.10.3 Intensification and movement:

The depression moved in a northwesterly direction, intensified into a deep depression lay centred near lat. 7.5^{0}N and long. 88.5^{0}E at 0000 UTC of 5 December. It continued to move in the same direction and lay centred near lat. 8.5^{0}N/long. 87.5^{0}E at 1200 UTC of 5 December. The system continued to lie the south of upper air ridge and hence it moved almost in a westerly direction thereafter towards Sri Lanka coast. Due to interaction with land surface it weakened into a depression over the southwest Bay of Bengal and lay centred at 0300 UTC of 7 December near lat. 8.5^{0}N and long. 82.5^{0}E. It was located at 1200 UTC of the same day near lat. 8.5^{0}N and long. 81.5^{0}E, close to Sri Lanka coast near Trincomalee (43418). Due to continued interaction with land surface and increase in vertical wind shear, the system further weakened into a well marked low pressure area at 1500 UTC of 7 December. The well marked low pressure area emerged into Comorin area on 8 December and into southeast Arabain Sea off Kerala coast on 9 December as a low pressure area. The best track parameters of the system are shown in Table 2.10.1. A few satellite imageries of the system are shown in Fig. 2.10.1. The upper tropospheric wind pattern at 200 hPa level based on LAM analysis at 0000 UTC during 4-7 December are shown in fig. 2.10.3. The vertical wind shear of horizontal wind between 850-200 hPa levels over the region based on LAM analysis at 0000 UTC during 4-7 December are shown in fig. 2.10.2.

2.10.4 Realised weather and damage:

Under the influence of the system heavy rainfall occurred at isolated places in Tamil Nadu. The chief amounts of rainfall (≥7) are given below:
9-12-2008:- Puducherry-9, Nagapattinam-8.
No damage has been reported due to this system.

Table 2.10.1: Best track Positions and other parameters for Deep Depression over the Bay of Bengal (4-9 December 2008)

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
4-12-2008	0300	6.5/90.0	1.5	1006	25	4	D
	0900	7.0/89.5	1.5	1006	25	4	D
	1200	7.0/89.5	1.5	1006	25	4	D
	1800	7.0/89.0	1.5	1006	25	4	D
5-12-2008	0000	7.5/88.5	2.0	1004	30	5	DD
	0300	7.5/88.5	2.0	1004	30	5	DD
	0900	8.0/88.0	2.0	1004	30	5	DD
	1200	8.5/87.5	2.0	1004	30	5	DD
	1800	8.5/87.0	2.0	1004	30	5	DD
6-12-2008	0300	8.5/85.0	2.0	1006	30	5	DD
	0900	8.5/84.5	2.0	1006	30	5	DD
	1200	8.5/84.0	2.0	1004	30	5	DD
	1800	8.5/83.5	2.0	1004	30	5	DD
7-12-2008	0000	8.5/83.0	1.5	1006	25	4	D
	0300	8.5/82.5	1.5	1006	25	4	D
	0900	8.5/82.0	1.5	1006	25	4	D
	1200	8.5/81.5	1.5	1006	25	4	D
	1500	Weakened into a well marked low pressure area over Sri Lanka and adjoining southwest Bay of Bengal.					

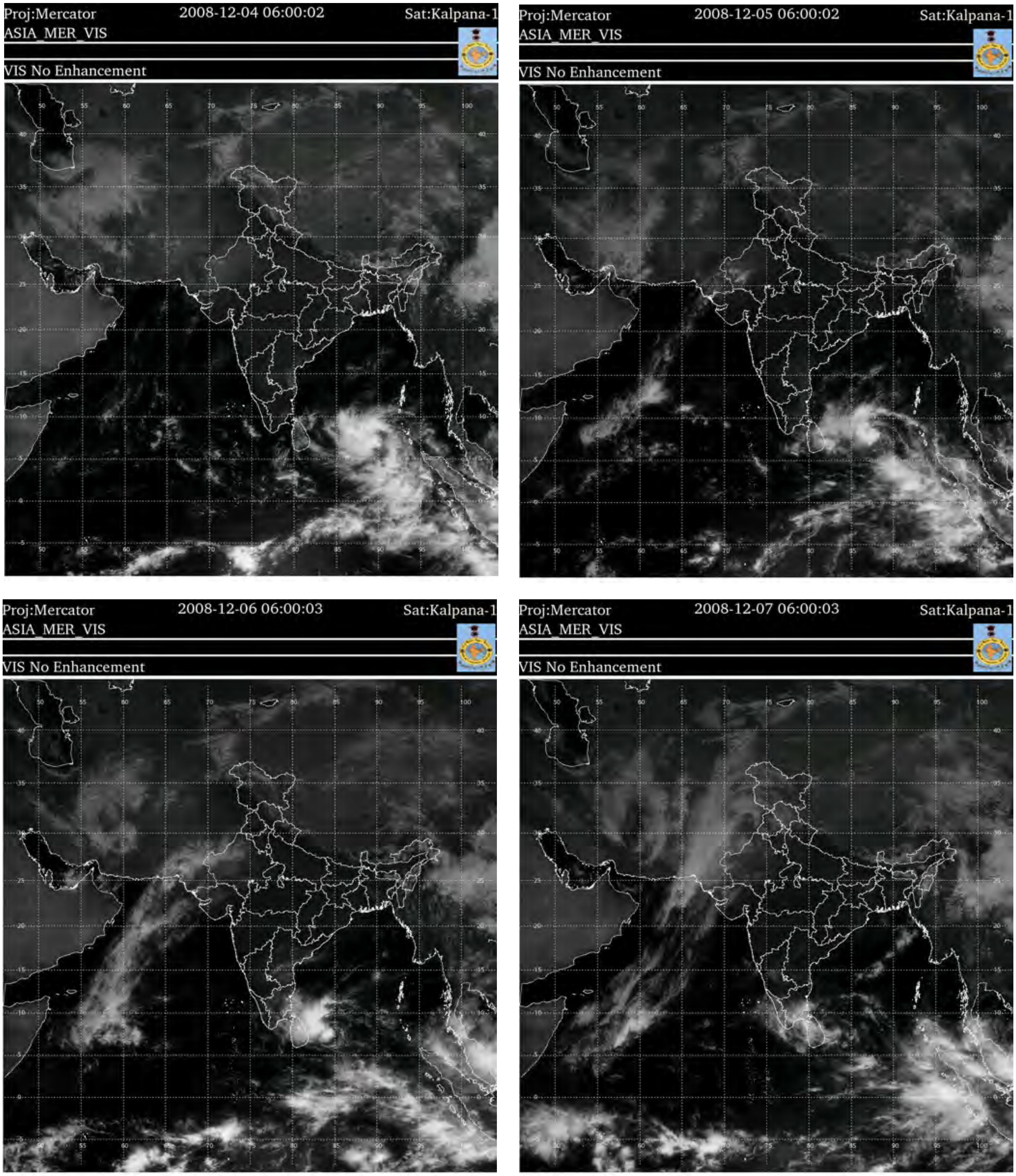

Fig. 2.10.1 INSAT imageries at 0600 UTC during 4-7 December, 2008 indicating convection in association with the system.

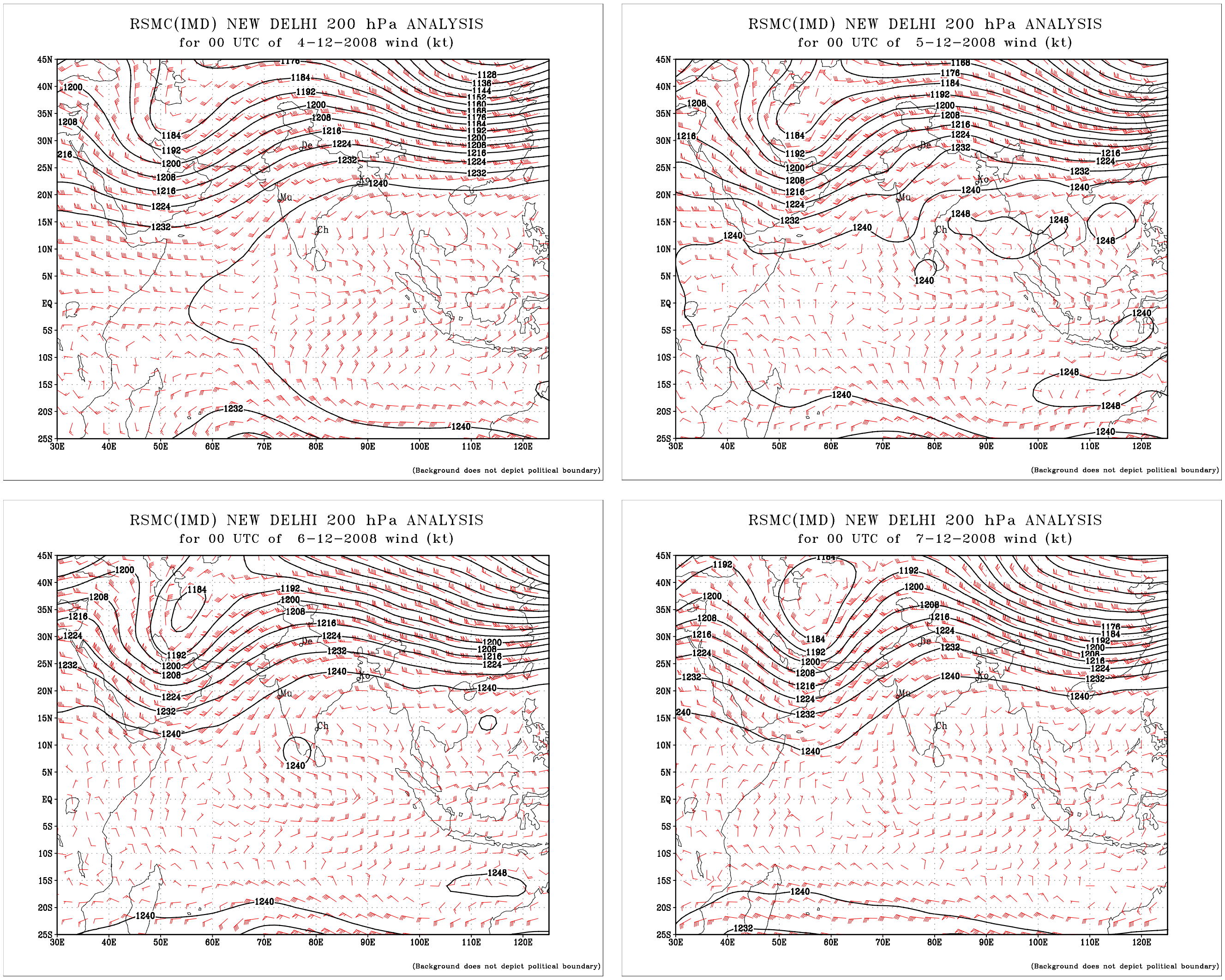

Fig. 2.10.2. LAM analysis at 0000 UTC during 4-7 December, 2008

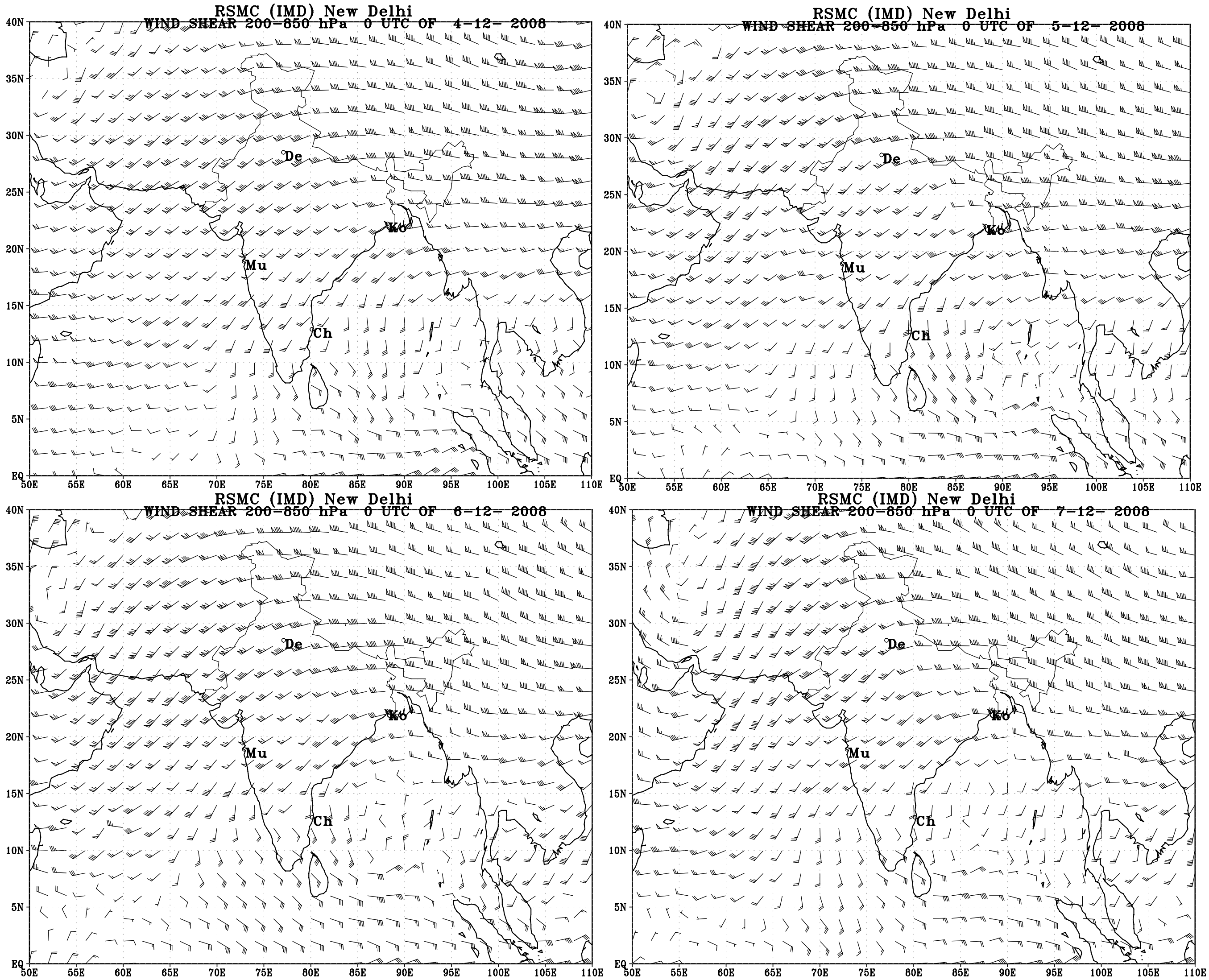

Fig. 2.10.3. Vertical wind shear of horizontal wind based on LAM analysis at 0000 UTC during 4-7 December, 2008.

CHAPTER – III

PERFORMANCE OF STATISTICAL AND DYNAMICAL NWP MODELS DURING CYCLONE SEASON 2008

The performance of various dynamical and statistical models during 4 cyclones developed during 2008 is analysed and discussed below.

3.1. Bay of Bengal Very Severe Cyclonic storm "NARGIS " of May 2008

3.1.1. Track prediction by NWP models

Fig. 3.1(a,b,c) display the forecast track positions of the system by various NWP models (QLM, ECMWF, MM5, UKMO and WRF) with the initial condition of 29 April, 30 April and 1 May 2008. It is encouraging to note that all the NWP models consistently indicated that the very severe cyclonic storm **NARGIS** would recurve to the northeast. The QLM model of IMD showed northerly movement initially, but during subsequent forecast hours it showed north-east to easterly movement. MM5 of IMD showed northeasterly to easterly movement. ECMWF showed north-easterly movement initially and during subsequent forecast hours it showed easterly movement. UKMO showed easterly movement persistently. WRF of IMD also showed easterly movement. Numerical products were also available from other Centres like IIT Delhi and SAC, Ahmedabad and these products were found quite useful.

In Table 3.1. landfall errors of different models are presented. The landfall errors in the 24 hours to 48 hours forecasts by MM5 of IMD, WRF of IMD, ECMWF and UkMO are found to be between 10 km to 110 km and average landfall time error is between –6 hours to 6 hours.

The forecast errors are summarized in Table 3.2. The QLM showed mean forecast error of 10 km to 285 km for the forecast range 12 hours to 48 hours. MM5 of IMD showed mean forecast error of 150 to 160 km for the 72 hours forecast range. ECMWF showed mean forecast error of 140 to 170 km for the forecast range up to 72 hours. WRF of IMD showed mean forecast error of 95 to 225 km for the forecast range of 24 hours to 72 hours. UKMO showed mean forecast error of 90 to 310 km for 24 hours to 72 hours forecast range.

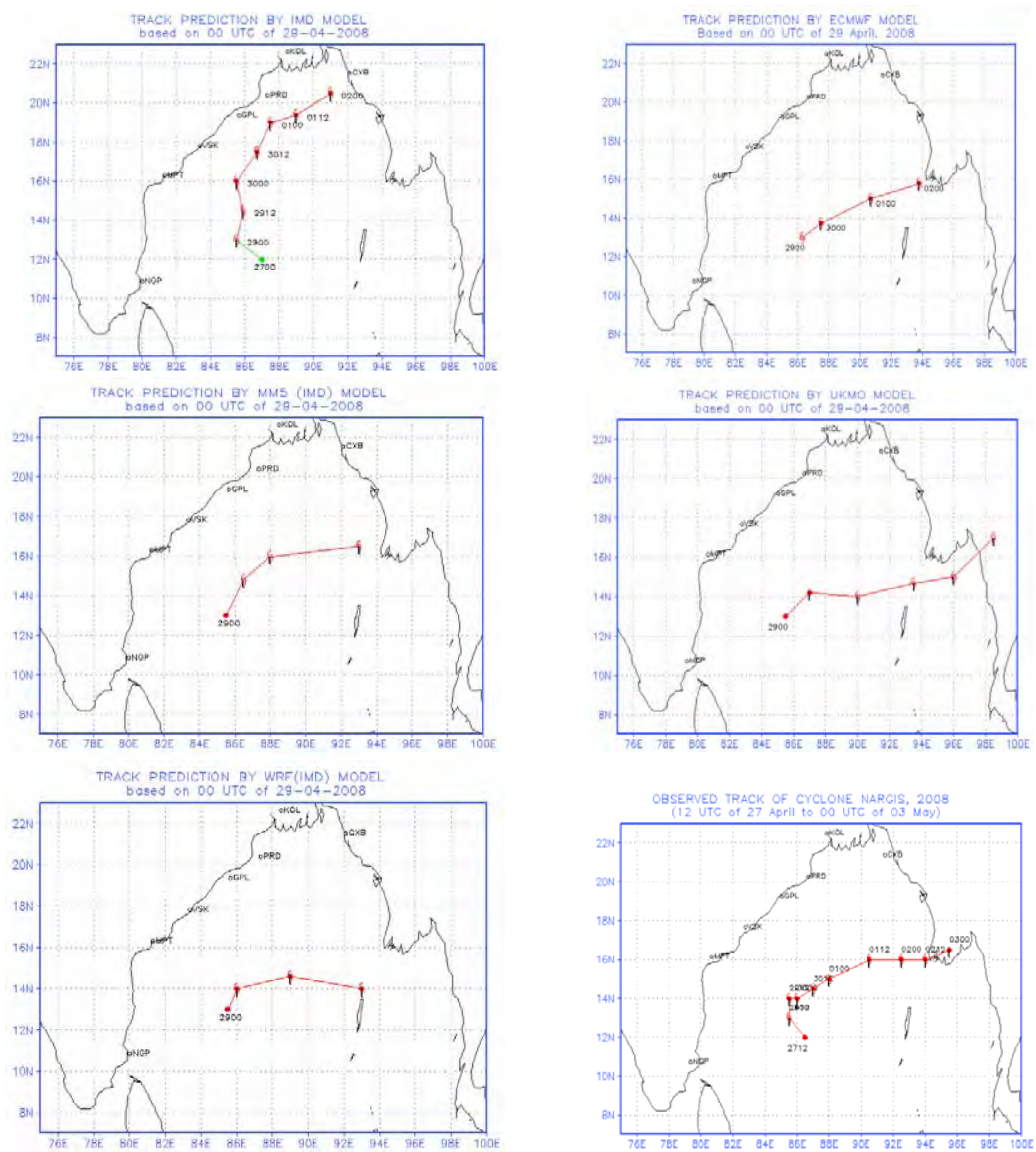

Fig. 3.1(a): Model Performance: 72 hours forecast tracks based on initial condition of 29 April 2008

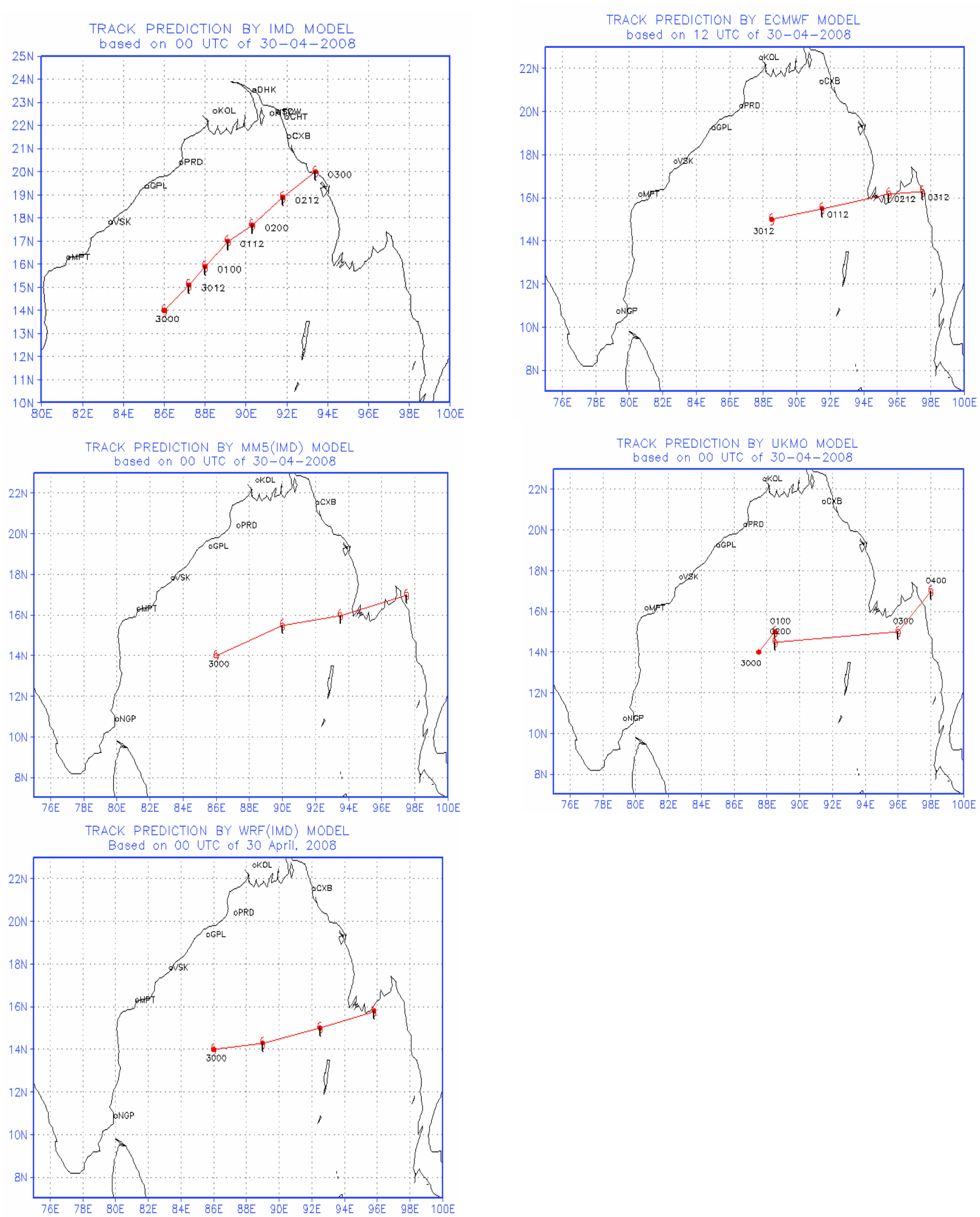

Fig. 3.1(b): Model Performance: 48 hours forecast tracks based on initial condition of 30 April 2008

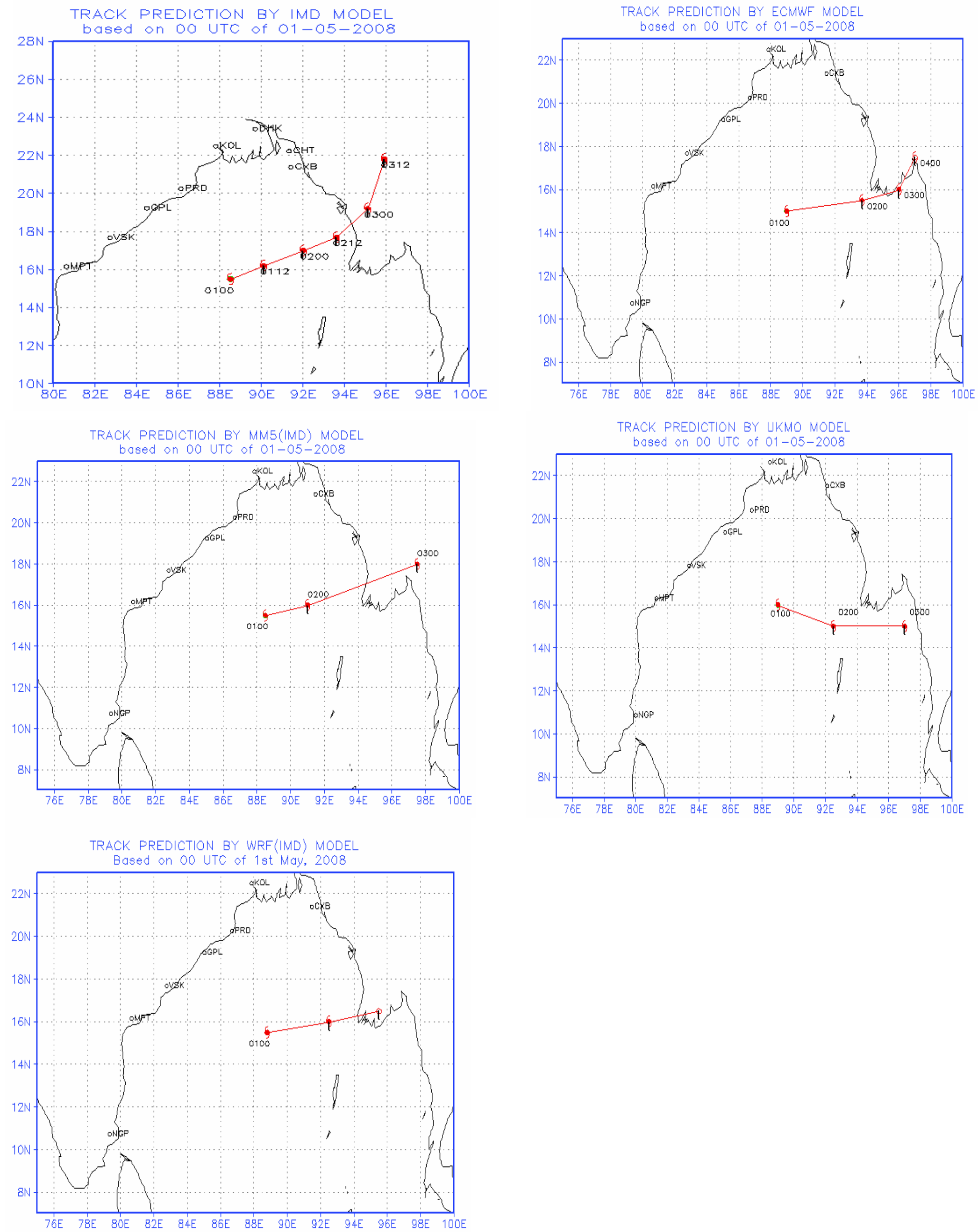

Fig. 3.1(c): Model Performance: 24 hours forecast tracks based on initial condition of 1 May 2008

Table 3.1: Forecast Landfall Errors of "NARGIS" of April-May, 2008

Models		Initial Date/time	Landfall Lat/Lon	Landfall Position Error (Km)	Landfall time error (IST)
QLM (IMD)	i) 72hr FC ii) 48hrFC iii) 24hr FC iv) 12hr FC	2904/00 3004/00 0105/00 0205/00	No landfall 20.0/93.5 18.5/94.5 close to obs.	- 430 km 300 km 10 km	- 12 hrs early 5 hr late 3 hrs early
MM5 (IMD)	i) 72hr FC ii) 48hrFC iii) 24hr FC	2904/00 3004/00 0104/00	No landfall close to obs. 17.0/94.7	- 10 km 110 km	- 8 hrs early 1 hr early
ECMWF	i) 72hr FC ii) 48hrFC iii) 24hr FC	2904/00 3004/12 0104/00	No landfall close to obs. 15.8/95.2	- 10 km 50 km	- 8 hrs early 7 hrs early
UKMO	i) 72hr FC ii) 48hrFC iii) 24hr FC	2904/00 3004/00 0104/00	No landfall 15.0/94.8 15.3/94.8	- 150 km 110 km	3 hrs delay 5 hrs delay 4 hrs early
WRF (IMD)	i) 72hr FC ii) 48hrFC iii) 24hr FC	2904/00 3004/00 0104/00	No landfall 15.8/95.8 16.2/94.4	- 85 50 km	- 11 hr delay 1 hr delay
T254	i) 72hr FC ii) 48hrFC iii) 24hr FC	NA 3004/00 NA	NA 15.4/95.5 NA	NA 120 km NA	NA 11 hr delay NA

Table 3.2: Forecast Errors of "NARGIS" of April-May, 2008

Models	Initial Date/time	12hr error	24 hr error	48 hr error	72 hr error
QLM (IMD)	2904/00 3004/00 0105/00 0205/00	- - - ≈ 10 km **(mean)→**	240 380 120 - **(245.0)**	435 120 305 - **(285.0)**	940 432 - - **(686)**
MM5 (IMD)	2904/00 3004/00 0105/00	**-** **-** **-** **(mean)→**	104 220 160 **(160)**	111 105 270 **(160)**	77 220 - **(150)**
ECMWF	2904/00 3004/**12** 0105/00	**-** **-** **-** **(mean)→**	164 120 140 **(140)**	275 162 77 **(170)**	140 - - **(140)**

UKMO	2904/00	**-**	110	242	180
	3004/00	**-**	54	460	175
	0105/00	**-**	110	231	-
		(mean)→	**(90)**	**(310)**	**(175)**
WRF (IMD)	2904/00	**-**	25	116	228
	3004/00	**-**	132	110	85
	0105/00	**-**	123	94	-
		(mean)→	**(95)**	**(105)**	**(155)**
T254	2904/00	**NA**	**NA**	**NA**	**NA**
	3004/00	**-**	**430**	**105**	**120**
	0105/00	**NA**	**NA**	**NA**	**NA**

3.1.2. Intensity prediction

GPP values computed (Kotal et al, 2009) for this cyclone on the basis of real time model analysis fields along with the GPP values for Developing Systems and Non-Developing Systems are shown in Table 3.3. The higher GPP values (> 8.0, the threshold value) at early stages of development (T.No. 1.0, 2.0, 2.5) clearly indicated that the cyclone "**NARGIS**" had enough potential to intensify into a developing system.

Table 3.3: Genesis potential parameter (GPP) for Developing System, Non-Developing System and Cyclone "NARGIS"

GPP ($x10^{-5}$) →			
T.No. →	1.0	2.0	2.5
Developing	11.1	13.3	13.5
Non-Developing	3.4	4.6	2.7
Cyclone "**NARGIS**"	11.1 (00UTC/27.04.2008)	16.5 (12UTC/27.04.2008)	13.3 (00UTC/28.04.2008)

The 12 hourly intensity forecast (Kotal et al, 2008) valid up to 72 hours (Table 3.4) showed that during the initial forecast hours the model could not indicate rapid intensification. However, as the forecast hour increased, the model could peak up the intensity increase at the 60 hour and 72 hour forecasts with an underestimation of 2 knots and overestimation of 14 knots respectively.

Table 3.4: Model (SCIP) performance for intensity prediction

Based on ↓	Forecasts hours →	00 hr	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
00 UTC of 28th April 2008	Observed (knots)	35	55	55	65	65	65	65
	Forecasts (knots)	35	39	41	49	53	63	79
	Error (knots)	-	-16	-14	-16	-12	-2	+14
12 UTC of 29th April 2008	Observed (knots)	65	65	65	65	65	77	90
	Forecasts (knots)	65	67	59	92	96	110	106
	Error (knots)	-	+2	-6	+27	+34	+33	+16
00 UTC of 30th April 2008	Observed (knots)	65	65	65	65	77	90	--
	Forecasts (knots)	65	67	71	71	80	86	--
	Error (knots)	-	+2	+6	+6	+3	-4	--
12 UTC of 30th April 2008	Observed (knots)	65	65	65	77	90	--	--
	Forecasts (knots)	65	69	69	84	84	--	--
	Error (knots)	-	+4	+4	+7	-6	--	--
00 UTC of 01st May 2008	Observed (knots)	65	65	77	90	--	--	--
	Forecasts (knots)	65	69	73	86	--	--	--
	Error (knots)	-	+4	-4	-4	--	--	--

It is very encouraging to note that all the12-hourly forecasts based on observations of 00 UTC on 30 April (Table 2.4), 12 UTC of 30 April (Table 2.5) and 1 May (Table 2.6) valid up to 60 hours, 48 hours and 36 hours (till landfall) respectively are considerably improved. The model could capture the intensification with errors ranging from 2 knots to 7 knots. This showed that the updated forecast could provide improved forecast values.

3.1.3. Track prediction by statistical models

The CLIPER model and the Space Application Centre (SAC) model based on chaos theory and generic algorithm were utilized for track prediction of this system. The performance of CLIPER and SAC models are shown in Table 3.5 and 3.6 respectively. As expected these models showed large errors beyond 24 hrs forecast period.

Table 3.5: Track Forecast error of CLIPER model

Base Time/Date	12 hrs F/C	24 hrs F/C(km)	36 hrs F/C(km)	48 hrs F/C(km)
1200/27-04-08	77	24	90	152
0000/28-04-08	141	281	335	511
1200/28-04-08	102	123	260	413
0000/29-04-08	54	103	235	366
1200/29-04-08	119	253	385	661
0000/30-04-08	125	255	534	-----
1200/30-04-08	86	330	531	684
0000/01-05-08	241	448	606	754
1200/01-05-08	158	289	377	-----
0000/02-05-08	126	187	-----	-----
Mean	**123**	**220**	**372**	**506**

Table 3.6: Track Forecast error of SAC model

Base Time/Date	12 hrs F/C	24 hrs F/C(km)	36 hrs F/C(km)	48 hrs F/C(km)
1200/28-04-08	25	138	128	146
0000/29-04-08	90	54	63	85
1200/29-04-08	124	200	273	443
0000/30-04-08	78	129	232	238
1200/01-05-08	31	158	190	175
0000/01-05-08	195	278	297	325
1200/01-05-08	8	92	179	-----
0000/02-05-08	97	189	-----	-----
1200/02-05-08	65	------	-----	-----
Mean	**79**	**154**	**194**	**235**

3. 2 Cyclonic Storm " RASHMI" of October 2008

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Figure 3.2 (i) display the observed track and forecast tracks of the cyclone by the operational NWP models based on 24, 25 & 26 October 2008 up to 72 hours. The UKMO and QLM model tracks are not included as these products were not available. Observed track of **RASHMI** is included in the diagrams to visualize the performance of the models. The corresponding landfall forecast errors and 24-hourly track prediction errors of NWP models are summarized in Table 3.7 and Table 3.8 respectively. The 72 hours forecasts based on 00 UTC initial conditions of 24 October depicted large error by all these models except the JMA (Japan Meteorological Agency). The 48 hours forecasts error varies from around 15 km to 200 km with lowest error of JMA and largest error of T254 model. The 24 hours forecasts error varies from around 40 km to 115 km with lowest error of ECMWF and largest error of GFS model. Forecasts based on 00 UTC initial conditions of 25 October depicted wide variation of errors. The 48 hour forecasts error varied from around 45 km to 540 km with lowest error of MM5 and largest error of T254 model. The 24 hour forecasts error varied from around 85 km to 315 km with lowest error of ECMWF and largest error of GFS model. The 24 hour forecasts error based on 00 UTC initial conditions of 26 October varies from near landfall to 150 km with lowest error of GFS and largest error of T254 model.

Table 3.7: Forecast Landfall errors of RASHMI

Based on →	**00 UTC of 24.10.2008**		**00 UTC of 25.10.2008**		**00 UTC of 26.10.2008**	
Models	**Landfall Position Error (Km)**	**Landfall time error**	**Landfall Position Error (Km)**	**Landfall time error**	**Landfall Position Error (Km)**	**Landfall time error**
ECMWF	No landfall	-	76	5 hrs delay	30	2 hrs delay
MM5	No landfall	-	95	10 hrs early	10	6 hrs early
UKMO	-	-	31	2 hrs delay	56	2 hrs delay
T254	No landfall	-	41	23 hrs delay	20	3 hrs delay
QLM	-	-	20	12 hrs early	25	1 hr early
GFS	No landfall	-	66	8 hrs early	0	2 hrs early
JMA	56	5 hrs early	10	1 hr delay	46	1 hr early

Table 3.8: Track forecasts errors of RASHMI

Based on →	00 UTC of 24.10.2008				00 UTC of 25.10.2008			00 UTC of 26.10.2008	
Models	**00 hr (Km)**	**24hr (Km)**	**48hr (Km)**	**72hr (Km)**	**00 hr (Km)**	**24hr (Km)**	**48hr (Km)**	**00 hr (Km)**	**24hr (Km)**
ECMWF	NA	39	123	549	63	84	227	168	10
MM5	NA	91	188	549	228	294	43	110	100
UKMO	-	-	-	-	56	218	56	77	55
T254	NA	107	198	646	77	119	541	0	151
QLM	-	-	-	-	0	154	308	0	100
GFS	NA	117	178	293	123	315	113	103	0
JMA	NA	44	15	61	207	148	84	160	68

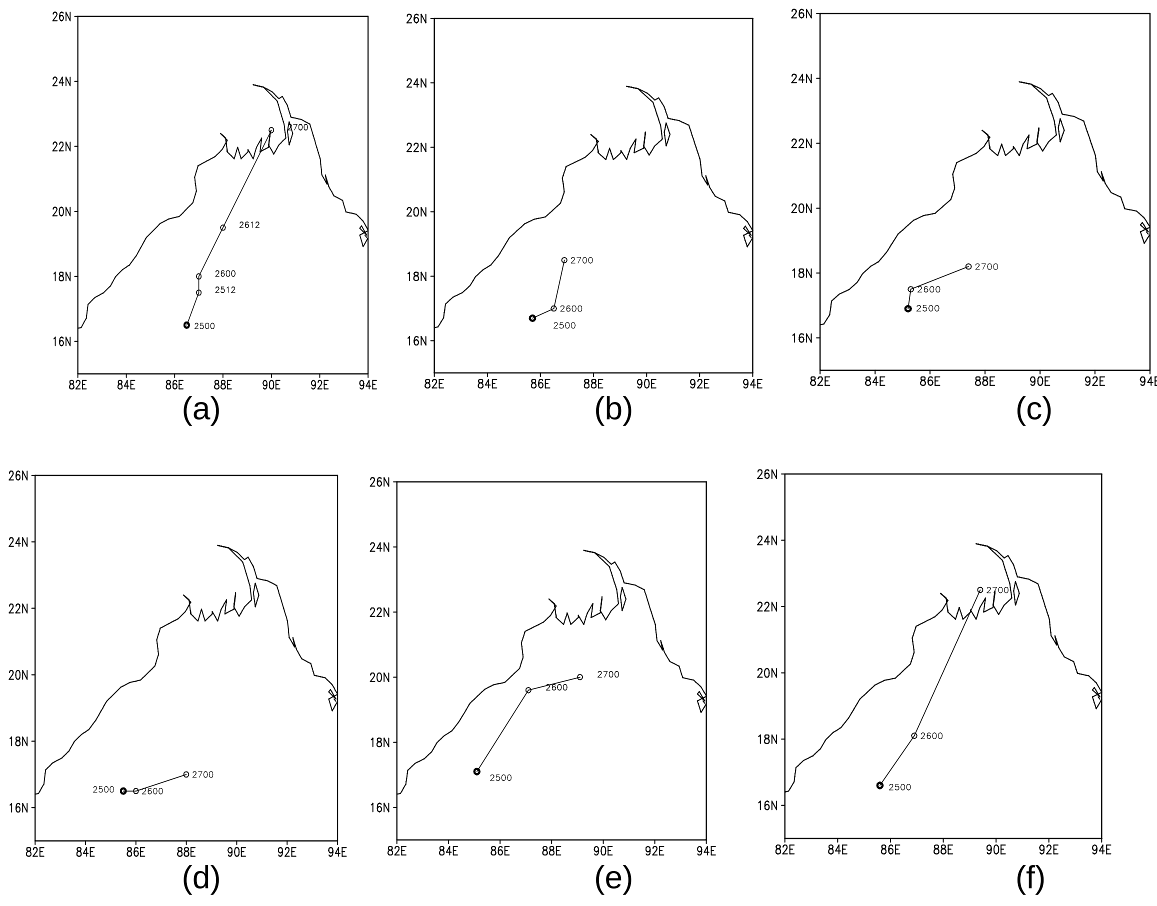


Fig. 3.2 (i) Inter-comparison of observed track of cyclone "RASHMI" and track predicted by different operational NWP models based on 00 UTC of 24 October 2008 (a) Observed (b) ECMWF (c) MM5 (d) T254 (e) GFS (f) JMA

In the case of landfall errors (position and time), based on 00 UTC of 24 October all models showed no landfall till 00 UTC of 27 October except JMA with an error of around

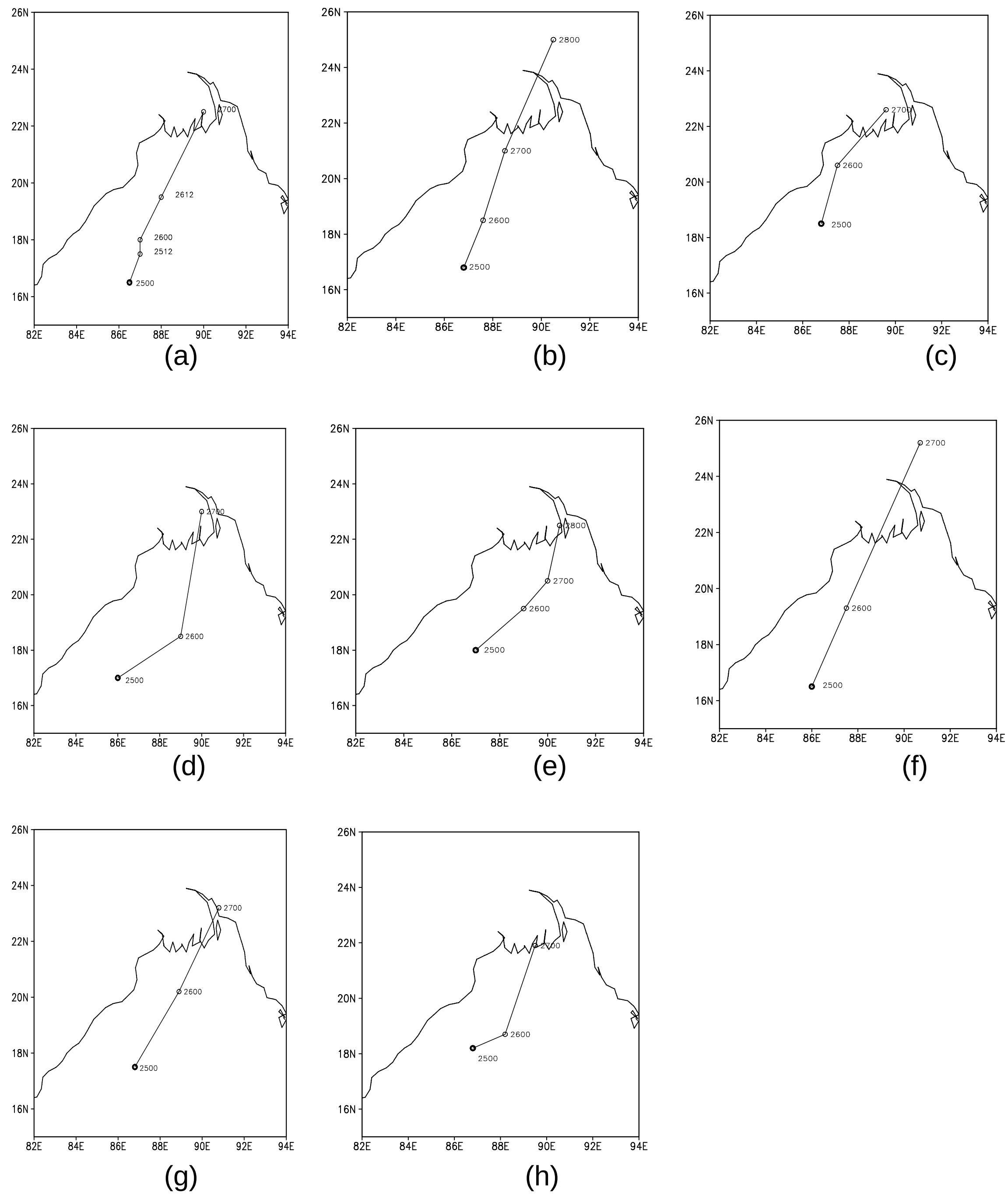
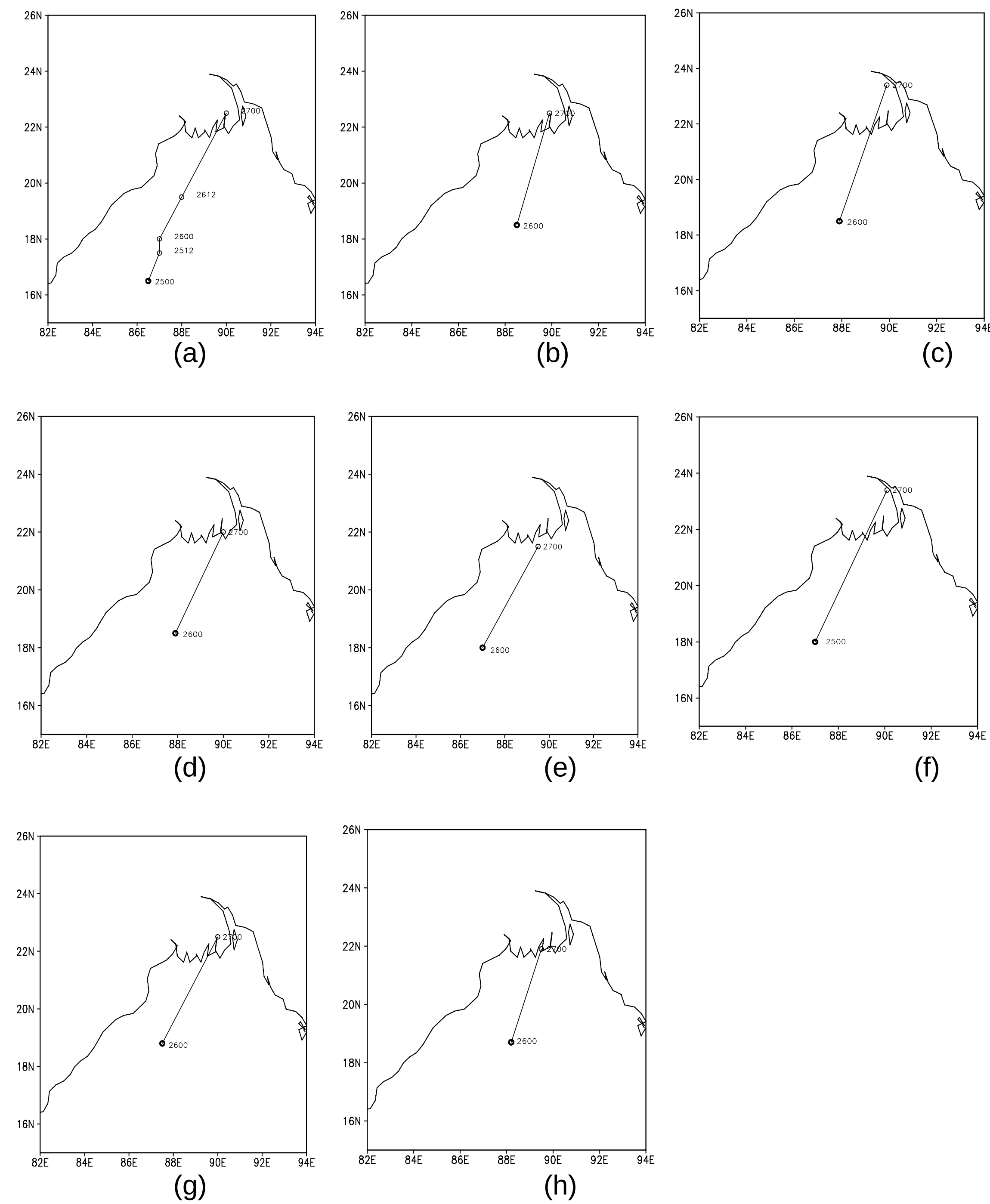


Figure 3.2 (ii) Inter-comparison of observed track of cyclone "RASHMI" and track predicted by different operational NWP models based on 00 UTC of 25 October 2008 (a) Observed (b) ECMWF (c) MM5 (d) UKMO (e) T254 (f) QLM (g) GFS (h) JMA

55 km and 5 hours early. Based on 00 UTC of 25 October, the landfall errors varied from around 10 km to 95 km and time error varied from 12 hours early to 23 hours delay. The lowest error is found to be for the model JMA with an error of around 10 km and 1 hour delay. Updated forecast based on 00 UTC of 26 October shows improvement of landfall error for all models. The maximum landfall error is found to around 55 km for UKMO model. The landfall time error varied from 6 hour early to 3 hour delay. The lowest error is found to be for the model QLM and JMA and largest error for MM5 model.



3.2.2 Intensity prediction

Analysis of GPP

GPP values computed for this cyclone on the basis of real time model analysis fields along with the GPP values for Developing Systems and Non-Developing Systems are shown in Table 3.9. The higher GPP values (> 8.0, the threshold value) at early stages of development (T.No. 1.0, 1.5, 2.0) clearly indicated that the cyclone "**RASHMI**" had enough potential to intensify into a developing system.

Table 3.9: Genesis potential parameter (GPP) for Developing System, Non-Developing System and Cyclone "RASHMI".

GPP ($x10^{-5}$) →			
T.No. →	1.0	1.5	2.0
Developing	11.1	12.3	13.3
Non-Developing	3.4	4.2	4.6
Cyclone "**RASHMI**"	10.9 (00UTC/24.10.2008)	15.8 (00UTC/25.10.2008)	10.6 (00UTC/26.10.2008)

The SCIP model could predict the intensification into cyclonic storm (Take 3.10). The 12-hourly wind speed forecasts .

Table 3.10 Model (SCIP) performance based on 00 UTC of 26 October 2008

Forecasts hours →	00 hr	12 hr	24 hr
Observed (knots)	30	35	45
Forecasts (knots)	30	33	37
Error (knots)	-	-2	-8

3.2.3. Performance of statistical models

The CLIPER model and the SAC model based on chaos theory and generic algorithm were utilized for track prediction of this system. The performance of CLIPER model is shown in Table 3.11.

Table 3.11(a): Track Forecast error of CLIPER model

Base Time/Date	12 hrs F/C	24 hrs F/C(km)	36 hrs F/C(km)	48 hrs F/C(km)
0000/25-10-08	118	127	308	680
1200/25-10-08	50	68	363	-------
0000/26-10-08	135	448	-------	-------
1200/25-10-08	223	-------	-------	-------
Mean	131	214	335	680

Table 3.11(b): Landfall forecast error of CLIPER model

Base time of forecast	Landfall point error (Km)	Landfall time error (hrs)
250000	360	19 D
251200	197	19 D
260000	325	4 D
261200	63	04

D: Delay

As the SAC model requires past six position in six hourly interval, it was run based on 0000UTC of 26 October. The 12 hr and 24 hr forecast errors are about 87 km and 264 km respectively. Based on 261200 UTC, the 12 hr forecast error is about 136 km. The landfall error, according to this model has been 263 km and 20 km respectively with time error of 15 hrs and 4 hrs delay, based on 260000 UTC and 261200 UTC respectively.

3.3: Bay of Bengal Cyclonic Storm, KHAI MUK (14-15 November 2008)

3.3.1 Track Prediction by NWP models

The forecast track and the observed track based on 0000UTC of 14 and 15 November 2008 are shown in Fig. 3.3 and corresponding forecast track errors are presented in Table 3.12(a-c).

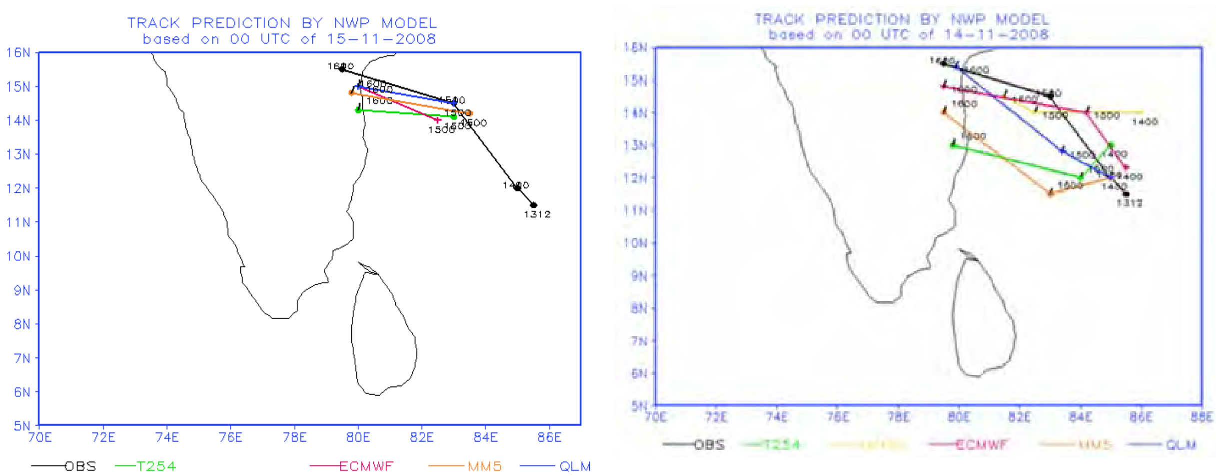


Fig. 3.3. Forecast tracks of NWP models based on 0000 UTC of 14 and 15 November 2008.

Table 3.12(a): Track Forecast Errors (km) of KHAI MUK based on initial condition of 14 November 00 UTC

Model	Initial error	24hr fcst	48hr fcst
QLM	00	202	58
ECMWF	65	144	78
T254	111	299	279
UKMO	248	78	248
MM5	00	333	166

Table 3.12(b): Track Forecast Errors (km) of KHAI MUK based on initial condition of 15 November 00 UTC

Model	Initial error	24hr fcst
QLM	00	57
ECMWF	78	80
T254	78	175
MM5	65	85

Table 3.12(c) : Landfall errors (km) of KHAI MUK

Model	Based on 13/00UTC	Based on 14/00UTC	Based on 15/00UTC
ECMWF	6hrs early	No delay	1 hr delay
T254	14hrs delay	1 hr delay	1 hr delay
UKMO	1hr delay	8hrs delay	---
MM5	1hr delay	1hr early	1hr delay
QLM	---	1hr early	2hr delay

3.3.2 Intensification prediction

GPP values computed for this cyclone on the basis of real time model analysis fields are shown in Table 3.13. The GPP values though it initially showed intensification, it did not predict so based on 0000UTC of 14 November 2008

Table 3.13: GPP for Developing System, Non-Developing System and Cyclone "KHAI MUK"

GPP ($x10^{-5}$) →			
T.No. →	1.0	1.0	1.5
Developing	11.1	12.3	12.3
Non-Developing	3.4	4.2	4.2
Cyclone "**KHAI MUK**"	12.5 (00UTC/12.11.2008)	12.3 (00UTC/13.11.2008)	8.3 (00UTC/14.11.2008)

The statistical-dynamical cyclone intensity prediction model (SCIP) could predict the intensification into cyclonic storm of the system. The 12–hourly intensity prediction based on 00 UTC on 14 November 2008 showed that the model (SCIP) could pick up the intensification of the low pressure system into cyclonic storm of intensity 35 knots at 12 hour and there is an underestimation of intensity by 5 knots and overestimation of 6 knots at 24 hour and 36 hour forecast respectively. The 12-hourly wind speed forecasts based on 00 UTC of 14 November 2008 along with observed wind speed is given in the Table 3.14.

Table 3.14: Model (SCIP) performance based on 00 UTC of 14 November 2008

Forecasts hours →	00 hr	12 hr	24 hr	36 hr
Observed (knots)	30	35	40	30
Forecasts (knots)	30	35	35	36
Error (knots)	-	0	-5	6

3.3.4. Performance of statistical models

The CLIPER model and the SAC model based on chaos theory and generic algorithm were utilized for track prediction of this system. The performance of CLIPER model is shown in Table 3.15(a).

Table 3.15(a): Track Forecast error of CLIPER model

Base Time/Date	12 hrs F/C	24 hrs F/C(km)	36 hrs F/C(km)	48 hrs F/C(km)
1200/13-11-08	88	164	153	79
0000/14-11-08	143	134	174	332
1200/14-11-08	112	299	419	-------
0000/15-11-08	139	235	-------	-------
Mean	120	208	249	205

As the SAC model requires past six positions in six hourly intervals, it was run based on 1200UTC of 14th November. The performance of this model is shown in Table 3.15(b).

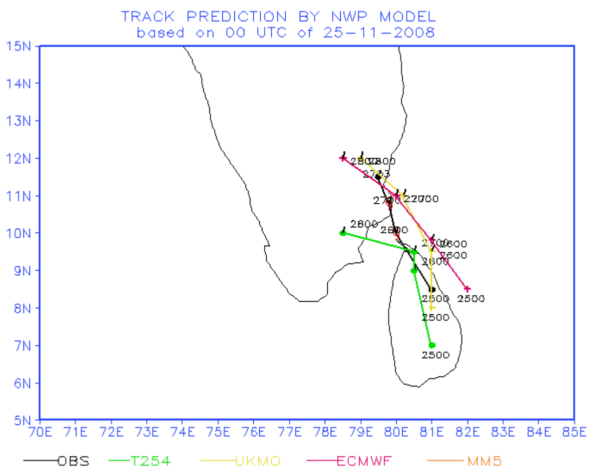
Table 3.15(b): Track Forecast error of SAC model

Base Time/Date	12 hrs F/C	24 hrs F/C(km)	36 hrs F/C(km)	48 hrs F/C(km)
1200/14-11-08	185	231	443	-------
0000/15-11-08	70	246	-------	-------
1200/15-11-08	86	-------	-------	-------
Mean	114	238	443	-------

3. 4 Bay of Bengal Cyclonic Storm “NISHA” of 25-27 November 2008

3.4.1. Track prediction by NWP models

The forecast track and the observed track based on 0000 UTC of 25 and 26 November 2008 are shown in Fig. 3.4 and corresponding forecast track errors are presented in Table 3.16(a-c)



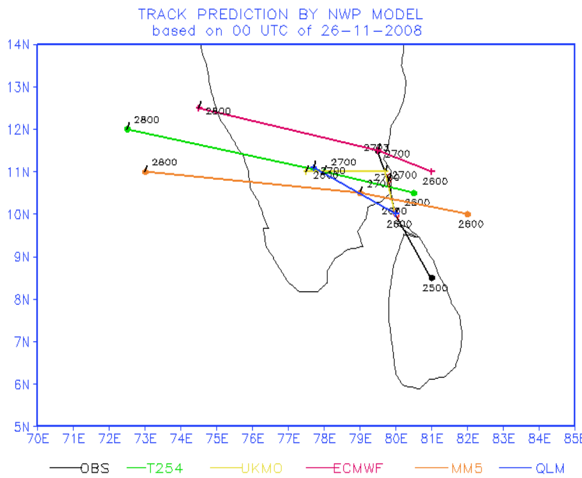


Fig. 3.4. Forecast tracks of NWP models based on 0000 UTC of 25 and 26 November 2008.

Table 3.16(a): Track Forecast Errors (km) of NISHA with initial condition of 25 November 00 UTC

Model	24hr fcst	48hr fcst
ECMWF	113	49
T254	124	164
UKMO	124	80

Table 3.16(b); Track Forecast Errors (km) of NISHA with initial condition of 26 November 00 UTC

Model	Initial error	24hr fcst
ECMWF	157	84
T254	78	201
UKMO	22	24
MM5	222	94
QLM	00	235

Table 3.16(c): Landfall point Errors (km) and time errors of NISHA

Model	Based on 25/00UTC	Based on 26/00UTC
ECMWF	3hrs delay	3hrs early
T254	18hrs delay	10hrs delay
UKMO	3hrs delay	1hr early
MM5	8hrs early	6 hrs delay
QLM	---	12hrs early

3.4.2 Intensity prediction

GPP values computed for this cyclone on the basis of real time model analysis fields are shown in Table 3.17. The higher GPP values (> 8.0, the threshold value) at early stages of development (T. No. 1.0, 2.0) clearly indicated that the cyclone “**NISHA**” had enough potential to intensify into a developing system.

Table 3.17: Genesis potential parameter (GPP) for Developing System, Non-Developing System and Cyclone “NISHA”

	GPP ($x10^{-5}$) →		
T.No. →	1.0	1.5	2.0
Developing	11.1	12.3	13.3
Non-Developing	3.4	4.2	4.6
Cyclone “**NISHA**”	14.5 (00UTC/24.11.2008)	---- (00UTC/25.11.2008)	21.7 (00UTC/26.11.2008)

3.4.3. Performance of statistical models

The CLIPER model was run based 0000 UTC of 25th November. The 12 hr and 24 hr forecast errors wereabout 134 km and 280 km respectively. As the SAC model required past six positions in six hourly intervals, it was run based on 1800 UTC of 26th November. The 12 hr forecast error was about 94 km.

CHAPTER-IV

PERFORMANCE OF RSMC, NEW DELHI IN TRACK AND INTENSITY PREDICTION OF THE CYCLONES DURING 2008

The performance of RSMC-New Delhi in track and intensity prediction of the 4 cyclones during 2008 are presented and discussed below:

4.1. Very severe cyclonic storm, 'NARGIS'

Likely formation of low pressure area over southeast Bay of Bengal and its further intensification was indicated in the daily bulletin issued from NHAC from 23 April onwards. The first special tropical weather outlook for the WMO/ESCAP Panel member countries including Myanmar intimating the formation of depression over the Bay of Bengal was issued at 0600 UTC of 27 April based on observations of 0300 UTC.

The tropical cyclone advisories to WMO/ESCAP Panel member countries including Myanmar were issued in every three hourly intervals from 28 April onwards till 0000 UTC of 3 May.

The first tropical cyclone advisory indicating landfall over Myanmar coast was issued at 0600 UTC of 1 May based on observations of 0300 UTC. It was indicated in the bulletin that the system would cross Myanmar coast between lat 16^0N and 18^0N around night of 2 May 2008. On 2 May morning, it was indicated in the bulletin that the system would cross Myanmar coast near 16^0N around evening of the same day.

The forecast for maximum intensity (T 5.0) corresponding to maximum sustained wind speed of 90 knots was predicted and maintained in the tropical cyclone advisories for WMO/ESCAP Panel member countries from 2100 UTC of 1 May based on observations of 1800 UTC. The number of bulletins issued is as follows.

<u>International</u>
Special Tropical Weather Outlook – 3
Tropical Cyclone Advisories – 41
Tropical Cyclone Advisories for international civil aviation – 19

According to operational bulletin issued by RSMC, New Delhi there is 64 Kms forecast average error in 12 hrs and 112 kms in 24 hrs. In 24 hrs predicted intensity forecast there is about T0.5 average error.

Landfall error	**Point error**	**Time error**
(i) 12 hrs landfall error	55 kms	1 ½ hrs
(ii) 24 hrs landfall error	110 kms	2 hrs
(iii) 36 hrs landfall error	110 kms	3 ½ hrs

The performance of RSMC, New Delhi compared to various NWP models guidance is shown in Fig. 4.1.

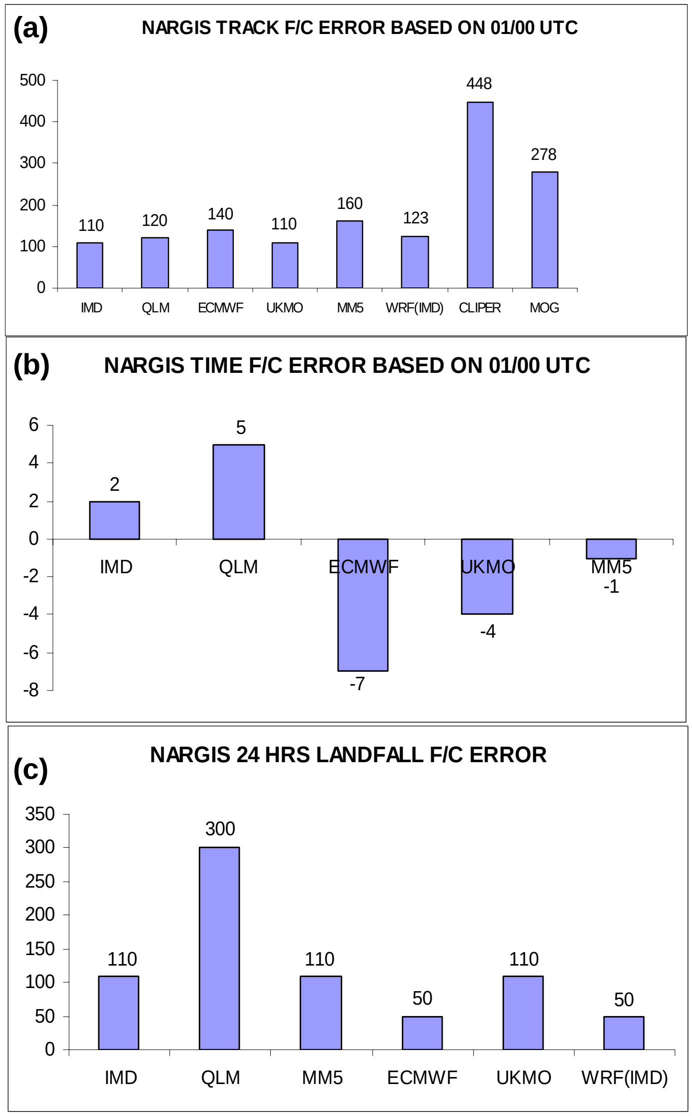


Fig.4.1. (a) 24 hours track forecast error based on 00 UTC of 01.05.2008 (km), (b) landfall time error (km) based on 00 UTC of 01.05.2008 (km) and (c) 24 hours landfall forecast error

4.2. Cyclonic storm, 'RASHMI'

The system was monitored by IMD and warnings were issued to various national and international agencies and to public through its cyclone warning organizations. The warnings issued by RSMC, New Delhi are given below.

Special Tropical Weather Outlook – 05
Tropical cyclone advisories – 06

Tropical Cyclone Advisories for international civil aviation– 03

Based on 250300 UTC observation and analysis, it was predicted that the system was likely to move in a northerly direction initially. Based on 250900 UTC observation and analysis, it was predicted that the system is likely to move in a north-northeasterly direction towards West Bengal-Bangladesh coast. As per the actual track, the system moved initially in a northeasterly direction and then in a north-northeasterly direction towards Bangladesh coast. The performance of RSMC, New Delhi compared to various NWP models guidance is shown in Fig. 4.2.

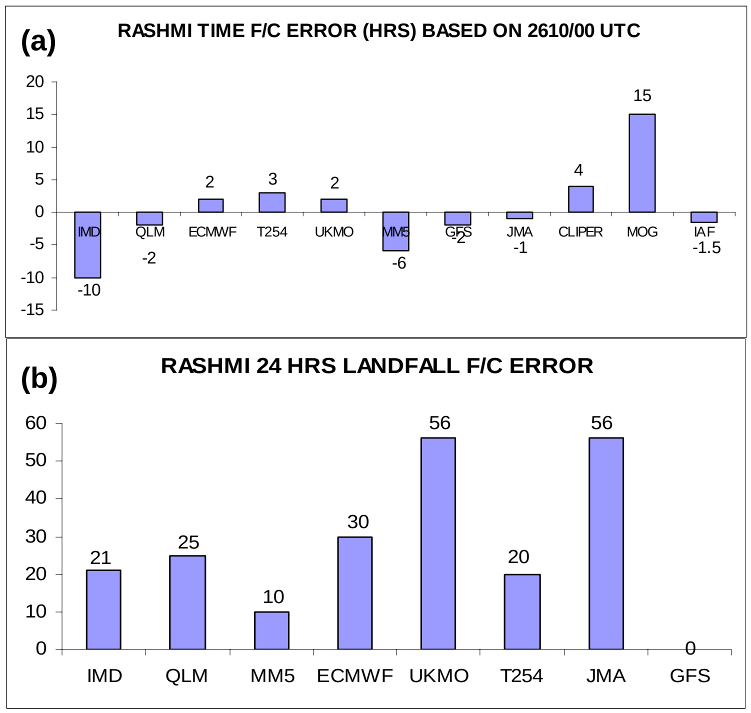


Fig.4.2. (a) 24 hours landfall time error (km) based on 00 UTC of 01.05.2008 (km) and (b) 24 hours landfall forecast error

4.3. Cyclonic storm, 'KHAI MUK'

The system was monitored by IMD and warnings were issued to various national and international agencies and to public through its cyclone warning organizations. The warnings issued by RSMC, New Delhi are given below.

Special Tropical Weather Outlook – 04
Tropical cyclone advisories – 07
Tropical Cyclone Advisories for international civil aviation– 04

Formation of a low pressure area over southeast Bay of Bengal and its westwards movement was firstly forecasted on 5th November. On 12th November, it was predicted that low pressure area is likely to intensify into a depression and move in west-northwesterly direction. Based on 131200 UTC observations and analysis, it was predicted that the system will intensify further and move in west-northwesterly direction towards north Tamilnadu-south Andhra Pradesh coasts. Based on 140300 UTC observations and analysis, it was predicted that the system will intensify further into a cyclonic storm and move in northwesterly direction towards Andhra Pradesh coast. As per the actual track, the system moved in a northwesterly/west-northwesterly direction towards Andhra Pradesh coast. The performance of RSMC, New Delhi compared to various NWP models guidance is shown in Fig. 4.3.

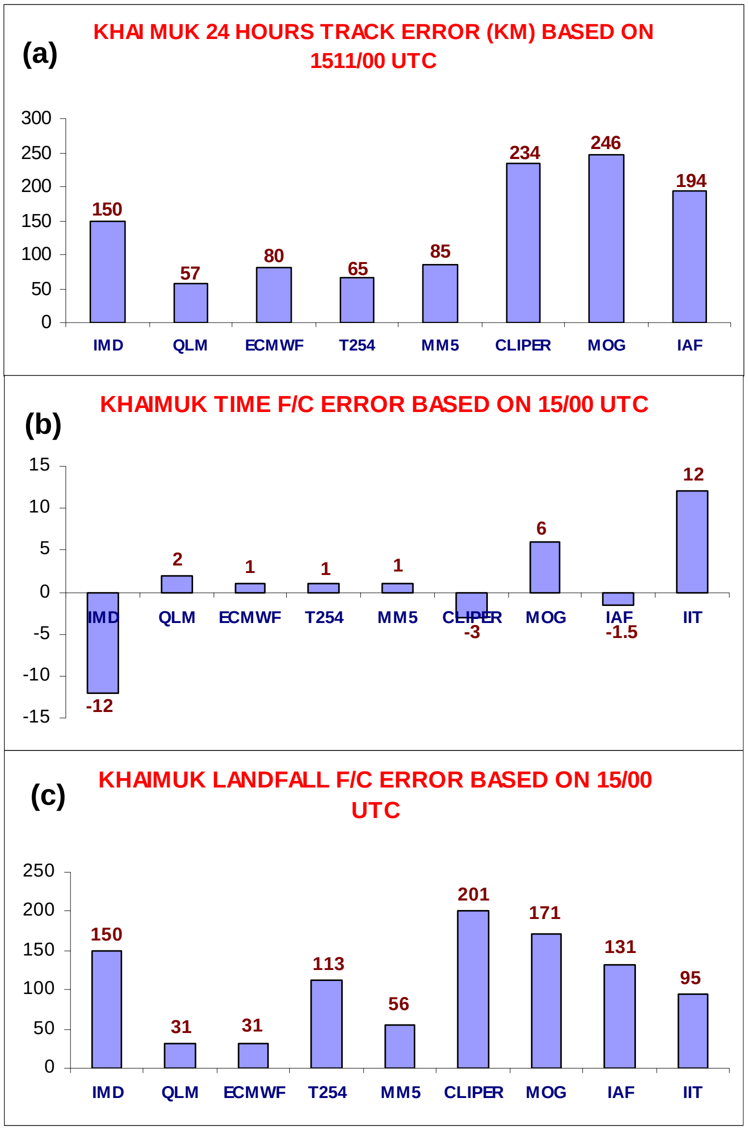


Fig.4.3. (a) 24 hours track forecast error (km), (b) landfall time error (km) and (c) 24 hours landfall forecast error (km) based on 00 UTC of 15.11.2008

4.4. Cyclonic storm, 'NISHA'

The system was monitored by IMD and warnings were issued to various national and international agencies and to public through its cyclone warning organizations. The warnings issued by RSMC, New Delhi are given below:

Special Tropical Weather Outlook – 03
Tropical cyclone advisories – 07
Tropical Cyclone Advisories for international civil aviation– 04

On 19th November, it was predicted about the formation of a low pressure area over southeast Bay of Bengal around 25th. Based on 250900 UTC observation and analysis, it was predicted that the system is likely to intensify further and move slowly in a northwesterly direction and cross Tamil Nadu coast between Pamban and Nagapattinam by 26th November 2008 night. . As per the actual track, the system moved in a northerly/northwesterly direction and crossed Tamilnadu coast north of Nagapattinam near lat. 11.3^0 N between 0000 & 0100 UTC. The performance of RSMC, New Delhi compared to various NWP models guidance is shown in Fig. 4.4.

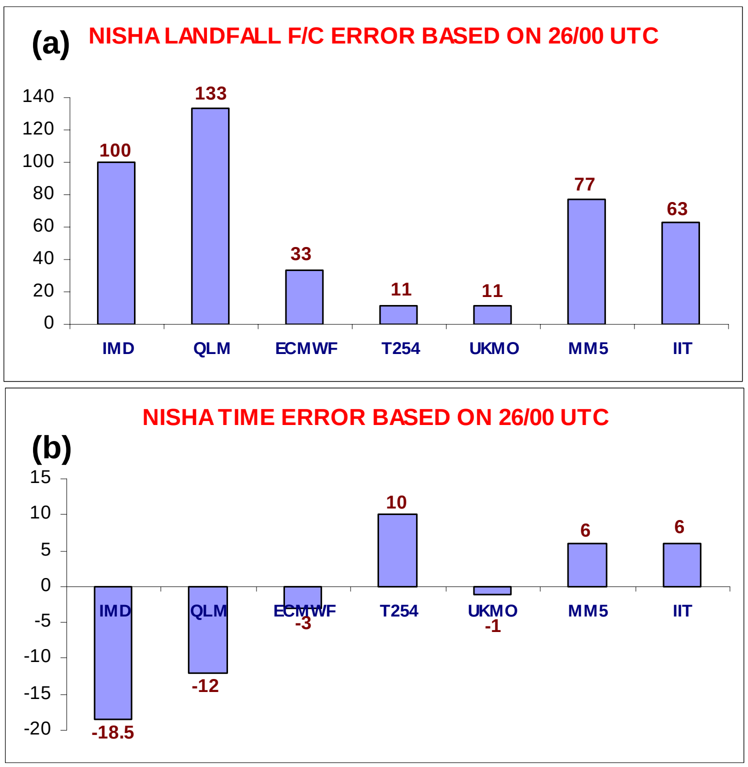


Fig.4.4. (a) 24 hours landfall forecast error (km) and (b) 24 hours landfall time error (km) based on 00 UTC of 26.11.2008

The average landfall error of cyclonic storms during 2008 are given below.

Landfall error	Point error	Time error
(i) 12 hrs landfall error	43 kms	3½ hrs
(ii) 24 hrs landfall error	95 kms	10 ½ hrs
(iii) 36 hrs landfall error	137 kms	10 hrs

The average landfall error was less than the long period average error for the landfalling cyclones over the north Indian Ocean

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Photographs showing damage in Myanmar caused by Very Severe Cyclonic Storm "NARGIS"