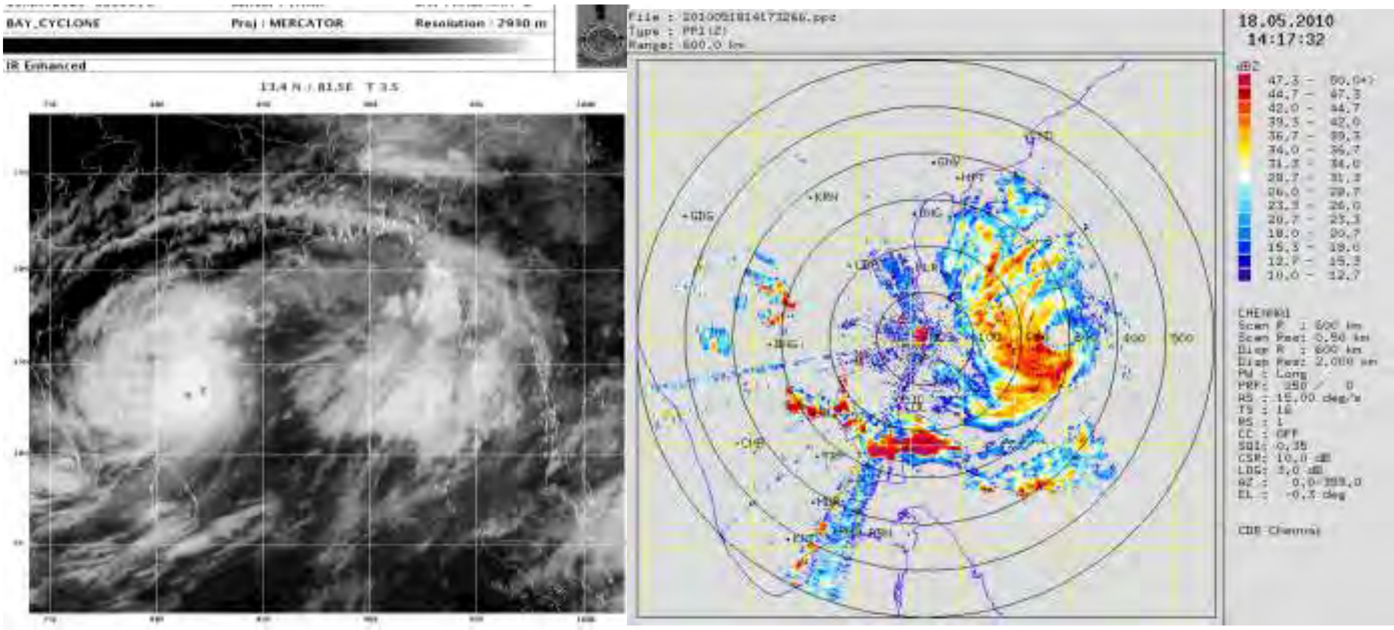
WMO/ESCAP
PANEL ON TROPICAL CYCLONES
ANNUAL REVIEW 2010



Satellite & DWR imageries of Severe Cyclonic Storm, ‗LAILA‘

WORLD METEOROLOGICAL ORGANISATION
AND
ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC

WMO

ESCAP

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PREFACE

First commenced in 1997, the publication of ***WMO/ESCAP Panel*** - *Annual Review* has entered thirteenth year of issue for the year 2010. Considerable efforts have gone into producing this document in order to make it useful scientifically and informative for the members of panel. Panel Members are encouraged to make more contributions for further improvement of this publication.

WMO and ***ESCAP*** have played a commendable role in disaster mitigation efforts in the Panel region through continued interaction with the governments of the member countries. There is increasing realization that disaster mitigation effort must encompass all spheres including scientific research on natural hazards, establishment of integrated-all-hazard early warning system and most importantly, empowering communities to be self reliant for timely and proper response to warnings. Despite rapid technological advances made in the recent past, the problem of generating accurate weather forecasts and associated warnings / advisories and their timely dissemination to the communities at highest risk continues to be a great challenge. In order to make the early warning system more effective, it is essential that the Panel Members take new initiatives. The basic aim of the panel is to improve the quality and content of cyclone warnings, devise methods for quick dissemination of warnings and flood advisories and ensure proper response by concerned agencies and the community.

This review highlights the achievements made during the year, 2010 in the region in pursuance of the goals set out by the ***WMO / ESCAP*** *Panel* and the activities of other international and national organisations in support of the above tasks, within the overall objective of mitigating the impact of natural hazards. I would like to express my sincere thanks to all the Panel Members for their valuable inputs and contributions and hope for the same in future.

B.K. Bandyopadhyay

Chief Editor

WMO AND THE WMO / ESCAP PANEL ON TROPICAL CYCLONES

WORLD METEOROLOGICAL ORGANIZATION (WMO)

The World Meteorological Organisation (WMO), of which 185 States and Territories are Members, is a specialised agency of the United Nations. The objectives of the organisation are:

- To facilitate international co-operation in the establishment of networks of Stations and Centres to provide Meteorological and Hydrological services and observations;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardisation of meteorological and related observations and ensure the uniform publication/circulation of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services and
- To encourage research and training in meteorology and, as appropriate, in related fields and to assist in co-ordinating the international aspects of such research and training.

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (ESCAP)

The Economic and Social Commission for Asia and the Pacific (ESCAP) aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific, including the social aspects of such development, with a view to raising the level of economic activity and standards of living and maintaining and strengthening the economic relations of countries and territories in the region, both among themselves and with other countries in the world. The commission also:

- Provides substantive services, secretariats and documentation for the Commission and its subsidiary bodies;
- Undertakes studies, investigations and other activities within the commission's terms of reference;
- Provides advisory services to Governments;
- Contributes to the planning and organisation of programmes of technical co-operations and acts as executing agency for those regional projects decentralised to it.

WMO / ESCAP PANEL ON TROPICAL CYCLONES

Huge loss of human life, damage to property and unbearable sufferings of human beings caused by tropical cyclones in coastal areas in various parts of the globe like Atlantic, Pacific, China Sea and North Indian Ocean (NIO) coast are regular features.

The disaster potential due to cyclones is particularly high in the North Indian Ocean comprising the Bay of Bengal & the Arabian Sea region, being associated with high storm surge, which is the greatest killer in a cyclone. This region has the distinction of having experienced the world's highest recorded storm tide of 41 feet (1876 Bakherganj cyclone near Megna estuary, Bangladesh) followed by 13 metres over West Bengal coast on 7th

October, 1737 in association with another super cyclone . Past records 5show that very heavy loss of life due to tropical cyclones have occurred in the coastal areas surrounding the Bay of Bengal. In the recent past, during the year 1998, the state of Gujarat in India experienced the impact of a very severe cyclonic storm, which crossed coast north of Porbandar (42830) on June 9, 1998 and caused huge damage to public property near Kandla Port (42639). A Super Cyclonic Storm that crossed east coast of India near Paradip (42976) in Orissa state on October 29, 1999 took a toll of 9885 lives and caused huge damage to property in 12 districts of the state. Apart from causing large-scale devastation to agriculture and plantation crops, it also affected entire infrastructure on communication, power and transport. The storm surge of 5-6 m height was experienced in areas close to and southwest of Paradip. This cyclone was century‘s most intense cyclone and its unusual feature was that it remained practically stationary after crossing coast and battered the State of Orissa for 36 hours. In June, 2007 another super cyclone ‗Gonu‘ developed over southeast Arabian Sea moved north-westward crossed Oman coast and then entred into Gulf of Oman and made second landfall over Iran coast. It caused huge damage to the property and loss of lives in Oman and Iran.

Realising the importance of an effective cyclone warning and disaster mitigation machinery in the region, WMO and ESCAP jointly established the Panel on Tropical Cyclones in 1972 as an inter-Governmental body. Its membership comprises the countries affected by tropical cyclones in the NIO. Its Member countries are Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman and Thailand.

The Panel is one of the six regional tropical cyclone bodies established as part of the WMO Tropical Cyclone Programme (TCP) namely Miami, Honolulu ,Tokyo, New Delhi, La Reunion and Nadi that aims at promoting and co-ordinating the planning and implementation of measures to mitigate tropical cyclone disaster.

It also aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific including social aspects of such developments, with a view to raising the level of economic activity and standards of living and maintaining and strengthening the economic relations of countries and territories in the region, both among themselves and with other countries in the world.

The first session of WMO/ESCAP Panel on Tropical Cyclones was convened in Bangkok, Thailand in January 1973. The functions of the Panel are:

- To review regularly the progress in various fields of tropical cyclone damage prevention;
- To recommend to the member countries plans and measures for the improvement of community preparedness and disaster prevention;
- To promote, prepare and submit to member countries plans for co-ordination of research programmes and activities on tropical cyclones;
- To facilitate training of personnel from member countries in tropical cyclone forecasting and warning, flood hydrology and its control within the region;
- The plans for co-ordination of research programmes and activities concerning tropical cyclones within member countries;

- To prepare and submit, at the request and on behalf of the member countries requests for technical, financial and other assistance offered under United Nations Development Programme (UNDP) and by other organisations and contributors and
- To consider, upon request, possible sources of financial and technical support for such plans and programmes.

In carrying out these functions, the Panel on tropical cyclones committee maintains and implements action programmes under the five components of meteorology, hydrology, disaster prevention and preparedness, training and research with contributions and co-operation from its Members and assistance by the UNDP, ESCAP, WMO and other agencies.

The Panel at its twelfth session in 1985 at Karachi (Pakistan) adopted a comprehensive cyclone operational plan for this region. The basic purpose of the operational plan is to facilitate the most effective tropical cyclone system for the region with existing facilities. The plan defined the sharing of responsibilities among Panel countries for the various segments of the system and recorded the co-ordination and co-operation achieved. The plan also recorded the agreed arrangements for standardization of operational procedures, efficient exchange of various data and its archival related to tropical cyclone warnings, issue of a tropical weather outlook, cyclone advisories and aviation advisory bulletin for use of aviation as per recommendation No. 1/21 of ICAO in its 12th meeting of 161st session held at Montreal, Canada during 09-26 September, 2002 from a central location having the required facilities for this purpose, for the benefit of the region and strengthening of the operational plan.

The operational plan is evolutionary in nature. Its motivation is to update or raise the text of the plan from time to time by the Panel and each item of information given in the annexes to the plan be kept upto date by the member country concerned.

COMMITTEE ON WMO/ESCAP PANEL ON

TROPICAL CYCLONES (2010 – 11)

Chairman : Dr Somchai Baimoung (Thailand)

Vice-Chairman : Dr Thein Tun (Myanmar)

Chairman drafting committee: Mr S.H. Kariyawasam (Sri Lanka)

TECHNICAL SUPPORT UNIT (TSU)

ISLAMABAD, PAKISTAN

Co-ordinator : Dr. Qamar-uz-Zaman Chaudhry

Meteorologist : Mr. Ata Hussain

WMO SECRETARIAT FOR TROPICAL CYCLONE PROGRAMME (TCP)

Mr. Michel Jarraud	**: Secretary General**
Dr. Tokiyoshi Toya	**: Regional Director for Asia and South-West Pacific**
Mr. Koji Kuroiwa	**: Chief, TCP Division**

UNITED NATIONS ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (UNESCAP)

Mr. Yuichi Ono	**: Chief, Disaster Risk Reduction Section**
Mr Clovis Freire	**: Economic Affairs Officer, Disaster Risk Reduction**

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Dr. Xuan Zengpei	**: Director, ICT & Disaster Risk Reduction**

INTRODUCTION

Publication of ―WMO/ESCAP Panel on Tropical Cyclones–Annual Review commenced with the review for the year 1997. This was as per the decision of the Second Joint Session of the WMO/ESCAP Panel on Tropical Cyclones and Typhoon Committee held at Phuket, Thailand 20-28, February 1997. The present Annual Review-2010 contains primary contribution from the Panel member countries.

Chapter I contains detailed information on national programmes and activities related to meteorology, hydrology, disaster prevention and preparedness, training and research as supplied by Panel Members. Technical and administrative support provided and activities undertaken by the Panel.

A summary of Tropical Cyclones during 2010 is given in the first part of Chapter II. Earlier, tropical cyclones were identified by their geographical locations. From post monsoon season 2004, the practice of naming each tropical cyclone individually has been adopted in the north Indian Ocean basin also. Tropical disturbances are classified as per the practice introduced at Regional Specialised Meteorological Centre (RSMC)–Tropical Cyclones New Delhi. The classification of disturbances is shown in the following Table. The term ―Cyclone‖ used in the present text is a generic for the four categories of cyclonic disturbances (S.N. 4 to 7) in the Table.

Classification of low-pressure systems at RSMC – Tropical Cyclones, New Delhi

S No.	Maximum sustained surface wind Speed in knot (kmph)	Nomenclature
1.	Less than 17 (< 31)	Low Pressure Area (L)
2.	17 to 27 (31-49)	Depression (D)
3.	28 to 33 (50- 61)	Deep Depression (DD)
4.	34 to 47 (62 –88)	Cyclonic storm (CS)
5.	48 to 63 (89 – 117)	Severe Cyclonic Storm (SCS)
6.	64 to 119 (118 –221)	Very Severe Cyclonic Storm (VSCS)
7.	120 and above (≥ 222)	Super Cyclonic Storm (SuCS)

The second part of Chapter II contains a brief report on tropical cyclones affecting Panel countries during 2010. Based on the real time and climatological data available with India Meteorological Department (IMD), India, special features of the 2010 tropical cyclone season are highlighted. It also contains realized weather and the damages caused due to cyclones. All units used in the chapters are as per standard norms.

In the context of Chapter II, sustained winds refer to wind speeds averaged over a period of 3 minutes. Kilometer per hour (kmph) / knot is the unit used for wind speed as well as speed of movement of tropical cyclones. The S.I. unit of hecta-Pascal (hPa) is used for atmospheric pressure. Reference time used is primarily in Universal Time Coordinate (UTC). Wherever possible, station names contained in WMO Weather Reporting-Observing Stations (WMO/OMM-No.9 Volume A) are used for geographical reference with code.

Chapter III consists of contributed articles / research papers on tropical cyclones received from Member countries and scientists from various organizations.

Chapter IV contains outlines of Activities of PTC Secretariat during the Intersessional Period 2010-2011

CHAPTER-I

WMO/ESCAP PANEL ACTIVITIES IN 2010

1.1 METEOROLOGICAL ACTIVITIES

Activities of member countries on WMO/ESCAP Panel for the year 2010 were presented at the thirty-eighth session of the WMO/ESCAP Panel on tropical cyclones held at New Delhi, India from 21-25 February, 2011. Under this item, matters relating to the basic observational network, the telecommunication links and data-processing systems established in the region to fulfill the requirements of WMO‘s World Weather Watch Programme were reviewed. The Panel reviewed the activities under the meteorological component of the Members during the past year. These are briefly summarized below:

Bangladesh

Meteorological Data from RTH New Delhi and 10 synoptic observatories of Bangladesh Meteorological Department (BMD) are exchanged on routine basis through WMO‘s GTS. All the 35 observatories of BMD have been connected with National Meteorological Communication Centre (NMCC) Dhaka either by TP or Telephone and Single Side Band (SSB) etc. or by all the three systems. Some of the observatories are connected through internet with NMCC and data are collected on real time basis by using Meteorological Data Acquisition software. The communications between Storm Warning Centre (SWC) and Radar Station at Cox‘s Bazar and Khepupara have been upgraded to Very Small Aperture Terminal (VSAT) link. NMCC uses Message Switching System (MSS) software obtained from WMO/UNDP Regional Computer Network programme for reception and transmission of all meteorological data.

BMD has been using JMA Global Spectral Model (GSM) for Numerical Weather Prediction since October 2010. The resolution for the surface is 0.25°x0.25° and for upper air is 0.5°x0.5°. The model out are updated every day accordingly at BMD‘s website www.bmd.gov.bd

India

a. Surface Observatories

The network of surface meteorological observatories consists of total 1073 Stations.
The breakup of various categories is as follows:

Category of Departmental Observatories

CLASS	RMC DELHI	RMC CHENNAI	RMC KOLKATA	RMC MUMBAI	RMC NAGPUR	RMC GUWAHATI	Total
I , II (a), IV, VI & SMO (Dept.)	55	53	32	29	17	14	200
II (b), II (c), II (d), III & IV, V, VI Io & EMO (Non Dept.)	108	71	46	32	47	26	330
V (Non Dept. HMO)	64	17	55	21	12	11	180
TOTAL	227	141	133	82	76	51	710

High Wind Speed Recorders (HWSRs)

A newly designed HWSR system has been installed at Puri and same is already installed at other coastal stations along Bay of Bengal. These are Digha Visakhapatnam, Chennai, Nellore, Machilipatnam & Karaikal. On the West coast it is installed at Mumbai (Colaba).

AWS & ARG

India Meteorological Department (IMD) is in the process of strengthening of its surface observational network in a phased manner. A network of 125 Automatic Weather Stations (AWS) has been established during the year 2006-07 out of which 108 are functional.

Under the IMD Modernization Programme Phase-I, 550 AWS, a TDMA earth station has been installed and so far 382 AWS station have been installed & commissioned. The sensors for parameters including air temperature, relative humidity, atmospheric pressure, rainfall, wind and Global Solar Radiation are being interfaced with each AWS. Out of 550 AWS planned for installation, 127 will be Agro AWS with additional sensors for parameters soil temperature, soil moisture, leaf temperature and leaf wetness. Meteorologically unrepresented districts of India are being considered on priority for installation of AWS.

The network is required to meet the needs of diverse services of IMD such as Weather Forecasting, Cyclone Warning and Hydrological Studies etc. The network is planned in such a way that data sparse regions of the country particularly north and northeastern states have uniform distribution of AWS.

There are 253 meteorologically unrepresented districts in India. Typically, one AWS is planned for installation in each unrepresented district. A meso network of 12 AWS has also been established in and around National Capital Region. Under the modernization project phase-I, a fairly uniform and dense surface observational network of 550 AWS is expected to be available to meet operational forecasting requirements (both synoptic and mesoscale) of the nation.

Under modernization project it is proposed to establish a network of 3600 Automatic Rain Gauge (ARG) stations all over India during the period 2007-2012. In order to improve of districtwise rainfall monitoring, a network of 1350 ARG stations is being established during Phase-I of the modernization project. It is planned to install at least two ARG stations in each district of India during Phase-I of the project. Under the project 1350 ARGs, 356 ARG have been installed of which 287 are functional. Out of 1350 ARG, 500 stations are being equipped with additional sensors for temperature and humidity observations. The ARG stations are also being installed on priority in flood prone river basins such as Brahmaputra, Ganga, Mahanadi, Tapi, Narmada, Godavari and Krishna.

Improvement in Maintenance/Servicing of Various Surface Meteorological Instruments

Imparting training to departmental personnel in maintenance and upkeep of the surface airport meteorological instruments has been a regular activity.

Recent Achievements

1. Under the scheme ―Upgradation of standard test facility for barometer and thermometer", various calibration standards were procured. Dead Weight Testers, Digital standard barometers 100 nos., Thermoelectric Pyranometers 5 nos. & Temperature Bath 2 nos., have been procured.

2. Comparison of AWS data received through Kalpana – 1 Satellite with Co-located obsy. data is in progress.

Future Plans

Several developmental schemes/plans are under way at different stages. Some of these are:

- Establishment of a network of 10 Lightening Detection Systems
- Development and supply of Hand Held data logger for Automation of Surface Observatory.

b. Upper Air observatories

In IMD, upper air observations are taken at 39 Radiosonde/Radiowind stations including 2 stations for radiosonde data only, twice a day on operational basis. These observations provide Met data i.e. pressure, temperature, humidity & wind at various levels in the atmosphere up to an altitude of 30-35 kms.

There are 62 Pilot Balloon observatories spread all over the country conducting upper air wind measurements 2- 4 times a day providing wind speed and direction up to a maximum altitude of 10 kms employing optical theodolites.

Recent Developments

Upper air data of IMD network was doubted for many years by leading Numerical weather Prediction (NWP) centers of the world and observations were rejected by data assimilation systems. IMD is undergoing modernization and has adopted a strategy to replace the obsolete systems. To achieve the standards of data quality required by the NWP centers, various aspects of modernization including upgradation of observing system and transmission of data to central data centre in real time have been planned covering representativeness, accuracy of observations, achieved heights & timeliness. Apart from the data quality, regularity of observations, completeness and timeliness of the collection of observational data at the center concerned, are very important. To enable this, all TEMP data generated from GPS stations had been broadcast to GTS through SOCKET transmission. Web based portal for on line monitoring of Upper air network has also been started. Performance of the ascents, achieved heights, message dissemination time, Total number of ascents taken, MISDA reported, comparative performance of the all stations, stock statement etc can be monitored.

To improve the performance of pilot balloon observation, new optical theodolites have been installed at all 62 locations. Hand held data loggers have also been implemented at all 62 locations for computation. All the PB observations are now working on semi automatic computation system.

In recent years, the Upper Air Radiosounding System based on Global Positioning System (GPS) is used as an effective method resulting to improved observation accuracy and allowing simplification of ground equipment. Accordingly, in the first phase of modernization, ten stations have been upgraded with new GPS based Upper air systems in 2009. After the introduction of new systems, data quality has improved substantially at these stations, which has been validated by ECMWF. Recently another GPS system has been installed at New Delhi to facilitate the nowcasting during Commonwealth Games in October‘2010.

At present the RS/RW network comprised of GPS system at 11 places, 10 IMS1500 Radiotheodolites installed in 2002 & at remaining stations Ground System of indigenous make installed in 1992-93.

Brief description of ground equipment

Originally IMD was maintaining a network of 39 radars. Based on their usage, they are categorized as storm Detection and Cyclone detection radars. 17 Radars out of 39 have become very old and obsolete and are under process of written off and future upgradation.

(c) Radar

Cyclone Detection radars located along the east and west coast operate in S-band and storm detection radars located all over the country operate in X-band of frequency range.

(i) Cyclone Detection Radars (CDRs)

At present there are 10 Nos of S-Band Radars are operational. Out of 10 Radar 7 are Doppler Weather Radar operational at Chennai, Kolkata, Machilipatnam, Visakhapatnam, Sriharikota (SHAR), Delhi (Palam) and Hyderabad. 3 conventional CDRs are working at Kochi, Karaikal and Paradip. SHAR Sriharikota has indigenous DWR developed by ISRO. S-Band radar at Mausam Bhavan was for testing/training purpose and has already been dismantled and in its place C-Band Dual Polarimetric Doppler Weather Radar will be installed. This radar is expected to be commissioned by July 2011.

(ii) Storm Detection Radars (SDRs)

There are at present 5 SDR working at Nagpur, Agartala, Ranchi,Kolkata and Guwahati for the purpose of storm detection. 2 S-band radars are also working one each at Sriganganagar and Jaisalmer for monitoring development of convective clouds and thunderstorm formation. Radars at Nagpur and Agartala are under replacement with DWR in phase-I of Modernization.

(iii) Wind Finding Radars

There are 3 X-band wind finding radars working at Bhubaneswar, Ahmedabad and Bangalore.

(iv) Weather cum Wind Finding Radars

There are 2 X-Band radars used for weather cum wind finding purpose. These are installed at Machilipatnam and Karaikal. Two radars at Mohanbari and Srinagar have been dismantled. Doppler Weather Radar being installed at Mohanbari under Modernization phaseI & likely to be commissioned by 2011.

Status of Radar

S.No.	In working order
1.	Sriharikota, DWR, S-Band
2.	Machilipatnam, DWR, S-Band
3	Visakhapatnam, DWR, S-Band.
4	Chennai, DWR, S-Band
5.	Kolkata, DWR, S-Band
6.	Delhi (Palam), DWR, S-Band
7	Hyderabad, DWR, S-Band
8	Kochi, CDR, S-Band
9	Karaikal, CDR, S-Band
10.	Paradip,CDR, S-Band
11.	Sriganganagar, SDR, BEL S-Band
12.	Jaisalmer, SDR, BEL S-Band
13.	Nagpur, SDR, BEL X-Band
14.	Agartala, SDR, BEL X-Band
15.	Kolkata, SDR, EEC X-Band
16.	Ranchi, SDR, EEC X-Band
17.	Guwahati, SDR, EEC X-Band
18	. Machilipatnam, MMR, BEL X-Band
19.	Karaikal, MMR, BEL X-Band
20.	Bangalore, Wind Finder, EEC X-Band
21.	Ahmedabad, Wind Finder, EEC X-Band
22.	Bhubaneshwar, Wind Finder, EEC X-Band

(v) Future Plans

(i) Procurement of 2 Nos. of DWRs from M/s BEL Bangalore

IMD is procuring two nos. of DWRs from M/s BEL, Bangalore under an ongoing scheme for replacement of existing radars at Bhuj and Kochi. The radar meant for Kochi has been installed at Mumbai due to some technical reasons. These radars are under installation at Mumbai and Bhuj and are likely to be commissioned by end of April, 2011.

(ii) Commissioning of 12 Nos. of DWRs

In first Phase of modernization plan of IMD, 12 Nos DWRs are to be installed at Delhi (Palam), Hyderabad, Agartala, Nagpur, Patna, Mohanbari, Patiala, Lucknow, Bhopal, Goa, Paradip, and Karaikal. Radars at Mumbai, Bhuj and Goa are dismantled. All the 12 Nos DWRs procured from M/s Metstar China have reached at respective stations. Out of 12 Nos, two DWRs have already been commissioned. Installation of rest 10 Nos DWRs at Agartala, Nagpur, Patna Mohanbari, Patiala, Lucknow, Bhopal, Goa, Paradip, and Karaikal is in progress.

(iii) Procurement of 2 C-band DWRs

IMD is procuring 2 C-band dual polarized DWRs for installation in the IMD's radar network. These C-band DWR will be installed at Delhi (HQ), Mausam Bhawan and at M.C. Jaipur. Supply order has already been placed in May, 2010. Both these radars are expected to be installed / commissioned by July, 2011.

(iv) Procurement of Disdrometers for calibration of rain rate at DWRs stations.

IMD has inducted 7 DWRs in its observational network and 14 more will be added by the end of first phase of modernization. With the aim to calibrate / validate rainfall data of these DWRs, 9 Nos of Disdrometers are being precured. Out of 9 Nos of Disdrometers 5 Nos will be purchased under FDP scheme which is also approved and 4 Nos will be procured under Atmospheric Observational System and this scheme has also been approved. Indent for these Disdrometers have already been submitted. These are expected to be installed / commissioned by September, 2011.

(e) Procurement of Mobile Radar

IMD is procuring one Mobile radar for monitoring high impact weather event.

On completion of the modernization phase I, IMD will have 21 DWRs in its observational network. In the II and III phase of modernization, 34 more DWRs will be procured and inducted in the total network of 55 DWRs to bring entire country under radar coverage. Locations for 20 DWR installation have already been identified. The program of installation of 20 out of 34 DWRs is expected to be completed by December, 2014.

(vi) Establishment of National Weather Radar Operation Centre (NWROC) at New Delhi (HQ)

Action for setting up National Weather Radar Operation Centre (NWROC) has been initiated.. The scheme has been included in the IInd phase of modernization under networking of radars.

(d) Meteorological Satellite

(i) Current status:

At present IMD is receiving and processing meteorological data from two Indian satellites namely Kalpana1 and INSAT3A. Kalpana1 was launched on 12th September, 2002 and is located at 74^{0} E. INSAT3A was launched on 10th April, 2003 and is located at 93.5^{0} E. Kalpana1 and INSAT3A both have three channels Very High Resolution Radiometer (VHRR) for imaging the Earth in Visible (0.55-0.75

um), Infra Red (10.5-12.5um) and Water vapour (5.7-7.1um) channels having resolution of 2X2 kms in visible and 8X8 kms in Water vapour (WV) and Infrared (IR) channels. In addition the INSAT3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62-0.69um), Near IR (0.77-0.86um) and Short Wave IR (1.55-1.77um) bands of Spectrum. The Resolution of CCD payload in all the three channels is 1km X 1km. At present about 48 nos. of satellite images are taken daily from Kalpana1, which is the main operational satellite and 9 images are taken from INSAT3A. Imaging from CCD is done 5 times during daytime only. All the received data from the satellite are processed and archived in National Satellite Data Centre (NSDC), New Delhi.

INSAT Meteorological Data Processing System (IMDPS) is processing meteorological data from INSAT VHRR and CCD data and supports all operational activities of the Satellite Meteorology Division on round the clock basis. Cloud Imagery Data are processed and transmitted to forecasting offices of the IMD as well as to the other users in India and foreign countries.

Apart from generating half hourly cloud imagery, IMDPS produces Satellite Data derived products from the processed data as follows:

- Cloud Motion Vectors (CMVs) are derived using three consecutive half hourly images from the operational Kalpana1Satellite.CMVs are generated at 00, 03, 06, 09, 12, 15 & 18 UTC using IR imagery data.
- Water Vapor Winds (WVWs) are derived using three consecutive half hourly images from the operational Kalpana1 Satellite. WVWs are generated at 00, 03, 06, 09, 12, 15 & 18 UTC using water vapour imagery data.
- Sea surface Temperatures (SSTs) are computed at 1^0 x 1^0 grid intervals from all Kalpana1 data on half hourly /daily /weekly/monthly basis.
- Outgoing Longwave Radiation (OLR) are computed at 0.25^0 x 0.25^0 grid intervals from Kalpana1 data on half hourly /daily /weekly/monthly basis.
- Quantitative Precipitation Estimates (QPE) are generated at 1^0 x 1^0 Grid from Kalpana1 imagery on half hourly/daily/weekly/monthly basis.
- At present Dvorak technique is widely used but manually applied. Recently efforts have been made for automization of this technique. Automated Dvorak technique is running in experimental mode at Synoptic Application Unit, Satellite Meteorology Division.

Recently three ground stations have been installed in New Delhi, Guwahati and Chennai for receiving real time MODIS and NOAA data. The following products are being received regularly:

A) Geophysical Products derived from NOAA

1. Atmospheric temperature profile
2. Atmospheric water vapour profile
3. Surface emmissivity
4. Surface Temperature
5. Fractional cloud cover

6. Cloud Top Temperature
7. Cloud Top Pressure
8. Tropopause height
9. Cloud Liquid Water Content
10. Total Column Precipitable Water
11. Cloud Type (including Fog)
12. Total Ozone from GOME
13. Total Ozone from HIRS
14. Ozone Profiles
15. Land Surface Temperature
16. Sea Surface Temperature
17. Normalized Difference Vegetation Index (NDVI)
18. Fog detection

B) Geophysical Products derived from MODIS

MODIS Level 2 geophysical products (Terra and Aqua)

1. MODIS cloud mask (MOD35)
2. MODIS cloud top properties (MOD06CT)
3. MODIS atmospheric profiles, precipitable water and stability indices (MOD07)
4. MODIS aerosol product (MOD04)
5. MODIS Sea Surface Temperatures (IMAPP product)
6. Normalized Difference Vegetation Index (NDVI)
7. Enhance Vegetation Index (EVI)
8. Land Surface Temperature (LST)

From 2007 onwards, Satellite Application Unit of IMD is getting half hourly satellite imageries throughout day and night. Using the half hourly satellite imageries, Satellite Application Unit of IMD is involved in interpretation of satellite imageries and issuing different types of Satellite Bulletins: Satellite bulletins based on 3hourly INSAT cloud imageries are prepared and transmitted to all the forecasting offices on Global Telecom Service (GTS) through RTH. New Delhi, Special hourly satellite bulletin in case of cyclone over Bay of Bengal or Arabian Sea, heavy rainfall advisory bulletins are also transmitted & uploaded on IMD website in addition to routine bulletins.

The proper monitoring and tracking of cyclonic storm, thunderstorm, Fog (day and night) and other Severe weather phenomena‘s using half hourly imageries of Kalpana1 and products from NOAA/MODIS/METOP are quite useful in issuance of timely warning/advisory to the users and thus saving property and life.

With the Web Archival System-A system developed at IMD KALPANA1/ INSAT3A data products and imageries are being archived for one month.

On 23rd September 2009 polar orbiting satellite OCEANSAT–II has been launched by ISRO, which carries a ku-band pencil beam scatterometer to provide ocean surface winds at 10 m height for early detection of Tropical cyclones.

(ii) Digital Meteorological Data Dissemination:

IMD transmits processed imagery, GTS data, meteorological and facsimile weather charts to field forecasting offices distributed over the country using the Digital Meteorological Data Dissemination (DMDD) 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 DMDD receiving stations in S-band. DMDD receiving stations analyse weather imagery and other data to generate required forecast. There are 37 no. of DMDD stations installed in India. Three DMDD receiving stations are also operating in neighbouring SAARC countries at Sri Lanka, Nepal 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 5886 MHz and that of downlink is 2586 MHz.

(v) Future Plan:

Under INSAT3D programme, a new Geostationary Meteorological Satellite INSAT3D is being designed by ISRO. It will have an advanced imager with six imagery channels (VIS, SWIR, MIR, TIR1, TIR2, & 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 2011 and will provide much improved capabilities to the meteorological community and users. In preparation for the reception and processing of these data, Space Application Centre of Indian Space Research Centre Organisation (SACISRO) has installed a data reception and processing system to process the data from the INSAT3A and Kalpana1satellites. 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 Longwave 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 Vectors (CMV)
10. Water Vapour Winds (WVW)
11. Upper Tropospheric Humidity (UTH)
12. Temperature, Humidity profile & Total Ozone
13. Value added parameters from sounder products
    a) Geopotential Height
    b) Layer Precipitable Water
    c) Total Precipitable 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

(iii) Cyclone Warning Dissemination:

A specially designed Cyclone Warning Dissemination System (CWDS), which works via the INSAT Satellite, provides area specific service even when there is a failure of conventional communication channels. A set of 252 analog and 101 digital CWDS receivers have been deployed in vulnerable coastal areas in the east and west coast. This network will be replaced shortly by 500 new CWDS, which are modern and easy to maintain.

(iv) IPWV measurements by GPS Satellites:

At present five GPS receiving stations are installed at New Delhi, Kolkata, Guwahati, Chennai, and Mumbai for measurements of Integrated Precipitable Water Vapour.

Meeting

Meeting of Coordination Group for Meteorological Satellites (CGMS) –38 was held in New Delhi from 8th –12th November 2010. Various agencies like EUMETSAT, NOAA, JMA, KMA, delegates from Russia and various other countries participated in the meeting.

A bilateral meeting between officers of IMD and EUMETSAT was held in DGM office, New Delhi on 9th Nov'2010. EUMETSAT agreed for one EUMETCAST receiving station and also agreed to help IMD becoming a centre of excellence of WMO.

For Technical and scientific cooperation related to INSAT3D satellite data applications between the Ministry of Earth Sciences (MoES) / India Meteorological Department (IMD) and the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) an Implementing Arrangement regarding INSAT-3D Satellite Data (IA-3D) has been signed by Director General of Meteorology and ,Assistant Administrator for Satellite and Information Services , National Oceanic and Atmospheric Administration (NOAA) at Washington D.C. on 6th October, 2010**.**

Prediction Models in Operational Use During the Year 2010

IMD operationally runs three regional models WRF(NMM), MM5 and Quasi Lagrangian Model (QLM) for short range prediction during cyclone condition. MM5 model is run at the horizontal resolution of 45 km with 23 sigma levels in the vertical and the integration is carried up to 72 hours over a single domain covering the area between lat. 30^o S to 45^o N long 25^o E to 125^o E. WRF (NMM) is run 4 times a day at the horizontal resolution of 27 km.

IMD also makes use of NWP products prepared by some other operational NWP Centres like, ECMWF (European Centre for Medium Range Weather Forecasting), GFS(NCEP), JMA (Japan Meteorological Agency), UKMO etc. A multimodel ensemble (MME) technique for predicting the track of tropical cyclones for the Indian Seas is developed and implemented in the operational mode. The MME is developed applying multiple linear regression technique using the member models MM5, QLM, GFS (NCEP), ECMWF and JMA.

All All these NWP products are routinely made available on the IMD web site www.imd.gov.in.

(i) Global Forecast System

With the commissioning of High Performance Computing System (HPCS), National Centre for Environmental Prediction (NCEP) based Global Forecast System (GFS T382) has been made operation at the H/Q of IMD, incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. Currently, it runs twice in a day (00 UTC and 12 UTC).

(ii) Regional Forecast System

The mesoscale forecast system WRF (ARW) with 3DVAR data assimilation is being operated daily twice, at 27 km and 9 km horizontal resolutions for the forecast up to 3 days using initial and boundary conditions from the IMD GFS382. The WRF (ARW) is run at the horizontal resolution of 27 km and 9 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours, the outer model domain covers the area between lat. 25^o S to 45^o N long 40 o E to 120 o E. At ten other regional centres, very high resolution mesoscale models (WRF at 3 km resolution) are made operational.

(iii) Future Plan

IMD has the plan to implement latest version of NCEP HWRF for the Indian basins with the assimilation of local observations. The model has the provision for vortex relocation and moving nesting procedure. In this direction action has been already initiated and the model is exceeded to be available in the operational mode by the end of 2011.

(f) Telecommunication Network in IMD

IMD maintains a very Extensive Telecommunication Network with Central Hub in its National Meteorological Telecommunication Centre (NMTC) at New Delhi, which is connected with Five State of the art Regional Automatic Messages Switching Systems (AMSS) at Delhi, Kolkata, Chennai, Mumbai and Guwahati. AMSS at RTH New Delhi is upgraded with state of the art AMSS (Transmet) supplied by the M/s MFI, under the Modernization Project of IMD. For collection of Meteorological Data from the entire country and the neighboring Region/ Countries at NMTC, various modes of communication viz. dedicated leased line circuits, fax, internet, high speed data terminals, VPN connectivity, VHF / WalkieTalkie have been installed at various locations dispersed throughout the country & neighbourhood. A new Transmet (RTH) System, an Automatic Message Switching System (AMSS) to receive, check and route the meteorological data and products according to WMO standards/ requirements & Central Information and Processing System (CIPS), High end database management system having task centre to develop, test and operationalise meteorological tasks for real time generation of meteorological products have been installed and are operational. GTS has ten links and five circuits through internet connectivity. The details of communication facilities at RTH New Delhi are given below:

(1) VPN Link (2 mbps) …. For National Links.
(2) RMDCN Link (1 mbps) … For connectivity with four countries.
(3) 64 Kbps IPLC and VPN over Internet .. For connectivity with 11 countries.
(4) Internet Link (45 mbps) – From Tata communication Ltd.
(5) Internet link (45 mbps) – From Bharti Airtel.
(6) Email
(7) FAX
(8) Digital Met. Data Dissemination through INSAT
(9) Telephone
(10) IMD Web sites http : www.imd.gov.in & http://www.mausam.gov.in IMD INTRA Portal metnet.imd.gov.in
(11) VSAT
(12) IVRS at 26 locations / cites.

- For public weather information, Interactive Voice Response Systems (IVRS), popularly known as ‗Weather on Telephone' has been installed at 26 stations (mainly state capitals) throughout the country. One can access current weather and forecasts for major Indian cities by dialing a toll free number 1800-180-1717.

- 52 (44 commissioned + 8 to be commissioned) Stations have been provided VPN Connectivity, and are functioning for operational purpose.

- 27 Stations have been equipped with 64 kbps high speed data terminals.

- A network of 26 VSATs is being installed at selected seismological observatories, Cyclone Detection Radar stations, Cyclone Warning Centres for reception of observational data utilizing communication Transponder of INSAT. Out of 26 stations, 23 stations have been installed and commissioned.

- A Satellite Data Dissemination System (SADIS2G) (receive only) is in operation at New Delhi to receive Aeronautical Meteorological Information from International Civil Aviation Organization (ICAO) Centers which are routed to four International Airports of India for National and International Flight briefing and for providing data in GRIB/BUFR format for Wind/Temperature and Sig. WX. Charts.

Maldives

(a) Upper air Observation

Radio-sonde observations at the Meteorological Office, Gan (WMO # 43599) that were discontinued in 2009 were resumed in 2010 when UK Met Office graciously donated consumables sufficient for 1 year.

Like last several years, no upper-air observations were made at Male' (WMO # 43555) in 2010 as well. There is no upper air sounding equipment in Male'.

The location of Maldives in the Indian Ocean happens to be a data sparse area, upper air observations from the south and central Maldives are very important to us as well as the entire meteorological community in the region. Hence, Maldives urge assistance from WMO/ ESCAP and Panel members to consider rebuilding of our upper air network.

(b) Surface Observations

Maldives has 5 meteorological stations. All are manned 24 hours, both synoptic and aviation reports are made on all five stations. Only one of them is categorized additionally as upper-air station.

Hanimaadhoo (43533) surface
- Male' (43555) surface
- Kadhdhoo (43577)surface
- Kaadehdhoo (43588)surface
Gan (43599) surface + radiosonde

Total of 23 Automatic Weather Stations (AWS) has been installed up to 2010 and are in operation.

(c) Rainfall Stations

Across the country, Maldives has 7 rainfall stations which measure only accumulated rainfall for 24 hours and reading are collected at 0300UTC for national use only.

- HA. Kela
- Sh. Funadhoo
- B. Dharavandhoo
- M. Muli
Dh. Kudahuvadhoo
Th. Veymandoo Gn.
Fuvanmulah

(d) Meteorological Satellites and Doppler Weather Radar

Digital Meteorological Data Dissemination System

Digital Meteorological Data Dissemination (DMDD) system donated by India Meteorological Department (IMD) receives WMO coded GTS data, half hourly cloud imagery from Kalpana and Fax charts in LRIT/HRIT format transmitted by IMD and display on a high resolution color monitor. Images can be further enhanced using different image processing functions and can be focused more on the area of interest. This system has the capability to plot the received met data by values or contours on a specific image. With all these features it helps forecasters to do more precise predictions. However, this system has been malfunctioning during 2010 and IMD is taking measures to repair the system.

Maldives' Satellite Data receiving ground station GEOSAT

500. System components:

- Antenna (with L-band feed)
- Satellite receiver (input 50ohm,frequency 130-145MHz, Demodulation FY2C HiRID)

The High Resolution Satellite Image Receiving System GEOSAT 500 made by Australians and the Doppler Weather Radar received as part of Multi-hazard Early Warning System are currently not functioning. Local technicians were unable to diagnose or rectify the problem or fault.

(e) Numerical Weather Prediction

Maldives Meteorological Service continues to run WRF model as a trial basis and although planned to expand this service last year, could not achieve that goal due to budget constraints.

(f) Telecommunications

The 10mbps internet service and the computer based telecommunication system between the local Meteorological Offices and the National Meteorological Centre (NMC), functioned very well.

NMC's Global Telecommunications System (GTS) and Message Switching System (MSS)

MESSIR-COMM message switching system developed by COROBOR is a TCP/IP based multi-channel communication link that is capable of handling vast amount of data. Although this GTS is in operation throughout 2010, Maldives received many complains from other countries of not receiving our radio-sonde observation (TEMP) message through GTS. Likewise, the monthly CLIMAT report sent via GTS is also reported not received by users. Therefore, we request India to look into this matter and to work with us closely to solve this problem.

(g) Forecaster's Workstation

MICAPS (meteorological data analyzing) System donated by China Meteorological Administration (CMA) is being used as an important in the Forecasting Office.

(h) Meteorological information through internet

The official website of the Maldives Meteorological Service http://www.met.gov.mv has served its users with current weather updates, forecasts, warnings, met reports and aviation weather charts.

Myanmar

(a) Meteorological Satellite Reception and data Processing System (MTSAT)

Based on the report of WMO Facts Finding Mission in February 2009, the Government of Japan provided the valuable Meteorological Satellite Reception and data Processing System (MTSAT), worth of USD (175,000) to Myanmar, in order to promote the tasks on daily weather issues, forecasts and early warnings of Department of Meteorology and Hydrology(DMH). Under the program of Japan International Cooperation Agency, MTSAT system was installed successfully by four engineers from the manufacturing company, at Nay Pyi Taw in January 2011. Data received from MTSAT are also sent to weather forecasting sections of Yangon (Kaba Aye) and Yangon International Airport through Internet network. However the Fung Yun Cast receiving system had been no longer operational since November 2009 due to the expiry of software license, the satellite imageries are received now through the MTSAT receiver.

(b) Forecasting Services of DMH

National Meteorological Center Yangon, Nay Pyi Taw issues day-to-day routine weather forecasts and cyclone warnings. The forecast, warning, bulletin and news issued by DMH are as follows:

Daily, Dekad, Monthly and Seasonal Weather & Water level forecast
Aviation weather forecast,
Squall wind weather forecast
Sea route forecast
Storm warning, Storm surge warning
Untimely rainfall warning
Heavy rainfall warning
Strong wind warning
Fog warning
Bay bulletin
Agro-meteorological bulletin

(c) Storm News, Warnings and Dissemination

24x7 Storm Watch Centers: Nay Pyi Taw Multi Hazard Early Warning Centre, Yangon Forecasting office, Mingladon International Airport Aviation Forecasting office and all coastline observatories watch the storms whenever cyclones develop in the Bay of Bengal. Moreover various meteorological websites like TMD.IMD, JTWC, NCEP, JMA etc., are used for cyclone monitoring. Storm news and warnings are issued at frequent intervals for national and international users in various sectors. Special storm warnings accompanied with color code and possible storm affected specific areas are issued hourly to all news media. National televisions televised all hourly news continuously in footnote rolling format frequently. The dissemination of cyclone information such as cyclone forecasts and warnings are an important task for disaster preparedness in Myanmar. DMH plays an important role by initiating the warning related to the formation of tropical disturbances in the Bay of Bengal and transmitting the warnings to National Disaster Management Committee (NDMC), National Disaster Risk Committee (NDRC) and other higher authorities, NGOs, UN Offices and etc. Cyclone warnings are transmitted without delay to the local authorities through telephone, fax, mobile phones, VHF, emails, Port wireless, websites, radio and TV.

(d) DMH's Website:

DMH's new website (http://www.moezala.gov.mm) is going to be operational from 23 March 2011. It will link with the existing website (http://www.dmh.gov.mm), which was launched since 2005 WMO Day. The forecasting products like daily weather reports, weather analysis maps and warnings are created and timely updated in DMH website.

Oman

(a) Upper Air Observation

The Sultanate of Oman operates two upper air-observing stations, located at Muscat (41256) and Salalah (41316) respectively. Both these are equipped with Vaisala's Digicora GPS wind finding system. The radiosonde was upgraded to Visalla RS92 equipment. One flight is launched at 00Z from each of these stations on a daily basis.

(b) Ship Weather Reports

Weather Reports from Ships are received through GTS as well as from Muscat Coastal Radio Station. In addition Ship reports are also received from the Royal Oman Navy.

(c) Wave Measurements

One wave radar measurement station was installed offshore of Qalhat (Sur)- another two wave measurement stations located offshore Sohar Station and Mina Salalah Station.

(d) Synoptic Land Stations

The number of Synoptic Land Stations being inserted into the GTS still remained at 32 stations. Thirty Six Additional AWS stations were procured in 2010 and installation is expected to be completed in 2011.

(e) Weather Radars

Five S-Band Dual Polarization Doppler Weather Radars was Tendered and Awarded to a German Firm Selex (Gematronix). The installation and commissioning of these Weather Radars will be completed in 2012.

(f) Telecommunication

All the meteorological stations operated by the Directorate General of Meteorology and Air Navigation (DGMAN) are connected to the Message Switching System (MSS) computer located at the Central Forecasting Office at Muscat International Airport by a reliable dial-up telephone link (Telephone lines and GSM Network).

The MSS is connected to the RTH Jeddah by a dedicated link at 64 kbps based on TCP/IP protocol.

In addition a 4 Mbps Internet leased line has been established as well as for transmitting and receiving meteorological data with different meteorological centers such as New Delhi and Abu Dhabi.

Beside this connection is used to receive the boundary data initiated from the German weather service to be used for the Omani model.

This connection has in its structure different servers as ftp server which is used for serving different users with special meteorological data. All these servers are protected by a firewall.

(g) Satellite reception

- There are two locations with Ground Receiving Satellite Stations Muscat and Salalah.
- These include HRPT Polar Orbiters operated by USA and China as well as Metop by Eumetsat.
- Geostationary Satellites including Eumetsat MSG with DWDsat in addition to Eumetsat MFG seven as well as to the Chinese FY2 satellite.

(h) Data Visualization

The Directorate General of Meteorology and Air Navigation (DGMAN) is using a visual weather application for visualizing the meteorological data and GRIB format coded data. It is proved to be a useful tool for visualization, analyzing and forecasting the weather.

(i) Computer Workstations

Data Processing System

Global Numerical Weather Prediction NWP products are received via Internet, GTS, DWD Sat. We receive products from ECMWF, UK Met office and German Weather Service DWD.

Current operational processing capabilities consist of a PC Cluster of 20 nodes with total of 40 processors. Dual AMD Opteron 3.0 is used for each node. All nodes are connected via very fast Interconnection network using 24 Infiniband switch with guarantees 3Gbps full duplex.

Recently, new processing element under pre-operational status is being tested. It consists of 72 nodes with total of 756 threads. Quad-core AMD 3.2 processor are used and interconnected using 144-port Infiniband switch.

Local Oman Regional Model ORM was established with the kind cooperation of National Weather Service of Germany DWD. The details of the model versions as follow:

A] High Resolution Model HRM is Hydrostatic limited-area numerical weather prediction model for meso-a and meso-p. Main prognostic variables are:

Surface pressure (ps), Temperature (T), Water vapour (qv) Cloud water (qc), Cloud ice (qi), Ozone (optional), Horizontal wind (u, v) and Several surface/soil parameters. More details are available on the model website (http://www.met.gov.om/hrm/index.php).

DGMAN runs HRM with two model resolutions:

ORM_28: 28x28 km resolution. It covers the area between 30^0 E, 7^0 N (lower left corner) to 78^0 E, 35.25 N (Upper right comer) with mesh size of 0.25 degree. There are 193x114 grid points and 40 vertical layers. The model is running on 20 nodes from the PC Cluster. It produces up to 78-h forecast at 00 and 12 UTC. The following figure shows the domain area.

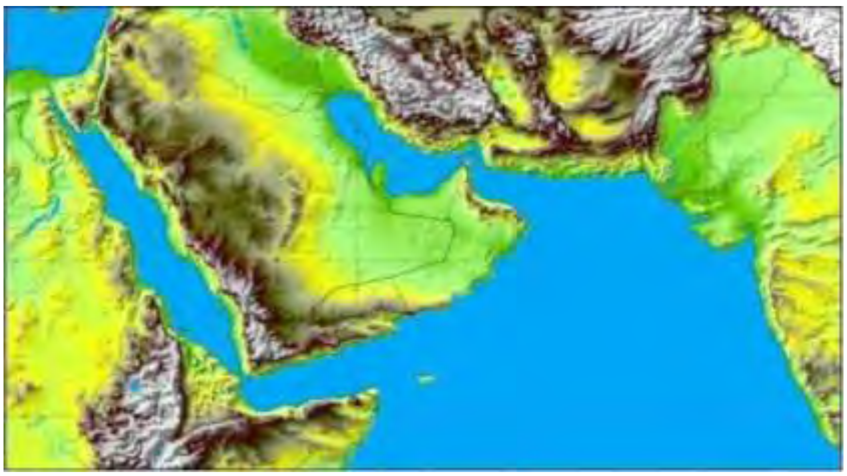


Fig 1: ORM_28km resolution domain

ORM_07: 7x7 km resolution. The operational version of the model covers the area between 48.5.0 E, 14.0 N (lower left comer) to 63.5E, 29.0 N (Upper right comer) with mesh size of 0.0625 degree. There are 241x241 grid points and 40 vertical layers. The model is running on 20 nodes from the PC Cluster. It produces up to 78-h forecast at 00 and 12 UTC. The following figure shows the domain area.

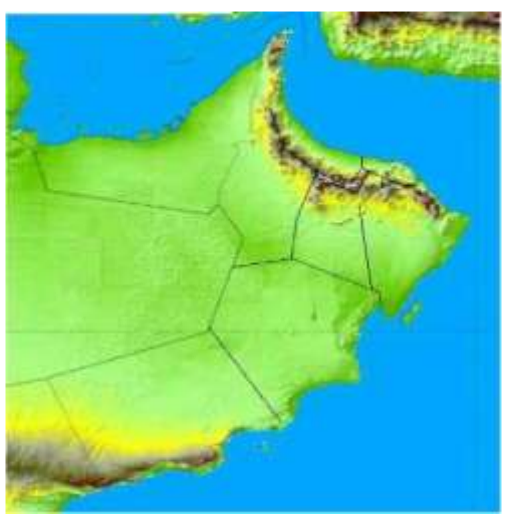


Fig. 2: Operational ORM_07km resolution domain

Under the new processing element, ORM_07 is run over the domain shown in Figure 1. On this configuration there are 769x453 grid points and 60 vertical layers.

B] Consortium for Small-scale Modeling COSMO is a non-Hydrostatic limited-area numerical weather prediction model for meso-a and meso-p. Main prognostic variables are: pressure perturbation (p'), Temperature (T), specific humidity (qv) Cloud water (qc), Cloud ice (qi), Horizontal/virtical wind (u, v) and Several surface/soil parameters. More details are available on the model website (http://cosmo-model.cscs.ch)
DGMAN COSMO model with kind cooperation with DWD. The operational version of the model runs on 7x7 km covers the same domain of ORM_07 as shown in Figure 2. COSMO was introduced to enhance the accuracy of predicting local rainfall over Hajar Mountains and adjoining area during summer and to compare the forecast with the forecast of ORM_07. Under the new processing element, COSMO model is run using two different model resolutions. The first resolution is 7km and covers the model domain shown in Figure 2.

C] A WAM based wave model was established with the kind cooperation of GKSS of Germany, which covers the Arabian Sea, gulf of Oman and Arabian gulf. WAM model run of 28km resolution and it runs on a single processor on the PC cluster.

Under the new processing element WAM is run over the domain shown in Figure 1 using 14km resolution and close to the Omani coast with 3.5km resolution.

D] Tsunami Model for the Oman Sea and India Ocean: Comit Model from IOC is used to develop some hypothetical experiments to simulate tsunami waves propagation and indentation.

(j) Module Output Statistics (MOS)

The Directorate General of Meteorology and Air Navigation (DGMAN) successfully established a MOS based on ORM_07. MOS output is generated with each Model run. MOS is an approach to incorporate NWP forecasts information into statistical weather forecast. After installing MOS we noted improvement in Temperature and wind forecast. In addition we were able to get a probability forecast for thunderstorms and fog.

(k) Verification Package

The Directorate General of Meteorology and Air Navigation (DGMAN) managed successfully to develop its own verification package. The developed system verifies the continuous weather parameters such as T_2m, TD_2m and for the categorical weather parameters such as Total precipitation. The system generates different statistical scores such as Hit rate with a margin of error, Bias, Root Mean Squared Error (RMSE). The package provides a friendly UGI to allow the user to select different choices (Model type, stations list, observation time, weather element and statistical score) to be verified. This system will help find the systematic errors in the Model output, which can be tuned.

The package is being used in several countries such as UAE, Brazil, Jordan, Malaysia, Hungary, Vietnam, Iran, University of Berlin, Kenya and Madagascar. Panel Members may get a copy also if they request Oman's P.R.

Aeronautical Services

In order to meet ICAO recommended practices and to fulfill the requirements for Aviation the Directorate General of Meteorology and Air Navigation (DGMAN) installed a SADIS workstation as early as 1996. The Department pay's to the UK Met Office the annual contributions for obtaining SADIS data and Products. In addition all the SADIS data and products are also received thru an FTP Server from UK as a back up. A new service was also established for the provision of en-route flight folders for all Airlines operating in the Sultanate which is accessed through a Web Portal.

Pakistan

(a) Strengthening of AWS Observational Network in Pakistan

During 2010-2011, PMD have established 10 AWS and 45 precipitation monitoring stations to strengthen its observational network making the total number of AWS and precipitation monitoring stations 35 and 500 respectively. These stations have been established mostly in the arid/ semi arid regions of the country. Further, PMD also started generating Drought Monitor for the entire country fortnightly (using GIS) which is also updated on PMD's website.

(b) Numerical Weather Prediction at PMD

Pakistan Meteorological Department has been using High resolution Regional Model (HRM) of DWD (the National Meteorological Service of Germany) as an operational model for numerical weather prediction since January, 2007. Initially the model was run with 28 Km resolution, however, from March 2008 on wards, the model was started to run with 22 Km resolution and the simulations are being performed twice a day by using GME data of 0000UTC and 1200UTC. Further, the model output (prognostic charts) are also uploaded at PMD‘s website www.pakmet.com.pk. In 2009, PMD procured additional servers/hardware with processing power of 1.7 TFLOPS to upgrade its existing computer system and run the model with the resolution of 7 km. However, the upgradation of HRM at 7 km resolution was not successful for Pakistan due to complex topography. The HRM, a hydrostatic model is limited in representing the full spectra of waves (e.g., trapped lee waves), which are connected to steep slopes. Therefore, after upgradation of hardware, the model with 11 km resolution has been operational since September 2010. Now PMD is planning to implement a non-hydrostatic model with higher resolution. In this regard, PMD is seeking support of DWD (Germany) and WMO for capacity building in NWP based on COSMO model (Consortium for Small scale Modeling), a non-hydrostatic regional atmospheric model.

Sri Lanka

(a) Upper Air Observations

Radar wind observations in Colombo (43466) were carried out throughout except for a very few occasions. Sonde observations were done three times a week as the shortage of equipment. Out of three, two sonde observations were done using the old equipment and one were performed using the new GPS sounding. Pilot balloon observations were done at 0000, 0600 and 1200 GMT at Hambantota (497), Puttalam(424). The obscured surrounding of the ancient city Anuradhapura (421) was found to be not suitable for pilot observations hence; the pilot observations were not performed at the beginning of the year and shifted to Polonnaruwa, more towards the east with effect from May, with new annual transfers effective.

(b) Synoptic Observations

Data reception from 22 operational stations with the two stations commenced in 2009 namely, Polonnaruwa and Anuradhapura (No WMO number assigned yet) was very good. Observations taken and sent in plain language by Sri Lanka navy at Trincomaiee (43418) are coded at NMC. Out of RBCN stations, silent climate TEMP data, Colombo (43466), due to non availability of continuous data and nine RBSN stations are operational.

(c) Meteorological Satellites

The reception of HRPT imageries are still not possible as the system is irreparable and funds are being sorted for a new one. Revived the FENYUNGCast system and operational.

Digital Meteorological Data Dissemination system (DMDD) donated by the Government of India through India Meteorological Department was in operation. However, it became unserviceable towards the end of the year. Joint efforts with IMD are being made to correct.

(d) Ships and Aircraft Reports

Ship observations are still not received at Colombo radio shore station. However, many are received through GTS. Reception of AIREPS at Airport Meteorological office is poor.

(e) Telecommunications

Data and information exchange with RTH New Delhi internet lease line operated throughout. The system is integrated with SADIS and there are three visualizing terminals. It also provides the warning with alarm in case of information provided by PTWC and JMA with regard to potential tsunami situation.

(f) Improvement of facilities/Technical Advancement

15 telemeter rain gauges were installed during the year at rain induced disaster prone areas to facilitate early warning about disasters and, along with this there are 19 locations with this facility.

Completion of access road, site preparation and commencement of foundation work done for installation of Doppler radar at Gongala Peak. Factory training for hardware and software has been completed.

With the improvement of security situation, Jaffna Meteorological office has been identified for reconstruction at a new location and a block of land has been acquired.

Storm surge model, as per WMO/ESCAP training received, is operational as a routine at the NMC.

Thailand

- The Panel was informed by the representative of Thailand with pleasure that under the bilateral cooperation between Thailand and Myanmar after NARGIS a new radiosonde installation at Yangon would be completed by 2011
- The Panel noted the improvement in the upper air network in Thailand, three radiosondes which started the installations in the Northeast, the South (east coast) and the South (west coast) in 2011. Totally there are 5 radiosonde stations in Thai Meteorological Department
- To strengthen severe weather observations and monitoring networks, and nowcasting of the country, three C-band Doppler Radars which started the installation in the Songkhla province, Surat Thani province (Samui) and Surin province in 2010. Totally there are 25 weather radars in the TMD's precipitation monitoring network.
- To enhance the capability in receiving meteorological information derived from the different platforms of meteorological satellites, such as MTSAT, FY-2, TIROS (NOAA-16, NOAA-18, NOAA-19), FY-1, FY-3, MODIS, METOP, the TMD‘s implementation of the satellite signal receiving station, which began its installation in 2009, is now being in the last phase of the installation process, and it is expected to be successfully completed and will be in the operation in the early 2011.
- The IIT Storm Surge Model was adopted and applied using the 1 km. resolution bathymetry data interpolated from the GTOPO1. The maximum storm surge height map along the coastal areas of the Gulf of Thailand for each tropical storm category/ strength has been produced.
- To improve the receiving-disseminating of meteorological data on the network of the Global Telecommunication System (GTS) in order to fully support the information exchange in the form of the Table Driven Code Form (TDCF) as specified by the WMO, the TMD‘s Meteorological Telecommunication Data Storing and Recording Project has been under implementation. Its installation

was started in 2009, and is expected to complete by the end of 2011. The completion of this project will also lead to the increase in potential of TMD to be the RTH Bangkok WIS portal in the South East Asia region.

- To develop and enhance the telecommunication network for severe weather and weather-related disaster warning of the country, and to develop the whole country observation data collecting system
- To improve the aviation meteorological data reporting system, the improvement will disseminate the present meteorological data, forecast data, and the warning of severe weather data to pilots by using Short Wave Radio System. The project will take one year to complete, thus it will be in the TMD's operation by the end of 2011.
- To produce and display weather map of the Table Driven Code Form (TDCF) data, the Weather Chart Display System (WDS) has been developed. The WDS runs on the Messir Vision system to facilitate and assist forecasters to be able to visualize and analyze weather patterns produced by the system on an hourly basis.

Activities of WMO

The representative of WMO reported that the average availability of SYNOP reports ranged from 16% to 100% during 2010. The availability continued to be more than 70% for all countries, except for Myanmar and the Maldives, with the latter showing a significant decrease from 53% in the previous year to 16% in 2010. Overall, the total availability of reports also decreased slightly to 86% (in 2010) from 87% the previous year. The availability of expected TEMP reports on the MTN from a total of 53 upper-air stations (remained unchanged in 2009/2010) in the RBSN operated by Members of the WMO/ESCAP Panel on Tropical Cyclones according to the results of the IWM exercise carried out on a quarterly basis in 2009/2010 is also provided in the table below. The average availability of TEMP reports ranges from zero to 57%. The availability is less than 25% for the Maldives with Myanmar not reporting as in the previous year.

Overall, in spite of a decrease in the number of reports received from a majority of Panel Members in 2010 compared to the previous year, the average percentage of the total number of TEMP reports received increased slightly from 43% to 45% per cent during the same period. Deficiencies in surface and especially upper-air data coverage over certain areas in the region continued to be caused mainly due to financial difficulties encountered by countries concerned to rehabilitate and operate both observational and telecommunication equipment. Inadequate funds also resulted in the lack of trained staff, essential instruments and consumables.

As regards the relatively low availability of TEMP from India, the Panel was informed by the delegates of India that it is due mainly to the time-consuming process of procurement of the consumables as well as their qualities, the problem is being addressed by IMD. The Panel also raised the issue of non-reporting of TEMP from Sri Lanka, while upper-air observation is being performed normally three times a week at the station in Colombo. The Panel noted that the upper-air station of Sri Lanka should be duly registered at RBSN. It therefore requested the WMO Secretariat to take an action to facilitate the registration.

Noting the great significance of increasing the availability of upper-air data, the Panel also drew attention to the AMDAR Programme. As the Programme is conducted mainly on a regional basis, the Panel urged the Members to collaborate with the airlines for promoting the regional AMDAR programmes.

Following the 2010 extraordinary meeting of the Commission for Basic Systems (CBS) in Namibia, it is now clear that WIS has moved from its development stage and into implementation. Three candidate GISCs (Offenbach, Beijing and Tokyo) along with 15 DCPCs are now in preoperational mode. These and several other GISCs, including New Delhi, will be operational following endorsement from Congress XVI. The project to upgrade the Main Telecommunication Network (MTN) component of the GTS has now completed, and this improved MTN will form the core network of WIS connecting all GISCs. The Manual on WIS (WMO No. 1060) was prepared by CBS, along with the draft amendments to include WIS in the Technical Regulations (WMO No. 49) which will all be presented to Congress XVI for approval. These combined with a Guideline to WIS (WMO No. 1061) and guidelines for WMO Metadata for WIS (http://wis.wmo.int) will allow all Members to begin to implement the new WIS functionality. It is expected that GISC New Delhi will take the leading role in ensuring Members of the Panel on Tropical Cyclones also implement and benefit from the new functionality of WIS.

CBS Extraordinary 2010 also updated the Manual on GTS (WMO No. 386) and Manual on Codes (WMO No. 306) to allow the exchange of information in the form of Common Alerting Protocol (CAP) between WMO Members. This is in line with the decision of the WMO Council that recognized the benefits of using the Common Alerting Protocol (CAP, ITU Recommendation X.1303), which is a content standard designed for all-hazards and all- media public alerting, for the dissemination of weather, climate and water related alerts and warnings. Thus CAP will now be supported in the virtual all hazards network within the WIS- GTS.

To allow the Members to benefit fully from WIS, it is essential that NMHS start to make plans to implement WIS functionality in their programme plans and that committees such as the Panel on Tropical Cyclones work with the GISCs and WMO secretariat to ensure their programmes include WIS implementation as a priority activity in the coming WMO 16th financial period

1.2. HYDROLOGICAL ACTIVITIES

Bangladesh

BMD provides all sorts of data, information and weather forecast to the Flood Forecasting and Warning Centre (FFWC) of Bangladesh Water Development Board (BWDB). A Metropolitan Area Network (MAN) between Storm Warning Centre (SWC), Dhaka and FFWC was established in 1998 through which FFWC receives meteorological and hydrological data (including rainfall and water discharge data of upstream) along with Radar and Satellite images.

Through the completion of the establishment of Meteorological and Hydrological Doppler Radar at the north-eastern part of Bangladesh under JICA

Grant Assistance, FFWC is being connected by VSAT link to get all the radar information for flood and flash flood monitoring and forecasting. Also during execution of JICA's Technical Cooperation on the Human Capacity Developmen, training will be imparted to FFWC for radar data calibration and its utilization.

India

The Hydrometeorological Division at New Delhi was established for providing the necessary technical and operational support to various Central / State Govt. Organisations and other agencies in the field of Hydromet design flood forecasting, water management and agricultural planning purposes. In the performance of these activities, this discipline carried out compilation of rainfall statistics, hydrometeorological analysis of different river catchments for project authorities and provides meteorological support for flood warning and flood control operations to field units of Central Water Commission. Research Programmes in (a) Design Storm Analysis, (b) Rainfall Frequency Analysis and (c) Quantitative Precipitation Forecast are the ongoing hydrometeorological activities. The main activities of the Division are;

(a) Rainfall Monitoring

(i) Real time monitoring of dsitrictwise daily rainfall is one of the important functions of IMD. A network comprising a large number of raingauge stations is utilized under Districtwise Rainfall Monitoring Scheme (DRMS). Based on real time daily rainfall data, weekly districtwise, sub-divisionwise and statewise rainfall statics are prepared on weekly.monthly and seasonal basis in the form of rainfall tables and maps. Districtwise and sub-divisionwise rainfall statistics provides important information useful to the agricultural scientists, planners and decision makers.

(ii) The software used for preparation of districtwise rainfall summary has been modified in all the six hundrad forty districts of India on rainfall bulletin.

(iii) Preparation of weekly sub-divisionwise/districtwisse / statewise rainfall reports including the statistics for the country as a whole as well as for the four regions viz, North-West India, South Peninsula, Central India and North East India. During the Monsoon Season 2010 daily sub-division rainfall report (169 reports including Oct.) were prepared and supplied to the Cabinet Secretary and other users

(iv) Week by week progress of rainfall for the districts and subdivisions were put up on the website.

(b) Flood Meteorological Service

Flood Meteorological Service of IMD provides the following inputs to Central Water Commission (CWC) through their 10 Flood meteorological Offices (FMO estabhlished in different parts of India for operation flood forecasting. FMO's are located at Agra, Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna in the flood prone areas which caters to the river catchments Lower Yamuna, Betwa, Ken and Chambal, Narmada, Tapi, Deman Ganga, Sabarmati, Banas and Mahi, Ajoy, Mayuraksi and Kangasbati, Mahanandi, Brahmani and Subernarekha, Brahmaputra, Dehand, Lohit, Subansiri, Manas, Dhansiri and Barak, Godavari and Krishna, Teesta, Upper Ganga, Ghaghra, Gomati, Rapti and Sharada, Upper Yamuna and Sahibi, Lower Ganga, Kosi, Baghmati, Gandak, Burhi Gandak and Sone respectively.

15372 QPF;s were issued by FMO's during the Flood 2010, and supplied to Central Water Commission for flood forecasting purposes. From this year lead time of QPF is enhanced and now it is issued at 0930 1ST instead of 1200 1ST earlier. This unit is mainly engaged in developing Quantitative Precipitation Forecast(QPF) model using different dynamical models for river basins during flood season. For this Mahanadi Basin is taken as pilot project for the flood seasons 2009 and 2010 by using IMD's MME forecast and IMD's WRF(9kmX9km) model was also partly utilized in the flood season 2010 with 48 hours lead time.

(c) Design Storm Studies

Design Storm Studies are being conducted to evaluate design storm estimates (rainfall magnitude and time distribution) for various river catchments/ projects in the country, for use as main input for design engineers in estimating design flood for hydraulic structures, irrigation projects, dams etc. on various rivers. This estimation of design values is required for safe and optimum design of storage and spillway capacity. On the request of Central Govt./ State Govt., Private Agencies, design storm values (Standard Project Storm, Probable Maximum Precipitation along with Time Distribution) are being provided for users as main input. For Govt. agencies, these studies are being carried out free of cost and for private / profit earning agencies on payment basis. The detailed project reports are being sent in respect of the projects completed on payment basis.

During the year 2010, design storm studies of thirty six (36) projects have been completed and results communicated to the concerned project authorities. The work of preparation of PMP Atlas for Krishna Basin has been initiated. Two JRF's have been posted for the purpose.

(d) International Hydrology Programme Unit (IHP)

The activities of IHP are taken care by Indian National Committee of Hydrology (INCOH) located at NIH Roorkee. IMD is the member of INCOH. The activities of IHP are coordinated by Hydromet Division. Shri N. Y. Apte, Scientist 'F' attended the meeting of Hindu Kush- Hydrological Cycle Observation System (HKH-HYCOS) at International Centre for Integrated Mountain Development(ICIMOD), Kathmandu, Nepal for Development of Flood Information System from 23-25 June 2010 and Dr. (Mrs.) Surinder Kaur, Scientist 'F' attended the 7th meeting of International Coordination Group (ICG)) of Asia Water Cycle Initiative (AWCI) in Tokyo, Japan from 5-6 Oct,2010 under Global Earth Observation System of Systems(GEOSS) which is a regional effort in Asian region.

(e) Storm Analysis Studies

For designing medium and small structures like bridges, culverts, drainage structure etc. depth duration frequency analysis is carried out. For this purpose India have been divided into hydrometeorological homogeneous 7 zones and 26 sub-zones.

For the purpose of railway and road bridges construction a committee has been formed viz, "Flood Estimation Planning & Co-ordination Committee" and the work is carried out jointly by the 4 departments viz, India Meteorological Department (IMD), Central Water Commission (CWC), Research Design Standard Organisation(RDSO), under Ministry of Railway and Ministry of Transport. This study has been carried out for 24 sub-zones and published in the form of CWC's Reports.

An Atlas of State-wise Generalised Isopluvial Maps of India has been prepared in four parts containing 2,5,10,25,50 & 100-year 24-hour return period maps of all states of Indian mainland.

(f) World Bank Funded Hydrology Project

Ministry of Water Resources had conceived hydrological project with the assistance of World Bank. The objective of the project is to generate Reliable, Comprehensive, User Friendly, Quality data base of various hydrological components under Hydrological Information System. The project is planned to be implemented for a period of 6 years. The Hydrology Project Phase - II commenced on 05.04.2006 and its target date of completion is 30.06.2012. IMD is to look after all aspects of Hydrometeorology under the project and assist the 13 participating states to:

i. Establish Hydromet Network by undertaking joint inspection tours for site selection.
ii. Capacity Building of state personals by imparting training in Hydrometeorology.
iii. Validation of the Hydromet Data collected by the states under the project.
iv. Establish data centres in participating states.

Central Hydromet. Observatory (CHO)

A Central Hydromet Observatory is situated at IMD, New Delhi for taking observations and for demonstration as a Model observatory to visitors. During the year 2010 about 2512 students and teachers from various schools/Govt./Private Institutions visited the Central Hydromet Observatory to get familiarization of India Meteorological Department and working of C.H.O. During Commonwealth Games, CHO supplied observatory data to MFI (Meteor France International) to Met. Safdarjung for forecasting of Weather. This practice is still continuing four times a day i.e; at 03, 06, 09, and 12 UTC. to Met. Safdarjung and two times a day i.e; at 03 and 12 UTC to NHAC.

Contribution of Central Water Commission in India

Central Water Commission (CWC) has been entrusted the responsibility of flood forecasting in the country. CWC maintains 878 stations for hydro-meteorological observations and issues flood forecasts for 175 stations in the country. During the year 2010, 7508 forecasts were issued. Out of this 6489 were stage forecast and 1019 inflow forecast to reservoirs. Out of the 7508 forecasts issued, 7369 were found to be within the permissible limits of accuracy. The percentage of accuracy is 98.15%.

Modernisation of Flood Forecasting Network of CWC

In view of requirement of real time flood forecasting for undertaking measures by the State Governments like evacuation of people during floods from flood affected areas to the safer places as well as optimum reservoir operations for mitigating flood damages, CWC has undertaken modernization of its flood forecasting and data collection network. So far, telemetry system has been installed at 221 stations and 2 Earth Receiving Stations have been set up at Jaipur and Burla. During XI Plan, the works are in progress for installation of telemetry system at 222 stations, 1 Earth Receiving Station with new TDMA technology at New Delhi and setting up of 10 Modelling Centres besides 11 Modelling Centres which have already been set up. Under the modernized system, the data collection is being done with sensor-based equipments, transmission of data is done through satellite and VSAT systems, the flood forecasts are formulated using state-of-the-art mathematical model like MIKE-11 and the flood forecasts are disseminated expeditiously to the local administration reducing the human errors and time taken in earlier manual processes. CWC has also planned to install telemetry stations at remaining 234 stations so that the entire network of 175 flood forecasting stations and their Base Stations including rainfall stations is covered.

Classification of Various Flood Situations

Danger level Fixed in consultation with beneficiary, i.e., the concerned State Authorities based on risk to properties in the area.

Warning Level Generally 1 m or as deemed fit below Danger Level fixed in consultation with the beneficiary.

HFL Highest Flood Level-ever recorded

Category of Flood	Criteria	Colour code
Low	When Water Level touches or exceeds the Warning Level	Yellow Bulletin
Moderate	When Water Level touches or exceeds the Danger Level but remains below 0.5 m of HFL	Yellow Bulletin

High	When Water Level is less than previous HFL but within 0.5 m of HFL **even if it is equal to or below danger / warning level**	Orange Bulletin
Unprecedented	When Water Level touches or exceeds previous HFL **even if it is equal to or below danger / warning level**	Red Bulletin

Flood situation in the year 2010

During the period from 15th May to 15th October, seven stations namely Karimgunj on river Kushiyara in Karimgunj district of Assam, Basua on river Kosi in Supaul District of Bihar, Haridwar, Kannauj, Ankinghat, Kanpur on river Ganga in Dehradun District of Uttarakhand, Kannauj District, and Kanpur District respectively of Uttar Pradesh, Moradabad on river Ramganga in Moradabad District of Uttar Pradesh crossed the previously recorded HFL.

(a) Unprecedented Flood Situation

Assam

The river Kushiyara at Karimgunj crossed the previous HFL during the period 1600 hours of 10th June 2010 to 1400 hours of 11th June 2010. It attained a peak level of 16.57 m on 10th June 2010 at 2300 hours which was 2 cm above the previous HFL of 16.55 m observed on 9th September 2007. Afterwards, it fell below the unprecedented flood situation.

Bihar

The river Kosi at Basua in Supaul district of Bihar crossed the previous HFL on 3 occasions on 20th, 21st and 24th August 2010. It attained a peak level of 48.89 m on 20th and 21st August 2010. However on 25th August 2010 at 0700 hours, the river attained a peak level of 49.17 m between 0600 and 0900 hours which was 30 cm above its previous HFL of 48.87 m attained on 11th July 2004.

Uttarakhand

The river Ganga at Haridwar in Dehradun district of Uttarakhand crossed the previous HFL on one occasion on 19th September 2010 between 8 and 10 hours. It attained a peak level of 296.30m between 08 to 10 hours of 19th October 2010 and then fell below the previous HFL. The peak attained at Haridwar was 7 cm above the previous HFL of 296.23 m attained on 02.09.1978.

Uttar Pradesh

The river Ramganga at Moradabad in Moradabad District of Uttar Pradesh crossed the previous HFL of 192.68 m recorded on 03.09.1978 by 2300 hours of 20th September 2010 and attained a peak level of 192.88 m between 02 and 03 hours of 21st September 2010 and then fell. It fell below previous HFL by 0600 hrs of 21st September 2010.

The river Ganga at Kannauj in Kannauj district of Uttar Pradesh crossed the previous HFL of 126.24 m attained on 29th August 1998 by 1400 hours on 23rd September 2010. It attained a peak level of 126.78 m between 0700 and 1200 hours of 27th September 2010. It fell below the previous HFL by 1000 hours on 30th September 2010. The peak attained in this flood was 0.54 m above the previously recorded HFL.

The river Ganga at Ankinghat in Kanpur district of Uttar Pradesh crossed the previous HFL of 124.31 m recorded on 9th September 1978 by 0500 hrs of 26th September 2010. It attained a Peak level of 124.49 m between 05 and 06 hours of 28th September 2010 and fell below the previous HFL by 24 hours of 28th September 2010. The peak attained in this flood was 0.18 m above the previously recorded HFL.

The river Ganga at Kanpur in Kanpur District of Uttar Pradesh crossed the previous HFL of 113.48 m recorded on 2nd September 1967 by 0700 hrs of 25th September 2010. It attained a peak level of 114.075 m between 14 and 18 hours of 29th September 2010 and then started falling. It fell below the previous HFL by 16 hours of 2nd October 2010. The peak attained in this flood was 0.595 m above the previously recorded HFL.

The river Ganga at Kanpur in Kanpur District of Uttar Pradesh crossed the previous HFL of 113.48 m recorded on 2nd September 1967 by 0700 hrs of 25th September 2010. It attained a peak level of 114.075 m between 14 and 18 hours of 29th September 2010 and then started falling. It fell below the previous HFL by 16 hours of 2nd October 2010. The peak attained in this flood was 0.595 m above the previously recorded HFL.

(b) High flood situation

Assam

The river Kushiyara at Karimgunj in Karimgunj District of Assam was flowing in High flood situation during the period 8th June 2010 to 12th June 2010, from 15th to 22nd June 2010 and from 21st to 22nd September 2010.

The river Beki at Road Bridge was in High Flood situation on 27th June 2010,11th July 2010, 18th July 2010 and 21st July 2010.

The river Kopili at Kampur was in High flood situation was in High Flood Situation during the period 10 hours of 10th October 2010 to 05 hours of 11th October 2010.

Bihar

The river Kosi at Basua was in High flood situation on 21st July 2010 to 23rd July, 1st and 2nd August 2010 and from 22nd August 2010 to 27th August 2010. It was again flowing in High Flood Situation on 29th August, 8th and 16th September 2010.

The river Bagmati at Benibad is in High Flood situation from 26th August 2010 to 30th August 2010.

Uttar Pradesh

The river Ghaggra in Elgin Bridge in Barabanki District was flowing in High Flood situation from 25th August 2010 to 27tK August 2010. The river Ghaggra at Ayodhya in Faizabad District was flowing in High Flood situation from 25th August 2010 to 5th September 2010.

The river Yamuna at Mawi was flowing in High Flood Situation on 10th September 2010 and from 21st September to 22nd September 2010.

The river Ramganga at Moradabad and Bareilly was in High Flood Situation from 20th September to 22nd September 2010 and from 20th September to 24th September 2010 respectively. The river Ganga at Kannauj was flowing in High Flood Situation from 27th August 2010 to 3rd September 2010 and from 18th September 2010 to 1st October 2010. The river Ganga at Kanpur was flowing in High Flood Situation from 27th August 2010 to 4th September 2010 and from 19th September 2010 to 3rd October 2010. The river Ganga at Ankinghat was flowing in High Flood Situation from 22nd September 2010 to 1st October 2010. The river Ganga at Dalmau in Rae- Bareilly District was flowing in High Flood Situation from 28th September 2010 to 2nd October 2010.

Uttarakhand

The river Ganga at Rishikesh in Dehradun district was flowing in High Flood Situation on 19th September 2010. The river Ganga at Haridwar was flowing in High Flood Situation on 19th September 2010.

National Capital Territory, Delhi

The river Yamuna at Delhi Railway Bridge was flowing in High Flood Situation on from 22nd September to 23rd September 2010.

(c) Moderate Flood Situation

The rivers in Brahmaputra and its tributaries, Barak, Tista and its tributaries, River Godavari and its tributary of Indravathi and river Krishna and its tributary of Tungabhadra experienced moderate flood situation during the year 2010.

(d) Low Flood Situation

Other than the rivers which experienced moderate flood situation, low floods were also witnessed in Rivers Mahanadi, Burbhalang, Vamsadhara in Orissa and Andhra Pradesh.

Reservoir Inflow Forecast

Most of the reservoir in the country is having very good storage as on the 15th October 2010. During peak floods heavy inflows were received in Narora Barrage on river Ganga and Hathnikund Barrage on river Yamuna. These two barrages have recorded the heaviest releases on record during the spell of floods in September 2010. Other than this, good inflows have been recorded in other reservoirs in Godavari, Krishna, Mahanadi, Tapi basins also.

Formulation and issue of Flood Forecast during 2010

The field Divisions of CWC are responsible for formulation and issue of flood forecasts whenever the river stage is touching or crossing the Warning Level or the inflow exceeds the criteria for issuing the inflow forecast. They formulate the forecast taking into account the flow in the base stations as well as the rainfall in the intervening catchment and the travel time available for the water to reach the downstream areas. The forecasts are then disseminated to concerned beneficiaries through the fastest communication mode. The performance of these forecasts is assessed by having certain criteria for accuracy. In the case of stage, the stage forecast is within permissible limit, if the actual level is within +/- 0.15 m of the predicted stage. In the case of inflow forecasted, the forecast is within permissible limit if the actual inflow attained at the reservoir is within +/- 20% of the forecasted inflow.

During the year 2010, 7508 forecasts were issued. Out of this 6489 were stage forecast and 1019 inflow forecast to reservoirs. Out of the 7508 forecasts issued, 7369 were found to be within the permissible limits of accuracy. The percentage of accuracy is 98.15%. In the case of stage forecast out of 6489 issued, 6393 were found to be within permissible limit with a percentage accuracy of 98.52%. While for inflow forecast, out of 1019 forecast issued 976 were within permissible limit of accuracy with a percentage accuracy of 95.8%.

Maldives

There are no much hydrological issues in the Maldives; only a few lakes or swamps exist here.

Myanmar

(a) Hydrological services

Hydrological Division of DMH is responsible for issuing daily river forecast and flood forecast along 8 major rivers: Ayeyarwady, Chindwin, Sittaung, Thanlwin, Dokehtawady, Bago Shwegyin and Ngawun. Whenever warnings are issued from River Forecasting Section (RFS) of D.M.H, the message is sent to the respective stations by telephone or Single Side Band (SSB) transceiver. As soon as head of the station receive the message of warning, he immediately inform the local authorities and other related departments in order to carry out the necessary action. At the same time the warnings are disseminated through the radio and television as well as through the Newspaper for general public.

RFS of D.M.H is using both simple and advanced techniques for issuing flood warning and bulletin to the users and public, and is also applying empirical models based on single and multiple regression analysis for forecasting peak flood level along Ayeyarwady and Chindwin rivers. The lead time for issuing flood warning is about one to two days for short range forecast and about seven to ten days for long range forecast, especially for deltaic area of Ayeyarwady. Flood usually occurs in each and every year at one river system or another. The occurrences of floods in Myanmar can be generally expressed as 6% in June, 23% in July, 49% in August, 14% in September and 8% in October. According to the previous 45 years' observation, severe flood years were noted as 1973, 1974, 1976, 1979, 1988, 1991, 1997, 2002, 2004 and 2007.

(b) Discharge Measurement

In order to provide runoff data, discharge and sediment discharge measurements are carried out every year at three sites in the selected three rivers by Hydrological Division, Upper Myanmar Division and Lower Myanmar Division. At the year 2010, measurements of discharge, sediment discharge and bed profile were implemented at Sagaing and Pyay for Ayeyarwady river and Monywa for Chindwin River.

(c) Acid Deposition Monitoring

As a national monitoring center of EANET (acid deposition monitoring network of East Asia), DMH is responsible to monitor acid deposition of Yangon rain water. After the installation of Ion chromatograph and Ultra pure water production system in August 2009 with the support of JICA, the Laboratory of DMH has been able to analyze the ion contents such as Cation NH_4^+, Na^+, K^+,Ca^{2+},Mg^{2+} and Anion SO_4^{2-}, NO_3^-,Cl, in addition to pH and EC. During the end of October 2010, the experts from Asia Center for Air Pollution Research - ACAP(former ADORC) has visited to the laboratory of DMH and they implemented the activities in accordance with the objectives of the mission: to exchange views and information on the institutional arrangement on the acid deposition monitoring of EANET in Myanmar; to discuss and exchange information on technical issues, especially QA/QC activities and data reporting, including check on condition of analytical instrument; to discuss the maintenance of sampling instruments, and Others.

(d) GIS application in Hydrology

GIS application in meteorology and hydrology is initial stage at the present. The government has invested about 100 million Kyats for establishment of GIS application in DMH. During 2010, DMH has developed flood hazard analysis and flood simulation by using IFAS for upper parts of Chindwin river, Ayeyarwady river and Shwegyin river. Development of river catalogue for Chindwin river basin is now in processing. Moreover, DMH is also implementing the flood hazard map for Bago township at Bago river basin by technical assistance by ICHARM and financial support by JICA.

(e) Myanmar National Committee for International Hydrological Programme

By the organization of DMH, Myanmar National Committee for International Hydrological Programme was formed in 2003 and the government assigned the Minister for Transport as Chairman, Deputy Minister for Transport as Vice Chairman and Director General of DMH as the Secretary of the National Committee. Chairmen of Yangon and Mandalay City Development Committees and Heads of Departments related to hydrology are members of the committee. Under the National Committee, five Working Groups are formed to implement research and task according to the guideline of International Hydrological Programme and also to participate and contribute in the meeting conducted by National Committee. Up to 2010, Myanmar National Committee for International Hydrological Programme had conducted five meetings including paper reading session.

(f) Occurrences of Floods in 2010

During 2010, there were floods in Dokhtawady river, Bago river and Kaledon river. In August, flood occurred at Myitnge in Dokhtawady river and it exceeded the danger level by !4 foot and stayed 3 days above danger level. The another flood at August was at Bago in Bago river and it exceeded the danger level by !4 foot and stayed 2 days above danger level. This flood caused the inundation about 2-6 feet at 9 wards at Bago and also flooded 2 feet depth on highway road between milepost No. 48/7 and 49/2 but there was no remarkable destruction. This flood was 7th highest flood at Bago by historical record (1965-2010). In October, the flood occurred at Kyauktaw of Kaledon and it exceeded about 1 foot above danger level and stayed about 1 day above danger level. This flood was also 6th highest flood at Kyauktaw by the historical record (1987-2010). This flood affected the 50 houses and 200 acres of paddy field by inundation. During October, another flood occurred at Myitnge in Dokhtawady river and this was second flood for Dokhtawady river for the year 2010. It exceeded *VA* feet above danger level and stayed 8 days above danger level. It inundated some roads, houses and agriculture crops from low land area. DMH has issued (4) flood warnings and (14) flood bulletins during 2010 flood season. At the year 2010, there were less flooding by historical record.

No flood occurred along Ayeyarwaddy, Chindwin, Sittoung, Thanlwin and Shwegyin rivers. But the water level of Hinthada, which is the lower station of Ayeyarwady river, reached 10 cm below danger level and the water level of Homalin, which is the upstream of Chindwin river reached 60 cm (about 2 feet) below danger level. Similarly, the water level of Hpa-an of Thanlwin river reached 30 cm (about 1 foot) below the danger level.

Apart from river flood, inland flood and severe landslide occurred at Buthitaung Township of Rakhine State, due to the continuous heavy rain which amounted (35.53) inches within (6) days during the second dekad of June 2010. It caused (76) death toll and affected (29) Wards and villages in Buthitaung Township.

The peculiar urban floods were also encountered in Central Myanmar during the first dekad of October, due to the locally heavy fall in the areas for (2) to (3) days, caused by the formation of depression in the North Bay. The rain enhanced overflowing of the small streams and inundated (2) to (5) feet in low land areas and streets of Mandalay and villages and wards of nearby townships.

Oman

The Ministry of Regional Municipalities and Water Resources is responsible for the hydrological measurements and the management of the water resources for the Country. During the year 2010, a measurements of all hydrological parameters were measured through (4681 monitoring stations).Station includes (rain gauges, wadi gauges, flow peaks, aflaj, springs and water level) in addition to 32 dams distributed all over the Sultanate.

(a) Rainfall

There are 304 rain gauges, of which 219 Automatic and 85 of standard type. About 30 of these rainfall stations are fitted with telemetry using GSM modems. During the year 2010 the coastal area of the country was exposed with exceptional rainfall as a result of tropical cyclone Phet. The maximum annual accumulated rainfall was 603 mm in Quryat, while 472 mm were recorded in Al-Sharqyah region. Mhoot in AlWusta region recored 68 mm. The other areas of the country recorded rainfall lesser the annual average.

(b) Wadi flow and floods

There are 137 wadi gauge stations to measure wadi flow and to compute flood volumes. In addition to 25 stations to measure the peak height of the wadi flow. The year 2010 is considered the largest year where high discharge rates were recorded since 1997. The total flood volumes during 2010 (712 Mm^3) which is about 3 times of the annual average. The highest recorded was (390 Mm^3) in Muscat region.

(c) Groundwater level measurements

The Ministry of Regional Municipalities & Water resources operate a network of 2107 groundwater wells measured for water levels. 1700 of them are measured every month and the rest measured every three months. Analysis of data showed that as a result of increase in recharge there is a gradual increase in water levels in most areas of the Sultanate, particularly for the shallow alluvium aquifer which represents the main supplied source of irrigation water.

(d) Recharge Dams

There are 3 types of Dams in Oman. 61 surface retention dams, 32 recharge dams and 11 flood protections dams. On the 32 recharge dams stations for measuring flow and sedimentation. A total of 78.5 Mm^3 was retained by recharge dams during 2010. In addition to this the Wadi Dayqah dam in Muscat region a total of 133 Mm^3.

(e) Events

The Ministry arranged 2 main water resources related conferences during 2010 these were:

- WSTA 9th Gulf Water Conference, Sultanate of Oman, 22-25 March, 2010 Water Sustainability in the GCC Countries, The Need for a Socio-economic and Environmental Definition.
- Training Workshop on Application of GIS and RS in Water Resources Management 19-22 December 2010, Muscat, Sultanate of Oman

(f) Achievements

Some of the main Ministry achievements are listed below:

- The Ministry has completed the work of Wadi Dhaiqa Dam its one of the biggest dams in Oman the storage capacity of it 100 Mm3, Water of this dam is allocated for agriculture and drinking. During June of 2010 as a result of Phet cyclone the dam exceeded its maximum capacity and overflowed.
- The Ministry has also completed 5 other dams for groundwater recharge, flood protection and storage. In addition to that there are 7 other dams under construction during this year.
- Several studies have been completed during the year including; dams construction, study of the increase groundwater level in some part of the country, study the water situation, use of gray water in desert, drilling of exploration wells, rehabilitation of monitoring wells, wadi gauges and rain gauges effected by cyclone.
- In surface water the ministry completed many studies including; identification of flood prone areas, preparation of hydrogeological map for the whole country.

(c) Training:

The Ministry of Regional Municipalities and Water Resources is very keen in training the staff. During the year 2010 the Ministry arranged for both local and overseas training and workshops:

(d) Future Plans:

The Ministry of Regional Municipalities and Water Resources is working on implementation of the five years plan starting from this year. The plans include exploration of new water resources in the country through drilling. Construction of more dams to store water and recharge the groundwater aquifers. Plans also include expansion of hydrological network and upgrade of automatic stations and including the telemetry systems. The other Ministry plans includes:

- Secure clean and safe drinking water.
- Reduce the water balance deficit.

- Implement water management policy, particularly in agriculture sector.
- Implement the Integrated Water Resources Management principles for sustainable water use.
- Protect water quality as a part of sustainable environmental approach.
- Encourage the investments in Non-Conventional water projects (Desalination and Wastewater treatment plants).

Pakistan

2010 Super Floods:

Pakistan suffered from history's worst extremely high floods during 2010-Monsoon season. Heavy rainfall spell during 28-30 July, 2010 in the north of Pakistan especially in Khyber Pukhtunkhwa (KPK) province and adjoining upper Punjab caused firstly severe flash flooding and then history's extreme high riverine flooding in Pakistan. The second wave of the flood in the Indus River and its tributaries was caused by the rainfall spell which occurred during 5-9 August 2010.

Losses & Damages (Source: NDMA, Pakistan)	
Deaths	1,985
Injured	2,946
Houses damaged	1,744,471
Population affected	20,184,550
Crop areas (Hectares)	2,244,644
Districts Affected	78
In terms of the number of people affected, the United Nations rated the flood as the greatest humanitarian	

PMD issued weather forecasts for these precipitation events a few days earlier. The second flood wave aggravated the already flooded fields of Punjab, KPK, Sindh and Balochistan provinces. This second flood wave practically merged with the first flood wave below Taunsa barrage (on the Indus River in Punjab) and created havoc in the surrounding areas and downstream Taunsa and the phenomenon is referred to as the "2010 Super Flood." The flood affected several areas in all provinces.

The riverine floods were predicted reasonably well by PMD‘s Flood Forecasting Division (FFD).

WMO and ESCAP took following actions with respect to Floods in Pakistan during 2010

(i) Establishment of Task Force on Pakistan Floods on 27 th August, 2010

WMO has established a Secretariat Task Force on the Pakistan floods at WMO on 27th August, 2010 which is led by senior officials of WMO.

(ii) WMO ad hoc liaison office at PMD, Islamabad 14 th October to 13 th November, 2010

In order to address hydrometeorological disaster risk reduction (DRR) challenges in Pakistan, WMO has offered its assistance to PMD. WMO ad hoc liaison office was opened at PMD Headquarters, Islamabad with Dr. Jaser Rabadi (WMO Representative for West Asia) to work as liaison officer from 14th October to 13th November, 2010.

(iii) WMO Expert Mission to Pakistan 4 th to 8 th November, 2010

In order to make assessment of the damages to hydrometeorological infrastructure and to further strengthen the hydrometeorological system in Pakistan, a six member WMO fact-finding and needs-assessment Mission comprising of experts in hydrology and DRR from UNESCAP, WMO, JMA, USA visited Pakistan from 4th to 8th November, 2010

In light of the recommendations of the WMO Expert Mission, it has been proposed to restore and strengthen the capacities of PMD with phased approach including: (i) short term needs (within less than one year), (ii) medium term needs (2-3 years) and (iii) long term needs (5-10 years).

Some of the main items of the recommendations/proposal include:

- Restoration of damaged meteorological and hydrological observational network;
- Establishment of around ten (10) localized Flash Flood Warning Systems for small rivers and streams (replica of Flash Flood Warning System for Nullah Lai basin (twin cities of Rawalpindi and Islamabad);
- Establishment of Regional Flood Forecasting Centers in KPK, Sindh and Balochistan provinces;
- Strengthening of Radar Network to give radar coverage to the whole country;
- Improvement in hydrological/flood forecast model and NWP model;
- Capacity building/human resource development.

The report of the WMO Expert Mission will be sent to the potential donors by WMO Secretariat for consideration of the support needed in the identified areas as per recommendations of the Mission in order to affectively address hydrometeorological DRR challenges in Pakistan.

(iv) UNESCAP Expert Group Meeting on Flood Risk Reduction in Islamabad-Pakistan on 9-10 November, 2010

In wake of 2010-Super Floods in Pakistan, ESCAP organized a one-day preparatory Meeting in Nanjing, China in September, 2010 for hosting a High-level Expert Group Meeting on Pakistan Floods. Consequently, the High-level ESCAP Expert Group Meeting on Reducing Flood Risk Reduction was held in Islamabad-Pakistan on 9-10 November, 2010 (in collaboration with NDMA, Pakistan). WMO Expert Mission reported to the meeting on the outcomes of the mission.

As a follow-up of this ESCAP Expert Group Meeting, PMD and SUPARCO are co-hosting a an ESCAP Workshop on Developing Capacity Resilience to Water-related Disasters in Pakistan through Space Application & Flood Risk Management in Islamabad-Pakistan during 1-4 March, 2011.

Sri Lanka

In Sri Lanka, the Department of Irrigation is the responsible agency for issuing warnings/advisories in floods. The hydrology division of the Department of Irrigation maintains 33 River Gauging stations which records hourly river water levels and equipped with manual rain gauges which records 3 hourly rainfalls. In addition, another 40 river gauges have been installed at tributaries and record daytime water levels which are read on contract basis. 19 Raingauge stations are also maintained by the department of irrigations and daily rainfall are measured by contract basis and the reports are collected monthly.

Special attention is paid to re-establish the river gauge stations and a few rainfall stations in the north and east. Computer generated hydrology data are provided for the development projects in these areas where data has been practically not available due to the unsettled situation prevailed in last 30 years.

There is ongoing project funded by World Bank (DSWRPP component in HMIS) to upgrade the existing hydromet stations and to establish new stations with automatic sensors with on time communication capacity to transfer the data to the Head office, Colombo. Under this project 50 gauging stations are to be newly installed of which 40 are equipped with discharge, river level and precipitation sensors.

Thailand

Office of Hydrology and Water Management, Royal Irrigation Department (RID) has responsibility of meteorological and hydrological data in the criteria of processing the data for studying or forecasting. There are 2,294 rain gauge stations and 522 stream flow gauge stations installed throughout Thailand. Flood management plans were set in terms of monitoring, prediction and warning by establishment of Water Watch and Monitoring System for Warning Center (WMSC) to monitor flood situations on a 24 hours basis. The state-of-art technologies were established, such as telemetry and flood forecasting systems. There has installed and operated about 208 telemetric stations in 13 of 25 main river basins have telemetry systems installed for water resources management and flood prevention and mitigation. RID collaborates with other national agencies (TMD, DWR, DDPM) to implement the plan for coping with local flood protection in economic zones where severe flood may occur through meetings and data sharing.

Activities of WMO

(a) WMO Flood Forecasting Initiative (FFI)

WMO Flood Forecasting Initiative (FFI) progressed with regard to the specific activities that are outlined in the Strategy and Action Plan of the Initiative, especially with regard to establishing Flash Flood Guidance Systems. The Flash Flood Guidance System project is of high importance for the region. In RA-II it is presently fully operational in the Mekong River Basin.

A workshop on the Strategy and Action Plan (SAP) on FFI was held in December 2009 in Geneva. That workshop aimed at the documentation of priority activities on national level to implement that SAP. The RA-II WGH reviewed the outcomes of the workshop and identified the following areas to be highly relevant for the region:

- Wide promotion of the Activity Plan - together with the Strategy and Action Plan - to NMHSs;
- Facilitated national consultations to sensitize National Meteorological and Hydrological Services for an improved cooperation. WMO is seen as the lead agency to facilitate these consultation
- Integration of the Plan in the hydrological domain of WMO's Tropical Cyclone Programme such as in the Working Group on Hydrology of the Typhoon Committee;
- Prepare a training module for the use of the SAP and Activity Plan in NMHSs;
- Fostering twinning agreements between NMHSs with the objective of sharing know-how and technology in improved cooperation and the development and use of advanced forecasting products and their dissemination.

Activities under WMO-FFI to be implemented in 2011 and onwards include:

- Intercomparison of forecasting models currently in use in the various WMO Regions, to help the countries in identifying the most suitable models to serve their requirements;
- Development of a framework for the assessment of service delivery capabilities of hydrological services in flood forecasting.

In an aim to make best use of meteorological forecasting products for hydrological purposes it is generally recognized in RA-II that QPE/QPF products are very important to improve hydrological service delivery. However, QPE/QPF has not been extensively used in real-time hydrological modeling maybe because: its uncertainty issues and because QPE/QPF products were developed for meteorological, not hydrologic purposes. QPE and QPF could be strengthened through enhanced coupled modeling and an end-to-end evaluation on QPE/QPF quality and impacts on flood and streamflow products for basins of diverse size and topography. To improve QPE and QPF, hydrologists could be encouraged to work with QPE/QPF groups to ensure that hydrological requirements for precipitation (QPE/QPF) can be considered.

The Associated Programme on Flood Management (APFM) that promotes the concept of Integrated Flood Management practices has progressed largely and in particular the development of Tools on a wide variety of flood management issues and the Help Desk established under the programme since June 2009.

(b) Regional activities

Thrust is to implement the RA-II (Asia) Strategic Plan for the Enhancement of National Meteorological and Hydrologic Services at the level of the services. Further, technical cooperation activities have been undertaken with a number of countries in the region, notably the support that WMO provides to the government of Pakistan after the disastrous floods in the monsoon season of 2010.

Progress has been made in the implementation of WHYCOS projects, and in particular the Mekong-HYCOS and the Hindu Kush Himalayan (HKH) HYCOS projects that are currently implemented. The objective of both HYCOS projects is the establishment of regional flood information systems.

The Coastal Inundation Forecasting Demonstration Project (CIFDP) is in full development with the objective to improve capacity for coastal flood forecasting and management (including deltas and estuaries. Major output of this project will be an end-to- end integrated software, coupling meteorological (tropical cyclone), hydrological (river) and ocean (storm surge) forecasting models to meet institutional end-users requirements.

The project aims to enhance NMHSs capabilities to produce and provide coastal inundation forecasting and warning services and to improving interactions between NMHSs, partners and end-users (Government, Disaster Management and Civil protection Agencies, Media, etc). Bangladesh has been chosen as the regional candidate to implement this demonstration project. Disaster Management Regulatory Framework, Section 11: Disaster Management Plans, and Standing Order Disaster, 2010) in the form of Response Plan for Cyclone Season. This response plan aims at eliminating or mitigating the cyclone risk by undertaking coordinated activities for the prevention of, preparation for, response to and recoveries from the impact of cyclone.

(c) Theme areas of the RAII WGH

With regard to achieve the objectives of the RAII WGH, the following theme areas are currently under implementation and first draft reports for each of these areas are expected by end of April. The theme areas are:

- ❖ Improving Institutional Capacity including the implementation of the RA II Strategic Plan for NHSs
- ❖ Disaster Mitigation – Implementation of the WMO Flood Forecasting Initiative including Flash Flood Forecasting Capabilities
- ❖ Water Resources Assessment, Availability and Use (Surface water and groundwater)
- ❖ Hydrological responses to climate variability and change and promotion of the use of climate information by water managers
- ❖ Regional exchange of hydrological data and information including WHYCOS and contributions of regional aspects of INFOHYDRO

(d) Regional Cooperation

As a major step forward, the WGH during its session in November 2010 decided to establish close links to the WGH of the Typhoon Committee. It was agreed that the RAII WGH would nominate its chair to represent activities of the WGH and likewise that the results of the proposed joint working areas be communicated during the 43rd session of the TC in January 2011. The four areas where joint activities are envisaged are documented below.

- Urban Flood Risk Management (UFRM)
- Flash Flood/Debris Flow/landslide Forecasting/Warning
- Assessment of the Variability of Water Resources in a Changing Climate
- Drought Monitoring and Forecasting based on Space based Information

(e) Recommendations

Recognizing the importance of hydrological forecasting in connection to activities of the PTC it is recommended that the PTC

- Considers the establishment of Working Groups in analogy to the Typhoon Committee (TC) with active involvements of hydrologists and seeks to enhance collaboration with the TC;
- Establishes links with the RAII WGH
- Develops a Requirements Document for hydrological services in support of PTC activities

1.3 DISASTER PREVENTION AND PREPAREDNESS

Bangladesh

Bangladesh is most vulnerable to recurring natural disasters including cyclone and the associated storm surge. These particular disasters are known to disrupt people's lives, livelihood, and devastable development momentum in some part of the country. Over the past few years, climate change has added significant perturbation in the hydrological cycle and increased the frequency and intensity of the hydro-meteorological disasters such as the cyclones. This reaches to the extent where the international community has placed Bangladesh as the worst victim of climate-induced disaster.

In view of the cyclone season, the government intends to implement the provisions of the National plan for disaster Management, 2010 (Section 10: Disaster Management Regulatory Framework, section 11: Disaster Management plans, and standing order Disaster, 2010) in the form of Response Plan for Cyclone Season. This response plan aims at eliminating or mitigating the cyclone risk by undertaking coordinated activities for the prevention of, preparation for, response to and recoveries from the impact of cyclone.

India

Cyclone Warning Services for disaster management

The extensive coastal belts of India are exposed to cyclonic storms, which originate in the Bay of Bengal and the Arabian Sea every year. These cyclones, which are accompanied with very heavy to extremely heavy rain, gales and storm surges cause heavy loss of human lives and cattle. They also cause extensive damage to standing crops and properties.

It is the endeavour of IMD to minimise the loss of human lives and damage to properties due to tropical cyclones by providing early warnings against the tropical cyclones. Cyclone warning is one of the most important function of the IMD and it was the first service undertaken by the department in1865. The cyclone warnings are provided by the IMD from the Area Cyclone Warning Centres (ACWCs) at Kolkata, Chennai & Mumbai and Cyclone Warning Centres (CWCs) at Vishakhapatnam, Bhubaneswar and Ahmedabad.

The complete Cyclone Warning Programme in the country is supervised by the Cyclone Warning Division (CWD) at Head Quarter Office of the Director General of Meteorology at New Delhi. The CWD monitors the cyclonic disturbance both in the Bay of Bengal and Arabian Sea and advises the Government of India at the Apex level. Information on cyclone warnings is furnished on a real time basis to the Control Room in the Ministry of Home Affairs, Government of India, besides other Ministries & Departments of the Central Government. This Division provides cyclone warning bulletins to Doordarshan and All India Radio (AIR) station at New Delhi for inclusion in the National broadcast/telecast. Bulletins are also provided to other electronic and print media and concerned state govts. The Deputy Director General of Meteorology (Cyclone Warning) and Deputy Director General of Meteorology (Weather Forecasting) Pune monitor technical aspects and review the standard practices in the area of cyclone forecasting.

Cyclone warning bulletins

The following is the list of bulletins and warnings issued by ACWCs/CWCs for their respective areas of responsibility:

(1) Sea area bulletins for ships plying in High Seas.
(2) Coastal weather bulletins for ships plying in coastal waters.
(3) Bulletins for Global Marine Distress and Safety System

(GMDSS).
Broadcast throughIndian Coastal Earth Stations.
(4) Bulletins for Indian Navy.
(5) Port Warnings.
(6) Fisheries Warnings.
(7) Four stage warnings for Central and State Govt. Officials.
(8) Bulletins for broadcast through AIRs for general public.
(9) Warning for registered users.
(10) Bulletins for press.
(11) Warnings for Aviation (issued by concerned Aviation MeteorologicalOffices).
(12) Bulletins for ships in the high seas through Navtex Coastal Radio Stations.

The cyclone warnings are issued to state government officials in four stages. The **First Stage** warning known as **"PRE CYCLONE WATCH"** issued 72 hours in advance contains early warning about the development of a cyclonic disturbance in the north Indian Ocean, its likely intensification into a tropical cyclone and the coastal belt likely to experience adverse weather. This early warning bulletin is issued by the Director General of Meteorology himself and is addressed to the Cabinet Secretary and other senior officers of the Government of India including the Chief Secretaries of concerned maritime states.

The **Second Stage** warning known as **"CYCLONE ALERT"** is issued at least 48 hrs in advance of the expected commencement of adverse weather over the coastal areas. It contains information on the location and intensity of the storm likely direction of its movement, intensification, coastal districts likely to experience adverse weather and advice to fishermen, general public, media and disaster managers. This is issued by the concerned ACWCs/CWCs and CWD at HQ.

The **Third Stage** warning known as **"CYCLONE WARNING"** issued at least 24 hours in advance of the expected commencement of adverse weather over the coastal areas. Landfall point is forecast at this stage. These warnings are issued by ACWCs/CWCs/and CWD at HQ at 3 hourly interval giving the latest position of cyclone and its intensity, likely point and time of landfall, associated heavy rainfall, strong wind and storm surge alongwith their impact and advice to general public, media, fishermen and disaster managers.

The **Fourth Stage** of warning known as **"POST LANDFALL OUTLOOK"** is issued by the concerned ACWCs/CWCs/and CWD at HQ at least 12 hours in advance of expected time of landfall. It gives likely direction of movement of the cyclone after its landfall and adverse weather likely to be experienced in the interior areas.

Different colour codes as mentioned below are being used since post monsoon season of 2006 the different stages of the cyclone warning bulletins as desired by the National Disaster Management.

Stage of warning	**Colour code**
Cyclone Alert	**Yellow.**
Cyclone Warning	**Orange.**
Post landfall out look	**Red.**

During disturbed weather over the Bay of Bengal and Arabian Sea, the ports likely to be affected are warned by concerned ACWCs/CWCs by advising the port authorities through port warnings to hoist appropriate Storm Warning Signals. The Department also issues **"Fleet Forecast"** for Indian Navy, Coastal Bulletins for Indian coastal areas covering up to 75 km from the coast line and sea area bulletins for the sea areas beyond 75 km. The special warnings are issued for fishermen four times a day in normal weather and every three hourly in accordance with the four stage warning in case of disturbed weather.

The general public, the coastal residents and fishermen are warned through State Government officials and broadcast of warnings through All India Radio and National Television (Doordarshan) telecast programmes in national and regional hook-up. A system of warning dissemination for fishermen through World Space Digital Based radio receivers is being planned.

(b) Organisational structure of disaster management in India

It is a three tier system:

- National Level
  - NDMA (National Disaster Management Authority)
  - NDM (MHA)
  - NIDM (National Institute of Disaster Management)
- State level
- District Level

(i) Role & Responsibilities of NDMA

NDMA as the apex body is mandated to lay down the policies, plans and guidelines for Disaster Management to ensure timely and effective response to disasters.

Towards this, it has the following responsibilities:

- Lay down policies on disaster management;
- Approve the National Plan;
- Approve plans prepared by the Ministries or Departments of the Government of India in accordance with the National Plan;
- Lay down guidelines to be followed by the State Authorities in drawing up the State Plan;
- Lay down guidelines to be followed by the different Ministries or Departments of the Government of India for the Purpose of integrating the measures for prevention of disaster or the mitigation of its effects in their development plans and projects;
- Coordinate the enforcement and implementation of the policy and plan for disaster management;
- Recommend provision of funds for the purpose of mitigation;
- Provide such support to other countries affected by major disasters as may be determined by the Central Government;
- Take such other measures for the prevention of disaster, or the mitigation, or preparedness and capacity building for dealing with the threatening disaster situation or disaster as it may consider necessary;

Lay down broad policies and guidelines for the functioning of the National Institute of Disaster Management

(ii) Role & Responsibilities of NIDM

- To undertake quality research covering both natural and human induced disasters, with a multi-hazard approach
- To work as a National Resource Center for the central and state governments in the country through effective knowledge management and sharing of best practices.
- To professionalize disaster risk reduction and emergency management in India and other neighboring countries by developing an independent cadre of professionally trained emergency and mitigation managers.
- To promote formal training and education for disaster management in India and in the region
- To build working partnerships with the Government, universities, NGOs, corporate bodies and other national and international Institutes of eminence.
- To link learning and action by building a synergy between institutions and professionals in the sector.

(iii) National Disaster Management

- National Crisis Management Committee (NCMC)
    - o NCMC will issue guidelines from time to time as required for effective response to natural disasters. All Ministries/Departments/Agencies at the national level shall comply with the instructions of NCMC.
- Ministry of Home Affairs (MHA)
    - o The Ministry of Home Affairs is the nodal agency at the National level for coordination of response and relief in the wake of natural disasters(except drought, pest attack & hailstorm). MHA will provide financial and logistic support to the State Governments, keeping in view, their resources, the severity of the natural disaster and the capacity of the State Governments to respond in a particular situation.
- National Executive Committee (NEC)
    - o The Disaster Management Act stipulates that the NEC under the Union Home Secretary will 'coordinate response in the event of any threatening disaster situation or disaster". NEC may give directions to the concerned Ministries/Departments of the Govt. of India, the State Governments and the State Authorities regarding measures to be taken by them in response to any specific threatening disaster situation or disaster.
- Other Central Ministries/Departments
    - o The other concerned Central Ministries/Departments/Organisations will render Emergency Support Functions (ESF) wherever Central intervention and support are needed by the State Governments.

(c) National Cyclone Risk Mitigation Project (NCRMP) -

The National Cyclone Risk Mitigation Project (NCRMP) is to be implementation in all the 13 cyclone affected coastal states and Union Territories (UTs) of the country, with financial assistance from the World Bank. It has four major components.

Component A: This component is aimed at improvement of early warning dissemination system by strengthening the last mile connectivity (LMC) of Cyclone warning and advisories from the authority to communities and to interact with the communities by the authority in the event of a cyclone affecting an area.

Component B: This component will have several sub-components like construction of cyclone shelters, connecting roads & bridges, saline embankments, coastal canals and plantation/re-generation of mangroves forests, shelter belt plantation etc.

Component C: This component includes Technical Assistance for hazard risk management and capacity building.

Component D: This component is related to project management and monitoring. The project will be implemented in a phased manner beginning with two highly cyclone vulnerable states like Andhra Pradesh and Orissa for which World Bank appraisal has already been completed. Implementation of the Project will lead to reduction of cyclone vulnerability of coastal States and UTs further. The Project will be implemented in a phased manner with the first phase beginning in 2010 and planned to be completed in 2015.

(d) National Disaster Management Guidelines — Management of Cyclones

National Disaster Management Guidelines — Management of Cyclones (hereafter called cyclone guidelines), has been formulated taking the concerned Central Ministries, Departments, States and UTs on board. The process also included wide consultations with scientific technical institutions, academics, technocrats and humanitarian organizations.

The formulation of these guidelines is an important step towards the development of plans for the management of cyclones and their attendant disasters. These have been prepared to provide guidance to the central Ministries, Departments and State authorities for the preparation of their disaster management plans. These guidelines call for a proactive, participatory, well structured, fail safe multidisciplinary and multi-sector approach at various levels. Information in detail can be obtained from NDMA website, http://www.ndma.gov.in

(e) National Disaster Response Force (NDRF)

As mandated by The Disaster Management Act, 2005 the National Disaster Management Authority, Govt. of India has constituted the National Disaster Response Force (NDRF), for the purpose of specialized response to a threatening disaster situation or disaster. Presently NDRF comprises eight battalions with further expansion to be considered in due course. Seven of these battalions have been positioned at nine different locations in the country based on the vulnerability profile. This force is being trained and equipped as a multi-skilled, high tech. force with state-of-the-art equipments.

(f) Public Awareness

In its endeavour to spread awareness amongst the masses, NDMA has launched Public Awareness campaigns through electronic and print media since November 2006. The focus was on building appropriate environment for disaster management and creating a high level of impact on the target audience. NDMA's awareness campaign is aimed at building individual capacity on the levels of risk perception, preparedness, self reliance and self confidence. Mode used are popular T.V. Channels, All India Radio and popular private FM Channels and Print Media.

(g) Mock Exercise

To facilitate the State Governments in reviewing the adequacy and efficacy of the State and Disaster Management Plans and to identify gaps in resources and systems, NDMA, in co-ordination with the vulnerable states, has embarked on conducting Mock Exercises on various natural (including cyclone) and man-made disaster. This will also help in inculcating culture of preparedness.

(h) Disaster Awareness in School Curriculum

Disaster management as a subject in Social Sciences has been introduced in the school curriculum for **Class VIII** & **IX.** The Central Board of Secondary Education (CBSE) which has introduced the curriculum runs a very large number of schools throughout the country and the course curriculum is invariably followed by the State Boards of Secondary Education.

Maldives

Maldives Meteorological Service is the authoritative organization in the country for issuing advisories and warnings related to meteorological, hydrological, tectonic and oceanographic disasters. To accomplish these tasks, MMS has prepared the Standard Operating Procedures (SOP) to act upon any likely event of meteorological, hydrological, tectonic and oceanographic disasters. MMS acquired a High Resolution Satellite Image Receiving System, Doppler Weather Radar, number of Automatic Weather Stations, broadband and short-period seismometers within the framework of establishing a National Multi-Hazard Early Warning System. Our sea level network comprises of three tide gauges in *Hanimaadhoo, Male'* and *Gan* to monitor low frequency changes in sea level associated with global sea level rise or decadal climate variations like other gauges in GLOSS network. They have been upgraded with more sensors such as radar/ pressure/ float based water level sensors, and the reference level float switch sensors and with these improvements, it shall even detect any slight variations in sea level due to a tsunami wave. The National Multi-Hazard Early Warning Centre (NMHEWC) of MMS conducts awareness programs targeting at public and students in different atolls periodically.

Warnings and advisories

The National Multi-Hazard Early Warning Centre issued timely and accurate severe weather warnings and advisories, disseminated them to the public through mass media and through its website.

Apart from severe weather or tropical cyclone warnings, earthquake or tsunami warning reports received from Pacific Tsunami Warning Centre, Japan Meteorological Agency and Indian Tsunami Early Warning Centre through internet and GTS were also disseminated to public satisfactorily in time.

Under the Standard Operating Procedures (SOP) of the Department, the warnings were additionally dispatched through cooperate SMS and Hotlines to designated authorities.

Myanmar

The main DPP measures of DMH are on two main components (1) Issuance of Early Warning from Multi-Hazards Early Warning Center(MEWC) (2) Public Education and Awareness Program.

(a) Issuance of Early Warning

The warnings issued by MEWC are as follows:

a) Storm warning, Storm surge warning
b) Strong wind warning
c) Heavy rainfall warning
d) Untimely rainfall warning
e) Flood warning
f) Minimum water level alert
g) Significant rise of water level
h) Tsunami warning

(b) Public Education and Awareness Program

Myanmar was actively involved in Indian Ocean Wave - 2009 Exercise conducted on 14 October 2009 (World Disaster Reduction Day) with Functional Exercise, including evacuation. It was conducted at tsunami prone coastal areas with the close cooperation of Local Authorities and DMH as below:

i. Palungtonetone village, Kawthaung Township, Tanintharyi Region
ii. Daminseik (Setse) village, Mon State
iii. Letkhukkone village, Kunchiankone Township, Yangon Region
iv. Leyinkwin village, Pinsalu Township, Ayeyarwady Region
v Sanpya Ward, Sittwe, Rakhine State

Apart from this kind of drill, DMH has close collaboration with Relief and resettlement Department (RRD), the focal point of Disaster Management. DMH Staff always participate as trainers in Disaster Management trainings, conducted by RRD. Regarding public education, 6 articles on weather phenomena and behavior of storm were printed in State media, *New light of*

Myanmar and the *Mirror* during 2010. Moreover, the functions and activities of Multi-hazard Early Warning Center also appeared in those newspapers as interview.

(c) Preparation of Project Proposals

DMH actively participated in preparation of Myanmar action plan on disaster risk reduction (MAPDRR), and under this plan DMH has prepared priority project proposals, which are to be implemented with cooperation of other related agencies as below:

a) Improved Meteorological, Hydrological and Seismological observation and forecasting (duration -18 months, estimated budget- 2130 million Kyats)
b) Up-gradation of Early Warning Center (duration- 24 months, estimated budget - 1595 million Kyats)
c) Risk Assessment of Myanmar (duration - 18 months, estimated budget – 180 million Kyats)
d) Hazard Maps of Myanmar (duration - 36 months, estimated budget - 305 million Kyats)
e) Multi-Hazard end to end early warning dissemination system (estimated budget - 175 million Kyats)

Oman

The National Committee of Civil Defense is the government unit responsible for disaster preparedness and response. It is chaired by H.E the Inspector General for Police and Customs (the equivalent of the minister of interior in most countries). It has 21 members from government and nongovernment agencies. The Committee is responsible for formulating national policies and strategies in regard to risk prevention and preparedness. The National Committee for Civil Defence (NCCD) keeps an excellent coordination and cooperation with the Meteorology department. During Phet, the national plan for disaster management was activated. Figure 1 below shows the main sectors which were activated to run operations during Phet.

Figure 1: Main NCCD sectors during Phet.

Table 1 below shows a summary of major NCCD operations and statistics during Phet.

Table 1: Tropical Cyclone Phet NCCD Statistics

1	Shelters	91
2	Number of people using shelters	12 870 people
3	Logistical support	23843
4	Emergency medical response	16 hospitals and health center
5	The number of deaths	16 people
6	The number of missing	2 people
7	The number of flights	3558
8	The number of Land Trips	17
9	The number of Communication stations affected	1997
10	The number of routes affected	59

(a) Main Events/Activities organized by the Executive Office of the NCDD

1. The executive office of the NCCD hosted an international workshop on information management in crises and emergencies.
2. A workshop on how to deal with radiation, chemical and biological accidents.
3. Symposium on the national system for crisis management with participation from ministries focal points and other related government agencies.
4. Training program for representatives of government agencies and coordinators of subcommittees on how to prepare contingency plans and crisis management in cooperation with a number of experts and specialists.
5. Participation in the crisis and disaster management course organized by the Royal Air Force of Oman in cooperation with the University of Bournemouth.
6. Participation in the planning for crisis and disaster management organized by the University of Bournemouth in collaboration with the British Royal Oman Police.
7. Regional volunteer teams.
8. Launching a website for the National Commission of Civil Defense (on experimental basis for now).
9. Participatations in the evacuation drill at Oman's Petroleum Development Company in port of Al-Fahal.

(b) Future Plans

There are royal directives to further improve the national plan for disaster management. Some of the main objectives to achieve that include:

1. Working towards establishing a fully equipped emergency management centre whose design needs to take into consideration all the physical and geographical features.
2. Building up-to-date databases for the civil establishments, roads,

physical features and Geographical Information Systems (GIS).

3. Relocating the food reserve stores all over the Sultanate's Governorates and Regions in order to expedite the emergency-related administrative procedures and support provision and develop a national system to distribute relief supplies in the affected areas.
4. Activating the special plan developed by NCCD on how to deal with disasters related to hazardous materials.
5. Establishing quickly deployable hospitals which can be airborne.
6. Furnishing the emergency shelters with the necessary equipment and services, including the food supplies.

Providing water reserves to the main hospitals for use in the event of desalination plants failure.

Pakistan

(a) National Disaster Management Plan

National Disaster Management Authority (NDMA) of Pakistan with assistance from JICA has prepared a National Disaster Management Plan for 2011-2021. It is a long term and holistic policy document for disaster risk management at national level. The Plan has been developed in harmony with Hyogo Framework of Action (HFA) 2005-2015 as agreed in UN-WCDR (January, 2005). It contains all the aspects of disaster management policy, strategies and actions including:

- National Hazard and Vulnerability Assessment
- Human Resource Development
- Community Based Disaster Risk Management
- Multi-Hazard Early Warning System

- Disaster Management Operation by type of Disaster, such as earthquake, flood, drought, cyclone, tsunami, etc.
- Action Programs of Disaster Management for 10 Years

For efficient execution of the National Disaster Management Plan the activities have been allocated to four stages of the Disaster Cycle. The Plan has been organized as per following four stages of the Disaster Cycle:

- Non Disaster (These activities include disaster mitigation leading to prevention and risk reduction)
- Pre-Disaster (These activities include preparedness to face likely disasters, dissemination of early warnings)
- During Disaster (These activities include quick response, provision of relief, mobilization of search & rescue and
- Post-Disaster (These activities include recovery and rehabilitation programs in disaster affected areas)

(b) Strengthening of Seismic Monitoring Network in Pakistan

PMD with support by the China Earthquake Network Center (CENC)/ China Earthquake Administration (CEA) has been implementing a project for Strengthening of Seismic Monitoring Network in Pakistan. Under this project site survey for installation of ten (10) broad band seismic stations has been completed and installation of the new seismic equipment is in progress. After installation, the new seismic stations will be integrated with the existing seismic network of PMD and total number of broad band seismic stations of PMD will become twenty (20). The strengthening of seismic monitoring network in Pakistan will help PMD in better monitoring of earthquakes and precise earthquake hazard assessment.

Sri Lanka

One Ministry was set up only for Disaster Management with effect from 30th April 2010.

The Disaster Management Centre (DMC) which is the leading state agency for Disaster management has the responsibility of implementing and coordinating national and sub national level programms for reducing the risk of disasters with the participation of all relevant stake holders.

DMC has implemented projects to mitigate the effect of floods in Ampara, Batticaloa, Polonnaruwa and Puttalam districts and landslides in Nuwaraeliya, Badulla, Matale and Kandy districts. In addition, flash floods frequently occurring in urban areas has been studied and found that inadequate maintenance of canals, unauthorized reclamation, inadequate capacity of culverts and bridges. Disaster management Centre has allocated Rs 100 Mn for the flood and landslide mitigation projects.

The dry and intermediate zones which are frequently affected by drought has been attended with rehabilitating small tank cascade systems, irrigation canals, providing drinking water schemes etc.

Hazard maps of various disasters are also under processed. Designing Disaster resistance school building structures have been prepared and submitted to the Ministry of Education and the same for Hospitals and housing sector are being developed by Technical Advisory Committee appointed by DMC.

Development of Disaster preparedness and response plans have been completed for 16 districts and workshops are being held at divisional and grama niladhari level preparation activities.

Emergency Operation Centre with coordination of Technical Agencies for warning and advisory preparation and other stake holders, forces, police, UNICEF, UNCHR, WFP.UNESCAP, UNOCHA and Red Cross etc. immediately responded to take early actions for warning dissemination, relief, search and rescue etc, at the time of disasters.

Three Tsunami evacuation drills were conducted during the year for coastal areas. 52 Early warning towers along the coast were commissioned and another 25 are projected to build. The communication links in different modes are being established.

National Safety Day was organized in Jaffna district, in collaboration with District Secretariat and the Northern Provincial Council on 26th December. The objectives of the National Safety day are to commemorate all those who have lost their lives due to disasters and to create a culture of Safety and disaster awareness among general public. The National Disaster Management Coordination Committee (NDMCC) stakeholders have given their fullest support by sponsoring floats, prizes for school children, prizes for journalists, etc. The live telecast of the entire proceedings was carried out by Independent Television Network.

NDMCC was formed to provide a platform for the Disaster Management Stakeholders from governmental, non governmental, academic, private and media sector to meet on a regular basis and to coordinate matters related to disaster risk reduction as per the Hyogo Framework for Action (HFA). It is chaired by the Secretary to the Ministry of Disaster Management and helps to avoid duplicating of efforts and optimize utilization of resources. This platform has been supported by UNDP under United Nations International Strategy for Disaster Reduction (UNISDR)

DMC has also continued the work of publication of quarterly news letter with the assistance of UNDP. The editorial board comprises of representatives from National Building Research Organization (NBRO), Metrological Department, Ministry of Disaster Management, UNDP, Sri Lanka Red Cross and DMC. The first three quarterly Newsletters were printed in English, Sinhala, and Tamil languages.

DMC with SLMD conducted three tsunami drills to assess the performances and to find gaps of tsunami warning communication system and public preparation during the year.

The relief measures are taken predominantly by National Disaster Relief Services Centre(NDRSC) which was under the Ministry of Relief Services came under the purview of Ministry of Disaster Management it self for more efficient relief services (with effect from 30th April 2010). NDRSC has allocated over Rs 262million of which more than 86% was for flood relief (increased by about 20 % compared with previous years). 6.3% of the total allocation being the second for drought relief. Allocation to recover the damages due to strong winds and land slides have been 4.5% and 1.2% respectively while all the other natural, man made and wild elephant attacks etc. have been accounted for about 3%.

Six roving seminars were conducted for the farmers in three districts where agricultural activities are prominent to educate them in climate and weather on agriculture. The programme was funded by WMO. Members of Department participated in programmes in climate, weather, disaster management and climate change to make aware the public in various disciplines (administrators, flight operators, teachers, armed forces, University and school children and teachers.

Thailand

As one of the intermediary agencies in Thailand Disaster Management, Department of Disaster Prevention and Mitigation or DDPM is primary responsible for imposing and implementing program policy, formulating operational guidelines and establishing criteria on disaster management. In addition, DDPM still organizes and conducts training activities which are related to all disaster management by collaboration with local and international organizations. Recently, Disaster Management in Thailand has been focused on preparedness activities to reduce the vulnerability impacts and increase the resilience in disaster prone areas, as well as general public by using Community-Based Disaster Risk Management (CBDRM) approaches. As the center in disaster management of Thailand, DDPM in cooperation with all national involved agencies has initiated various successful projects, such as CBDRM, One Tambon (Sub-district) One Search and Rescue Team (OTOS), Mr. Disaster Warning, and Civil Defense Volunteers (CDVs). Through such programme, there are over 1 million villagers and local officers trained all over Thailand.

Future Activities

- More activities are expected to come. This is due to the fact that the Work Program under the Asean Agreement on Disaster Management and Emergency Response (AADMER) has been launched and Thailand will need to implement many activities under the Work Programme such as disaster risk identification, monitoring and assessment, trainings, relief and recovery. Many of these new initiatives under ASEAN are cyclone-related.
- New initiatives under TC such as TC Urban Flood Risk Management

Project

As the chair of Working Group in Disaster Prevention and Preparedness, DDPM held the first kick-off meeting of the working group as requested by the committee at the 36th PTC Session (held in Muscat, Oman from 2-6 March, 2009). Department of Disaster Prevention and Mitigation (DDPM), Thailand hosted and organized the Workshop on Need Assessment of PTC WG-DPP in Implementation of Coordinated Technical Plan (CTP) in Bangkok, Thailand from 25-28 August, 2009, with the support toward the participants and experts from UN ESCAP and WMO. The result of the meeting is provided in the Summary Report of the WG-DPP Workshop. And in 2010, Thailand, in corporation with WMO/ESCAP, hosted Panel on Tropical Cyclones WG-DPP Meeting to finalize the Annual Operation Plan (AOP) on 18 August at United Nations Conference Center, Thailand. And also training on Preparation on Disaster Management Drills and Observance of DDPM National Crisis Management Drill 2010 (C-MEX 10) in Chantaburi Province on 19-20 August 2010.

1.4 TRAINING

Banglsdesh

Mr. Md. Abdul Mannan, & Mr. Md. Nurul Karim, Meteorologist, participated in the —ICTP Targeted Training activity: statistical methods in seasonal prediction” at ICTP, Italy from 02-13 August 2010

Mr. Md. Hafizur Rahman, Meteorologist, participated in the —seventh post graduate Course in Satellite Meteorology and Global Climate (SATMET7)” at Ahmedabad, India from 01 August 2010-30 April 2011.

Mr. Md. Shameem Hassan Bhuiyan, Meteorologist, participated in the —USDA Cochran fellowship program” at USA, from 25 October- 02 November 2010.

Ms. Arjumand Habib, Director, participated in the —GEO VII plenary meeting and 2010 GEO ministerial summit” at Beijing, China from 03-05 November 2010.

Mr. Shamsuddin Ahmed, AD, participated in the —Challenge Programme on Climate, agriculture and development priorities and scenario development workshop” at New Delhi, India from 08-10 November 2010

India

The training activities at Regional Meteorological Training Centre (RMTC) Pune are as follows:

I) Current Status:

The following regular courses are running at Central Training Institute Pashan, Pune

i. Advanced Meteorological Training Course in General Meteorology with one foreign candidate from Maldives,
ii. Forecasters Training Course in General Meteorology
iii. Intermediate Training Course in General Meteorology

In addition to these courses, the refresher courses on the thematic topics are also being conducted.

II) On going projects:

Under World Bank aided Hydrology Project Phase II, the following regular courses are running:

i) Basic Hydromet Observer Course

ii) Hydromet Supervisor's Course

iii) Senior Level refresher course

III) Future Plans:

Annual Training Calendar for the Year 2010 - 2014 is given below:

Routine Courses in IMD				
S.No.	**Course Name**	**Duration**	**Date of commenceme**	**Eligibility Criteria**
1.	Advanced Met Training Course	One year	Second Monday of September of	B.Sc*. (with Physics or Maths as main subject) /M.Sc./B.E./ B.Tech.
2.	Forecasting Training Course	Six months	Second Monday of March and September every year	B.Sc. (with Physics or Math as main subject) and after successful completion of Intermediate Met.
3.	Intermediate course in General Meteorology (For Basic Met Training course	Four months	Second Monday of March, July and November every year	B.Sc. (with Physics or Maths as main subject) after successful completion of Basic Met. Training course.
4	Integrated Basic Training Course	Six months	Ab-initio training	Fresh recruited Scientific Asst. (MT) with B.Sc.(Phy., Math) qualification
5	Lab Assist Modular Course	Two months	Second Monday of February, June and October	Departmental Met. Attendant who have passed SSC and working in same cadre for 5 years
6	Training Course for Radio Mech. / Mech. Asst/ Mech.	3 weeks	Twice in a year	Departmental candidates with IT I passed

Courses under Hydrology Project Phase II

S.N.	**Name of the Course**	**Number of batches to be conducted**
1	Basic Hydromet Observer's Course under	3
2	Hydromet Supervisor Course under	2
3	Senior Level Refresher Course under	1

Three Refresher Courses in a year, on the thematic topics.

Tropical Cyclone Forecasters' Training at RSMC New Delhi

- One official each from Sri Lanka and Myanmar had received familiarization training on tropical cyclones monitoring and forecasting at RSMC New Delhi during 1-12 February, 2010.

Future Plan:

1. Cyclone forecasters‘ training in RSMC, New Delhi has been completed for the year 2010 and same will be conducted in 2011.
2. The seminars/workshops will be conducted for the cyclone forecasters in India during March and September 2011 as pre-cyclone exercise.
3. A refreshers course in cyclone monitoring & prediction will be conducted in March 2011.
4. A workshop/conference on FDP- Cyclone (pre-pilot phase) will be conducted in 2011.

Other Trainings

- Training course for Linux Operating, System was conducted during 1-11 Feb at NDC by MFI in association with Focus Training Services, Pune as a part of Clisys implementation.
- An orientation programme of training of 10 observers of Part time Observatory of Tamilnadu was held at RMC Chennai during the period 8-12 March 2010. The observers were issued certificate by RMC Chennai.
- A training course on Oracle was conducted at NDC, Pune from 10 to 21 May 2010 for 10 officials by Meteo France International as a part of CLISYS implementation at NDC.
- Synergy Basic User Training was imparted to 16 officers/staff of RMC Mumbai by Mr. Hubert Brunet, Chief Forecaster, Meteo France International from 31 May to 4 June 2010.
- Intermediate Course (Instrumentation) batch XXXV commenced on 20 May 2010 and concluded on 17 September 2010 and Advanced Course (Instrumentation) batch XXII also commenced on 20th September 2010.
- MFI experts, from France imparted raining to officers at RMC Chennai during the period 7-11 June, 2010.
- One week training in forecasting using Synergie System was organized at NWFC during 9-13 August 2010 for the forecasters from RMC, New Delhi. Dr. M. Mohapatra, Scientist 'E' (CWD), Shri M. Duraisamy, Director and Dr. Naresh Kumar, Meteorologist delivered lectures on various aspects.
- A two weeks CLISYS Users Training Course was conducted for NDC officers & staff by MFI officials from 13 to 24 September and CLISYS Administrator's Training Course was conducted for NDC officers from 2 to 14 September 2010.
- An International School on Applications with the newest Multi-spectral Environmental Satellites was organised by scientists from SSEC Madison (USA) during 30th January to 5th February 2011 at New Delhi. There were trainees from Indian organisations e.g. IMD, NCMRWF, IITM, INCOIS, NIT- Delhi, IISc-Bengaluru, and Indian Air Force.
- Three officers were deputed to Madison, USA for training on visual display, navigation, retrieval of temperature and moisture profile

from INSAT-3D sounder.

Maldives

Ongoing Graduate level and Post-Graduate level programmes and Advance level courses funded by regular budget of Maldives Meteorological Services(MMS).

Name of Training Program	**Country**	**Duration**	**Participants**
Bachelor in Information Technology	Maldives	2008-2011	**1**
Bachelor in Information Technology	Sri Lanka	2010-2012	**1**
Master's in Meteorology	India	2010-2012	**1**
Advanced Met. Course	India	2010-2011	**1**

To build the capacity of MMS further and in accordance with the mandate and action plan, we urgently need to train our personnel. Coordination is required in Meteorology, Aviation, and Satellite Met, WRF/WAM, climate, tsunami propagation and storm-surge modeling.

Overall Priority	Course Name	Level	Number	Year 2011	2012	2013	2014	No. Being Trained	Estimated Costs (MVR)
1	Adv Meteorology	Adv Cert	6	2	2	1	1	1	**78,900.00**
2	Climatology Adv	Cert	1	1	-	-	-	-	
3	Climatology Intermediate	Cert	1	1	-	-	-		
4	Climatology	B.Sc	1	1	-	-	-	0	
5	Electronic & Elec Eng	Dip	2	1	-	1	-	0	**105,000.00**
6	Multi-Media	B.Sc	1	1	-	-	-	-	
7	Software Eng	B.Sc	2	-	1	1	-	-	
8	Electronic Eng	B.Sc	2	1	-	-	-	1	**550,000.00**
9	Meteorology	B.Sc	2	1	1	1	-	-	**2,50,000.00**
10	Seismilogy	Dip	2	1	1	-	-	-	
11	Intermediate Met	Cert	2	1	1	-	-	-	

Myanmar

Trainings conducted in Myanmar

Meteorological course Grade III was conducted from 15 November 2010 to 31 January 2011 with 30 trainees, 15 from DMH and another 15 from Military. IFAS application training was conducted by the guidance of two Experts from ICHARM and 20 trainees from DMH had an opportunity to attend the course during the last week of June 2010.

Expert dispatch program

In order to improve the disaster risk reduction in Myanmar, JICA had been provided short-term experts dispatch program on the Improvement of Tropical Storm Forecasting and Warning to DMH. Mr. Kunio AKATSU, a well experienced expert of Japan has been despatched to DMH from December 2009 to April 2010 for the first term, and technical transfer seminars have been conducted to improve the capacity of DMH weather forecasters.

Mr. AKATSU's second-term four months assignment was started again since mid December 2010, and the achievement of MTSAT installation can be counted as one outcome of his despatch assignment. Another outcome is enabling to provide mobile AWOS, which will be very efficient for instrument calibration, through JICA program. JICA despatched another two Lecturers from Japan Meteorological Agency - JMA and conducted Technical Guidance Seminar on MTSAT Data Utilization from 19 to 25 January 2011. About 17 DMH staffs have attended the seminar and received technical transfer from the Lecturers.

JICA will also despatch third batch and fourth batch expert on Improvement of Storm Surge Forecasting and Warning to DMH. After completion of Expert Despatch program, DMH is expected to have its own capacity for more precise cyclone and storm surge forecasting and warning by using advanced technology and sophisticated equipments.

Short Term Abroad Trainings

During 2010 several DMH staff had an opportunity to be trained under the below short term trainings conducted abroad as given below.

Sponsor	Training	Country	Duration	Participant
JICA	Cyclone & Disaster Warning Technology Training for Broadcast Engineer	Japan	1-19 February	3
	Reinforcement of Meteorological Services	Japan	14 Sep - 18 Dec	1
	Acid Deposition Monitoring	Japan	17 Oct- 18 Dec	2
TICA	On job training of Meteorological Instruments	Thailand	4 -27 July	3
	GIS & Remote Sensing	Thailand	19 July-6 Aug	4

	Heavy Rainfall Surveillances And Early Warning's during the south west monsoon	Thailand	7 June-2 July	5
	Training Program on Crop Weather Modeling	Thailand	10-29 October	5
KOICA	Training Program on Climate Change &Disaster	Korea	9-27 March	1
	Training Program an Analysis of COMS Data	Korea	26 Aug - 18 Sep	2
KMA	Training Workshop on Meso-scale Numerical Weather Predication -Phase 1	Korea	27 Sep -8 Oct	2
MTCP	4th International Course on Flood Mitigation and Storm Weather Management 2010	Malaysia	4 -22 October	1

Long Term Abroad Trainings/ Degree

Sponsor	Training/ Degree	Country	Duration	Participant
WMO	M. Sc (Meteorology)	Philippine	2 years	1
	M. Sc (Hydrology)	India	2 years	1
JICA	Operating Management of Earthquake, Tsunami and Volcano Eruption observation system	Japan	5-7-2010 to 31.3.2011	1
	Seismology Earthquake Engineering and Disaster Management Policy	Japan	2-9-2010 to 17.9.2011	1
TICA	Remote Sensing & GIS	Thailand	2years	1

Oman

Workshops, Seminars and Training Courses attended by the Met personnel during the year 2010 were as follows:-

Workshop/Seminar/Training Course	Country	No. of Persons
PhD. In Climate change	UK	1
PhD. In Storm Surge Forecasting	India	1
PhD. In wind power	Oman	1
PhD. In Network	Oman	1
Master in Statistics	Oman	1
Master in environment	Oman	1
EUMETSAT Satellite Application Course	Oman	10

Tropical Cyclone Workshop	France/Reunion	2
Dust Forecasting Course	Spain	1
database systems CLDB	Slovakia	1
moving weather system	Slovaki	2
numerical weather forecasts	Germany	1
Production of weather graphics for TV	Oman	4
programming languages	Oman	3
Total		30

Pakistan

Capacity Building of Neighbouring Countries by PMD

PMD under one of it development projects has been extending its training facilities to the NMHSs of the neighbouring developing and least developed countries for their capacity building through WMO Voluntary Cooperation Programme since 2008. For this purpose, special Preliminary Meteorology Courses (BIP-MT) were conducted in 2008, 2009 and 2010 at PMD's Institute of Meteorology & Geophysics (IMG), Karachi. The Government of Pakistan (through PMD) had been providing complete financial support (in lieu of travel and per diem) to the nominees of NMHSs for their participation in these courses.

In 2010, such a course was conducted successfully at IMG, Karachi from 20th March to 23rd July. In this course, eleven (11) Met. Personnel from NMHSs of neighbouring countries, Bangladesh (2), Bhutan (3), Myanmar (1), Nepal (2), & Sri Lanka (3) participated. Under this project, the fourth (and final) such course has also been scheduled in 2011. For this course, around six Met. Personnel from NMHSs of the neighbouring countries (Bangladesh, Bhutan, Myanmar, Nepal and Sri Lanka) are expected to participate. For the continuity of these training courses in the coming years, WMO is requested for necessary support.

Capacity Building/Training Abroad of PMD official

For the capacity building of its officials, PMD has been sending potential scientists abroad for postgraduate studies and higher trainings (MS, PhD etc.) in meteorology, seismology and climate sciences since 2006. So far, eight (08) officers have joined back to PMD. Two of these officers joined in 2010 after seeking higher studies from United Kingdom, Canada, Norway, China and Thailand. Two (02) of these officers have done their PhD in Meteorology, while six (06) officers have completed their MS in Meteorology and Earth Sciences. During 2010, two (02) scientists have also completed their JICA sponsored postgraduate studies in seismology and tsunamis from Japan.

At present, twelve (12) officers of PMD have been doing their MS/PhD in China since October, 2009. Ten (10) of these officers are doing their MS (Meteorology) at Nanjing University of Science and Information Technology (NUIST), China. China Meteorological Administration (CMA) and NUIST have been very kind to provide partial financial support towards this MS (Meteorology) programme in respect of PMD officers. The remaining cost has been born by the Government of Pakistan. These officers are expected to join PMD in July, 2011 after completion of their MS (Meteorology) at NUIST. While, two (02) of the officers have been doing their PhD (Meteorology) with scholarship by the Chinese Academy of Sciences covering around 70% of their expenditures. The remaining cost of their studies has been born by the Government of Pakistan.

In addition, during 2010 PMD scientists have availed around 30 fellowships for attending short-term trainings/ training workshops abroad. These fellowships have been offered mainly by WMO, China Earthquake Administration, UN ESCAP, UNESCO-IOC, China Meteorological Administration, JICA, and KOICA etc.

Training of Met. Personnel of PMD at IMG, Karachi

During 2010-2011, various regular and special courses on meteorology were also conducted at IMG, Karachi for Met. personnel of PMD as well as for participants from other relevant organizations including Met. branch of Pakistan Air and Naval Forces. These courses include Initial and Preliminary Meteorology Courses (BIP-MT), Basic Forecasting Course (BIP-M) and several others.

Training of PMD officials at COMSATS Institute of Information Technology, Islamabad

Around eight (08) officers of PMD have completed their MS (Meteorology) from Department of Meteorology, COMSATS Institute of Information Technology (CIT), Islamabad during 2010-2011. PMD has also been providing teaching faculty support to CIT.

Sri Lanka

a. Upon receipt of the offers from WMO, members of Scientific and Technical Staff of SLMD participated in the following training activities in the year 2010

1. Training in Tropical Cyclone Forecasting, 2-16th February - India, From 2/2/2010 to 16/02/2010
2. International workshop on" Towards the Successful Implementation of the WMO Information System in Asia, Japan, 08th to 12th march
3. I0C/WM0 Data Buoy Capacity Building Workshop, South Africa, 19th to 23rd April
4. 7th International workshop on Tropical Cyclone, Reunion of France, 14th to 20th November
5. 4th international Port Meteorological Officers Workshop, USA, From 06th to 13thDecember

b. One Meteorologist is receiving the Post graduate training in Meteorology in University of Philippines under WMO sponsorship

c. Six roving seminars on Weather, Climate and Agriculture were conducted in three districts for farmers and agricultural officers with the funding facilities provided by WMO.

d. Members of Department participated in programmes to make aware the public in various disciplines, (administrators, flight operators, teachers, armed forces, University and school children and teachers.

Thailand

In 2010, TMD received WMO/ TCTF/ TCS support to attend the training courses as follows:

- **Overseas Training**

During 1 January 2010-30 December 2010, the staff of TMD had participated in nine overseas trainings as shown in table**:**

No	Course	Duration	Country	Person
1	Tsunami Early warning in the Indian Ocean	22 Jan.10 - 13 Feb.10	Indonesia	1
2	Climate applications	7-11 Jan.10	Turkey	1
3	Satellite Meteorology	22 Jun.-2 July 10	China	3
4	Multi-Hazard Early Warning	10-28 May 10	China	1
5	Weather Radar	10-14 May 10	Turkey	1
6	Information management for Maritime Activity and Disaster Prevention	8 Jun-26 N0v.10	Japan	1
7	Numerical Weather Prediction	13-24 Sep.10	China	1
8	Mesoscale Numerical Weather Prediction Phase I	27 Sep.-8 Oct.10	Republic of Korea	2
9	Flood Mitigation and Stormwater Management 2010	4-22 Oct.10	Malaysia	1

- **Local Training**

No	Course	Duration	Person
1	Basic of Weather Forecasting Technique	30Aug.-3 Sep.10	40
2	Analyzing the Meteorological Satellite Data I	19-23 July 10	36
3	Analyzing the Meteorological Satellite Data II	2-6 Aug. 10	37
4	Meteorological Ozone and Radiation	23-27 Aug. 10	34
5	Numerical Weather Prediction Workshop on Data Assimilation	6-10 Sep. 10	30

Activities of WMO

The Panel reviewed the involvement of its Members in various education and training activities supported under WMO Voluntary Co-operation Programme (VCP), Regular Budget (RB), UNDP and TCDC arrangements.

The Panel noted the training events and workshops which were organized in 2010 for the benefit of its Members. Since its last session, the Panel had benefited from WMO's education and training activities through the provision of fellowships, attachments, relevant training courses, workshops, seminars, and the provision of advice and assistance to Members.

The Panel noted the forthcoming training events planned for 2011, and the Members were encouraged to make maximum benefit of the training seminars, workshops and courses to be organized or co-sponsored by WMO.

The Panel also expressed appreciation to its Members who offered their national training facilities to other Members under bilateral and cost-sharing arrangements. These national training institutions in the Region contribute significantly to the training of meteorological personnel and the cooperative efforts by the Panel Members have been found by the recipient countries to be very useful. The Panel strongly recommended that such endeavors should continue in the future and be strengthened.

The training activities offered by the Members are extremely valuable. Therefore the Panel Members were encouraged to advise WMO of their activities for reporting and planning purposes.

The Panel noted that WMO fellowships for long-term and short-term training continued to be granted to the Member countries of the Panel under the various WMO programmes.

1.5 RESEARCH

Bangladesh

Research studies have been carried out in the following topics by the members of the Department-

- ✓ Analysis of extreme rainfall events
- ✓ Analysis of Tropical cyclone "AILA".
- ✓ Analysis of significant Nor'wester events

India

(i) Forecast Demonstration Project (FDP) on landfalling cyclones over the Bay of Bengal

An FDP on landfalling tropical cyclones over the Bay of Bengal has been taken up. Its main objective is to minimise the error in prediction of tropical cyclone track and intensity forecasts, at least 48 hrs in advance. The programme has been divided into three phases

(i) Pre- pilot phase	:	15 Oct- 30 Nov. 2008 and 2009
(ii) Pilot phase	:	15 Oct- 30 Nov. 2010
(iii) Final phase	:	15 Oct- 30 Nov. 2011, 2012

Like last year, the pre-pilot phase was conducted during 15 Oct - 30 Nov, 2010. Several national institutions participated for joint observational, communicational and NWP activities. There were one very severe cyclonic storm, GIRI, one severe cyclonic storm JAL and a deep depression over the Bay of Bengal during the FDP comparison of 2010. There were 10 days of intense observation period conduced during this phase. However, the data and information collected during this period could be used for finding out the role of various dynamical and thermodynamical parameters associated with intensification and movement of cyclones over the Bay of Bengal during 15 October to 30 November 2010. Compared to 2008 & 2009, there were four additional observations viz. (i) on board observation from Sagarkanya cruise (ii) oceanset observation of surface wind (iii) observations from five buoys (iv) microwave imageries and products.

(ii) Cyclone hazard prone districts of India

National Disaster Management Authority (NDMA) NDMA constituted a sub-committee for the purpose of preparing list of cyclone hazard prone districts based on some scientific criteria as it is found that there are some anomalies in the list of hazard prone districts prepared by Building Material Technology Promotion Council (BMTPC), ministry of Urban Affairs, Govt. of India. The BMTPC, based on Hazard Vulnerability of India identified cyclone prone districts of India taking into consideration cyclone hazards of the coastal districts. These districts are also listed in cyclone guidelines published by NDMA. These lists have included some inland districts of a few states in northeast India which do not experience full impact of cyclone. Also, while preparing such list it appears that no weight was given for the number as well as intensity of cyclones crossing coast. Considering all the above, subcommittee constituted by NDMA subsequently suggested to prepare the first draft by Dr. G.S. Mandal, Specialist, NDMA and Dr. M. Mohapatra, Director, Cyclone Warning Division, IMD, New Delhi to be considered by the sub-committee. A report on cyclone hazard prone districts of India has been prepared and sent to the sub-committee for consideration. An attempt has been made to prepare a list of cyclone hazard prone districts by adopting hazard criteria.

(iii) Verification of Cyclone Warning

Systematic verification of operational cyclone track and intensity forecasts issued by IMD has been introduced. The verification of forecasts issued by RSMC, New Delhi has been included for the first time in the 'Report of Cyclone disturbances over the north Indian Ocean during 2008' which is published by RSMC-Tropical Cyclone New Delhi during January, 2009. The skill score of the IMD has also been calculated alongwith the bias like along track and cross track errors, latitudinal & longitudinal errors for the period of 2003-2010 as per international standard.

(iv) Seasonal prediction of cyclonic disturbances over the north Indian Ocean

The preliminary study has been completed to find out the potential predictors. The findings have been published in the Journal, Mausam. Further work is in progress to develop a regression model for prediction of frequency of cyclonic disturbances during monsoon season.

(v) Modulation of genesis and intensity of cyclonic disturbances by Madden Julian Oscillation

A study has been completed to find out the modulation of genesis and intensity of cyclonic disturbances over north Indian Ocean by Madden Julian Oscillation. The findings have been sent to the Journal Mausam for consideration of publication. The results of this study will be utilized for extended range prediction (10-20 days) of genesis of cyclonic disturbances over the north Indian Ocean.

(vi) Web enable version of IMD's Storm Track Atlas (e-Atlas):

The project of electronic version of IMD's Storm Track Atlas(e-Atlas) was undertaken by CWRC, RMC Chennai and was completed successfully. Digital database of the tracks of cyclones and depressions that formed over Indian seas during the period 1891-2006 was generated in-house. Now the project to make web enable version of IMD's Storm Track Atlas (e-Atlas) has also been taken up : CWRC, RMC Chennai for use of scientific community. The work is in progress and will be completed by the end of year 2011.

(vii) Individual Research

A number of papers are published every year in various journals. The detailed list is given below.

Papers published in various journals

Like operations, research is another priority area to transform research to operation. Some our research publications on improving cyclone forecasts are given below:

Kotal, S.D., Roy Bhowmik, S.K. and Mukhopadhaya, B., 2010, Real-time forecasting of the Bay of Bengal Cyclonic Storm —RASMI” of October 2008 – A statistical dynamical approach, Mausam, 61, 110

Kotal, S.D., Kundu P.K. and Roy Bhowmik S.K, 2009, An analysis of cyclogenesis parameter for developing and non-developing low pressure systems over the Indian Sea, Natural Hazards, 50,389-402

Kotal, S.D., Kundu P.K. and Roy Bhowmik S.K. , 2009, An analysis of Sea Surface Temperature and Maximum Potential Intensity of Tropical Cyclone over the Bay of Bengal, Met Application, 16,169-177

Kotal S.D., Roy Bhowmik S.K. and Mukhopadhaya B., 2009, Performance of IMD NWP based Objective Cyclone Forecast System during 2008-2009, IMD Met Monograph No. Cyclone Warning 4/2009

Pattanaik D.R., and Y. V. Ramarao, 2009, Track Prediction of Very Severe Cyclone 'Nargis' Using High Resolution Weather Research Forecasting (WRF) Model. Journal of Earth System Sciences, 118, 309-330.

Roy Bhowmik SK, Sen Roy Soma, Srivastava K, Mukhopadhaya B., Thampi SB, Reddy YK, Singh Hari,. Venkateswarlu S and Adhikary Saurav, 2011, Processing of Indian Doppler Weather Radar data for mesoscale applications, Meteorl. Atmos Phy, DOI.1007/s00703-0100120-x

Roy Bhowmik S.K. and Kotal S.D. 2010, A dynamical statistical model for prediction of a tropical cyclone, Marine Geodesy, 33, 412-425

Sen Roy Soma, Roy Bhowmik, SK, Lakshmanan, V, and . Thampi S.B., 2010, Doppler Radarbased Nowcasting of the Bay of Bengal Cyclone – Ogni of October 2006, J., Earth SCI. Sys, 119(2),183-199

Srivastava Kuldeep, Gao Jidong, Brewster K, Roy Bhowmik S.K. Xue Ming AND Gadi Ranu, Assimilation of Indian radar data with ADAS and 3DVAR techniques for simulation of a small scale tropical cyclone using ARPS model, Natural Hazards, DOI 10.1007/s11069-010-9640-4.

Real time forecasting of the Bay of Bengal cyclonic storm "RASHMI" of October 2008 - A statistical-dynamical approach. S. D. Kotal, S. K. Roy Bhowmik and B. Mukhopadhyay

Diagnostic study of a recurving cyclone - 'MALA' over the Bay of Bengal. Ramesh Chand and M. Mohapatra

An account of low level wind shear over Chennai airport - Part I : Observation and forecasting aspects .R. Suresh

Fractal analysis : Annual rainfall in Chennai. R. Samuel Selvaraj, R. Gayathri and S. Tamilselvi

Meteorological factors associated with July 2005 floods in river Jhelum. B. P. Yadav and S. C. Bhan

Large scale fluctuations of the Continental Tropical Convergence Zone (CTCZ) during pilot CTCZ phase-2009 and the evolution of monsoon drought in 2009D. R. Sikka, Ajit Tyagi and L. C. Ram

Technical feasibility on reception of VHRR signals from Kalpana-1 satellite in the event of contingency with the existing operational ground receiving system. J. K.S. Yadav, A. K. Chakarborty and R. K. Giri

Utilization of 'Aerostat' Doppler Weather Radar in nowcasting of convective phenomena. P. K. Arora and T. P. Srivastava

Performance evaluation of precipitation prediction skill of NCEP Global Forecasting System (GFS) over Indian region during summer monsoon 2008. V. R. Durai, S. K. Roy Bhowmik and B. Mukhopadhyay

Study of rainfall features over Goa state during southwest monsoon season. S. M. Metri and Khushvir Singh

Recent winter warming over India - spatial and temporal characteristics of monthly maximum and minimum temperature trends for January to March. A. K. Jaswal

Semi-quantitative precipitation forecasts for Kosi/Mahananda catchment by synoptic analogue method. K. M. Singh, M. C. Prasad, G. Prasad, R. Prasad and M. K. Jha

Study of rainfall departure over catchments of Bihar plains. T. N. Jha and R. D. Ram

Effect of broadcast and precise satellite orbits in the estimation of Zenith tropospheric delay and integrated precipitable water vapour from GPS. J. K. S. Yadav, R. K. Giri and D. K. Malik

Precipitable water vapour monitoring using ground based GPS system. N. Puviarasan, R. K. Giri and Manish Ranalkar

Relation between pressure defect and maximum wind in the field of a Tropical Cyclone -Theoretical derivation of proportionality constant based on an idealised surface pressure model. Y. E. A. Raj

Evaluation of Indian summer monsoon rainfall features using TRMM and KALPANA-1 satellite derived precipitation and rain gauge observation. V. R. Durai, S. K. Roy Bhowmik and B. Mukhopadhaya

Semi quantitative forecasts for Baghmati/Adhawara Group of rivers/Kamala Balan catchments by synoptic analogue technique. K. M. Singh, M. C. Prasad and G. Prasad

Signatures of northeast monsoon activity and passage of tropical cyclones in the integrated precipitable water vapour estimated through GPS technique

An indigenous state-of-the-art High Wind Speed Recording (HWSR) system for coastal meteorological observatories. R. D. Vashistha, K. N. Mohan and P. S. Biju

Seasonal prediction of cyclonic disturbances over the Bay of Bengal during summer monsoon season : Identification of potential predictors. M. Mohapatra and S. Adhikary

Statistical analysis of monsoon rainfall distribution over West Bengal, India. Avik Ghosh Dastidar, Sarbari Ghosh, U. K. De and S. K. Ghosh

Weather-based crop protection stewardship at Pattambi, Kerala. R. P. Samui, K. Karthikeyan and J. P. Sabale

Rainfall variability and probability pattern for crop planning of Roorkee region (Uttrakhand) of India. A. K. Bhargava, P. K. Singh, Vasu Mitra, Awadhesh Prasad and M. Jayapalan

Probability distribution functions of weekly reference crop evapotranspiration for Pune station of Maharashtra state, India. D. T. Meshram, S. D. Gorantiwar, H. K. Mittal and R. C. Purohit

A quantitative assessment of KALPANA-1 derived water vapour winds and their improvement from the use of NCEP first guess forecast fields. A. K. Mitra, P. K. Kundu, A. K. Sharma and S. K. Roy Bhowmik

Unprecedented rainfall over Bangalore city during October, 2005. M. Mohapatra, Naresh Kumar and B.K. Bandyopadhyay

Erraticness of the rainfalls in different regions of India. R. P. Kane

Impact of AMDAR observations from Lufthansa aircraft on Global Analysis-Forecast System. Surya K. Dutta, Munmun Das Gupta and V. S. Prasad

Stochastic modeling of the occurrence of rainfall over some districts of Assam during 1987-1992. G. N. Raha and S. C. Kakaty

Rainfall models - a study over Gangtok. K. Seetharam

Climatological and synoptic aspect of hailstorm and squall over Guwahati Airport during pre-monsoon season. G. K. Das, R. P. Samui, P. A. Kore, L. A. Siddique, H. R. Biswas and B. Barman

A severe hailstorm over Guwahati airport and its vicinity on 2nd April 2006 : Synoptic and thermodynamic perspectives. H. R. Biswas, D. Chakrabarti, P. A. Kore and G. K. Das

Maldives

Research projects on air-pollution were carried-out in the Climate Observatory of Hanimaadhoo.

Maldives Climate Observatory

Location in an Island called Hanimaadhoo (« 6N, « 73 E)

Major purpose Monitoring Transboundary Air pollution

Measurement Techniques Remote sensing mainly Passive, In situ Technique

Passive

Equipments Microtops and Cimel Sun photometer for Aerosol optical depth and for Ozone, Condensation Particle Counter (CPC) to measure number of particles, Sample mobility Particle Seizer (SMPS) to measure particle size, Aethelometer for Black carbon, Nephelometer for Scattering and pyranometers with sun tracer, for direct, diffusive radiation, Wet only collectors for collecting rain water for pH , EC, and ion analysis.

DATA shows that the country experiences high concentration of Aerosols in Northeast Monsoon compared to Southwest Monsoon and also rain analysis data shows increased acidity (pH<5) in rain water in some months in the northeast monsoon

Myanmar

Under the control of DMH, Research and Development Section is established recently in 2010 with the purpose for building capacity of younger generation, without having the proper facilities. The titles of research currently carrying out are mentioned below.

a) Dryness and wetness during 1970 to 2099
b) Drought Index for dry Zone of Myanmar in 21st Century
c) Storm track shift due to climate change over SE Asia
d) Climate change in Myanmar during 21st Century by ECHAM 5 Model with Global Warming Experiment
e) New definition of monsoon onset and withdrawal for Myanmar
f) Analyzed the Evapotranspiration in Dry zone

To equip this Section with proper facilities, which enable to run the Regional Climate Model, the cost is estimated as USD 50000. This required budget is still sought.

Pakistan

Wind Mapping of Northern Areas of Pakistan (Phase-II):

PMD with financial support by the Ministry of Science and Technology has been carrying out wind potential survey of various areas of the country since 2001. In Phase-II of this project, PMD carried out wind survey of Northern areas of Pakistan for determining the assessment of wind power potential of these areas. For the purpose of this project, the Northern areas of Pakistan included districts of Swat, Dir, Chitral, Gilgit, Skardu, Haripur, Shangla, Buneer, Nowshara, Peshawar, Mohmad Agency, Khyber Agency and Azad Jammu and Kashmir (AJK). The results of this study would ultimately provide a platform for the establishment of Wind Mills / Farms for power generation. The project was initiated in 2005-2006 and was completed in 2010-2011.

Wind data from 42 stations have been collected and analyzed. The reports of all 42 stations have been drafted on the basis of collected data. The comprehensive final draft report of this project is under preparation. The analysis of data suggests that Shaheed Gali (in AJK), Sost (in Gilgit-Baltistan region), Swat and Mardan in (Khyber Pakhtunkhwa province) have the potential for establishing small to medium scale wind power projects.

In Phase-III of this project, similar study would be carried out for northern and western parts of Balochistan province subject to availability of funds.

It is pertinent to mention that in Phase-I of the project, PMD has already completed the wind power potential of the coastal areas of Pakistan (Sindh-Makran coast). On the basis of the wind data analysis, a wind corridor in Gharo has been identified in Sindh, which covers an area of about 9,700 Square Kilometers and it has the exploitable Electric Power Generation Potential of 11000 Mega Watt.

A number of Research work / small projects related to forecasting Techniques, Climate Change, Climate modeling, Downscaling for Seasonal and Monthly Prediction, Verification of High resolution Regional Model (HRM), were also carried out by the scientists of PMD and they presented their research work at various conferences/ symposia / workshops at national and international levels during 2009-2010.

Sri Lanka

Research studies have been carried out in the following topics by the members of the Department

1. Analysis of extreme rainfall events
2. Analysis of rainfall change with the onset of SWM and NE monsoon
3. Impact of Indian ocean dipole to the weather in Sri Lanka
4. Checking the accuracy of the Astrological weather predictions
5. Studying the MJO effect

6. Studying for Seasonal Forecasting
    a. Using the forecasts provided by the regional websites
    b. Using the ITACS model
7. Developing a Visual Basic program and a Database for Training/Seminar participants information
8. Seasonal rainfall forecasting using CPT
9. Decreasing trend of tropical cyclones in Bay of Bengal and Arabian Sea

Activities of WMO

The Seventh International Workshop on Tropical Cyclones (IWTC-VII) was successfully held in La Reunion, France from 15 to 20 November 2010. Chaired by Chris Velden (USA) and Jeff Kepert (Australia), the quadrennial workshop brought together tropical cyclone researchers and operational experts (forecasters and warning specialists). Workshop participants reviewed and examined recent developments in the science of tropical cyclone forecasting and sorted out priorities for future research and operational activities with special regard to the varying needs of different regions. It was attended by 128 tropical cyclone experts from 38 WMO Members with the WMO/ESCAP Panel on Tropical Cyclones (PTC) being represented by 5 operational forecasters. The workshop proceeding is currently being finalized and will subsequently be distributed to participants and to PTC Members. Included in the proceedings are a number of very important and useful recommendations, formulated by the participants and addressed to the WMO Secretariat, to NMHSs and to the research community.

The Third International Conference on Quantitative Precipitation Estimation (QPE) and Quantitative Precipitation Forecasting (QPF) was successfully held in Nanjing, China from 18 to 22 October 2010. The five-day conference, attended by 107 experts covered a wide range of issues relation to QPF including new observational approaches and technique development for QPE, advances in data assimilation, modelling and verification for QPF, user needs and the challenges of operational QPF. One of the foci of the 2010 conference is on QPF for tropical cyclones and monsoons. The conference proceeding is currently being finalized and will be available for download at the WGTMR/WWRP webpage.

There are three organized projects on tropical cyclones which are currently underway namely:NW Pacific Tropical Cyclone Ensemble Forecast Project for Typhoon Committee members (Lead: Japan Meteorological Agency);

a) Typhoon Landfall Forecast Demonstration Project (Lead: Eastern China Regional Meteorological Center/CMA);
b) Severe Weather Forecast Demonstration Project (SWFDP) for Southern Africa (2008-2011; Lead: RSMC Pretoria) and for the South Pacific Islands (2009-2011; Lead: RSMC Wellington)

The book "Global Perspectives on Tropical Cyclones: From Science to Mitigation", edited by Johnny C.L. Chan (HK, China) and Jeffrey D. Kepert (Australia) was published in April 2010. The book is a completely rewritten, updated and expanded new edition of "Global Perspectives on Tropical Cyclones" (published in 1995) which in turn was a revision of A "Global View of Tropical Cyclones" (published in 1988). It presents a comprehensive review of the state of the science and forecasting of tropical cyclones together with the application of this science to disaster mitigation.

WGTMR's Expert Team on Climate Change Impacts on Tropical Cyclones is organizing the Second International Conference on Indian Ocean Tropical Cyclones and Climate Change tentatively in New Delhi, India in September 2011. The broad thematic areas of the conference includes: current status of the operational tropical cyclone forecasting and warning system, progress on the understanding of tropical cyclone genesis, climate change and tropical cyclone activity, tropical cyclone risk and vulnerability assessment and tropical cyclone disaster preparedness, management and reduction.

1.6 PUBLICATION

Publications issued under the programmes of the Panel fall into two categories **(a) Panel News, and (b) the Annual Review of the Tropical Cyclones** affecting the Bay of Bengal and the Arabian Sea. Information on the current status of each is presented below:

Panel News

Two issues of Panel News (No.29 and 30) were published during 2010-2011 and were distributed among the PTC Members, WMO, ESCAP and others concerned in thirty-eighth session of the PTC (New Delhi, India, 21-25 February, 2010). The publication of Panel News issue No. 31 has been scheduled in April 2010. The Panel therefore, requested the Members to kindly provide their contributions to PTC Secretariat through their Panel News Correspondents more actively to avoid any delay in the publication of the next issue. The Panel also requested the Members to please send updated information about their News Correspondents especially if there is any change. The Panel also requested the Members to consider provision of news material for Panel News in more pictorial format and having policy information and development activities in order to target the policy makers and planners more effectively and to make the Panel News more informative and attractive.

1.7 REVIEW OF THE TROPICAL CYCLONE OPERATIONAL PLAN

Mr. B. K. Bandayopadhyay, rapporteur of Tropical Cyclone Operational Plan (TCOP), presented a comprehensive review made to produce the 2010 version of the Operational Plan. He suggested that along with the naming of cyclones, its meaning should also be given by the respective countries. Further, he made a few comments to make the Plan more effective. The Panel appreciated Mr. Bandayopadhyay for his devotion to the Operational Plan during last year, noting in particular the heavy workload of the update process. It requested Mr. Bandayopadhyay to continue to serve as the rapporteur for 2011. The 2010 Edition of TCOP is available on the WMO TCP website. For the early issuance of the 2011 Edition of TCOP as well as alleviation of the workload, the Panel urged the Members to communicate their amendments, if any, to Mr. Bandayopadhyay as early as possible and not later than 31 March 2011.

A proposal was made by the WMO Secretariat to include in the Plan a summary of the study on suitable conversion factors between the wind speeds of different time ranges. The study was undertaken by the Systems Engineering Australia Pty Ltd (SEA) to arrive at suitable conversion factors between the WMO 10-minute standard average wind and 1-minute, 2-minute and 3-minute "sustained" winds. Arrangement has been made by WMO/TCP to include the summary in the regional tropical cyclone operational plans and manual. Noting the significance of setting guidelines for converting the maximum wind speeds of tropical cyclones, the Panel endorsed the proposal and decided to include the summary in the Chapter I

1.8 PTC SECRETARIAT

The Panel expressed its gratitude to the Government of Pakistan for hosting the PTC Secretariat and appreciated the services being rendered by Dr Qamar uz Zaman Chaudhry, Permanent Representative of Pakistan with WMO in his capacity as Secretary of PTC and Mr. Ata Hussain, Deputy Director (Coordination and International Met.) PMD as the Meteorologist of PTC Secretariat.

Secretary of PTC offered his thanks to the Panel on the confidence that Panel imposed on him and Pakistan with regards to the hosting of the PTC Secretariat.

The Panel was briefed by Mr. Hussain on the activities of PTC Secretariat during the intersessional period. The Panel expressed its satisfaction with the work of the PTC Secretariat.

Panel was informed that the launching of new website of PTC was under process. In this connection, necessary Registration Form along with prescribed fee and the proposed webpage design/format has been submitted by the PTC Secretariat to the service providers in Islamabad. The address of the website has been proposed to be: www.ptc.wmoescap.org. Some of its various webpages and links are under construction. For making the website more informative and useful, the PTC Members were requested to kindly send their views and comments to PTC Secretariat. The new email address of the PTC Secretariat has been proposed to be PTC.Sectt@ptc.wmoescap.org. In this regard, PTC Secretariat would formally inform the Members during coming weeks.

The PTC Secretariat provided the Panel with a detailed breakdown of its expenses incurred during the Intersessional period**.** Keeping in view some savings, PTC Secretariat requested the Panel for provision of US$ 4,000 for its expenses during the year 2011-2012.

1.9 SUPPORT FOR THE PANEL'S PROGRAMME

The Panel was informed of the technical cooperation activities of WMO and ESCAP in support of the programmes of the Panel carried out in 2010, including the WMO Voluntary Cooperation Programme (VCP), Trust Fund arrangements, Emergency Assistance Fund scheme and Technical Cooperation among Developing Countries (TCDC) activities, and expressed its appreciation to WMO, ESCAP and collaborating partners for providing assistance to Members of the Panel.

The Panel noted that, in 2010, Maldives and Myanmar made cash contributions to the Voluntary Cooperation Fund (VCP(F)). Two new VCP project requests were submitted by Pakistan for the restoration of Automatic Weather Stations (AWSs) and meteorological observing stations damaged by the severe floods in July-August 2010. A VCP project for Maldives for the provision of upper-air consumables at Gan station was supported by UK and completed in April 2010. China offered to provide support for upgrading FengYunCast receiving systems to CMACast for Myanmar and Sri Lanka.

The Panel was informed of the progress of the Trust Fund project for Sri Lanka for the installation of an S-band Doppler radar system, including completion of access road, site preparation and commencement of foundation work at Gongala Peak site. Two factory training courses (September/October 2010), Factory Acceptance Tests (September/October 2010 and January 2011), a Coordination Meeting (October 2010) were conducted at the premises of the supplier of the radar. The installation of the radar and relevant training are scheduled for the first half of 2011.

Within the framework of the TCDC, China organized the International Training Seminar on South-South Cooperation on Weather and Climate in November 2010 in Nanjing Regional Training Centre. Three members of the Panel participated in the Training Seminar. The 2010 China Study Tour was carried out in May 2010 in conjunction with the opening of the MeteoWorld Pavilion in Shanghai Expo 2010 and three members of the Panel participated in the Study Tour. It further noted that Pakistan's third training course was conducted from May to September 2010 for 10 meteorological officials from four countries (including Bangladesh and Sri Lanka). The fourth training course for 2011 was offered to Afghanistan, Bangladesh, Maldives, Nepal and Sri Lanka. India continued attachment training for tropical cyclone forecasters and storm surge forecasters and offered an INSAT Digital MDD to Myanmar in 2010. Thailand carried out on-the-job training and offered to provide an upper-air system and consumables to Myanmar. In expressing its appreciation to India, Pakistan and Thailand for their active contributions to the Panel's capacity development requirements through TCDC, the Panel encouraged other Members to exploit similar training opportunities for other Members, and agreed to continue sharing of information on training opportunities available for Panel Members.

The Panel also noted the recent and ongoing emergency assistance provided under the Emergency Assistance Fund scheme to WMO Members affected by natural disasters, including Bangladesh, Myanmar and Pakistan. Following Cyclone Sidr, three SSB transceivers and two sets of Automatic Weather Stations (AWSs) are being provided to Bangladesh with the support of France, UK, VCP(F) and the WMO Emergency Assistance Fund. Following Cyclone Nargis, hydrometeorological instruments including an AWS, an electric generator, PCs for storm surge modeling as well as short-term training and a long- term fellowship, were provided to Myanmar in 2008-2010, and more reliable Internet connectivity is to be provided with the Emergency

Assistance Fund and the VCP(F). Affected Members who need emergency assistance were advised to utilize this scheme, and all Members were requested to consider providing support to affected NMHSs.

The Panel was informed that, following the exceptional severe floods in Pakistan in July-August 2010, a WMO fact-finding and needs-assessment mission was carried out in November 2010 in collaboration with ESCAP and in coordination with UNESCO. The mission assessed the current capability of the Pakistan Meteorological Department (PMD) and assisted PMD in the development of a proposal for the enhancement of its meteorological and hydrological services to implement effective flood early warning systems. The findings and recommendations of the mission were reported to the Government authorities and to potential donor Members for consideration of assistance to restore essential hydrometeorological infrastructure (AWSs, conventional synoptic meteorological stations, etc.) in Pakistan.

The Panel was further informed that WMO is collaborating with the Regional Integrated Early Multi-Hazard Early Warning System for Africa and Asia (RIMES) for the development of, mobilizing resources for, and implementing joint projects for capacity building of NMHSs and other stakeholders. A similar Memorandum of Understanding (MoU) by RIMES with ADPC was concluded on 3 November 2010. A WMO-RIMES joint project proposal for "Reducing risks of tsunami, storm surge, large waves and other natural hazards in low elevation coastal zones" for Bangladesh, India, Maldives, Myanmar, Sri Lanka and Thailand was submitted to UNESCAP for funding under the ESCAP Tsunami Regional Trust Fund in August 2010, and the project has been approved in January 2011 for implementation.

In this connection, the Panel noted that the ESCAP Tsunami Regional Trust Fund, established in late 2005 with initial contribution of US$ 12.6 million for effective regional early warning systems for tsunamis, has officially expanded its scope in January 2011 to include other hazards and climate preparedness. The Panel Members were encouraged to utilize the above resource mechanisms to support the Panel's Programme.

In view of the close collaboration established between the WMO RA II Working Group on Hydrological Forecasts and Assessment and the Working Group on Hydrology of the Typhoon Committee, the Panel was encouraged to enhance cooperation with the WMO RA II Working Groups, among others, between Panel's WG on DPP and RA II WG on DRR and Service Delivery. The Panel noted with appreciation that WMO and UNESCAP would continue to undertake activities in support of the Panel on Tropical Cyclones.

1.10 PANEL ON TROPICAL CYCLONES TRUST FUND (PTCTF)

The establishment of the Panel on Tropical Cyclones Trust Fund (PTCTF) indicated a step towards achieving self-reliance of the Panel. At the moment, the Trust Fund is being used not only for the provision of institutional support but also as funding support to the representatives of Panel Members attending training events and conferences.

Members were urged to continue to enhance their contributions to the Trust

Fund as a substantial support for the Panel's activities.

A detailed financial report on the Trust Fund as of 31 December 2010 was submitted by WMO to the Panel

The Panel endorsed the use of the Trust Fund for 2011 for the following specific purpose:

- Support for the attachment training at RSMC New Delhi for per diem of the participants (US$ 6,000)
- Support to PTC Secretariat for its operating expenses including those for printing Panel News and running PTC-website. (US$ 4,000)
- Support for participation of PTC in the 8th Session of ICG/IOTWS, Melbourne, Australia from 3-6 May, 2011 (US$3,000)

Any other emergency expenditure that can be justified for the use of the PTCTF requires the concurrence of both the Secretary of PTC and the Chairman of the Panel on Tropical Cyclones

1.11 SCIENTIFIC LECTURES

The Panel devoted a session for the presentation of scientific lectures. The list of the presentations is as follows:

> Pakistan Super Floods 2010: Increasing Climate Change Indicators

by Dr. Qamar-uz-Zaman Chaudhr (Pakistan)

> Characteristics of best tracks of cyclones over the North Indian Ocean

by Dr. M Mohapatra (India)

> Enhancing Forecasting Capabilities for North Indian Ocean Storm Surges

by Prof. S. K. Dube (IIT)

> Modelling of Coastal Inundation due to Storm Surges

by Prof. A. D. Rao (IIT)

> Air Traffic Management applications of Tropical Cyclone Information

by Mr. Christopher Keohan (ICAO)

> ICHARM Support to Asian Countries in Disaster Risk Management

by Mr Osti Rabindra (ICHARM)

> Developing innovative strategies for flood-resilient cities

by Dr Yuichi Ono (ESCAP)

> Recent Advances on China Operational Tropical Cyclone Forecasting and Warning Services

by DrXu Yinglong (China)

> Meso-Scale simulation of tropical cyclones over the North Indian Seas
by Dr Potty Jayaraman (RIMES)

The Panel expressed its deep appreciation to the above lecturers for their informative and excellent presentations.

1.12 CLOSURE OF THE SESSION

The Panel expressed its sincere appreciation to the Government of India, the host country, for providing the excellent facilities, the venue, other arrangements and its warm hospitality. The Panel also expressed its deep appreciation to Dr Ajit Tyagi, Chairperson of the Panel, Dr Hrin Nei Thiam, Vice-chairperson of the Panel as well as Mr S.H. Kariyawasam, Chairman of the Drafting Committee, for their successful conduct of the session. The Panel also wished to express its gratitude to the Local Organizing Committee led by Shri B. K. Bandyopadhyay of India Meteorological Department for their hard work in organizing the session, assistance provided to the participants and producing a session report.

The thirty-eighth session of the Panel was concluded at 1300 hours on Friday, 25 February 2011.

CHAPTER –II

(A) CYCLONIC ACTIVITIES OVER NORTH INDIAN OCEAN DURING 2010

The north Indian Ocean witnessed the formation of eight cyclonic disturbances during 2010 (Table 1). Out of eight disturbances six cyclonic disturbances formed over the Bay of Bengal and two over the Arabian Sea. Out of the six cyclonic disturbances over the Bay of Bengal, one intensified upto the stage of very severe cyclonic storm (GIRI), two upto the stage of severe cyclonic storm (LAILA & JAL), one upto the stage of deep depression and rest two upto the stage of depression. Out of two cyclonic disturbances formed over the Arabian Sea, one intensified upto the stage of very severe cyclonic storm (PHET) and the other upto the stage of cyclonic storm (BANDU). Tracks of the cyclonic disturbances formed over the north Indian Ocean during the period is shown in Fig 2.1.

The salient features of the cyclonic disturbances during 2010 were as follows:

- The number of total cyclonic disturbances (depression and above) during the year was far below normal, as only 8 cyclonic disturbances formed during 2010 against the normal of 13 cyclonic disturbances. However, five cyclones formed during the year which is the first such year after 1998 when six cyclones formed.
- Out of five cyclones, three cyclones made landfall with atleast cyclonic storm intensity.
- There were no cyclonic disturbances formed over the north Indian Ocean during monsoon season (June-Sep.). Comparing with past records (1891-2009), there was only one such year viz. 2002. On an average, 7 cyclonic disturbances formed over the north Indian Ocean during the monsoon season. While the year 2002 was an all India drought year, the year 2010 was a normal rainfall year. It was mainly because of the fact that the absence of cyclonic disturbances was compensated by the number of low pressure areas over the region. There were 13 low pressure areas during the season against the normal of 6. Considering low pressure systems including lows and cyclonic disturbances (depression and above), about 13.5 such systems develop normally during monsoon season.
- The cyclone ‗Phet' over the Arabian Sea had the rarest of the rare track with two landfall points over Oman and Pakistan and longest track in recent years.

(a) Severe Cyclonic Storm, ―LAILA" over the Bay of Bengal (17-21 May, 2010.

A low pressure area developed over the southeast Bay of Bengal on 15 May 2010. It concentrated into a depression at 0600 UTC of 17 May over the southeast Bay of Bengal. It moved in a northwesterly direction and intensified into a severe cyclonic storm **‗LAILA'**. Moving in a west-northwesterly direction towards Andhra Pradesh coast. It crossed Andhra Pradesh coast near Bapatla between 1100 and 1200 UTC of 20 May 2010 as a severe cyclonic storm. It caused moderate damage over Andhra Pradesh with death of six persons. The special features of the storm are as follows:

- It was one of the rarest track in recent years, as the cyclone developed over southeast Bay of Bengal on 17 May, moved initially in a west-northwesterly direction towards south Andhra Pradesh and adjoining north Tamil Nadu coast till 19 May morning and then moved in a northwesterly to northerly direction and crossed Andhra Pradesh coast near Bapatla (about 50 km southwest of Machilipatnam) on 20 May evening. It then recurved north-northeastwards and weakened gradually.
- The cyclone slowed down during landfall period. It lay very close to coast after landfall maintaining cyclone intensity for about 12 hrs. after landfall.
- It was the first ever severe cyclone to cross Andhra Pradesh coast after 1990 in the month of May. A very severe cyclone crossed Andhra Pradesh coast near the same area during May, 1990.

(b) Cyclonic Storm, ‗BANDU‘ over the Arabian Sea (19-23 May 2010)

A cyclonic storm ‗BANDU‘ formed over southwest Arabian Sea off Somalia coast on 19 May, 2010. Initially it moved northwesterwards and later westwards. Due to interaction with land surface and colder sea, it dissipated over Gulf of Aden. It caused heavy rain in Somalia and Yemen.

(c) Very Severe Cyclonic Storm, ‗PHET‘ over the Arabian Sea(31 May-7 June 2010)

A very severe cyclonic storm, ‗PHET‘ developed from a low pressure area formed over the central Arabian Sea on 30 May,2010. The low pressure area concentrated into a depression over the same region on 31 May, 2010. Moving initially in a northwesterly direction, the system intensified into a cyclonic storm ‗PHET‘ on 1 June and attained maximum intensity of very severe cyclonic storm with maximum sustained wind speed of 85 kts on 2 June. It weakened gradually since 3 June, moved northwards and crossed Oman coast as a severe cyclonic storm with the wind speed of about 65 kts near latitude 21.5^{0}N on 4 June 2010. It then continued to move northwards, emerged into northwest Arabian Sea and then recurved eastwards and weakened gradually. It moved parallel to but close to Makaran coast and crossed Pakistan coast as a depression, close to south of Karachi on 6 June. It then moved east-northeastwards across south Pakistan and Rajasthan and weakened gradually into a well marked low pressure area over east Rajasthan and adjoining northwest Madhya Pradesh on 7 June. The salient features of this system are as follows.

- It was the rarest of the rare track in Arabian Sea as per the recorded history during 1877-2009. It was one of the longest tracks in recent years. The life period of the cyclone was also longer.
- As a result of such unique track, the system affected three countries, viz. Oman, Pakistan and India(Gujarat and Rajasthan). While there was loss of life

and property in Oman due to both heavy rain and gale wind, the loss of life and property in Pakistan was mainly due to heavy rain and there was no significant adverse impact in India, though there was heavy rain over Gujarat and Rajasthan.

(d) Very Severe Cyclonic Storm, ‗GIRI‘ over the Bay of Bengal (20-23 October, 2010)

A low pressure area formed over the east central Bay of Bengal on 19 October. It concentrated into a depression on 20 October over the same area. It intensified into a cyclonic storm, **GIRI** at 0600 UTC of 21 October. It then moved slowly northeastwards and intensified into a severe cyclonic storm at 0300 UTC of 22 October and into a very severe cyclonic storm at 0600 UTC of the same day. It then moved relatively faster in the same direction and crossed Myanmar coast between Sittwe and Kyakpyu around 1400 UTC of 22 October 2010 with estimated sustained maximum wind speed of about 105 kts. After the landfall, it continued to move northeastwards and weakened gradually. It caused loss of life and property in Myanmar due to heavy rain, gale wind and storm surge. The salient features of cyclone ‗Giri‘ are given below:

- Cyclone, Giri rapidly intensified from associated sustained maximum wind speed of 45 kts at 1200 UTC of 21 to 105 kts at 0900 UTC of 22 October 2010.
- No severe cyclone crossed Arakan coast prior to cyclone, GIRI during the month of October, as evident from the data of 1891-2009.
- The genesis and intensification of the system could be predicted by ECMWF model to a large extent. It predicted lowest estimated central pressure of 970 hPa well in advance with landfall near 20^0N and 93^0E between 1200 and 1800 UTC of 22 October 2010 well in advance against the lowest estimated central pressure of 950 hPa and landfall near 20^0N and 93.5^0E around 1400 UTC of 22 October 2010.

(e) Severe Cyclonic Storm, ‗JAL‘ (04-08 November,2010)

A severe cyclonic storm, JAL (4-8 November 2010) developed over the Bay of Bengal from the remnant of a depression which moved from northwest Pacific Ocean to the Bay of Bengal across southern Thailand. It moved west-northwestwards and intensified upto severe cyclonic storm on 6 November. However as the severe cyclonic storm, JAL moved to the southwest Bay of Bengal closer to India coast, it entered into a region of lower ocean thermal energy and moderate to high vertical wind shear in association with the strong easterlies in the upper tropospheric level. The high wind shear led to westward shearing of the convective clouds form the system centre and lower Ocean thermal energy led to unsustainability of convection over the region. Due to these two factors, the severe cyclonic storm, JAL weakened gradually into a deep depression and crossed north Tamilnadu – south Andhra Pradesh coast, close to the north of Chennai near 13.3^0N and 80.3^0E around 1600 UTC of 07 November 2010. It continued to move west-northwestwards and further weakened into a well marked low pressure area. Its salient features are as follows.

- The severe cyclonic storm, JAL weakened into a deep depression over the Sea before the landfall.
- The convective clouds were sheared to the west to a large extent on the date of landfall (7 November,2010). As a result, more rainfall occurred over the interior parts than the coastal regions.

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 2010

1.	Severe Cyclonic Storm, **‗LAILA‘** over the Bay of Bengal 17-21 May 2010.
2.	Cyclonic Storm, **‗BANDU”** over the Arabian Sea 19-23 May, 2010
3.	Very Severe Cyclonic Storm **‗PHET‘** over the Arabian Sea 31 May -07 June, 2010
4.	Depression over the Bay of Bengal 7-9 October 2010
5.	Deep Depression over the Bay of Bengal 13-16 October 2010
6.	Very Severe Cyclonic Storm **‗GIRI‘** over the Bay of Bengal 20-23 October, 2010
7.	Severe Cyclonic Storm, **‗JAL‘** over the Bay of Bengal 04-08 November, 2010
8.	Depression over the Bay of Bengal 7-8 December 2010

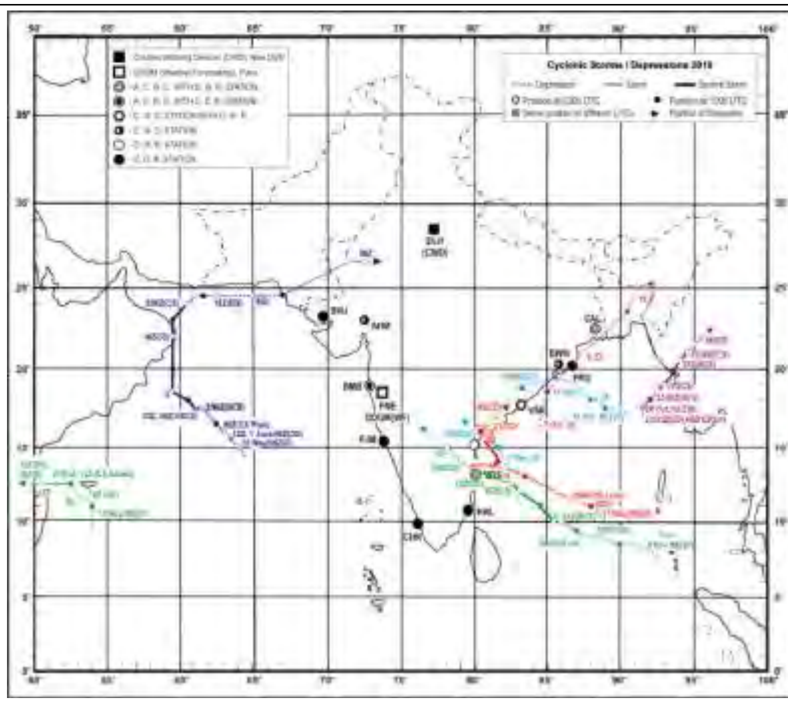


Fig. 2.1 Tracks of the cyclonic disturbances formed over the north Indian Ocean during the year, 2010

(B) Description of cyclonic storms

2.1 Cyclonic Storm' LAILA' over the Bay of Bengal (17-21 May, 2010)

2.1.1. Introduction:

A severe cyclonic storm, ‗LAILA' crossed Andhra Pradesh coast near Bapatla between 1100 and 1200 UTC of 20 May,2010. It caused wide spread rainfall with scattered heavy to very heavy rainfalls and isolated extremely heavy rainfalls (≥25 cm) over coastal Andhra Pradesh leading to flooding in low lying areas. Gale winds speed reaching 90-100 kmph were reported by the meteorological observatories in the coastal regions of Andhra Pradesh. The storm surge of 2 to 3 meters inundated the low lying areas of Guntur, Prakasham, West & East Godavari districts. The salient features of this cyclone are as follows.

(i) It was one of the rarest track in recent years, as the cyclone developed over southeast Bay of Bengal on 17 May, moved initially in a west-northwestwards and crossed Andhra Pradesh coast near Bapatla and then recurved north-northeastwards.

(ii) The cyclone slowed down during landfall period. It lay very close to coast after landfall maintaining cyclone intensity for about 12 hrs after landfall.

(iii) It was the first ever severe cyclone to cross Andhra Pradesh coast after 1990 in the month of May. A very severe cyclone crossed Andhra Pradesh coast near the same area during May, 1990.

The genesis, intensification, movement and characteristic features like pressure and wind are presented and discussed below along with the weather associated with system and damage caused thereof.

2.1.2 Genesis:

Southwest monsoon set in over Andaman Sea and adjoining south Bay of Bengal on 17 May,2010. Under its influence, the southerly surge over the region increased. It resulted in increase in the horizontal pressure gradient and the north-south wind gradient over the region. Hence, the lower level horizontal convergence and relative vorticity increased gradually over the southeast Bay of Bengal. According to INSAT imageries, a low level circulation appeared over southeast Bay adjoining south Andaman Sea at 1500 UTC of 15 May. It intensified into a vortex at 1200 UTC of 16 May with center near 9.0N/90.5E with intensity T 1.0. It led to the development of the low pressure area with at 1200 UTC of 16 May over the southeast Bay of Bengal and associated convective cloud clusters persisted over the region. It concentrated into a depression and lay centered at 0600 UTC 17 May near Lat. 10.5ºN/Long 88.5º E about 1000 kms southeast of Machilipatnam. The track of the system is shown in Fig.2.1. The best track parameters of the system are shown in Table 2.2. The INSAT imagery of the system at the stage of depression is shown in Fig. 2.2.

It was the shear pattern at the time of cyclogenesis with maximum convection lying to the southwest of the system centre. The lowest cloud top temperature was about -70 deg. C.

Considering the environmental factors for cyclogenesis, the sea surface temperature (SST) was warmer (about 28-30^0 C) over the Bay of Bengal, according to SST estimated by TMI. The ocean heat content was also favourable for genesis and intensification, as it was more than 100 KJ/cm^2. The wind shear between the layers (150-300) hPa & (700-925) hPa was low (05-10 knots) on 16 and 10-15 knots on 17 May according to METEOSAT observations. There was favourable lower level convergence and upper level divergence along with the lower level relative vorticity around the system centre. The system could gain upper level divergence as the upper tropospheric ridge roughly ran along 12-14^{0}N in association with an anti-cyclonic circulation located to the northeast of the system centre. The available ship observations suggested 30 knots wind to the southwest of the system centre at 0000 UTC of 17 May. The windsat observations also indicated 25-30 knots wind on 17 May in association with the system. The wind speed was relatively stronger in the southern sector due to strong southerly surge of the monsoon current. All these observations indicate that the environmental factors were favourable for genesis and further intensification of the system (Fig.2.3)

Table 2.2. Best track positions and other parameters of the severe cyclonic storm ―LAILA" over the Bay of Bengal during 17-21 May, 2010

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
17-05-2010	0600	10.5/88.5	1.5	1004	25	3	D
	1200	11.0/88.0	2.0	1000	30	5	DD
	1800	11.5/87.5	2.0	998	30	5	DD
18-05-2010	0000	11.5/86.5	2.5	998	35	6	CS
	0300	12.0/85.5	2.5	996	40	6	CS
	0600	12.5/84.5	3.0	992	45	8	CS
	0900	13.0/84.0	3.0	992	45	8	CS
	1200	13.0/83.5	3.0	990	45	10	CS
	1500	13.0/83.0	3.0	990	45	10	CS
	1800	13.0/82.5	3.0	990	45	10	CS
	2100	13.0/82.0	3.0	990	45	10	CS
19-05-2010	0000	13.5/82.0	3.0	990	45	10	CS
	0300	13.5/82.0	3.0	990	45	10	CS
	0600	13.5/81.5	3.5	986	55	15	SCS

	0900	14.0/81.5	3.5	986	55	15	SCS
	1200	14.0/81.5	3.5	986	55	15	SCS
	1500	14.0/81.5	3.5	986	55	15	SCS
	1800	14.5/81.0	3.5	986	55	15	SCS
	2100	14.5/81.0	3.5	986	55	15	SCS
20-05-2010	0000	15.0/81.0	3.5	986	55	15	SCS
	0300	15.5/80.5	3.5	986	55	15	SCS
	0600	15.7/80.5	3.5	986	55	15	SCS
	0900	15.8/80.5	3.5	986	55	15	SCS
	Severe cyclonic storm ‗LAILA‘ crossed Andhra Pradesh coast near Bapatla (16.0^{0} N/80.5^{0}E) between 1100-1200 UTC.						
	1200	16.0/80.5	-	990	45	12	CS
	1500	16.0/80.5	-	990	45	12	CS
	1800	16.0/80.5	-	990	45	10	CS
	2100	16.0/80.7	-	990	40	10	CS
21-05-2010	0000	16.2/80.8	-	990	35	10	CS
	0300	16.5/81.0	-	995	30	5	DD
	0600	17.0/81.5	-	999	20	3	D
	1200	Weakened into a well marked low pressure area over coastal Andhra Pradesh and adjoining area.					

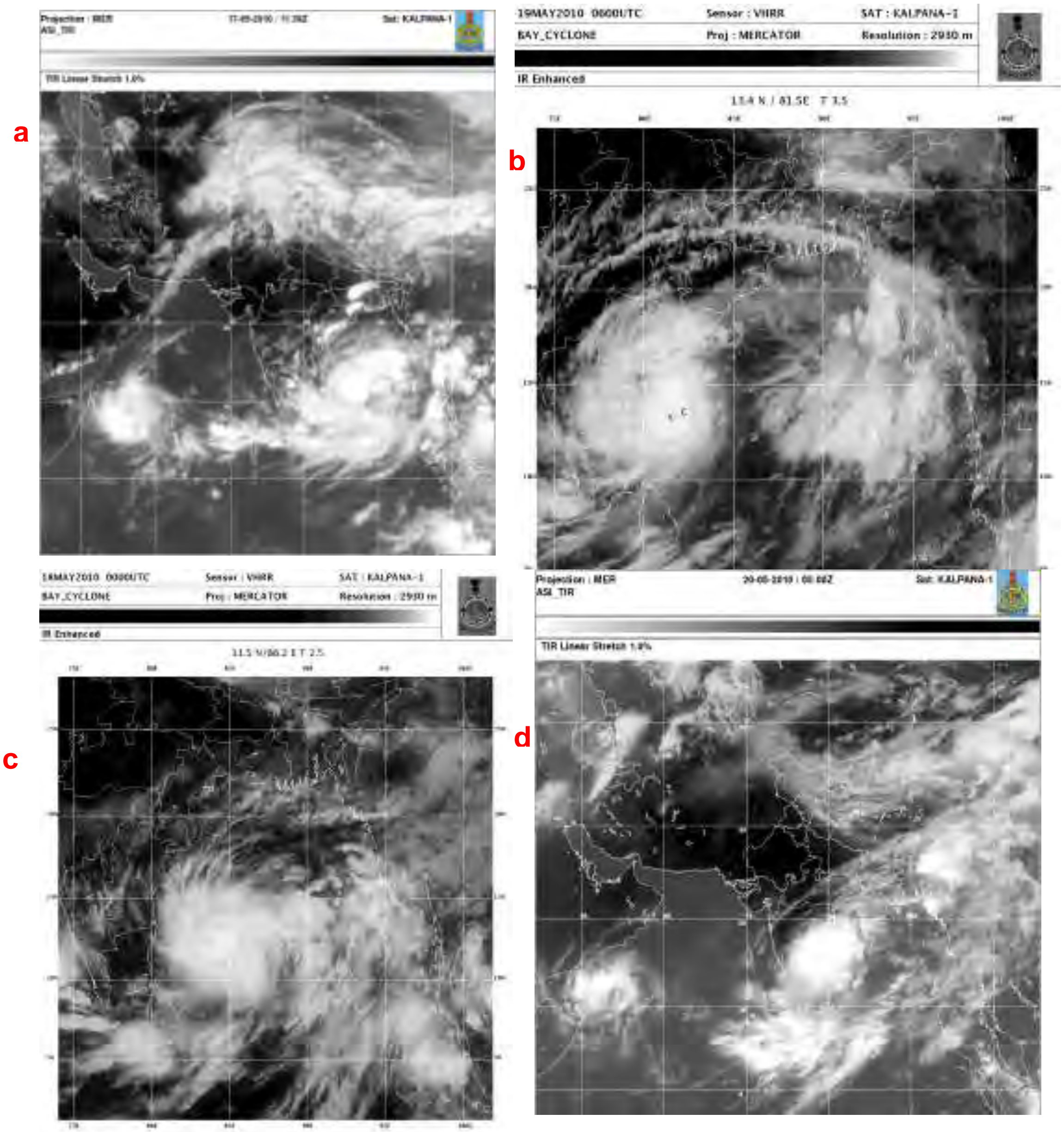


Fig. 2.2. INSAT imageries of SCS, LAILA at different stages of intensification (a) Depression, (b) cyclonic storm, (c) severe cyclonic storm and (d) severe cyclonic storm prior to landfall

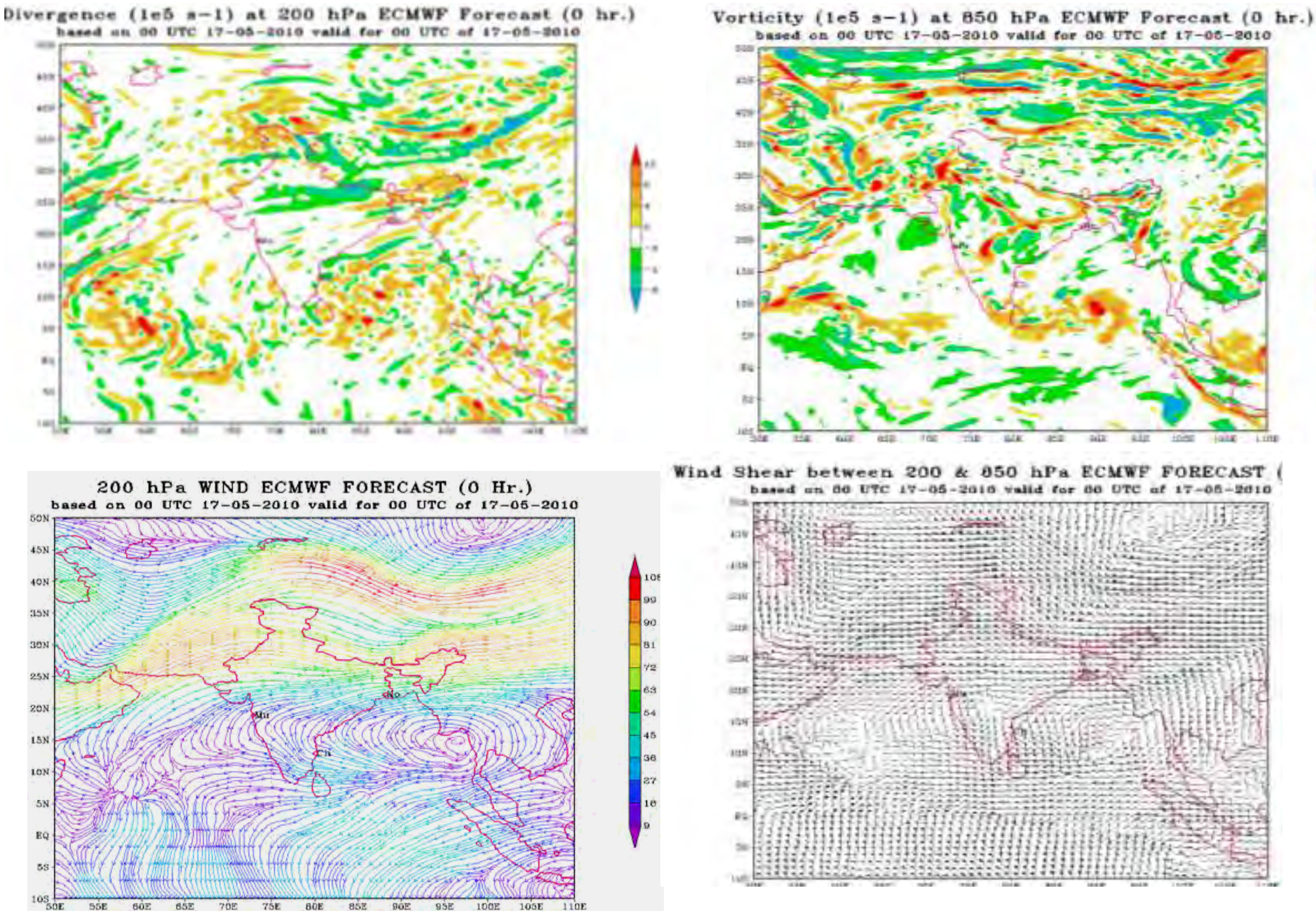


Fig. 2.3. ECMWF analyses (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 17 May 2010

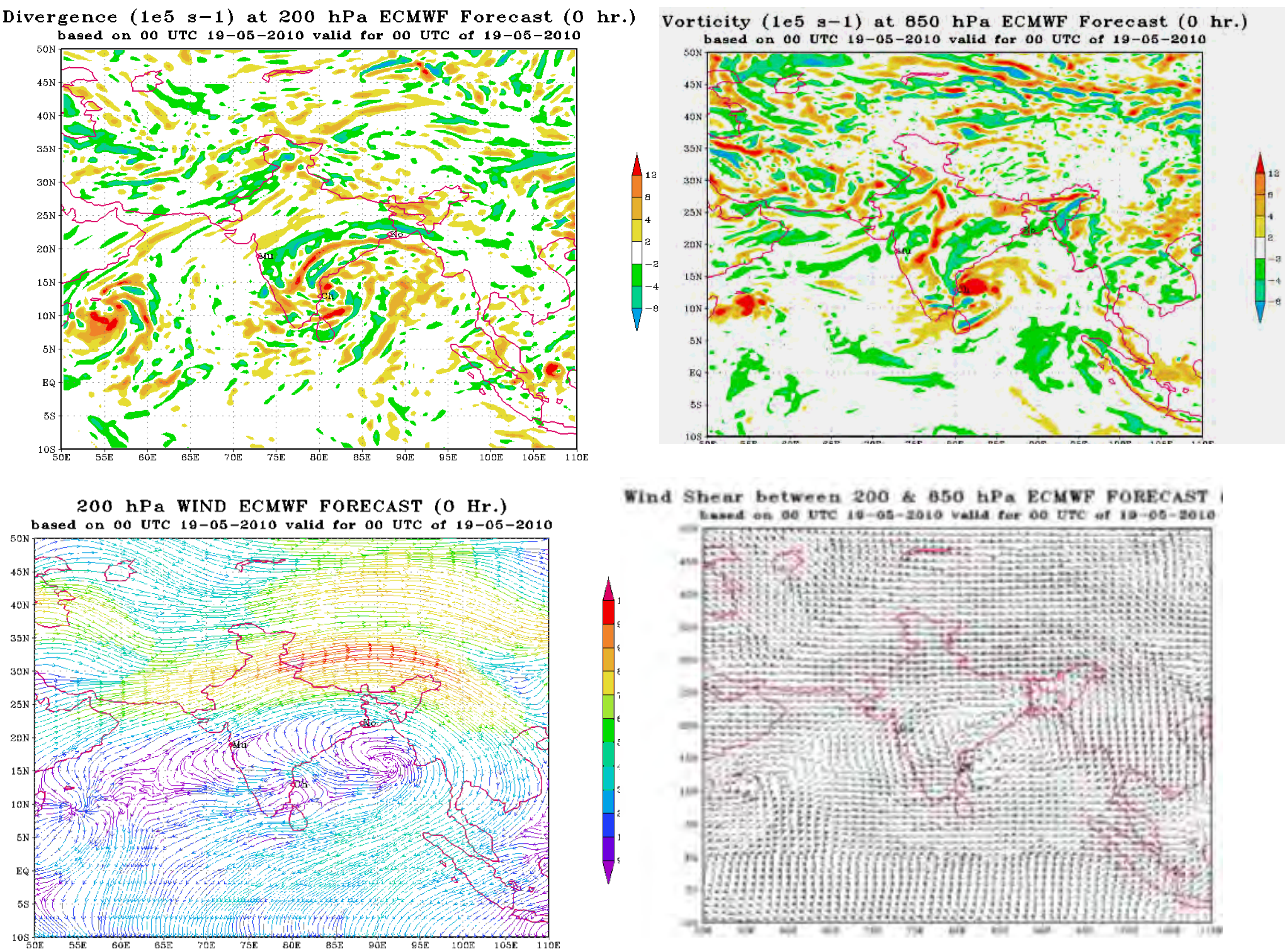


Fig. 2.4 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 19 May 2010

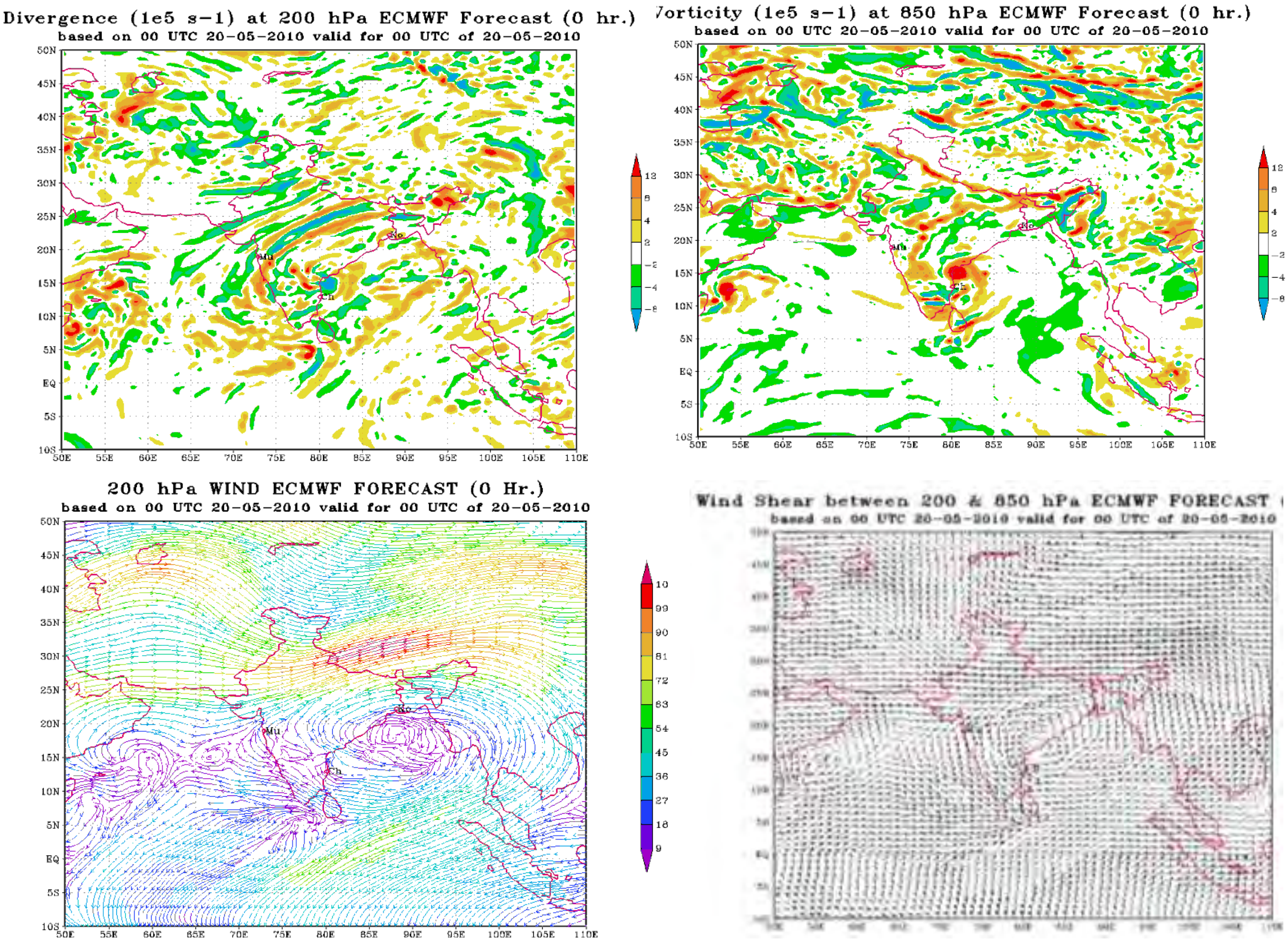


Fig. 2.5 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 20 May 2010

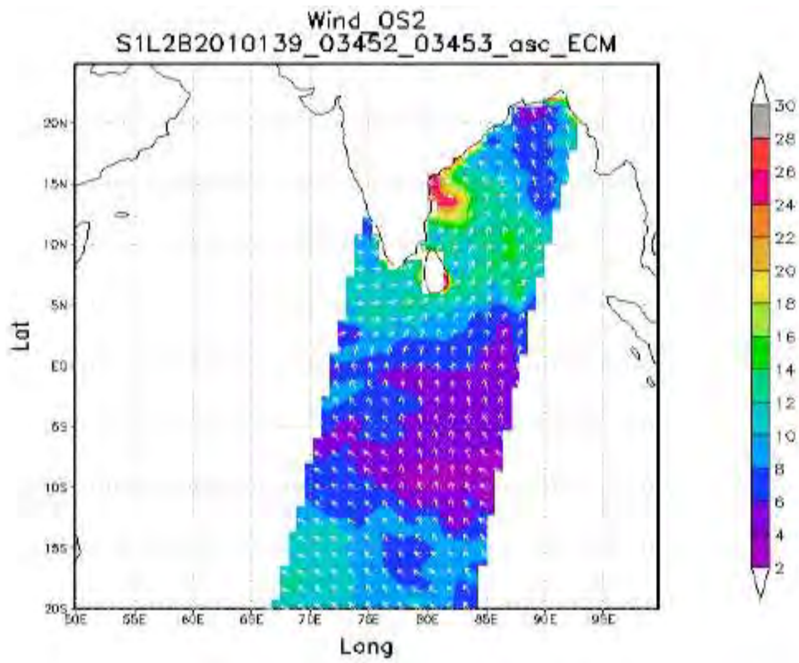


Fig.2.6. Laila Cyclone captured by Oceansat-2 Scatterometer at 0700 UTC of 19-05-2010(winds in metre per second)

2.1.3. Intensification and movement

The development of the system was very fast as the system intensified into a deep depression at 1200 UTC of 17 May with Dvorak's T number as T2.0 while moving northwestwards. Wind shear and shear tendency at this stage was between 10-20 kts and –10 kts respectively indicating further intensification. The system then moved west-northwestwards and gradually intensified into a cyclonic storm, LAILA at 0000 UTC of 18 May, 2010 over southeast and adjoining southwest Bay of Bengal, about 700 km east-southeast of Chennai.

It then moved northwestwards and intensified into a severe cyclonic storm at 0600 UTC of 19 May, 2010 over southwest and southeast Bay of Bengal about 150 km east-northeast of Chennai and 300 km south-southeast of Machilipatnam. It then moved slowly northwestwards to northwards direction and lay centred at 0300 UTC of 20 May over westcentral Bay of Bengal, about 50 km south of Bapatala. It moved then northwards very slowly and crossed coast near Bapatla between 1100 and 1200 UTC of 20 May. It weakened into a cyclonic storm after the landfall and lay over coastal Andhra Pradesh close to Bapatla at 1200 UTC of 20 May, 2010. Its motion continued to be slow in the north-northeasterly direction after the landfall and it further weakened into a deep depression at 0300 UTC of 21 May, 2010 near about 50 km north of Machilipatnam. Continuing its north-northeastwards movement, it further weakened into a depression at 0600 UTC and into a well marked low pressure area over coastal Andhra Pradesh and adjoining Telangana at 1200 UTC of the same day.

According to INSAT observation, at 2100 UTC of 19 May indication of slight weakening of the system was observed and its intensity was assigned as T 3.0 with center near lat.14.6N and long.81.1E.The system crossed Andhra Pradesh coast near lat.15.7N and long.80.1E at 0500 UTC of 20 May with intensity T 3.0 (Fig.2.2).

The cyclone, LAILA tracked along the southwestern periphery of the middle level sub-tropical ridge and hence in a west-northwesterly to northwesterly direction till 18 May. It moved in a north-northwesterly to northerly direction as the sub-tropical ridge in association with the anti-cyclonic circulation oriented itself in response to the approaching mid-latitude short wave westerly trough on 19 May. It subsequently moved in a north-northeasterly direction on 20 May onwards under the influence of the mid-latitude trough in westerlies and the anti cyclonic circulation over the Bay of Bengal. The ECMWF analysis at 0000 UTC of 17, 19,and 20 May 2010 explaining the above in upper level divergence lower level vorticity, 200 hPa level wind and vertical wind shear are shown in Fig, 2.4-2.5.

2.1.4. Structure and other parameters

The structure of the system was curved band except for one or two cases when it was observed as Central Dense Overcast (CDO) type with intensity of T3.5. The depth of intense convection was very high through out life period of the system with lowest cloud top temperatures ranging from -80 to -95 deg. C. It was maximum at 2100 UTC of 19 May, 2010.

Initially, the shape of the isobar was elliptical with its major axis along the horizontal when the system was in depression/deep depression stage and moving in a west-northwesterly/ northwesterly direction. It became circular at 0000 UTC of 18 May, when the system intensified into a cyclonic storm. It further changed shape to elliptical with major axis oriented from south-southwest to north-northeast on 19th indicating recurvature of the system. The scatterometry wind as observed by OCEANSAT-II on 19 May, 2010 is shown in Fig.2.6.

The estimated central pressure of the system gradually decreased from 1002 hPa at 0600 UTC of 17th to 986 hPa at 0600 UTC of 19th May (Table 2.2). It then started increasing after 0900 UTC of 20 May. The pressure drop at the centre was maximum (15 hPa) during the same period.

Considering the hourly coastal observations, the lowest pressure of 990.9 hPa was recorded over Machilipatnam at 0000 UTC of 21 May followed by 991.1 hPa over Ongole at 0800 UTC of 20 May and 992.3 hPa over Bapatla at 0100 UTC of 20 May, 2010. The 24 hr pressure fall was maximum (-10.1 hPa) over Bapatla at 0300 UTC of 20 May.

The estimated sustained maximum wind at the surface was 55 knots during 0600 UTC of 19 to 0900 UTC of 20 May, 2010. The hourly coastal observations indicated that maximum wind of about 35 knots was reported by coastal observatory stations in Andhra Pradesh.

2.1.5. Performance of AWS

Fall of station level pressure recorded at Kavali, Narsapur and Nellore AWS in Andhra Pradesh is shown is Fig.2.1.6. The lowest pressure of about 992 hPa was recorded by AWS stations at Nellore, Kavali (to the southwest of Machilipatnam) at about 0100 UTC of 20 May. It was about 996 hPa at 0000 UTC of 21 May over Narsapur as it lay to the northeast of Machilipatnam and the system moved north-northeastwards after landfall. The lowest pressure of 983 hPa was recorded over Darsi AWS (about 100 km west of Bapatla) at about 0100 UTC of 20 May, which does not seem to be correct as the system was still over the sea at that time.

Considering surface wind measured by coastal AWS, maximum wind of about 30 knots
was reported by Bapatla in the forenoon of 20 May(Fig. 2.8).

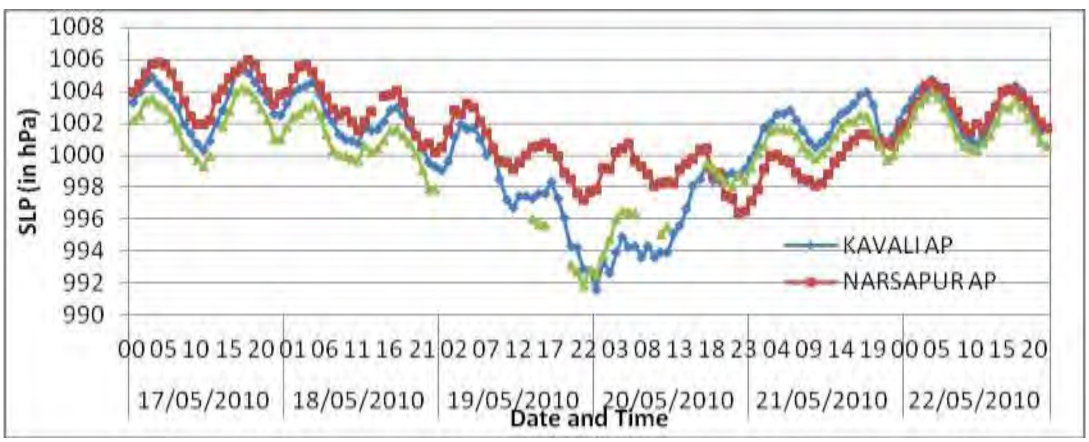


Fig. 2.7: Variation of sea level pressure (SLP) recorded at AWS as the cyclone —LAILA" approached the coast.

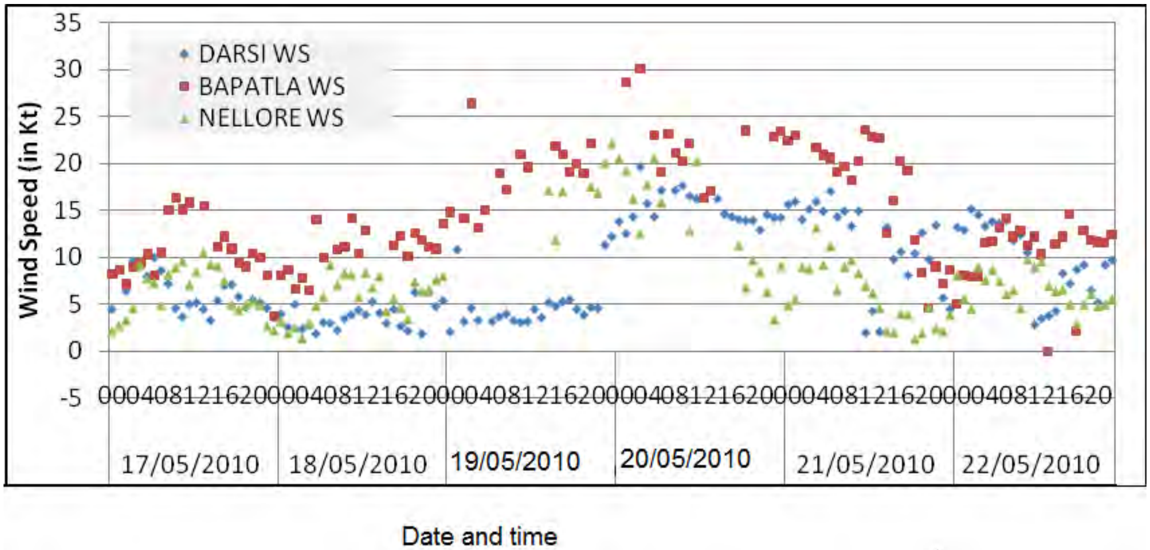


Fig. 2.8(a): Variation in wind speed recorded by AWS as cyclone —LAILA" approached the coast.

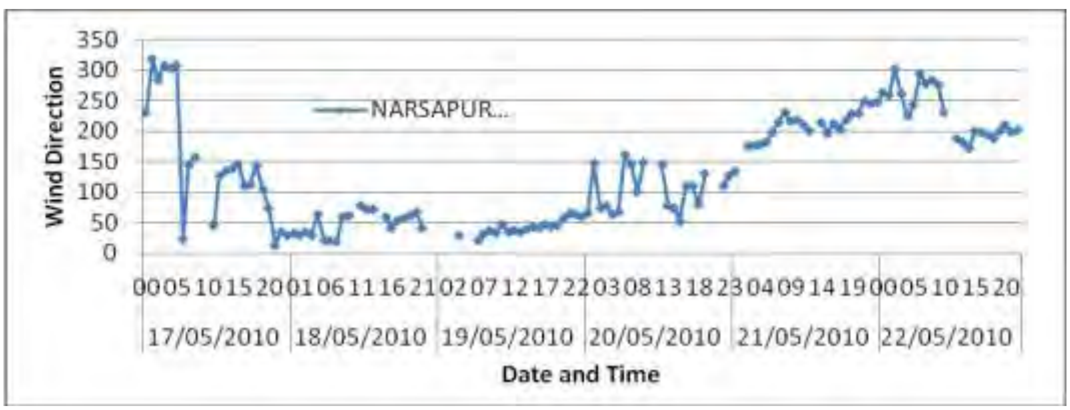


Fig. 2.8(b). Variation in Wind Direction recorded at Narsapur AWS as cyclone LAILA approached the coast.

The AWS network responded well during cyclonic storm LAILA except a few problems. The data reception from a few stations was intermittent. The variation of station level pressure, wind speed and wind direction and rainfall do not seem to be correct for a few stations.

2.1.6. Salient features of the system as seen by the DWR, Chennai:

i. Reflectivity field

Areal extent of reflectivity field in excess of 30 dBZ (~3 mm/hr) was relatively less (average radius ~ 300km), though detached bands of higher reflectivity could be seen occasionally in the southwest sector of the system. Vertical extent of reflectivity of 30 dBZ and higher was seen generally below 10 km above ground level. Reflectivity in excess of 50 dBZ (~50 mm/hr) were seen over the eye region and spiral bands. Eye of the cyclone with varying features (closed, circular, elliptical, ill defined etc) could be seen during the course of the system within the radar range. The radar based features and fixes from DWR, Chennai are shown in Table2.3. The typical DWR imageries are shown in Fig. 2.9-2.10.

ii. Velocity field

Maximum radial velocity recorded during the course of the system was around 48 mps at the height of 1 to 2 km agl, during the period around 06 to 09 UTC on 19th. As the arc of maximum wind was insufficient, radius of maximum wind could not be estimated with confidence. Analysis of Vertical time-section of wind over the radar station reveals that wind speed of the order of 65 knots prevailed above 1km to 4 km agl. Below 1km, speed gradually reduced and seen to be ~ 30 knots at 100 agl. The typical Volume Velocity Processing (VVP) imagery from DWR, Chennai is shown in Fig. 2.11.

Table 2.3. Cyclonic Storm LAILA - 18 to 20 May 2010: Radar based Features and Fixes (DWR, Chennai)

Date/ UTC	Estimated Centre				Radial wind		Motion speed	Remarks
	AZ deg	Range Km	LAT deg N	LONG deg E	height km	Speed mps		
18/0900	090	390	13.052	83.910	-	30	---	
1000	090	370	13.054	83.725	-	30	---	
1 100	87.7	340	13.181	83.444	-	33	W /25	
1200	89.1	330	13.105	83.353	-	33	W /20	
1300	88.0	300	13.157	83.074	-	33	W/25	Irregular Eye
1400	88.0	285	13.153	82.934	-	38	W/23	Irregular Closed Eye
1500	87.5	270	13.171	82.794	-	36	W/20	Irregular Closed Eye
1600	91.0	260	13.024	82.704	-	36	W/18	Circular E e
1700	90.4	245	13.052	82.565	3.5	42	W/16	Circular Open Eye
1800	93.0	235	12.957	82.469	3.5	43	W/16	Elliptical Open Eye
1900	91.4	218	13.021	82.314	3.4	43	W/14	Elliptical Open Eye
2000	91.9	206	13.008	82.202	3.2	43	W/18	Elliptical Open Eye
2100	89.5	206	13.086	82.023	2.8	43	W/1 I	Circular Open Eye
2200	87.5	200	13.149	82.145	2.8	43	W/10	Circular Open Eye
2300	83.5	190	13.266	82.043	2.7	42	NW/09	Irregular Open Eye
19/0000	80.0	183	13.359	81.964	2.3	42	NW/09	Irregular Open Eye
0100	79.0	187	13.394	81.995	2.4	36	NW/05	Irregular Open Eye
0200	72.0	175	13.561	81.836	1.8	30	NW/12	Elliptical Open Eye
0300	66.0	160	13.662	81.648	1.7	38	NW/14	Circular Closed Eye

0400	57.4	156	13.833	81.511	1.6	43	NW/17	Irregular Open Eye
0500	66.0	144	13.603	81.512	1.5	43	NW/I1	Irregular Open Eye
0600	63.0	130	13.608	81.366	1.4	43	NW/12	Irregular Open Eye
0700	60.0	134	13.680	81.368	1.4	45	NW/12	Irregular Open Eye
0800	60.0	134	13.680	81.368	0.9	40	NW/10	Eye ill defined Confidence poor
0900	59.0	133	13.696	81.348	0.9	42	NW/05	Eye ill defined
1000	53.4	149	13.877	81.402	1.1	42	NW/02	Eye ill defined Confidence poor
1 100	51.6	151	13.922	81.390	1.5	36	NW/05	Eye ill defined Confidence poor
1200	49.5	156	13.990	81.393	1.9	30	N/07	Eye ill defined Confidence poor
1300	46.9	169	14.118	81.437	2.5	30	N/08	Eye ill defined Confidence poor
1400	42.4	174	14.236	81.380	2.2	36	N/10	Eye ill defined Confidence poor
1500	System features as seen in Radar image are insufficient to attempt centre fix							
2100	18.0	181	14.632	80.811	2.1	Eye ill defined, confidence poor.		

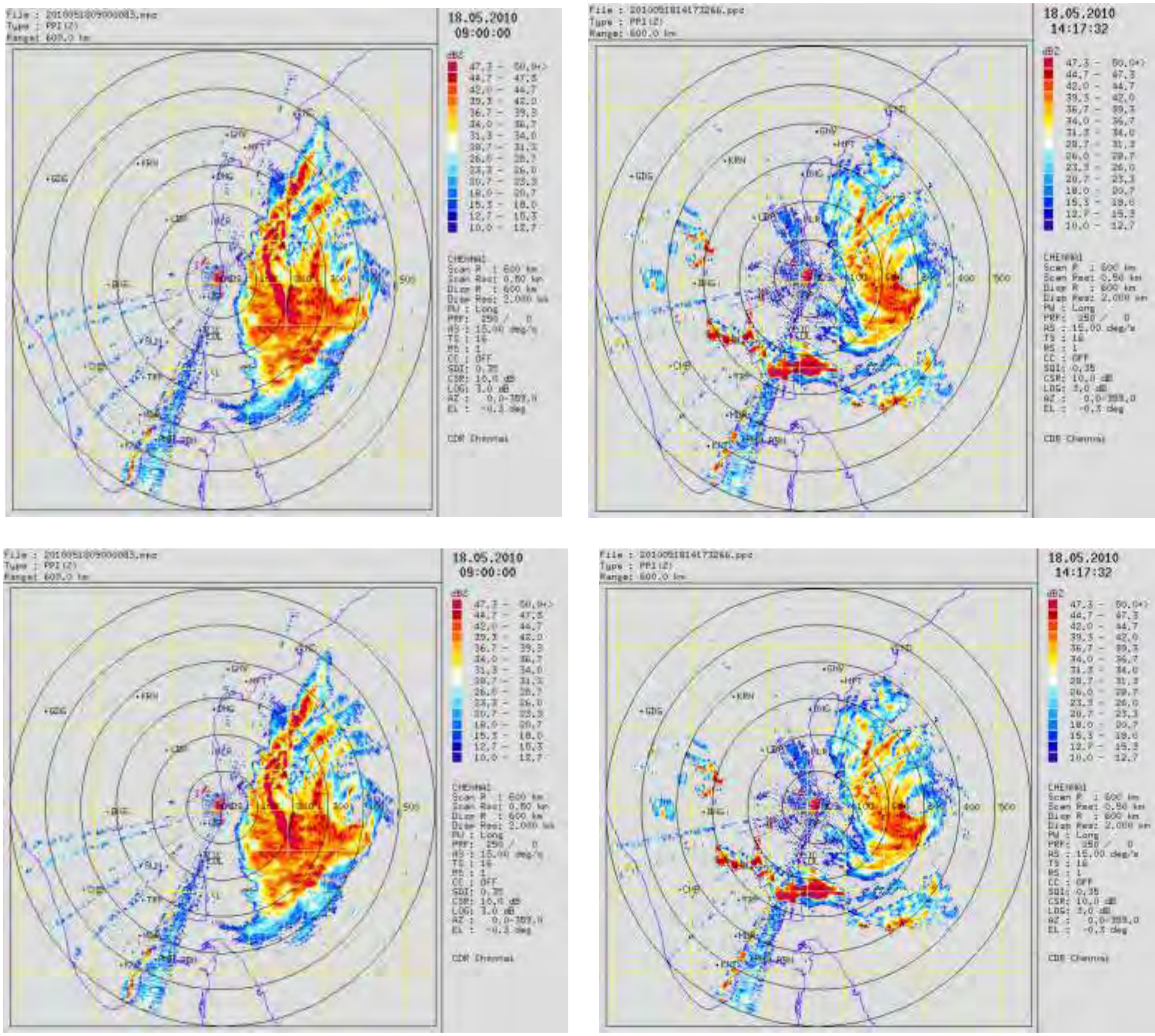


Fig. 2.9. Typical PPI(Z) imageries of SCS LAILA as observed by DWR Chennai

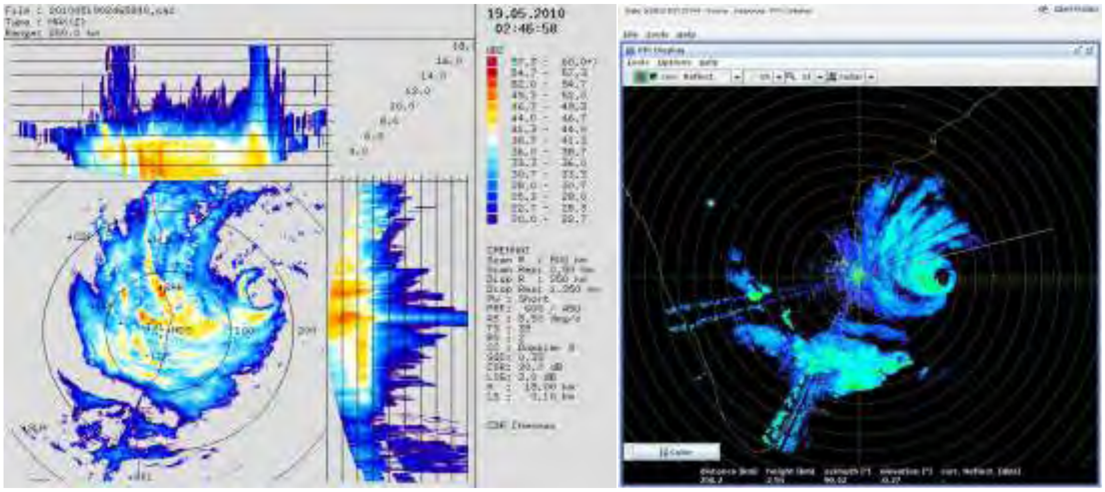


Fig.2.10. Typical Max(Z) and PPI imageries of SCS LAILA as observed by DWR Chennai

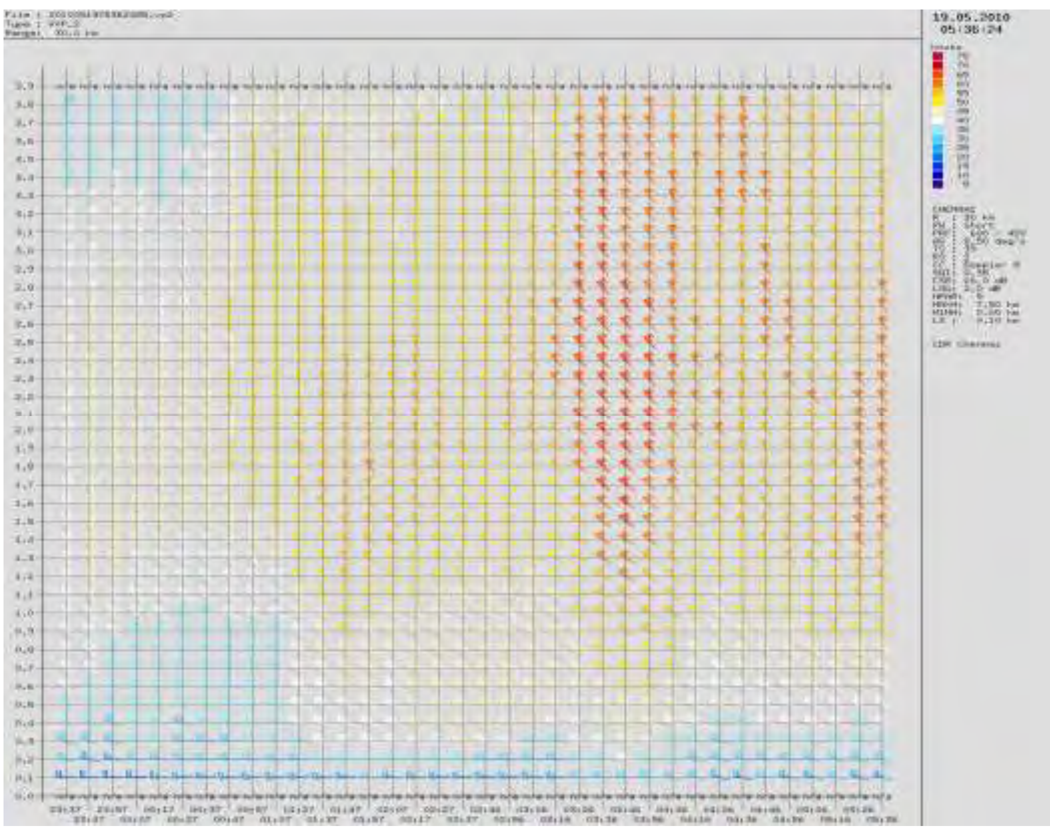


Fig. 2.11. Typical VVP imagery of SCS LAILA as observed by DWR, Chennai

2.1.7. Realised weather

(i) Heavy rain

Scattered heavy to very heavy rainfall with isolated extremely heavy rainfall occurred over coastal Tamil Nadu and Coastal Andhra Pradesh. Isolated heavy to very heavy falls also occurred over Orissa during 21-24 May, 2010. The chief amounts of rainfall (≥ 7 cm) as recorded at 0300 UTC of date are mentioned below. The spatial distributions of rainfall over Andhra Pradesh are shown in Fig.2.12.

19-05-2010

Tamil Nadu and Puducherry
Thozhudur (Cuddalore dt) 9 Chennai and Chennai airport 8 each, Anna University and DGP Office (both Chennai dt), Thiruvarur and Musiri (Thiruchirapalli dt) 7 each.

20-05-2010

Tamil Nadu and Puducherry:
Ponneri (Tiruvallur dt) 17, Cholavaram (Tiruvallur dt) 13, Chennai, Anna University (Chennai dt) and Tamaraipakkam (Tiruvallur dt) 11 each, DGP Office (Chennai dt) 10, Tiruvallur and Poondi (Tiruvallur dt) 9 each, Chennai Airport 8, Poonamally and Chembarambakkam (both Tiruvallur dt),Tiruttani and Arakonam (Vellore dt) 7 each.

Coastal Andhra Pradesh:
Kothapatnam 35, N.G.Padu 34, Ongole 32, Atchampet(G) 27, Maddipadu 26, Tangutur 22, chimakurthy 20, S. Konda 19, Narsapur 18, Tanuku & Tada 15 each, Sullurput 14, Pangalur & Amalapuram 13 each, Kandukur, Bhimavaram, Machilipatnam & Inkollu 12 each, Avanigadda, Chinaganjam, Konepi, Kaikalur, Kakinada Ulavapadu & Vetapalem 11 each, Bapatla, Chirala, Korisapadu, Koderu, Repalle , Kavali & Tadepalligudem 10 each, Nagram, Gudur, S.N.Padu, Vendatagiri Twon, Addanki & Bhattiprodu 9 each, Parchur, Karamchedu, Yaddanapudi, Gudlur, Gudivada , Nakirekallu, Kollurru, Darsi, Guntur & Rajahmundary 8, each Anakapalle, Elamanchili, Magalur, Panalur, Prathipadu, Tuni 7, Nellore 7, Peddapuram 7 each.

Rayalaseema:
Satyavedu 9, Trippathi AP 8, Rayadurg 8, Puttur 8, Srikalahasti 7

21-05-2010

Coastal Andhra Pradesh:
Addanki 52, Maadipadu 28 Chimakurthy, Nurendla, S.N. Padu 27 each, Tallur & Kothapatnam 26 each, Vinulonda 25, Savalyapuram 23, Bollapalli 20, Machavaram 19, Rompicherla, Tadepalle & Darsi 18 each, Nakirekkallu & N.G. Padu 17 each,

Kondepi 16, Manglagiri, Korisapadu, Zarugumalli, Kurichedu 15 each, Muundlamur, Tangulur. S. Konda & Ongole 14 each, Visakhapatnam AP, Elamanchili, Piduguralla, Bhimunipatnam, Bellamkonda & Duggirala 13 each, Pidugupalla, Vijayawada AP, Kandukur ,J. Pangulur & Donakonda 12 each, Vinjamur, Vizianagaram, karempudi, Ballikurava, Utavapadu, Pedakakani & Rajupalem 11 each, Podili, Narsipatnam, Visakhapatnam, Anakapalle, Dachepalli, Podili, Nadendila, Chebrolu & Thollur 10 each, Srungavarapukota, Cheepurupalli, Chodavaram, Bhimadole, Polavaram, Tiruvuru, Atchampet(G), Koyyalagudem & Tenali 9 each, Nandigama, Patapatnam, Chintalapudi, Guntur, Ranasthalam 8 each, Amalapuram,Sattenapalli, Paderu, Prathipsdu, Sompeta, Kalingapatanam, Tuni 7 each.

Rayalaseema:
Penukonda 10, Holagunda 7.

Orissa:
Paralachemundi 9.

22-05-2010

Coastal Andhra Pradesh:
Tiruvuru 25, Nuzvid 15, Palasa 11, Ichapuram 10, Chintalapudi 10, Salur 10, Sompeta 9, Mandasa, Tekkali 7 each.

Telngana:
Madhira 12, Yellandu 10, Venkatapuram 10, Bhadrachalam 9, Eturnagaram 7.

Orrisa:
Gopalpur 10, Berhmpur 9, Chhatrpur 8, Purushottampur 7, Krishnaprasad 7, Umarkote 7.

23-05-2010

Orissa:
Gopalpur 14, Athagarh 13, Dhenkanal & Berhmpur 10 each, Tikabali, Purushottampur & Chhatrpur 8 each, Rajkishorenagar & Krishnaprasad 7 each.

24-05-2010.

Orissa:
Jaipur & Gopalpur 9 each, Nilgiri & Berhmpur 8.

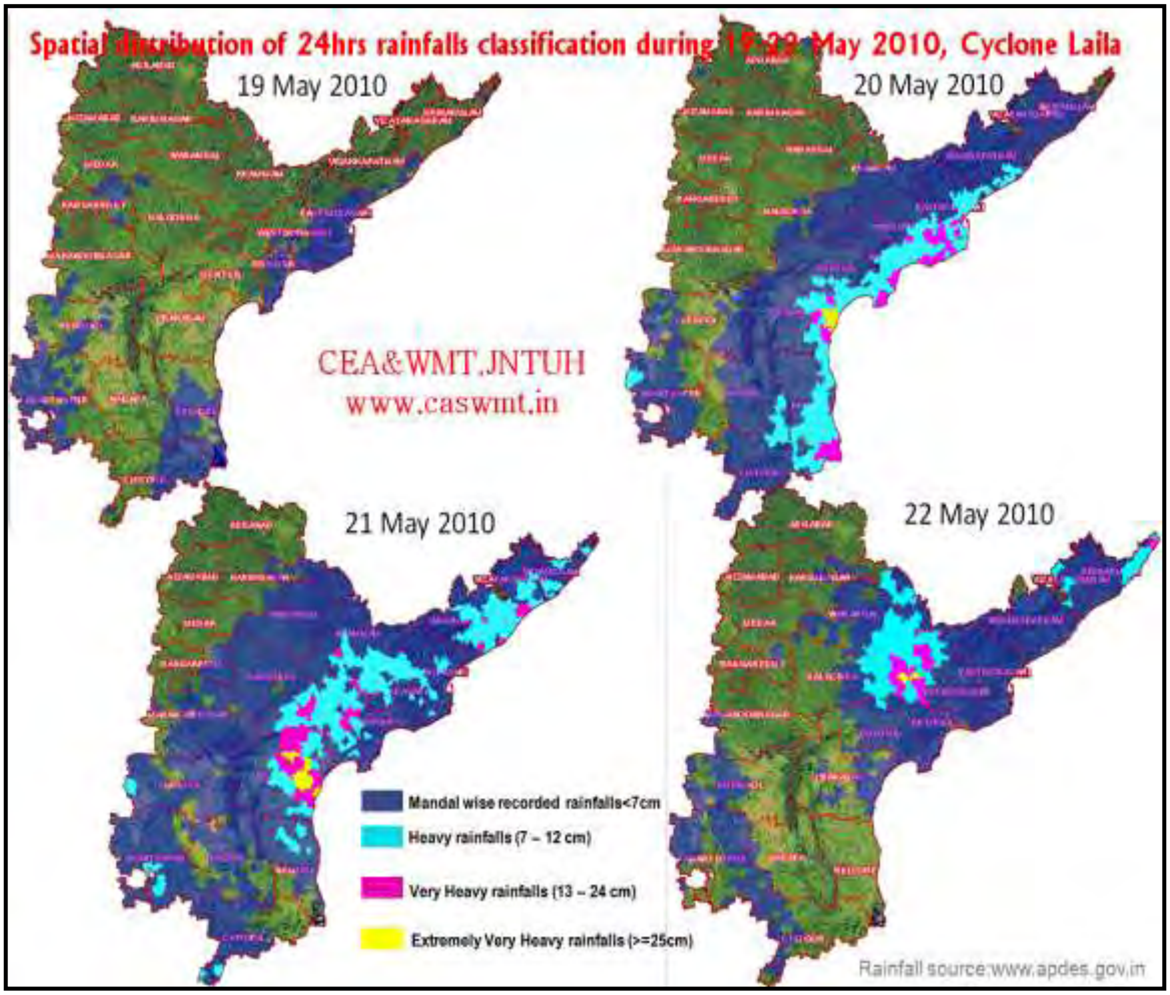


Fig. 2.12. Spatial distribution of rainfall over Andhra Pradesh due to SCSLAILA

(ii) Wind

Gale winds speed reaching 90-100 kmph were reported by the meteorological observatories of IMD. The damage caused by the cyclone suggests the wind speed of 90-100 kmph along coastal Andhra Pradesh at the time of landfall. The maximum wind of 53 kt was reported by Surya Lanka India Air Force (IAF) station near Bapatla. The high wind speed recorder at Machilipatnam recorded maximum surface wind of 59 knots

(iii) Storm surge

The storm surge of 2 to 3 meters inundated the low lying areas of Guntur, Prakasham, West & East Godavari districts.

2.1.8 Damage

- Number of human deaths : 06

Following are the damages over Andhra Pradesh due to cyclone, according to sources of Andhra Pradesh Government. Two typical photographs showing damage/ loss are shown in Fig. 2.13.

Agriculture department

- 11,351 Ha of agricultural crop are damaged so far as per the preliminary reports.
  - Prakasam 6320
  - Krishna 4000
  - Prakasam – 800
  - Kadapa – 396
  - Nellore – 347
  - East Godavari - 288

Horticulture department

- 7949 Ha of horticulture crop are damaged so far as per the preliminary reports.
  - Nellore 3383
  - Prakasam – 2220
  - Kadapa – 830
  - Guntur 604
  - Krishna 560
  - West Godavari -315
  - Ananthapur – 32
  - East Godavari – 4

Fisheries department

2 Fishermen missing in Krishna district.

416 **boats lost** worth Rs 87.25 lakhs.

- 260 in Prakasham
- 155 Krishna
- 1 Vizianagaram

Total 1643 **boats damaged** worth Rs 139.59 lakhs

- 679 in Krishna
- 355 in Nellore
- 540 Prakasham
- 30 Guntur
- 20 Visakhapatnam
- 16 srikakulam
- 3 Vizianagarm

Total 3648 **nets lost** worth Rs 297.83 lakhs.

- 1545 Krishna
- 1200 Prakasham
- 615 Guntur
- 245 Nellore
- 23 Vizianagaram
- 17 Visakhapatnam
- 3 Srikakulam

762 Ha of brackish water culture ponds inundated worth Rs 547 lakhs.
181.20 Ha of fresh water culture ponds inundated worth Rs 28.50 lakhs.

Energy department

- 58 electric substations (33 KV) affected. Electricity is affected in 692 villages.

Irrigation department

- 5 Minor Irrigation tanks damaged (3 in Prakasham, 1 in Nellore, 1 Chittoor).
- In East Godavari, Chagalnadu lift irrigation project canal is breached for 7 meters.

Housing department

- 172 houses damaged fully and 265 partly damaged so far.

Roads & Buildings department

- 3 overflows. Traffic restored at one location at KM 253/0 of D-O section of NH 214 A. Traffic interruption is still there at two other locations i.e. 209/6 and 226/0 of D-O section of NH-214 A as overflow is yet to recede.
- One R & B road breached at Prakasham district.
- 2 roads damaged (9.7 KM) in West Godavari.
- 300 meters of R&B road is damaged in Nellore district.

Animal husbandry department

- 367 domestic animals including 60 cows, 302 sheep and goat worth Rs 24.65 lakhs died.
- 57 Veternary buildings damaged worth Rs 285 lakhs.
- 475 Metric Tonnes of fodder damaged in Krishna worth Rs 11.87 lakhs.

Fig. 2.13 Damage over Andhra Pradesh Due to cyclone LAILA during 17-21, May 2010

2.2 Cyclonic Storm, ‗BANDU' (19-23 May, 2010)

2.2.1. Introduction:

A cyclonic storm, ‗BANDU' developed over the southwest Arabian Sea on 19 May. Moving in a west northwesterly direction, it dissipated over the Gulf of Aden before landfall, mainly due to colder Sea. The characteristic features of the system are discussed below.

2.2.2. Genesis

During onset phase of monsoon, a low pressure area formed over the southwest Arabian Sea on 18 May in association with persistent convection over the region. A low level cyclonic circulation was observed in the INSAT imagery on that day. Due to favourable conditions like warmer SST, higher Ocean thermal energy and favourable modulation of convection by the Madden Julian Oscillation (MJO), the low level circulation concentrated into a vortex (T1.0)over the same region on 18 May evening (1200 UTC) and in the surface chart, the low pressure area became well marked.. The well marked low pressure area concentrated into a depression with T1.5 at 0900 UTC of 19 May 2010 over southwest Arabian Sea near lat. 10.5^{0}N and long. 54.0^{0}E (Table 2.4). The genesis of the system was captured also by the Ocean surface wind as derived from Oceansat-II satellite (Fig.2.14).

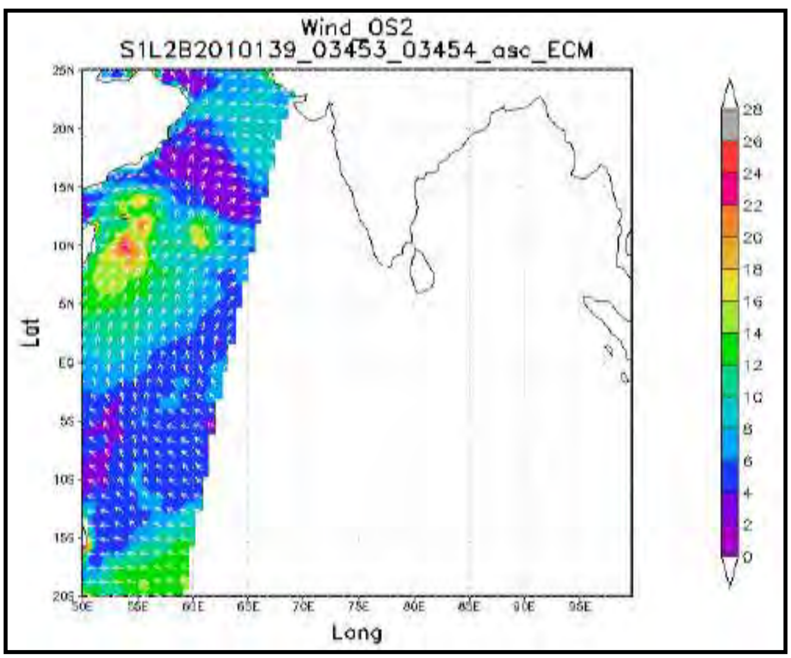


Fig.2.14. Genesis of cyclone, ‗BANDU' as captured by Oceansat-II (wind speed in metre per second) at 0850 UTC of 19 May 2010

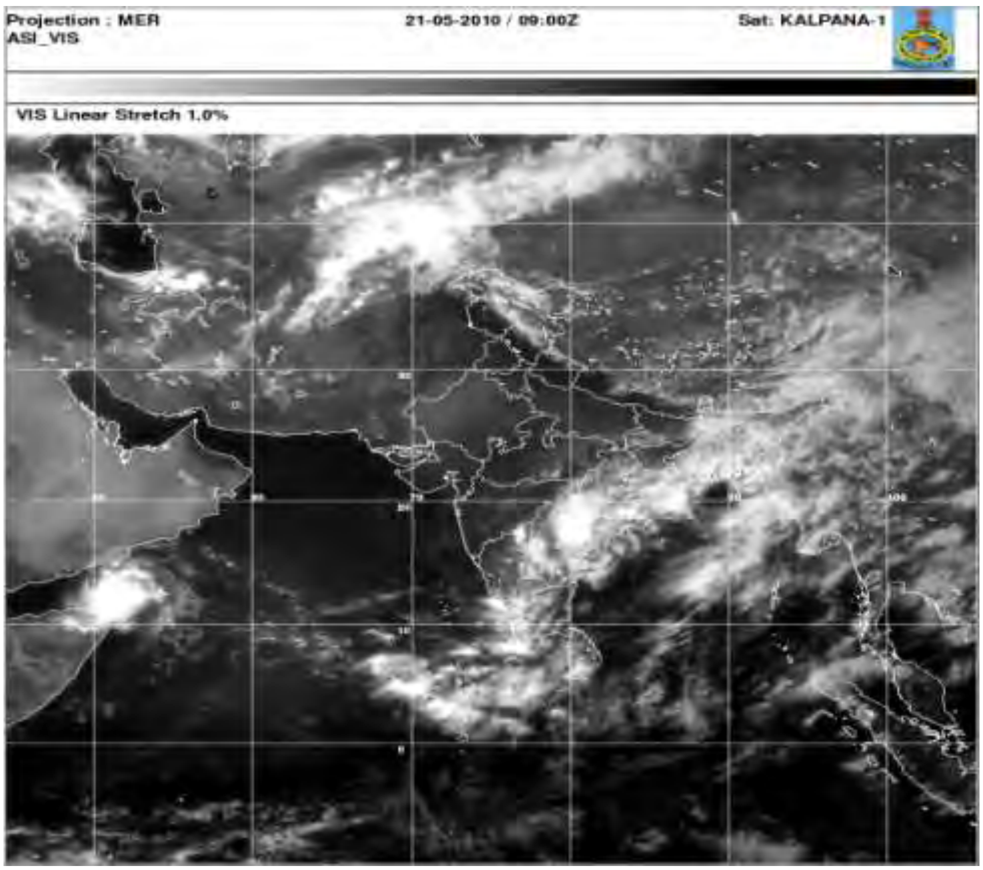


Fig. 2.15. Kalpana-1 imagery of BANDU: 21 May of 2010(0900 UTC)

2.3. Intensification and Movement

Due to continued favourable environmental conditions, the depression moved northwestwards and intensified into a deep depression over southwest Arabian Sea, near lat. 11.5^{0}N and long. 53.5^{0}E at 1800 UTC of 19 May. It then moved west-northwestwards and gradually intensified into a cyclonic storm, ‗BANDU' over westcentral Arabian Sea near 12.5^{0}N and long. 51.5^{0}E at 1200 UTC of 21 May 2010. However, due to interaction with land surface and colder Sea, it gradually weakened and dissipated over Gulf of Aden. It weakened into a deep depression at 1200 UTC and into a depression at 1800 UTC of 22 May. Further, it weakened into a low pressure area at 0000 UTC of 23 may 2010. The track of the system is shown in Fig.2.1. The best track parameters are shown in Table 2.4 The typical satellite imageries of cyclone, Bandu is shown in Fig. 2.15.

Table 2.4 Best track positions and other parameters of the cyclonic storm BANDU" over the Arabian Sea during 19-23 May, 2010

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
19.05.2010	0900	10.5/54.0	1.5	1002	25	3	D
	1200	11.0/54.0	1.5	1002	25	3	D
	1500	11.5/53.5	1.5	1002	25	4	D
	1800	11.5/53.5	2.0	1000	30	5	DD
	2100	11.5/53.0	2.0	1000	30	5	DD
20.05.2010	0000	11.5/53.0	2.0	1000	30	5	DD
	0300	11.5/53.0	2.0	999	30	5	DD
	0600	11.5/53.0	2.0	999	30	5	DD
	0900	12.0/53.0	2.0	999	30	5	DD
	1200	12.5/52.5	2.0	999	30	5	DD
	1800	12.5/51.5	2.0	999	30	5	DD
21.05.2010	0000	12.5/51.5	2.0	998	30	5	DD
	0300	12.5/51.5	2.0	998	30	5	DD
	0600	12.5/51.5	2.0	998	30	5	DD
	0900	12.5/51.5	2.0	996	30	6	DD
	1200	12.5/51.5	2.5	994	40	8	CS
	1500	12.5/51.5	2.5	994	40	8	CS
	1800	12.5/51.5	2.5	994	40	8	CS
	2100	12.5/51.0	2.5	994	40	8	CS
22.05.2010	0000	12.5/50.5	2.5	994	40	8	CS
	0300	12.5/50.5	2.5	994	40	8	CS
	0600	12.5/50.5	2.5	994	40	8	CS
	0900	12.5/50.0	2.5	996	35	7	CS
	1200	12.5/50.0	2.0	998	30	5	DD
	1800	12.5/50.0	1.5	1000	25	3	D
23.05.2010	0000	Weakened into a well marked low pressure area over the Gulf of Aden					

The dynamic parameters based on 0000 UTC ECMWF analysis of 21 May 2010 indicating favourable upper level divergence, lower level vorticity, upper air wind at 200 hPa level and vertical wind shear are shown in Fig. 2.16 Similar parameters on 22 and 23 May 2010 suggesting weakening of the system are shown in Fig. 2.17 and 2.18.

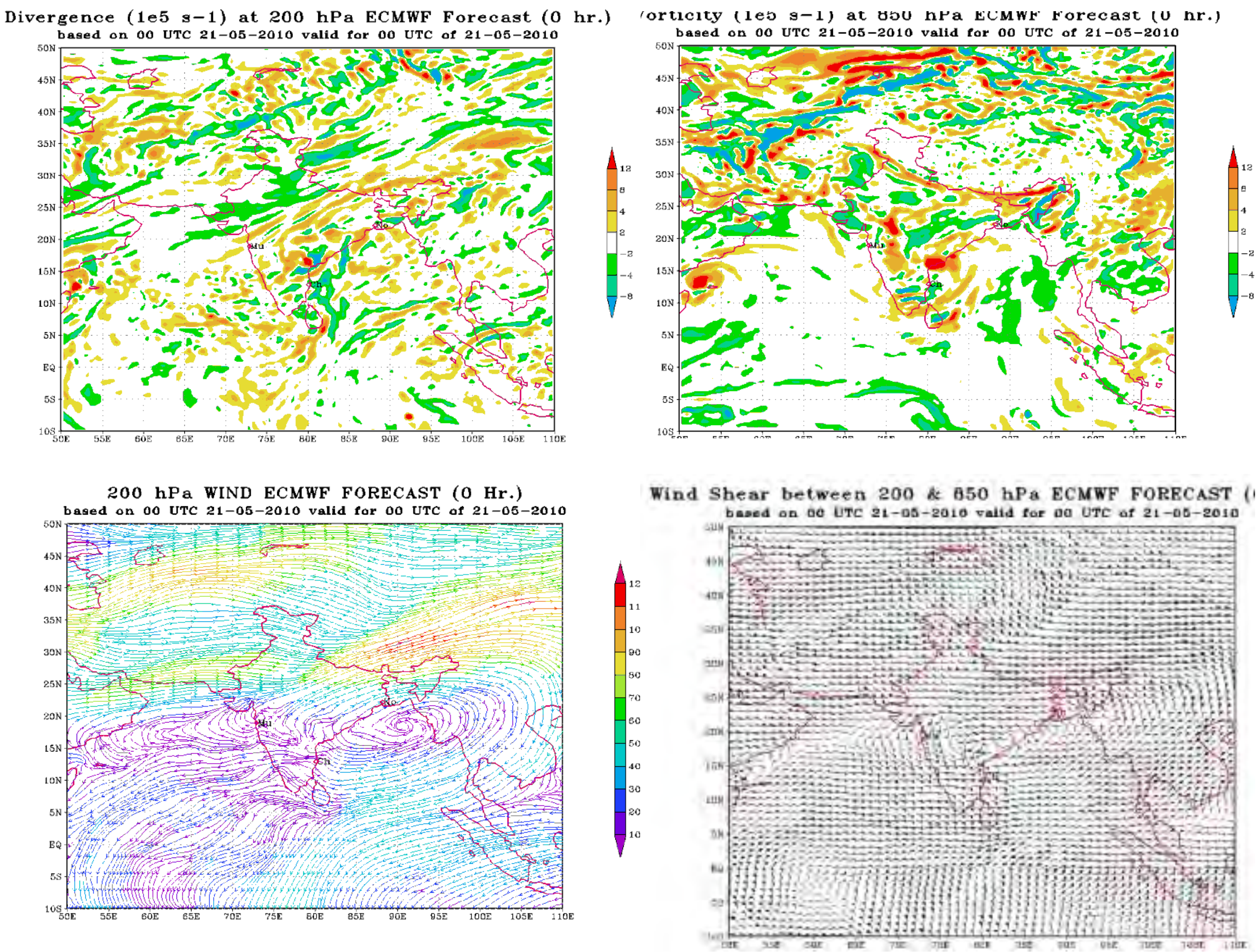


Fig. 2.16 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 21 May 2010

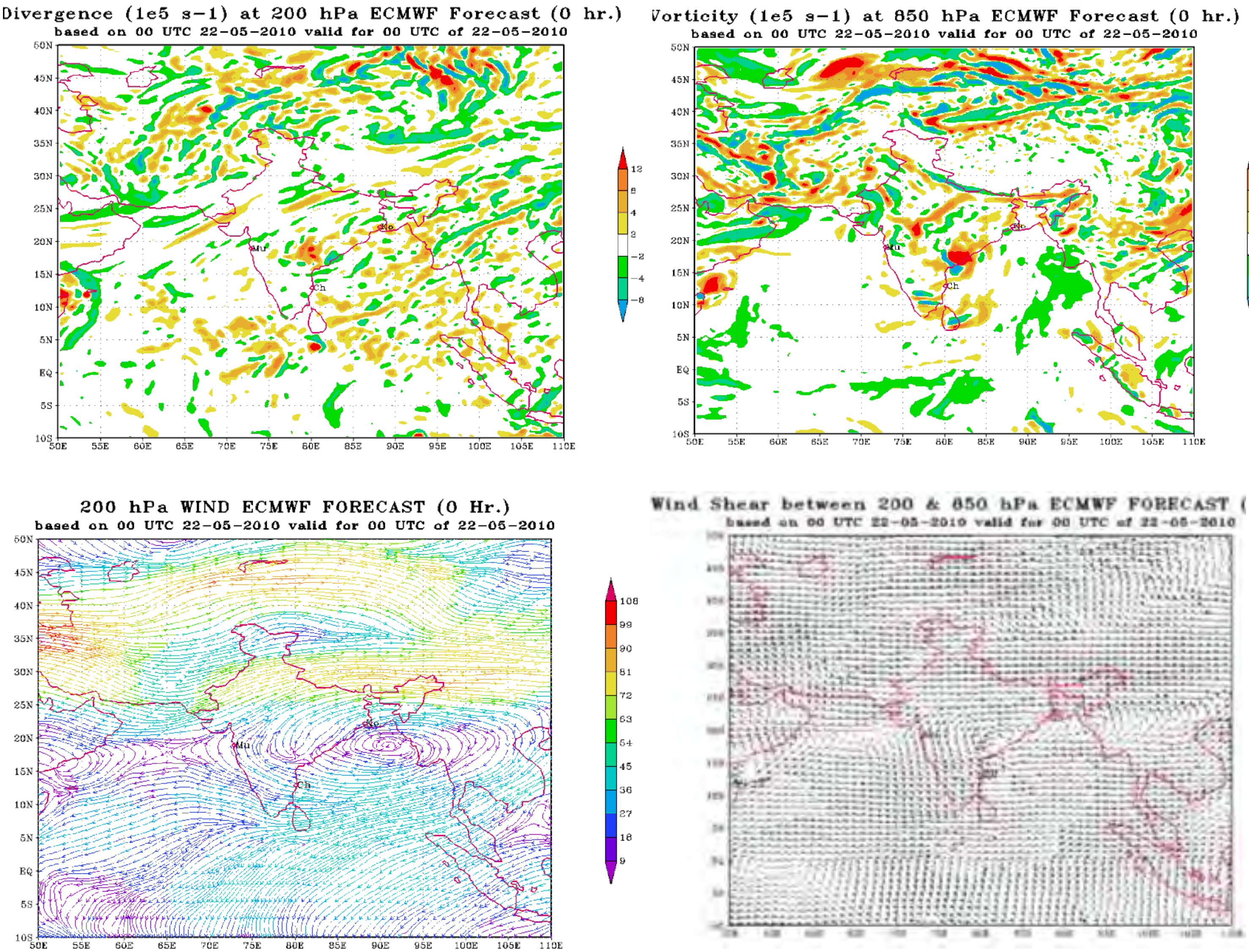


Fig. 2.17 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 22 May 2010

2.2.4. Structure

The lowest ECP of the system was 994 hPa with pressure drop of 8 hPa. The The maximum wind was estimated to be about 40 knots. According to satellite imagery, the structure of the system was curved band type with intensity of T2.5. The depth of intense convection was very high during cyclonic storm stage with lowest cloud top temperatures ranging from -75 to -85 deg. C. It was maximum at 2100 UTC of 21 May 2010.

2.2.5. Realised weather:

The system caused heavy rain in Somalia and Yemen.

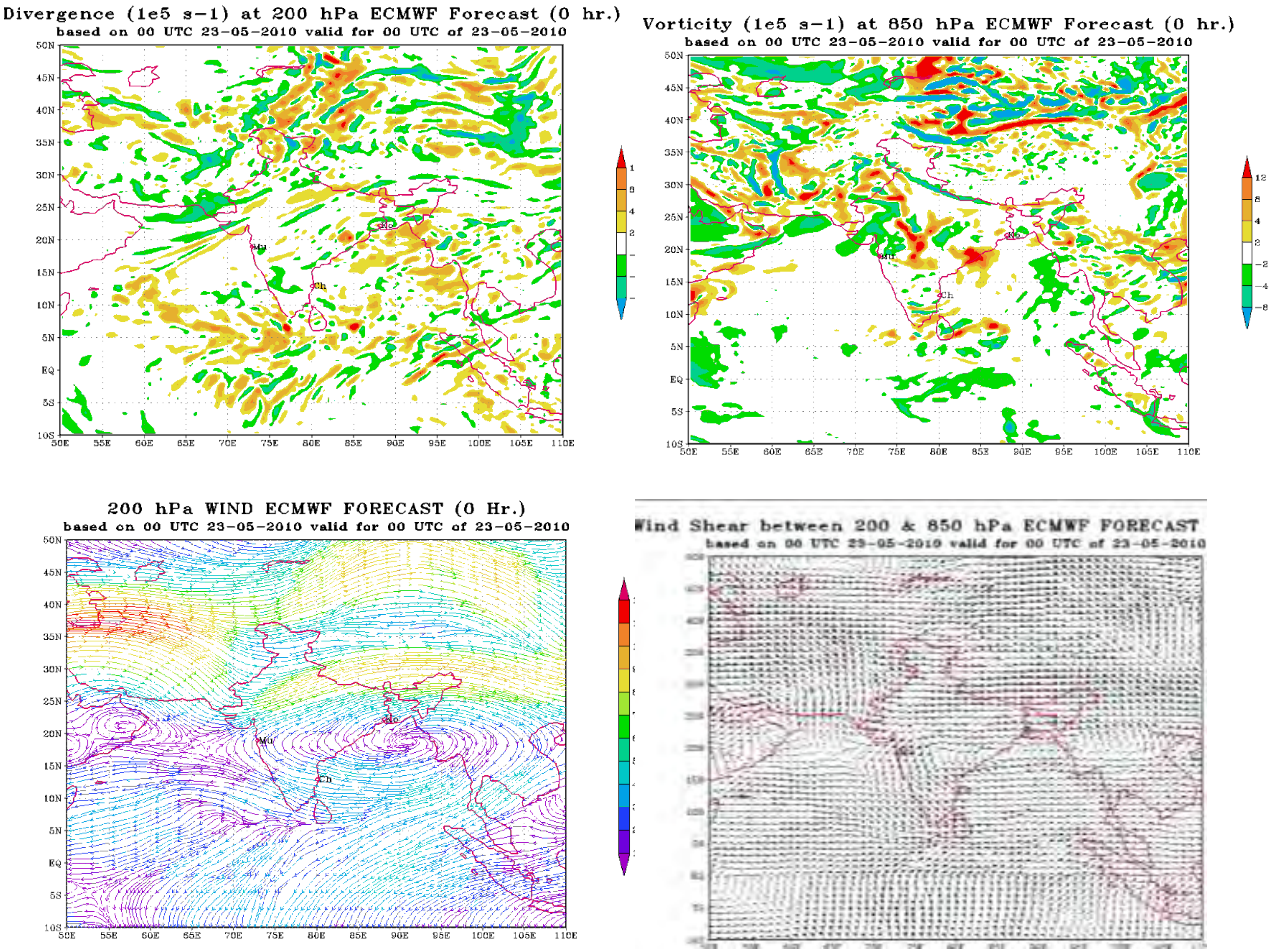


Fig. 2.18 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 23 May 2010

2.2.6. Damage

As the system weakened over the Sea, there was no damage over these countries due to wind and tidal wave.

2.3. Very severe cyclonic storm, ‗PHET' over the Arabian Sea (31 May – 07 June 2010)

2.3.1. Introduction

A very severe cyclonic storm, ‗PHET' developed over the Arabian Sea and crossed Oman coast with the wind speed of about 65 kt (125 kmph) near latitude 21.5^{0}N between 0000 and 0200 UTC of 4 June 2010. It then continued to move northwards, emerged into northwest Arabian Sea and then recurved eastwards and weakened gradually. It moved parallel to but close to Makaran coast and crossed Pakistan coast as a depression, close to south of Karachi between 1230 and 1330 UTC of 6 June. The salient features of this system are as follows.

- It was the rarest of the rare track in Arabian Sea as per the recorded history during 1877-2009.
- It was one of the longest tracks in recent years. The life period of the cyclone was also longer, as it was 8 days against the normal of 4-5 days.
- It had two landfall and affected three countries, viz., Oman, Pakistan and India
- The system weakened before landfall and crossed Oman as a severe cyclonic storm and Pakistan as a depression.

2.3.2. Genesis

In association with the southerly surge of monsoon during its onset phase, solid convective cloud cluster persisted over southeast and adjoining eastcentral Arabian Sea for a considerable period of time. At 0600 UTC of 30 May, it was assigned a low level circulation and at 1200 UTC of the same day, it was declared as a vortex centered at lat. 14.0^{0}N and long. 65.0^{0}E with intensity of T1.0 according to Dvorak's scale. Accordingly, it was declared as a low pressure area on 30 May, 2010. The low pressure area moved in a northwesterly direction and concentrated into a depression over the same region at 0300 UTC of 31 May 2010 with centre near lat. 15.0^{0}N and long. 64.0^{0}E. The track of the system is shown in Fig.2.1. The best track parameters are shown in Table 2.5.

Considering the environmental features; the SST was warmer (30-32^{0}C) and the tropical cyclone heat potential was more than 100KJ/cm^2 (Fig.2.19) over the region with depth of 26^{0}C isotherm extending upto more than 100 metres. The upper level divergence and lower level relative vorticity were also favourable for cyclogenesis and suggested further intensification as shown in Fig.2.20. There was deep convection in association with the system as the lowest CTT was -75$^{0\ C}$ at the time of formation of depression. There was moderate vertical wind shear favouring the genesis of the system

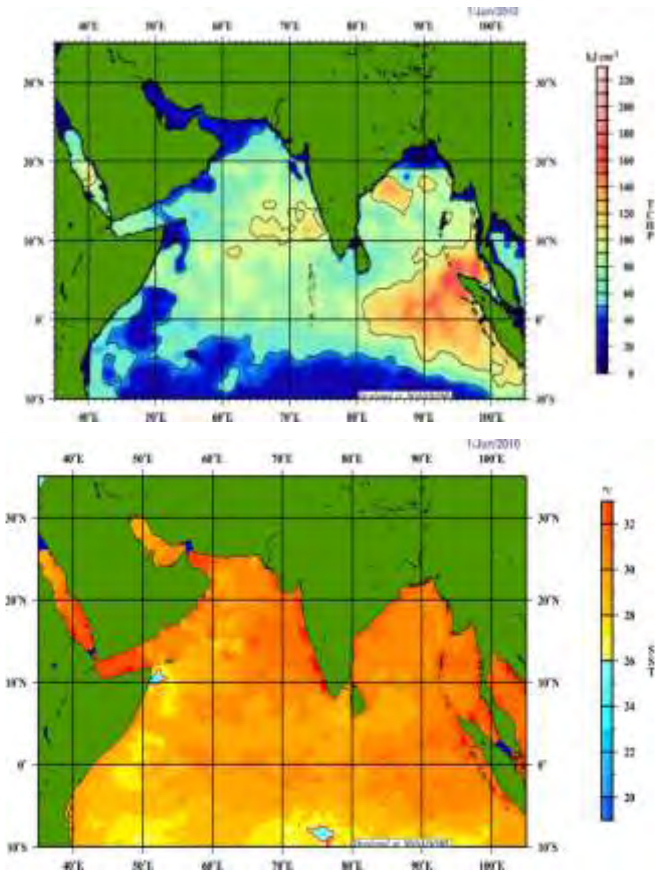


Fig.2.19 Tropical Cyclone Heating Potential (TCHP) and Sea Surface Temperature (SST) during genesis of cyclone, ‗PHET‘.

2.3.3. Intensification and movement

As the favourable conditions as discussed above with reduction of vertical wind shear (Fig.2.21 & 2..23) and increase in deep convection (lowest CTT=-80^0 C), the depression at 0000 UTC of 1 June, it intensified into a deep depression . At 0600 UTC of 1 June, when the system was centred near lat. 16.0^{0}N/long. 63.0^{0}E, the signs of rapid intensification were observed. It intensified into a cyclonic storm, PHET at 0900 UTC of 1 June with T2.5 and center near lat. 16.0^{0}N/long. 63.0^{0}E. The system intensified into a severe cyclonic storm at 0000 UTC of 2 June, when its eye was visible and the center was located near lat 17.5^{0}N/long. 61.0^{0}E. It further intensified into a very severe cyclonic storm with T4.0 at 0600 UTC of 2 June remaining practically stationary over the region. The intensity was increased to T4.5 with center at 18.0N/60.5E. The system was slowly moving north-westwards. At 0000 UTC of 3 June, signs of weakening were observed in the system and the intensity was decreased to T4.0. It maintained its north-westwards movement with intensity T4.0 and crossed Oman coast between 0000 & 0200 UTC of 3 June near lat. 21.5^{0}N. After crossing over to land, it assumed north/north-easterly movement. At 1200 UTC of 4 June it again entered into Sea with intensity T3.5. At 2300 UTC of 4 June signs of rapid weakening of the system were observed and the system weakened into a cyclonic storm with T3.0 at 0000 UTC of 5 June. Again its intensity was decreased to T2.5 at 0300 UTC of 5 June. It crossed the Pakistan coast close to south of Karachi between 1230 and 1330 UTC of 6 June 2010. . It then moved east-northeastwards across south Pakistan and Rajasthan and weakened gradually into a well marked low pressure area over east Rajasthan and adjoining northwest Madhya Pradesh in the evening of 7 June. It was the rarest of the rare track in Arabian Sea as per the recorded history during 1877-2009. It was one of the longest tracks in recent years. The life period of the cyclone was also longer.

Table 2.5 Best track positions and other parameters of the Very Severe Cyclonic Storm (VSCS) —PHET” over the Arabian Sea during 31 May – 7 June, 2010

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
31-05-2010	0600	15.0/64.0	1.5	1001	25	3	D
	1200	15.5/63.5	1.5	1001	25	3	D
	1800	15.5/63.5	1.5	999	25	4	D
01-06-2010	0000	15.5/63.5	2.0	998	30	5	DD
	0300	15.5/63.5	2.0	998	30	5	DD
	0600	16.0/63.0	2.0	996	30	5	DD
	0900	16.0/63.0	2.5	995	35	7	CS
	1200	16.5/62.5	2.5	994	35	7	CS
	1500	16.5/62.5	2.5	992	40	8	CS
	1800	17.0/62.0	3.0	990	45	10	CS
	2100	17.0/62.0	3.0	990	45	10	CS
02-06-2010	0000	17.5/61.5	3.5	986	55	15	SCS
	0300	17.5/61.0	3.5	984	60	18	SCS
	0600	17.5/61.0	4.0	978	70	24	VSCS
	0900	18.0/60.5	4.5	968	80	32	VSCS
	1200	18.0/60.5	4.5	964	85	36	VSCS
	1500	18.5/60.0	4.5	964	85	36	VSCS
	1800	18.5/60.0	4.5	966	85	36	VSCS
	2100	18.5/60.0	4.5	970	80	32	VSCS
03-06-2010	0000	18.5/59.5	4.0	974	75	28	VSCS
	0300	18.5/59.5	4.0	974	75	28	VSCS
	0600	19.0/59.5	4.0	978	70	24	VSCS

	0900	19.5/59.5	4.0	978	70	24	VSCS
	1200	20.0/59.5	4.0	978	70	24	VSCS
	1500	20.0/59.5	4.0	978	70	24	VSCS
	1800	20.5/59.5	4.0	980	65	22	VSCS
	2100	21.0/59.5	4.0	980	65	22	VSCS
04-06-2010	0000	21.5/59.5	4.0	980	65	22	VSCS
	The system crossed Oman coast near lat. 21.5^0 N between 0000 & 0200 UTC.						
	0300	22.0/59.5	--	982	60	18	SCS
	0600	22.0/59.5	--	984	60	18	SCS
	0900	22.5/59.5	--	984	60	18	SCS
	1200	23.0/59.5	3.5	984	60	18	SCS
	1500	23.0/59.5	3.5	986	55	16	SCS
	1800	23.0/59.5	3.5	988	55	14	SCS
	2100	23.5/60.0	3.5	990	50	12	SCS
05-06-2010	0000	24.0/60.5	3.0	990	45	10	CS
	0300	24.5/61.0	2.5	992	40	8	CS
	0600	24.5/61.0	2.5	992	40	8	CS
	0900	24.5/61.0	2.5	992	40	8	CS
	1200	24.5/61.5	2.5	992	40	8	CS
	1500	24.5/62.0	2.5	994	35	7	CS
	1800	24.5/62.5	2.0	994	30	5	DD
	2100	24.5/63.0	2.0	994	30	5	DD
06-06-2010	0000	24.5/64.0	2.0	994	30	5	DD
	0300	24.5/65.0	1.5	994	25	4	D
	0600	24.5/66.0	1.5	994	25	4	D
	0900	24.5/66.5	1.5	994	25	4	D
	1200	24.5/67.0	1.5	993	25	4	D
	The system crossed Pakistan coast, close to south of Karachi (near 24.7 ^{0}N and 67.2^0E between 1230 and 1330 UTC.						
	1500	25.0/68.0	--	993	25	4	D
	1800	25.0/69.0	--	991	25	5	D
07-06-2010	0000	26.5/71.0	--	993	25	5	D
	0300	26.5/71.5	--	993	25	5	D
	0600	26.5/72.5	--	995	20	3	D
	1200	Weakened into a well marked low pressure area over east Rajasthan and adjoining northwest Madhya Pradesh					

The dynamical parameters suggesting weakening of the system from 4 June onwards are shown in Fig.2.24-26. The INSAT imageries at different stages of intensity are showing Fig. 2.27.

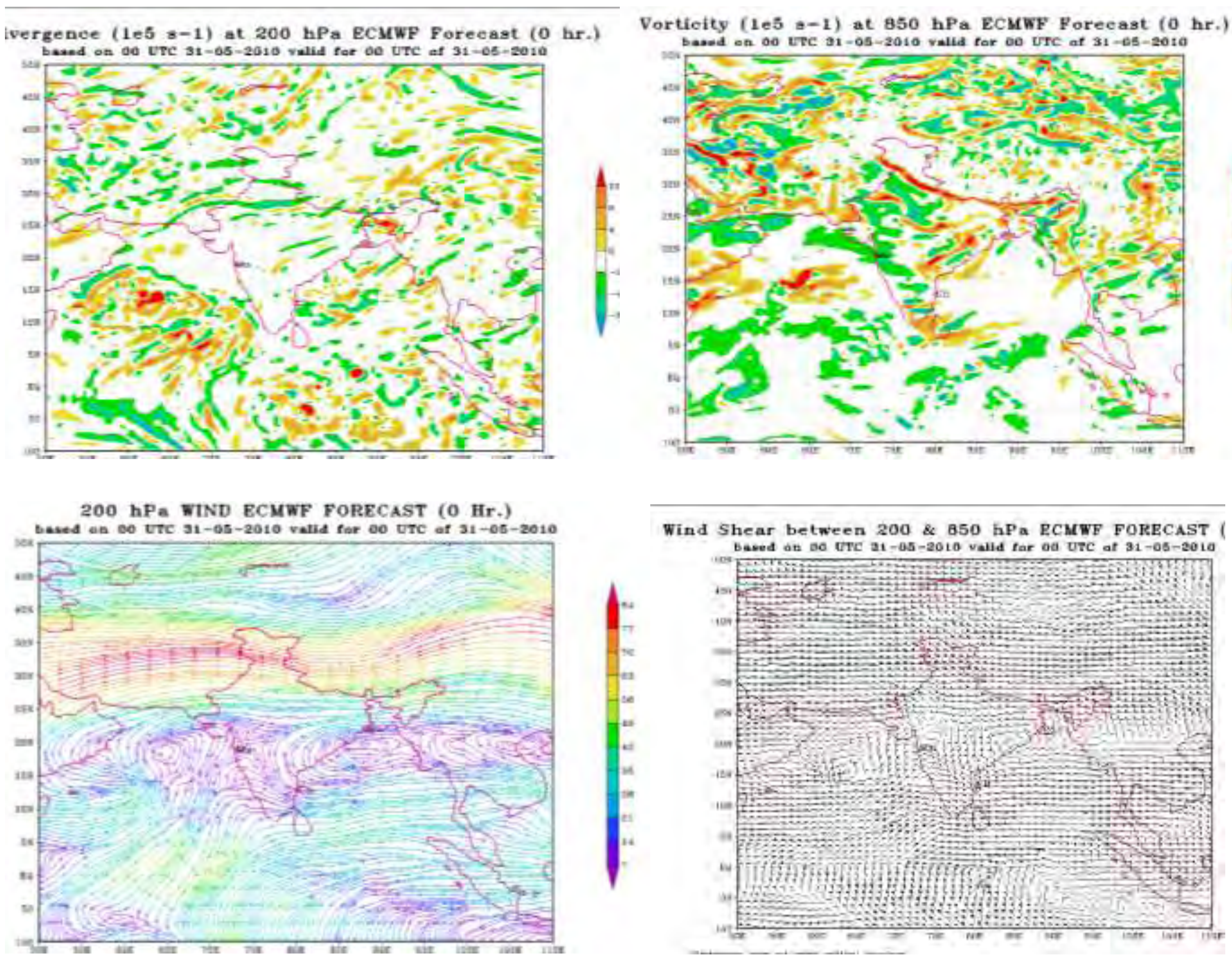


Fig.2.20 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 31 May 2010

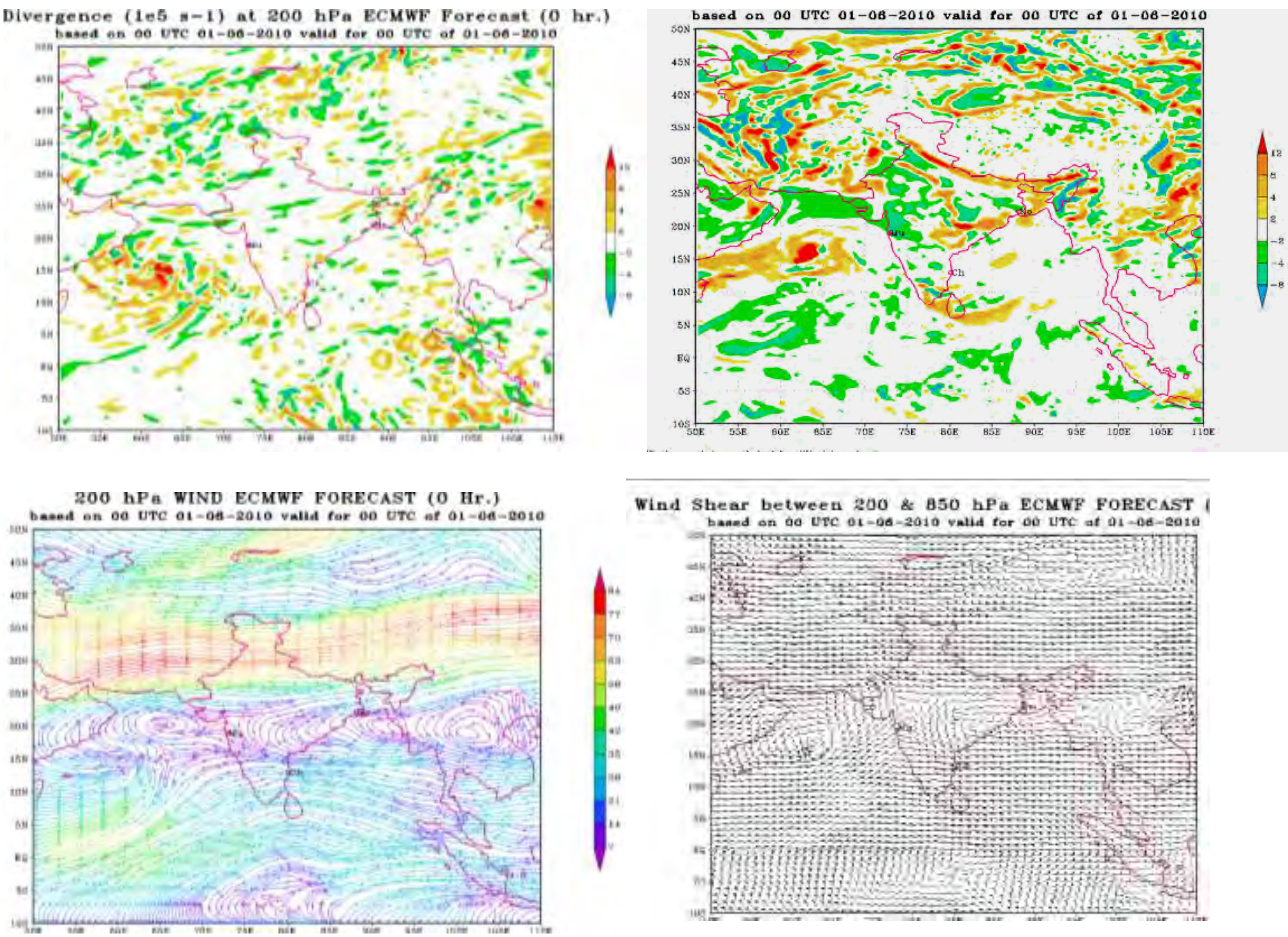


Fig.2.21 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 01 June 2010

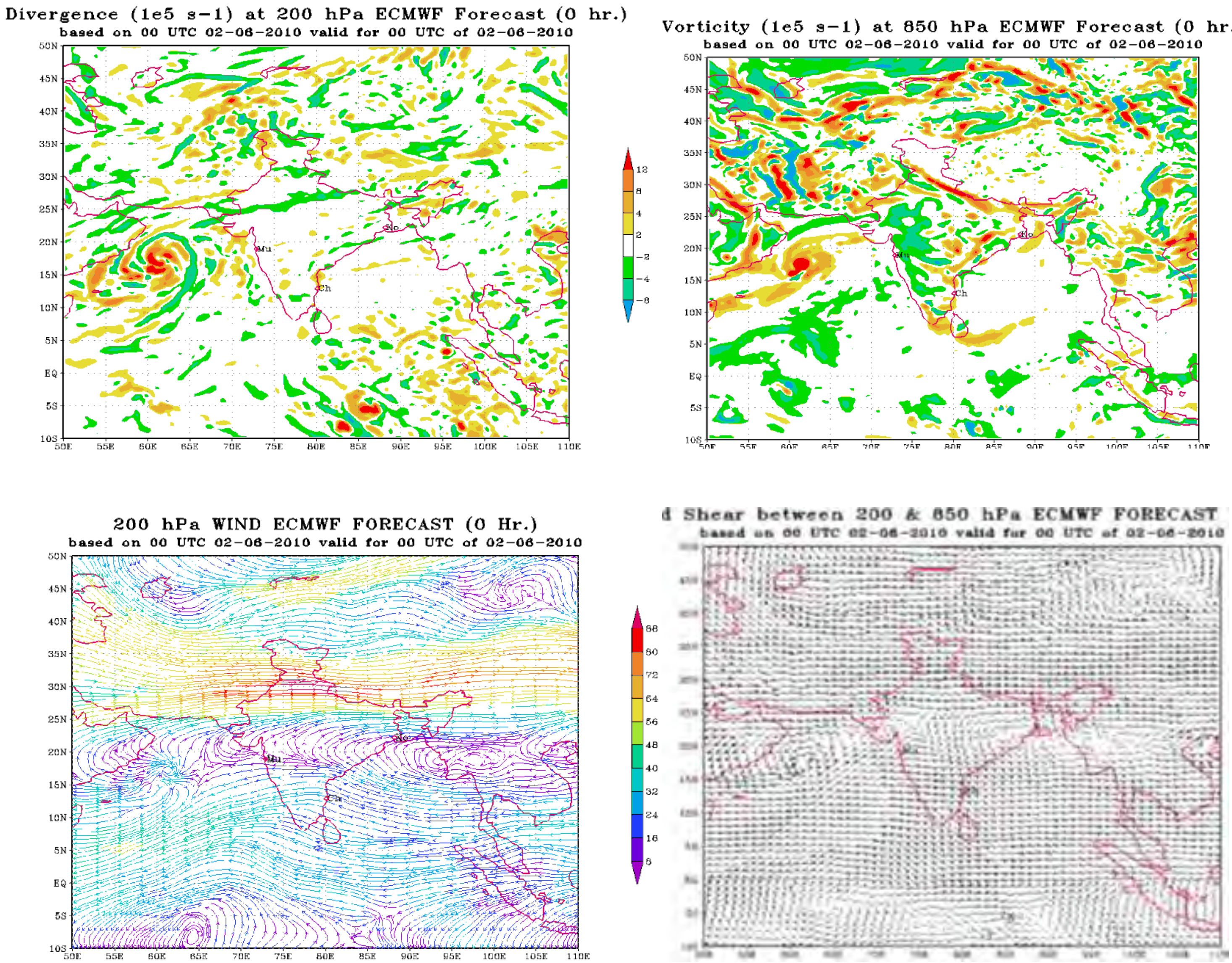


Fig.2.22 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 02 June 2010

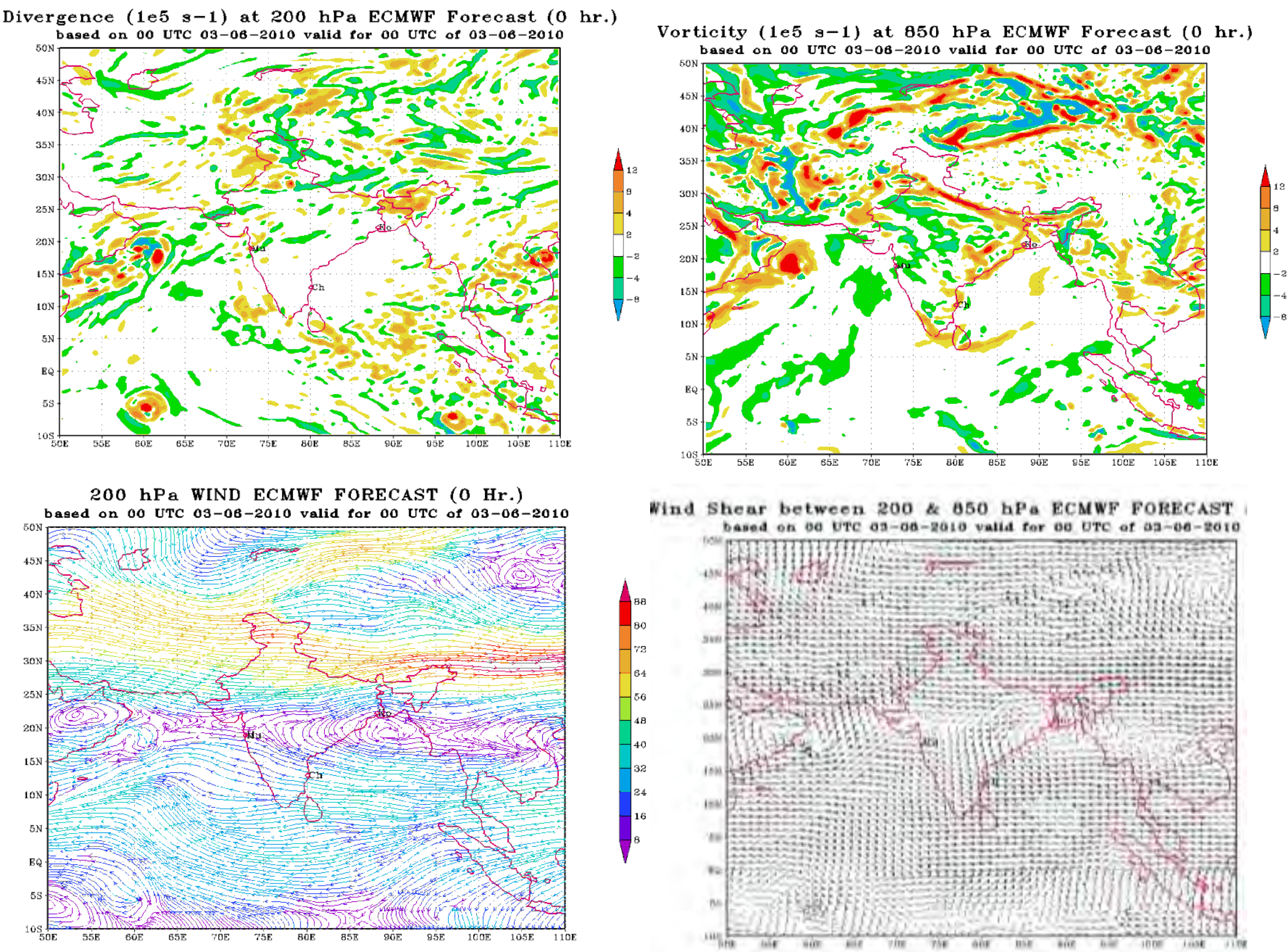


Fig.2.23 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 03 June 2010

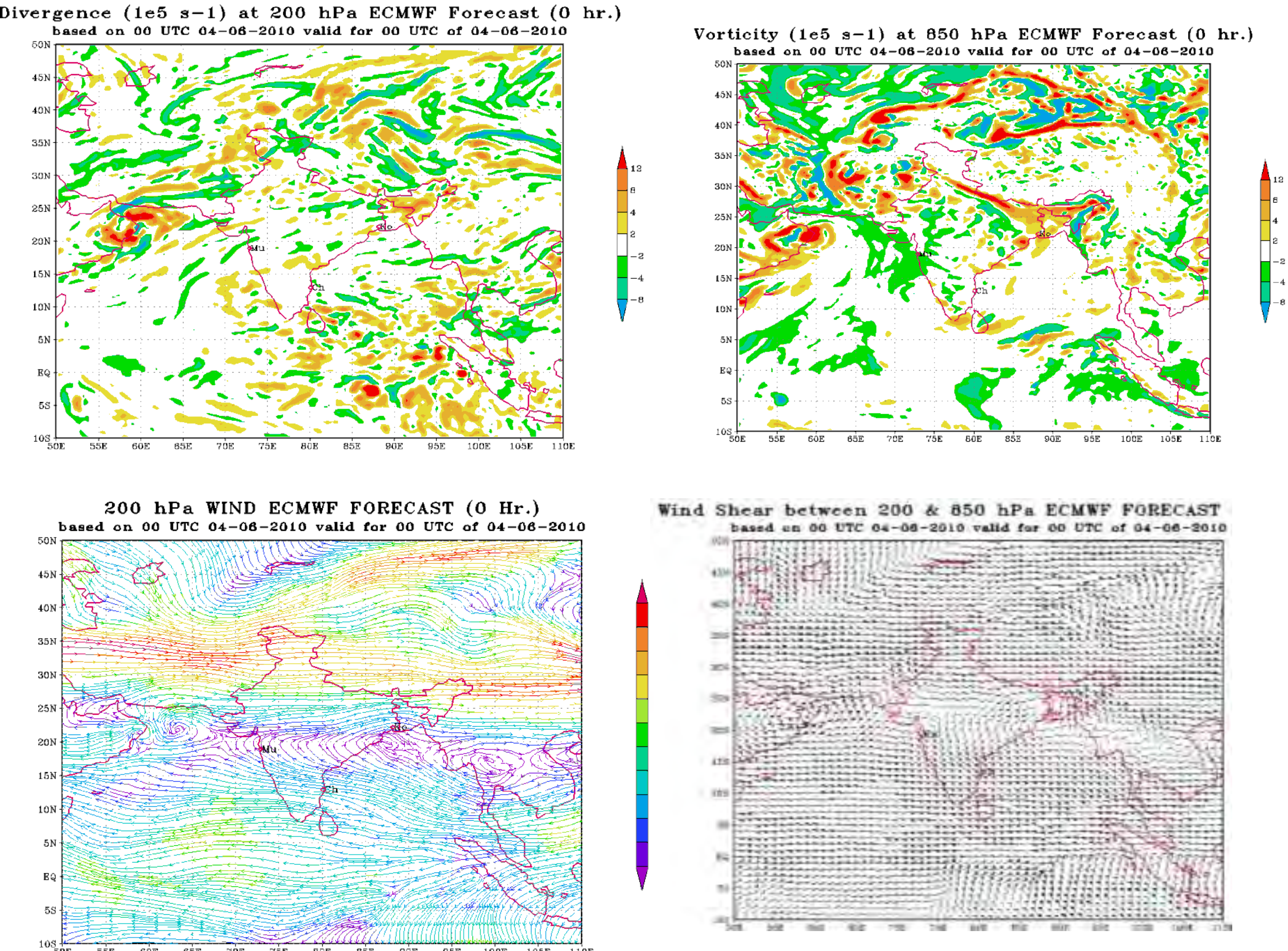


Fig.2.24 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 04 June 2010

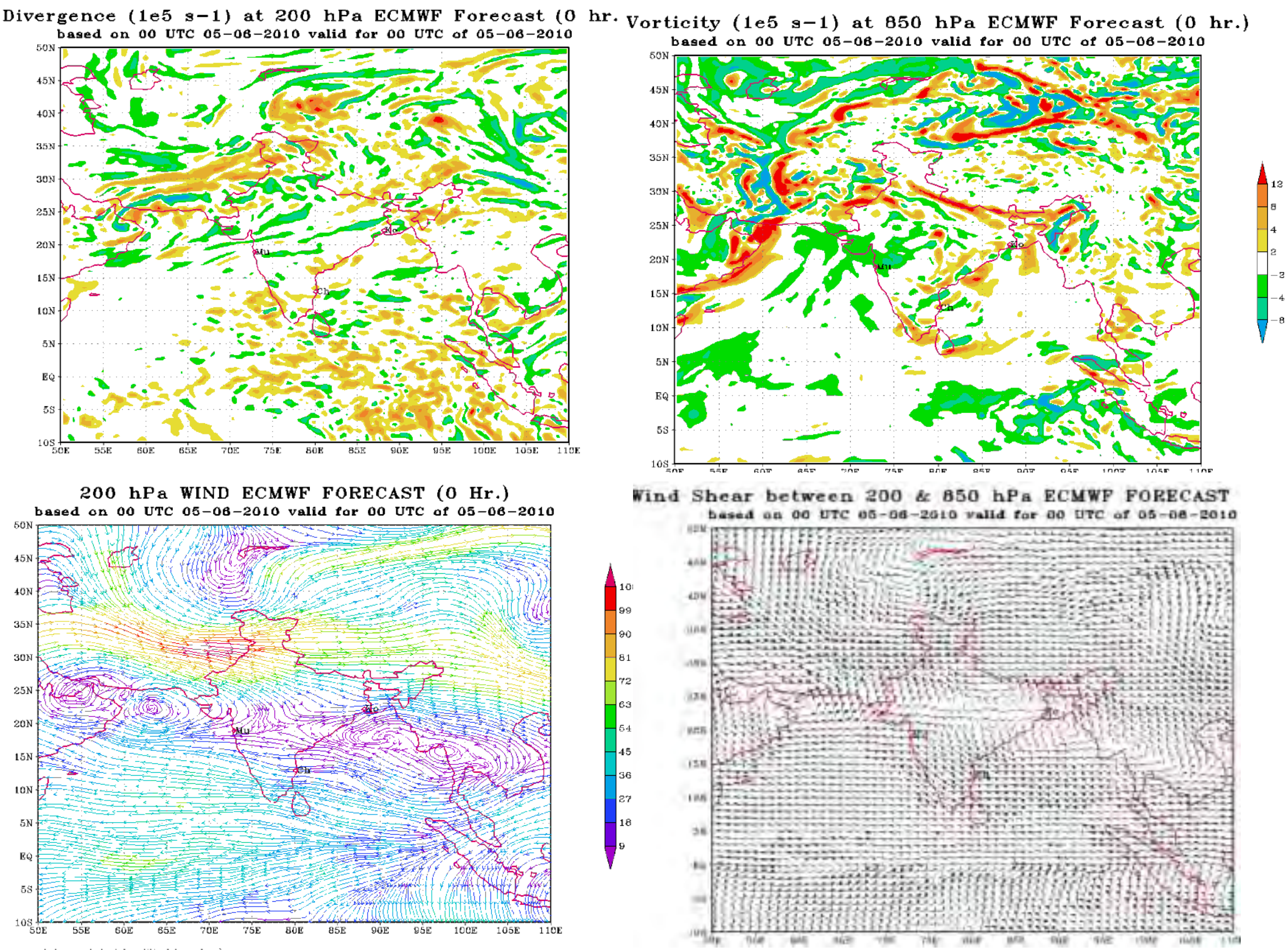


Fig.2.25 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 05 June 2010

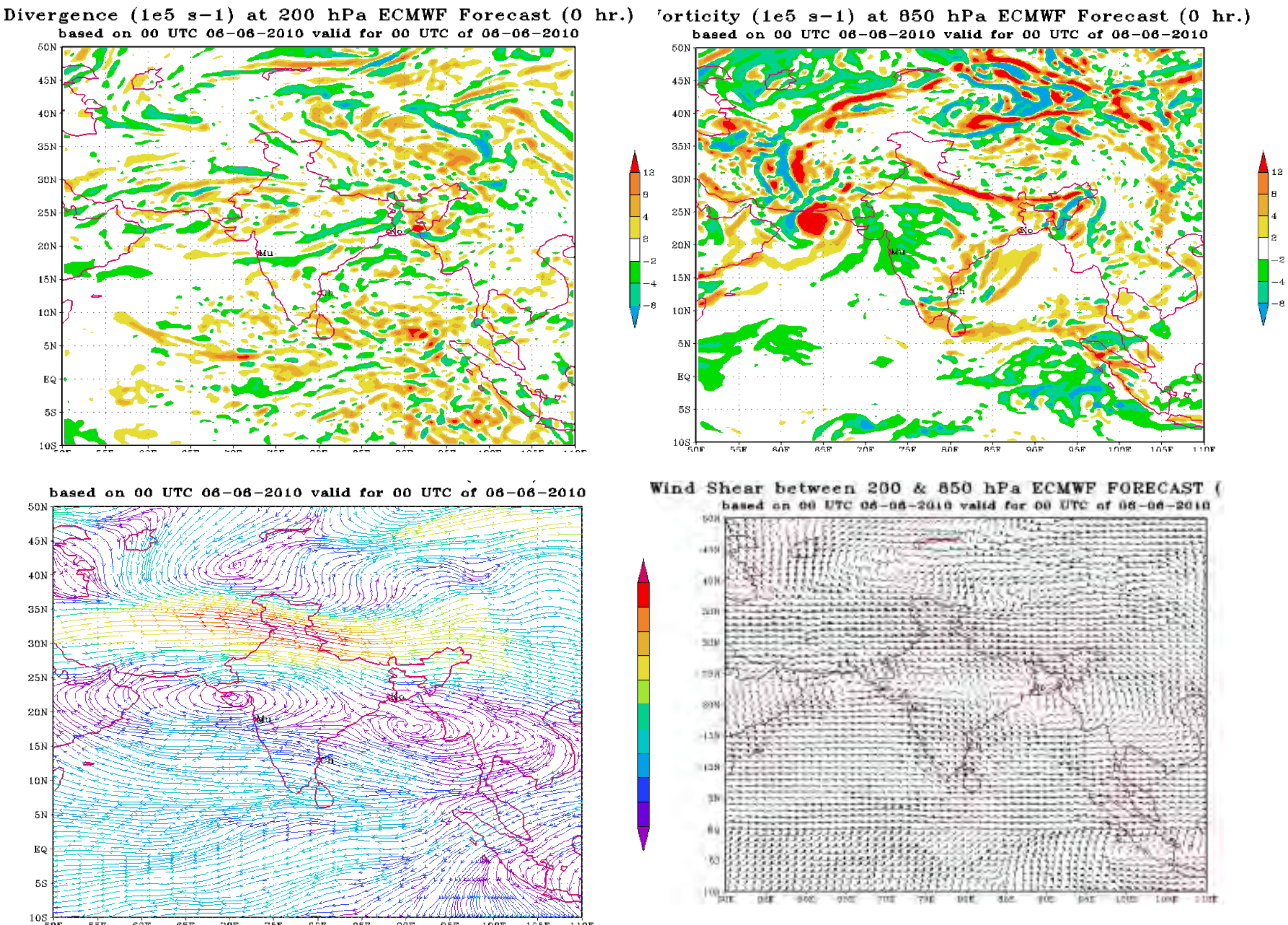


Fig.2.26 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 06 June 2010

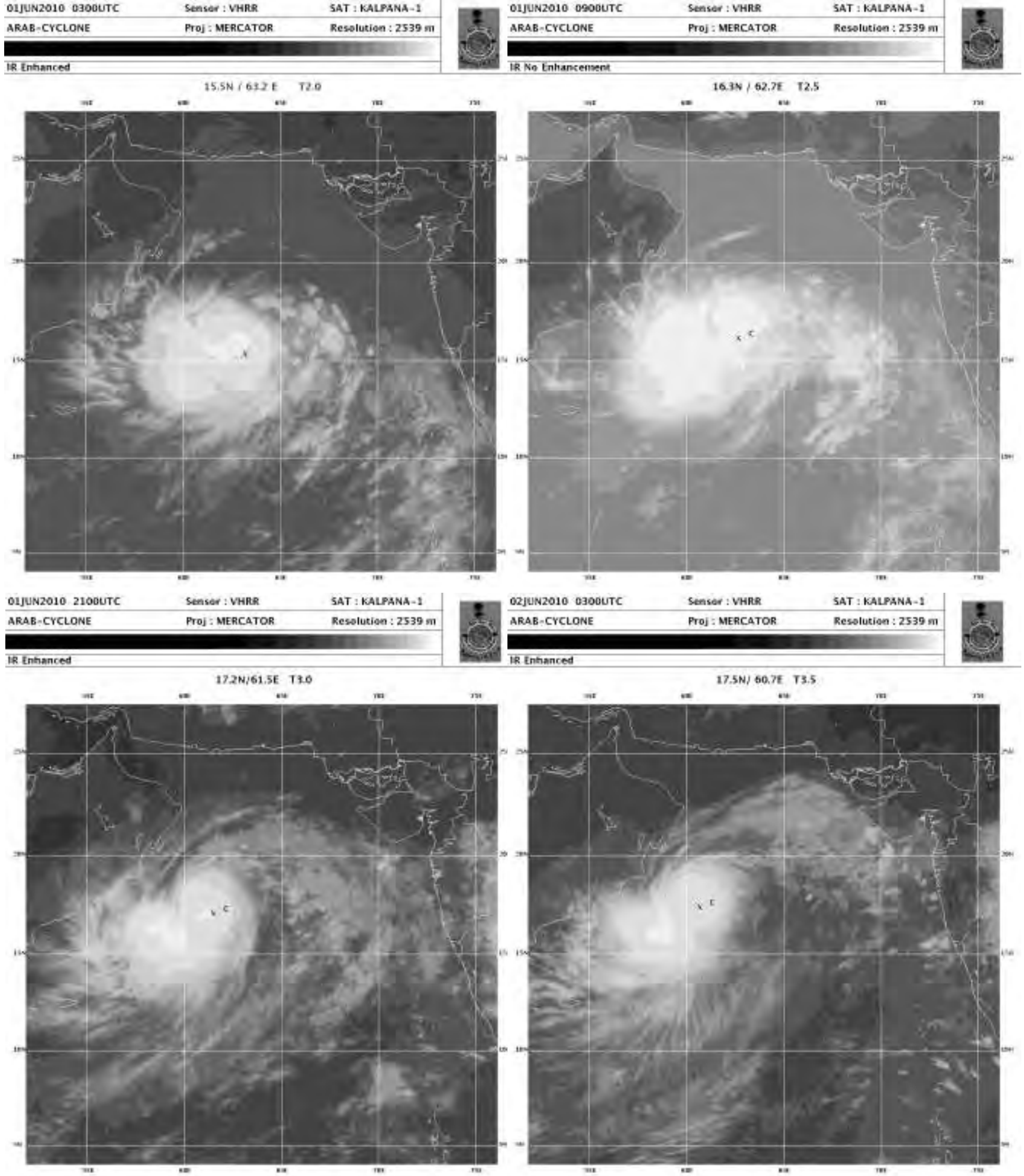


Fig.2.27 Kalpana imagery of cyclone, PHET showing different stages of intensity

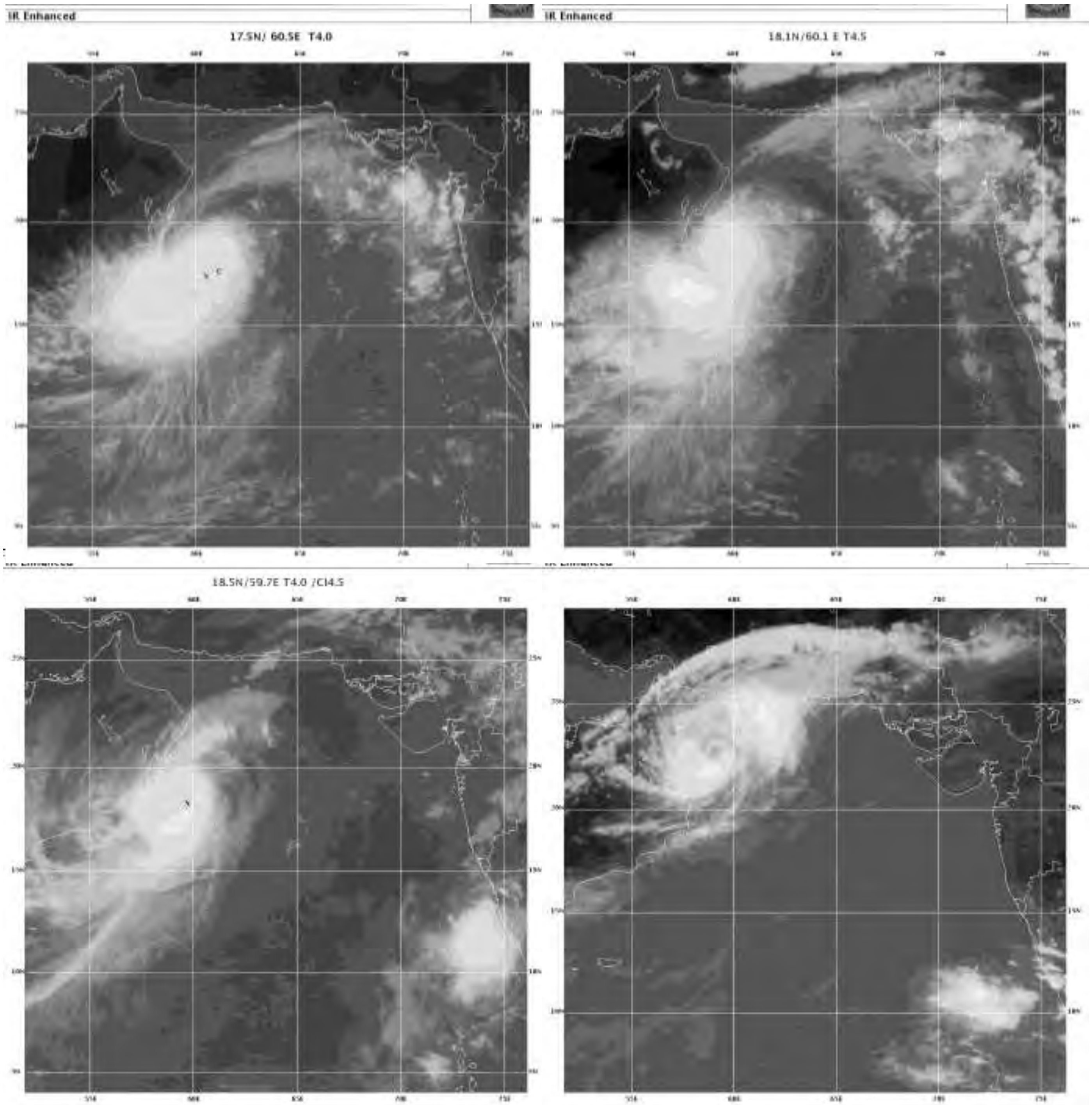


Fig. 2.27 (contd) Kalpana imagery of cyclone, PHET showing different stages of intensity

2.3.4. Structure and other Parameters

There was rapid intensification of the system from 31 May to 01 June 2010. The satellite imagery of the storm revealed an eye on early hours of 2 June.The

moderate resolution imaging spectroradiometer (MODIS) captured a visible image of PHET around 0700 UTC of 2 June and noticed an eye with a diameter of about 12 km. However, there was slight weakening of the system with disappearance of the eye in the later part of the day. The animation of the multi-spectral satellite imageries indicated that system regained 20 nm ragged eye on 3 June, that appeared to wobble as the cyclone underwent possible eye wall replacement.
At its maximum intensity, the radii of gale wind (34 knots or more) extended upto about 120 km and 64 knots wind extended upto about 55 km.

2.3.5. Realised weather

Heavy rains drenched Oman's east coast The sytem mainly moved eastwards close to but parallel to Makaran coast from 5 June onwards and weakened gradually further.Fairly widespread rainfall with isolated heavy falls occurred over west Rajasthan and Kutch region of Gujarat on 7 June. The entire western Rajasthan was badly affected by the spell of heavy rains due to Phet. The drought prone Jaislamer district of Rajasthan was hit with torrential rains. Chief amounts of rainfall are:

West Rajasthan
7 June: Jaisalmer 11, Phalodi 9.

Pakistan
6 June: Gawadar 37, Jiwani 21, Karachi Masroor 13, Pasni 13, Faisal Base 9, Karachi Sadar 8

RAJASTAN :
7 June: Pokran 12, Jaisalmer 11, Phalodi 9, Tehsil 9, Nokh -7
8 June: Lunkaransar -8, Taranagar -7, Laxmangarah -7

Gujarat Region:
7 June : Kadi -7,

Saurashtra : Kalyanpur -11, Mandvi -9, Lalpur -8, Rajkot Aero , Jamnagar Aero , Nakhatrana, Bhanwad , Naliya , Abadaga -7 each.

2.3.6. Damage

The death due to cyclone, PHET are as follows
Oman : 24
Pakistan : 15
India : 05
Total : 44

Strong winds uprooted trees and signboards in Oman, halted its oil and gas production due to bad weather as Cyclone Phet hit the small oil-producing country's coast. Jaisalmer district of Rajsthan was worst hit as 35 black bucks and 11 chinkaras were killed in Tal Chhapar wildlife sanctuary in Churu district. Chhapar sanctuary is one of the few places in India where black bucks are present in large numbers.Typical damage photograph from Oman coast are shown in.2.28.

Fig. 2.28 Damage photographs from Oman coast in association with cyclone, PHET

2.4. Very severe cyclonic storm, GIRI over the Bay of Bengal (20-23 October 2010)

2.4.1. Introduction

A very severe cyclonic storm, ‗GIRI' formed over the Arabian Sea on 20 October 2010 moving in a northeasterly direction, it crossed Myanmar coast between Sittwe and Kyakpyu around 1400 UTC of 22 October,2010 with estimated sustained maximum wind speed of about 190 kmph (105 knots). It caused damage to life and property of Myanmar. The salient features of this system are given below.

i. Cyclone, Giri rapidly intensified from associated sustained maximum wind speed of 45 knots at 1200 UTC of 21 to 105 knots at 0900 UTC of 22 October, 2010.
ii. No severe cyclone crossed Arakan coast prior to cyclone, GIRI during the month of October, as evident from the data of 1891-2009.
iii. The genesis and intensification of the system could be predicted by ECMWF model to a large extent. It predicted lowest estimated central pressure of 970

hPa well in advance with landfall near lat.20^0N and long.93^0E between 1200 and 1800 UTC of 22^d October 2010 well in advance against the lowest estimated central pressure of 950 hPa and landfall near lat. 20^0N and long. 93.5^0E around 1400 UTC of 22 October 2010.

2.4.2. Genesis

A low pressure area formed over the east central Bay of Bengal on 19 October. It concentrated into a depression at 1200 UTC on 20 October over the same area near lat.17.5^0N and. lat. 91.5^0E. The dynamical parameters like upper level divergence, lower level relative vorticity and vertical wind shear at 0000 UTC of 20 October 2010 (Fig.2.29) were favourable for intensification of the system. The wind shear was low to moderate (10-15 knots). The sea surface temperature was $28\text{-}32^0$C were over the region. The ocean heat content over the central Bay of Bengal was also favourable for intensification. The system lay close to the upper tropospheric ridge, which roughly run along 17.5^0N (Fig.2.29) in association with anticyclonic circulation.

2.6.3. Intensification and movement

Remaining practically stationary, it intensified into a deep depression at 0300 UTC of 21 October and into a cyclonic storm, **GIRI** at 0600 UTC of the same day. It then moved slowly northeastwards and intensified into a severe cyclonic storm at 0000 UTC of 22 October and into a very severe cyclonic storm at 0300 UTC of the same day. It then moved relatively faster in the same direction and crossed Myanmar coast between Sittwe and Kyakpyu around 1400 UTC of 22 October 2010 with estimated sustained maximum wind speed of about 190 kmph (105 knots). After the landfall, it continued to move northeastwards and weakened gradually. The best track parameters of cyclone GIRI are shown in Table 2.6. The track of the system is shown in Fig.2.1. The typical satellite imageries of the system are shown in Fig.2.30. The lowest ECP was estimated as 950 hPa with pressure drop of 52 hPa. Kyakpyu reported lowest pressure of 990.7 hPa with surface wind southerly to southeasterly 35 knots and 24 hrs pressure fall of 11.9 hPa at 0900 UTC of 22 October 2010 when system was located 50 km west of Kyakpyu.

Table 2.6 Best track positions and other parameters of the severe cyclonic storm ―GIRI" over the Bay of Bengal during 20-23 October, 2010

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
20-10-2010	1200	17.5/91.5	1.5	1002	25	4	D
	1800	17.5/91.5	1.5	1002	25	4	D
21-10-2010	0000	17.5/91.5	1.5	1002	25	4	D

	0300	17.5/91.5	2.0	1000	30	5	DD
	0600	17.5/91.5	2.5	998	35	6	CS
	0900	17.5/91.5	2.5	996	40	8	CS
	1200	18.0/92.0	3.0	990	45	10	CS
	1500	18.0/92.0	3.0	990	45	10	CS
	1800	18.0/92.0	3.0	988	50	12	CS
	2100	18.5/92.5	3.0	984	55	16	CS
22-10-2010	0000	18.5/92.5	3.5	980	60	20	SCS
	0300	19.0/93.0	4.5	974	80	30	VSCS
	0600	19.0/93.0	5.0	964	90	40	VSCS
	0900	19.5/93.5	5.5	950	105	52	VSCS
	1200	19.8/93.5	5.5	950	105	52	VSCS
	The system crossed Myanmar coast near lat. 20.0^0 N long. 93.5^0 E about 70 km east-southeast of Sittwe around 1400 UTC.						
	1500	20.0/93.5	--	966	80	36	VSCS
	1800	20.5/94.0	--	976	70	26	VSCS
	2100	20.5/94.0	--	986	55	16	SCS
23-10-2010	0000	21.0/94.5	--	992	45	10	CS
	0300	21.5/95.0	--	996	35	8	CS
	0600	22.0/95.5	--	998	25	4	D
	1200	The system weakened into a well marked low pressure area over central parts of Myanmar.					

Considering the environmental parameters, the low to moderate vertical wind shear continued throughout the life of the system (Fig.2.31 – 2.32). The warmer SST continued however with Ocean heat content becoming less than 100 KJ/cm^2. It seems vertical wind shear played a major role than the Ocean heat content for rapid intensification of the system on 21-22 October 2010. As the system moved to the north of the ridge gradually, the system recurved north-northeastwards.

2.4.4. Structure and other parameters

The system was tracked with the help of satellite cloud imageries from 0600 UTC of 20 to 1400 UTC of 22 October. The maximum intensity of T. No. 5.5 was reported from 0900 of 20 October till it crossed Myanmar coast. The Estimated Lowest Central Pressure (ECP) was 950 hPa from 0900 UTC till the system crossed Myanmar coast. The estimated maximum wind speed was 105 kts.
At 0900 UTC of 22, the cloud pattern indicated sharp improvement in organization and convection around the vortex centre and also decrease in diameter of EYE, which is indicative of explosive intensification.

Continued development took place as convection consolidated around the system and banding features formed along the western side of the low. Situated in an area of weak wind shear, further development was anticipated over the following days. Cyclone ‗GIRI‘was seen clearly by the Tropical Rainfall Measuring Mission

(TRMM) satellite twice on Oct. 21. The first good view was at 1534 UTC when TRMM data showed a very well organized storm with heavy rainfall south of Giri's partially formed eye. The heaviest rainfall was falling at about 2 inches per hour, south of Giri's eye. The second TRMM orbit at 2347 UTC captured Giri's rainfall. The wind speed increased to 80 knots at 0300 UTC of 22 October. The second TRMM image showed that Giri had developed a closed eye surrounded by powerful thunderstorms dropping heavy rainfall. Satellite imagery depicted a well-defined 46 km (29 mi) wide eye surrounded by deep convection. Accompanied by strong poleward outflow, additional strengthening took place despite Giri's proximity to land.

With the development of very intense convection, estimated lowest cloud top temperature was between -70 and -80 °C. Explosive intensification which took place with cyclone GIRI, is a more extreme case of rapid deepening that involves a tropical cyclone deepening at a rate of at least 2.5 hPa per hour for a minimum of 12 hours. Explosive intensification is rather rare, as conditions must be exceedingly favorable for cyclone intensification. Explosive intensification occurs regularly in the West Pacific basin, with the greatest frequency off the north coast of Australia; however, it has occurred numerous times in the Atlantic basin. It is rare in the North Indian Ocean, but Cyclone Giri is a good example of a storm going through explosive intensification in this basin.

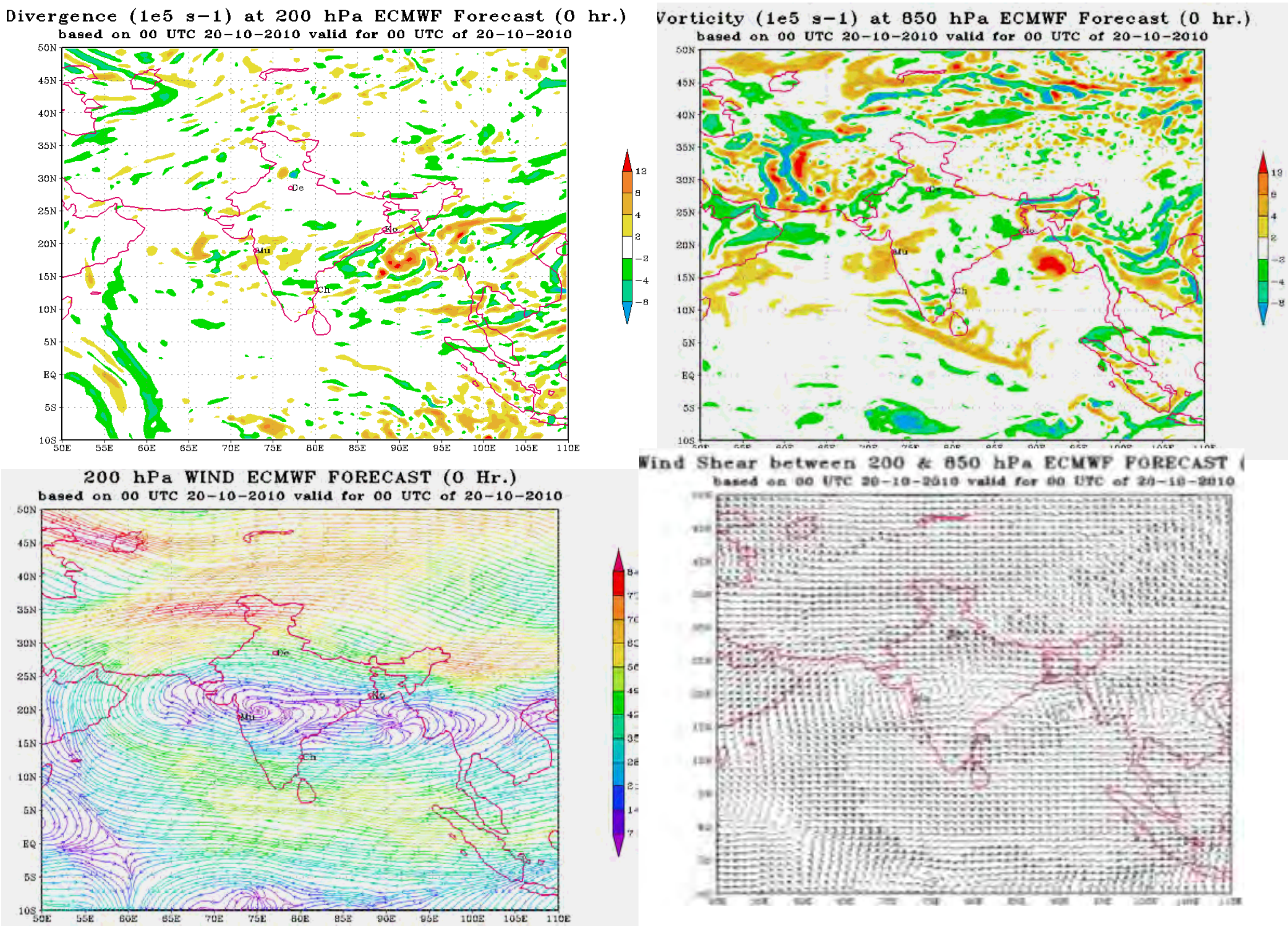


Fig.2.29 ECMWF analyses (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 20 October 2010

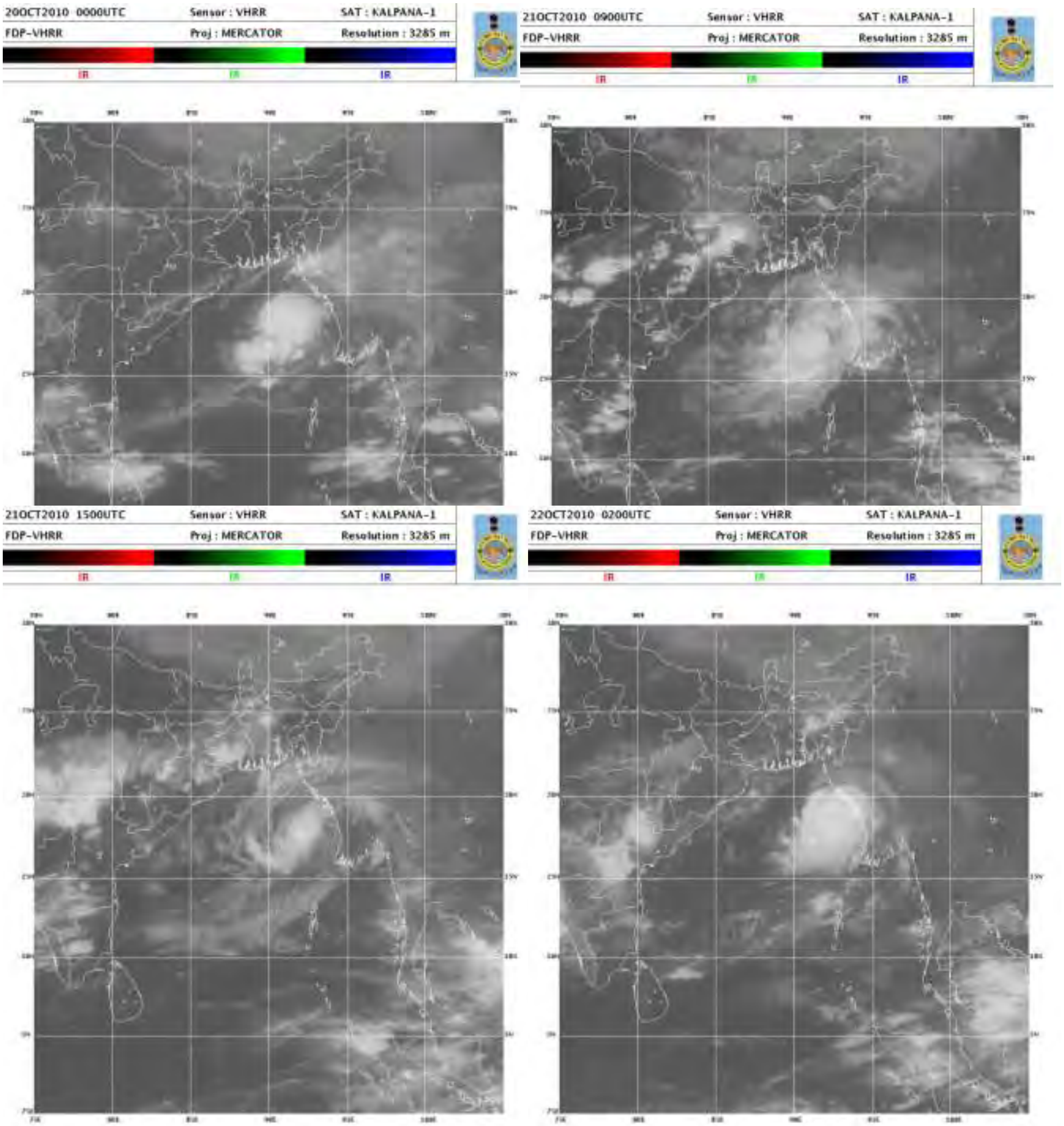


Fig. 2.30 Kalpana imageries of cyclone GIRI over the Bay of Bengal 0000, 0900, 1500 and 0200 UTC of 20, 21 and 22 October 2010.

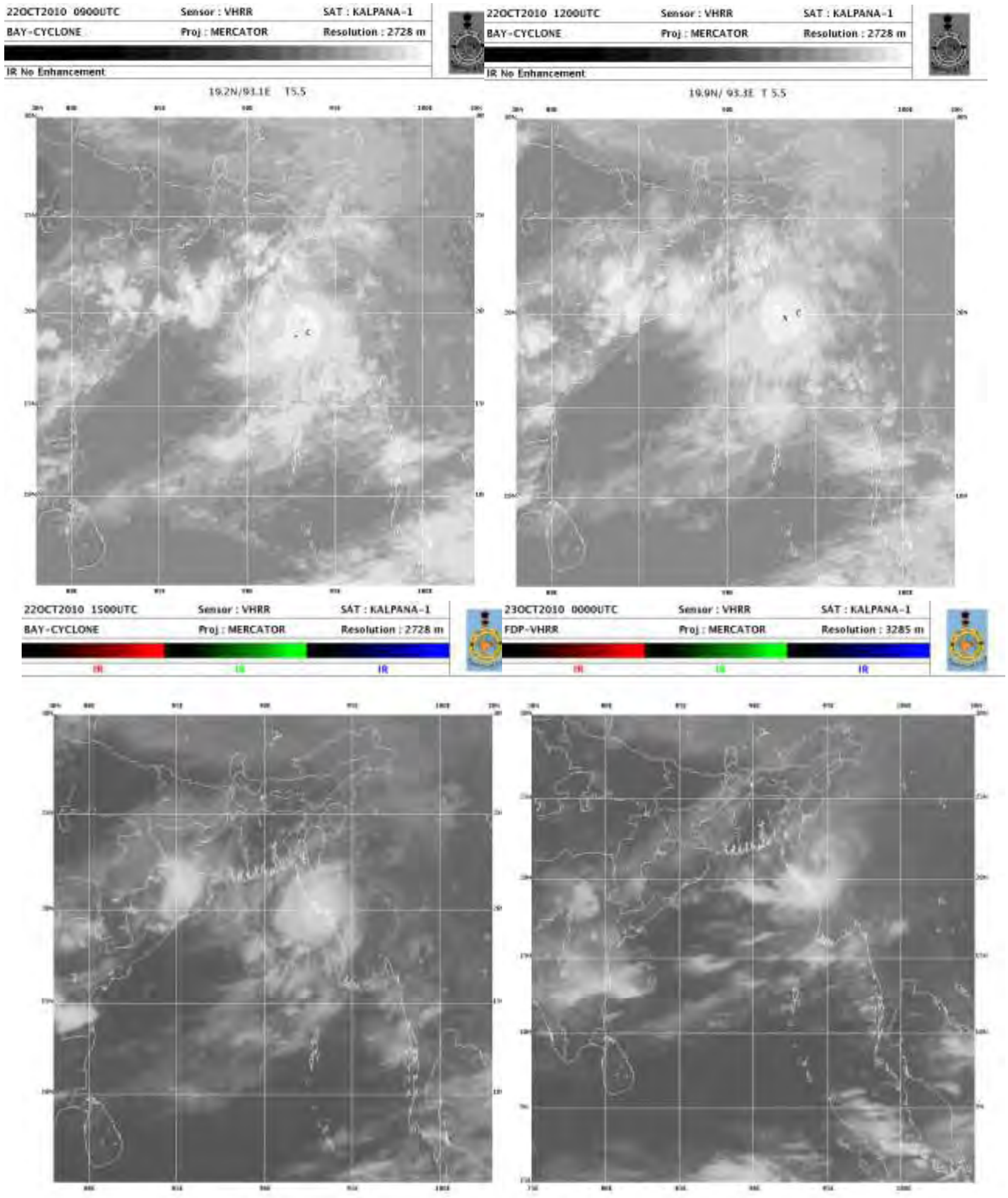


Fig.2.30 (contd.) Kalpana imageries of cyclone ‗GIRI' over the Bay of Bengal 0900, 1200, 1500 UTC of 22 October 2010and 0000 UTC of 23 October 2010.

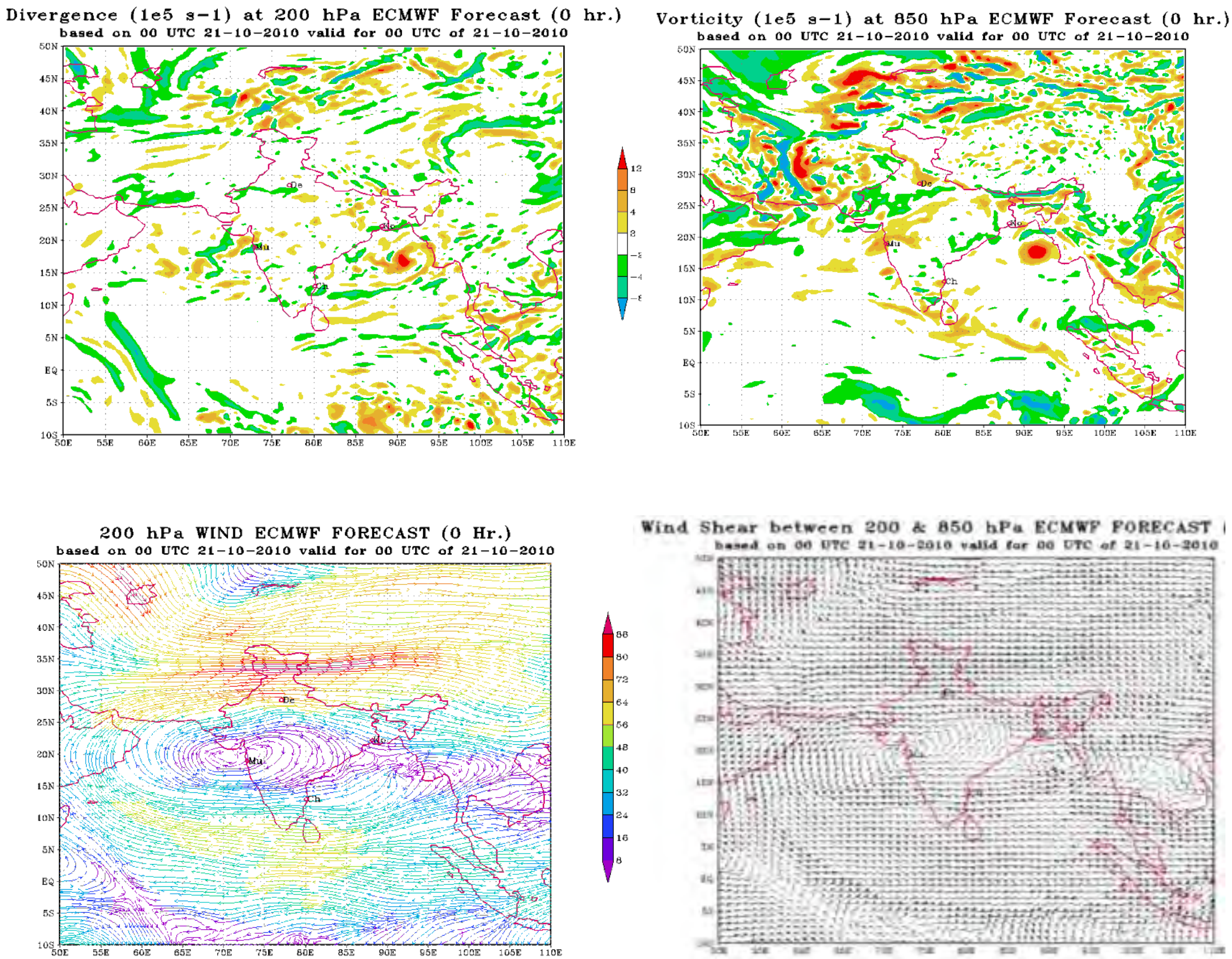
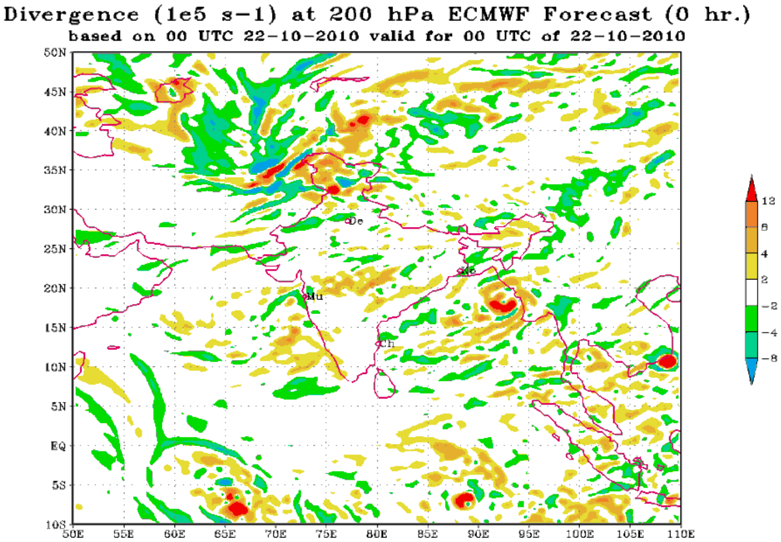
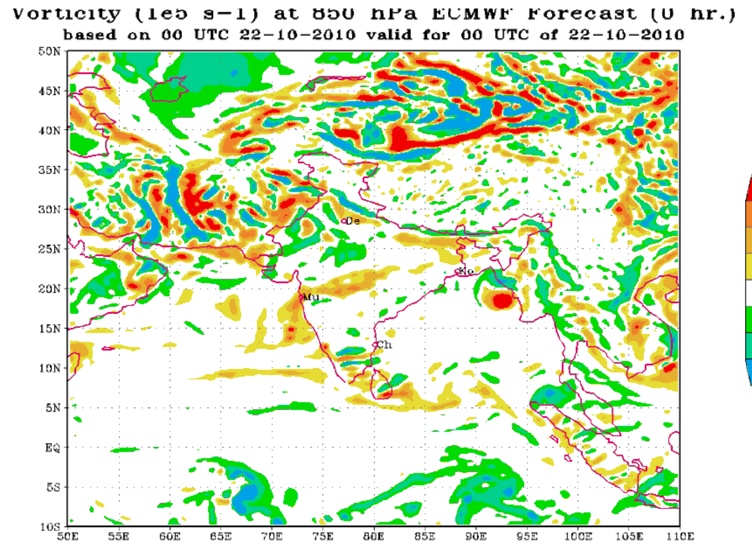


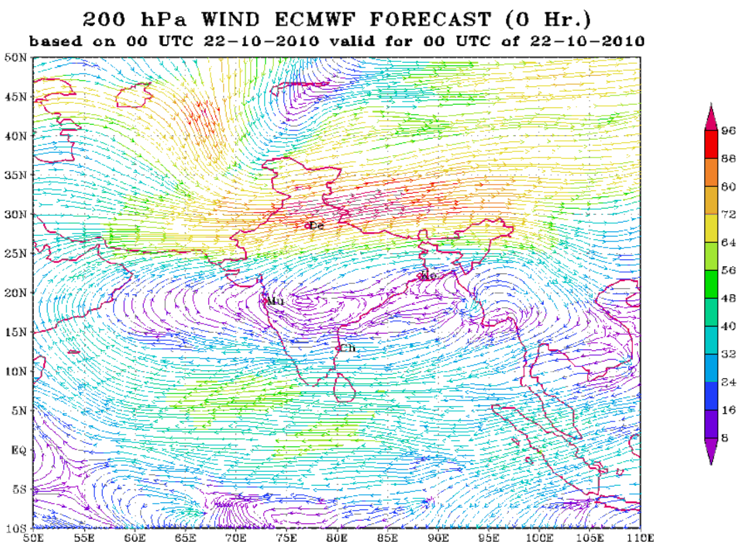
Fig.2.31 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 21 October 2010

2.4.4. Realised weather :

According to local media, Cyclone Giri brought a storm surge up to 3.7 m (12 ft), along with waves up to 8 m (26 ft). In Kyaukphyu, much of the city was left more than 1.2 m (3.9 ft) under water by the storm.







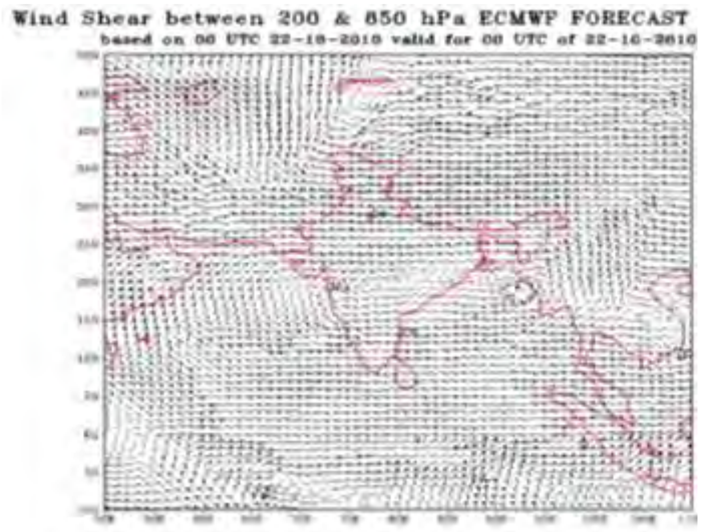


Fig.2.32 ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 22 October 2010

2.4.5. Damage:

157 fatalities had been confirmed as a result of Cyclone Giri. Damage from the storm amounted to 2.34 billion kyat (US$359 million). Myebon Township was the hardest-hit area in the country. Several villages were completely destroyed by the storm and many others were severely damaged. According to the United Nations, roughly 15,000 homes were destroyed by the storm throughout Arakan State. According to the United Nations Food and Agriculture Organization, 16,187 hectares (40,000 acres) of rice paddies were destroyed and another 40,468 hectares (100,000 acres) were damaged.

2.5 Cyclone ‗JAL' over the Bay of Bengal (04-08 November 2010)

2.5.1. Introduction

A severe cyclonic storm, JAL developed over the Bay of Bengal from the remnant of a depression which moved from northwest Pacific Ocean to the Bay of Bengal across southern Thailand. It moved west-northwestwards and intensified upto severe cyclonic storm on 6 November, 2010. However due to lower ocean thermal energy and moderate to high vertical wind shear, the severe cyclonic storm, JAL weakened gradually into a deep depression and crossed north Tamilnadu – south Andhra Pradesh coast, close to the north of Chennai near 13.3^0N and 80.3^0E around 1600 UTC of 07 November 2010. Its salient features are as follows.

- The severe cyclonic storm, JAL weakened into a deep depression over the Sea before the landfall.
- The convective clouds were sheared to the west to a large extent on the date of landfall (7 November 2010). As a result, more rainfall occurred over the interior parts than over the coastal regions.

2.5.2 Genesis

A depression formed over the West Pacific Ocean on 31 October, 2010 in association with an active Inter-Tropical Convergence Zone (ITCZ). It moved west-northwestwards across southern Thailand and emerged as a low pressure area over the south Andaman Sea on 2 November. Animated imageries indicated merging of mesoscale convective clusters along with increase in deep convection from 3 to 4 October 2010. Further there was improvement in covecting band. As a result, the well marked low pressure area continued to move west-northwestwards and concentrated into a depression at 0000 UTC of 4 November 2010 over southeast Bay of Bengal near lat. 8.0^0N and 92.0^0E. The track of the system is shown below in Fig.2.1. The best track parameters of the system are shown in Table 2.7.

The environmental conditions were favourable with higher SST (30-32^0C), higher Ocean heat content (>100 KJ/cm^2), increased low level relative vorticity and upper level divergence and lo vertical wind shear (Fig.2.33)

2.5.3 Intensification and movement

The system intensified into a Deep Depression in the early morning of 5 November and into a Cyclonic Storm ‗JAL' at 0600 UTC of the same day with centre near lat. 9.0^0N and long. 87.5^0E, about 900 km east-southeast of Chennai. The cyclonic storm ‗JAL' over southeast Bay of Bengal continued to move west-northwestwards and intensified further into a severe cyclonic storm in the early hours of 6 November. However as the severe cyclonic storm, JAL moved to the southwest Bay of Bengal closer to India coast, it entered into a region of lower ocean thermal energy and moderate to high vertical wind shear in association with the strong easterlies in the upper tropospheric level. The high wind shear led to westward shearing of the convective clouds form the system centre and lower Ocean thermal energy led to unsustainability of convection over the region. Due to these two factors, the severe cyclonic storm, JAL weakened into a cyclonic storm at 0600 UTC of 7 November 2010 over southwest Bay of Bengal with centre near lat.12.5^{0}N and long. 82.5^{0}E, about 250 km east-southeast of Chennai. It weakened further into a deep depression and crossed north Tamilnadu – south Andhra Pradesh coast, close to the north of Chennai near 13.3^{0}N and 80.3^{0}E around 1600 UTC of 07 November 2010. It continued to move west-northwestwards, further weakened into a depression at 0300 UTC and into a well marked low pressure area over Rayalaseema and adjoining south interior Karnataka at 0600 UTC of today, the 8 November 2010. The environmental condition supporting the intensification, weakening and movement of the system are shown in Fig.2.34 The weakening of the system before landfall could be attributed to lower Ocean heat content, though the SST was higher than threshold

It emerged into the east central Arabian Sea on 9 November. It then moved initially northwestwards towards Saurashtra & Kutch and adjoining Pakistan coast during 9-11 November. It then moved northeastwards across Saurashtra & Kutch and adjoining Pakistan and became less marked on 12 November 2010. The typical satellite imageries of the system are shown in Fig.2.35

2.5.4. Structure and other parameters

The system was tracked by Satellite from 0600 UTC of 2 Nov. till the landfall. The maximum intensity of T 3.5 was reported from 2100 UTC of 5 to 0500 UTC of 7 November. The Estimated lowest Central Pressure (ECP) observed was 988 hPa. The estimated maximum wind speed was 60 kts. As per DWR Chennai and DWR SHAR reports, the system started weakening from 0300 UTC of 7 November, while continuing its northwesterly track and crossed the coast as deep depression north of Chennai, close to SHAR around 1800 UTC.

The cyclone ‗Jal' formed in the south Bay of Bengal was well captured by the 3 data buoys viz. BD6, BD07_Omni & BD06_Omni, which are deployed in the Bay of Bengal; out of which 2 are equipped with sub-surface oceanographical instruments upto 500 meters depth which were deployed on 24 & 26 October 2010 and third buoy BD06 has an indigenize CPU. [The Buoys (i) BD06_OMNI (Lat. 9.9° N / Long. 88.4° E) Met Sub-Surface Ocean upto 500 meters depth (ii) BD07_OMNI (Lat. 8° N / Long. 88.5° E) Met. Sub-Surface Ocean upto 500 meters depth & Wave and (iii) BD6 (Lat. 17.989o N, Long. 88.089o E) Met and Sea Surface Current were recently deployed by NIOT.] The passage of the JAL was along these newly deployed Buoys. Among these Buoys, the BD07_OMNI buoy recorded maximum wind speed of 16 mps on 5 November around 2000 UTC.

DWR at Sriharikota recorded hourly observation from 0300 UTC of 6 November. It was observed that the Cyclonic Storm started moving towards the coast in a west-northwesterly direction. The structure/eye of the cyclone was not so well defined as the RADAR echoes did not have the required properties of a cyclone eye. A few typical DWR imageries of DWR, Sriharikota are shown in Fig.2.36.

Table 2.7 Best track positions and other parameters of the severe cyclonic storm — JAL‘ over the Bay of Bengal during 04-07 NOV, 2010

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
04.11.2010	0000	8.0/92.0	1.5	1002	25	3	D
	0300	8.5/91.0	1.5	1002	25	3	D
	0600	8.5/90.5	1.5	1002	25	3	D
	1200	8.5/90.0	1.5	1002	25	3	D
	1800	8.5/89.5	1.5	1002	25	4	D
05.11.2010	0000	9.0/88.5	2.0	1000	30	5	DD
	0300	9.0/88.0	2.0	1000	30	5	DD
	0600	9.0/87.5	2.5	998	35	6	CS
	0900	9.0/87.5	2.5	996	40	8	CS
	1200	9.5/87.0	2.5	994	45	10	CS
	1500	9.5/87.0	3.0	994	45	10	CS
	1800	10.0/86.5	3.0	992	50	12	CS
	2100	10.0/86.0	3.5	990	55	16	SCS
06.11.2010	0000	10.0/85.5	3.5	990	55	16	SCS
	0300	10.0/85.5	3.5	990	55	16	SCS
	0600	10.5/85.0	3.5	990	55	16	SCS
	0900	10.5/85.0	3.5	990	55	16	SCS
	1200	11.0/84.5	3.5	988	60	18	SCS
	1500	11.0/84.5	3.5	988	60	18	SCS
	1800	11.0/84.0	3.5	988	60	18	SCS
	2100	11.0/84.0	3.5	988	60	18	SCS
07.11.2010	0000	11.5/83.5	3.5	988	60	18	SCS
	0300	12.0/83.0	3.5	990	55	16	SCS
	0600	12.5/82.5	3.0	992	45	12	CS
	0900	12.5/81.5	2.5	994	40	8	CS
	1200	13.0/81.0	2.0	996	30	6	DD
	1500	13.0/80.5	2.0	998	30	5	DD
	The system crossed north Tamilnadu and south Andhra Pradesh coast close to north Chennai (43279) near 13.3^{0}N and 80.2^{0}E around 1600 UTC.						
	1800	13.5/80.0	--	1000	30	5	DD
08.11.2010	0000	14.0/79.0	--	1002	25	4	D
	0300	15.0/78.0	--	1004	25	3	D
	0600	The system weakened into a low pressure area over Rayalaseema and adjoining south interior Karnataka.					

The cloud heights were about 5 to 6 kms; the reflectivity in the wall cloud region was about 35-45 dBz maximum. General maximum velocities recorded are about 20-23 mps. The likely cloud center locations of the system are presented below along with related description. Arrangement of cloud, radial velocity diagrams are taken in to consideration while trying to fix the Cyclonic system center. DWR Chennai tracked from 0400 to 1800 UTC of 7 November. The vertical wind shear had detrimental effect on weakening the system at sea level. The centre of mass of dense convection area crossed north Cuddalore by about 0600 UTC of 7 November. Surface wind speed associated with the weak vortex was not more than 25 kts at any time.

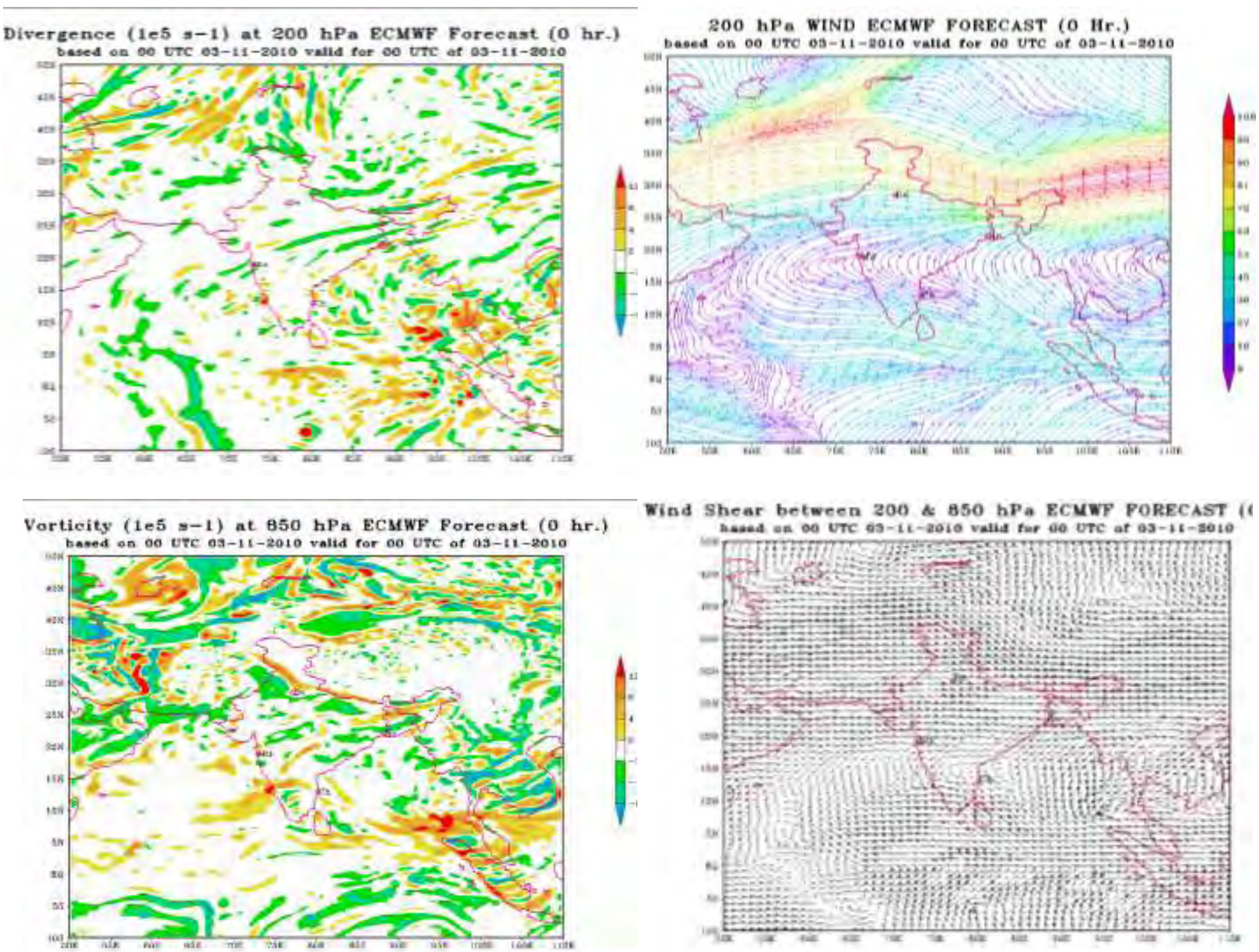


Fig.2.33 ECMWF analyses (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 03 November 2010

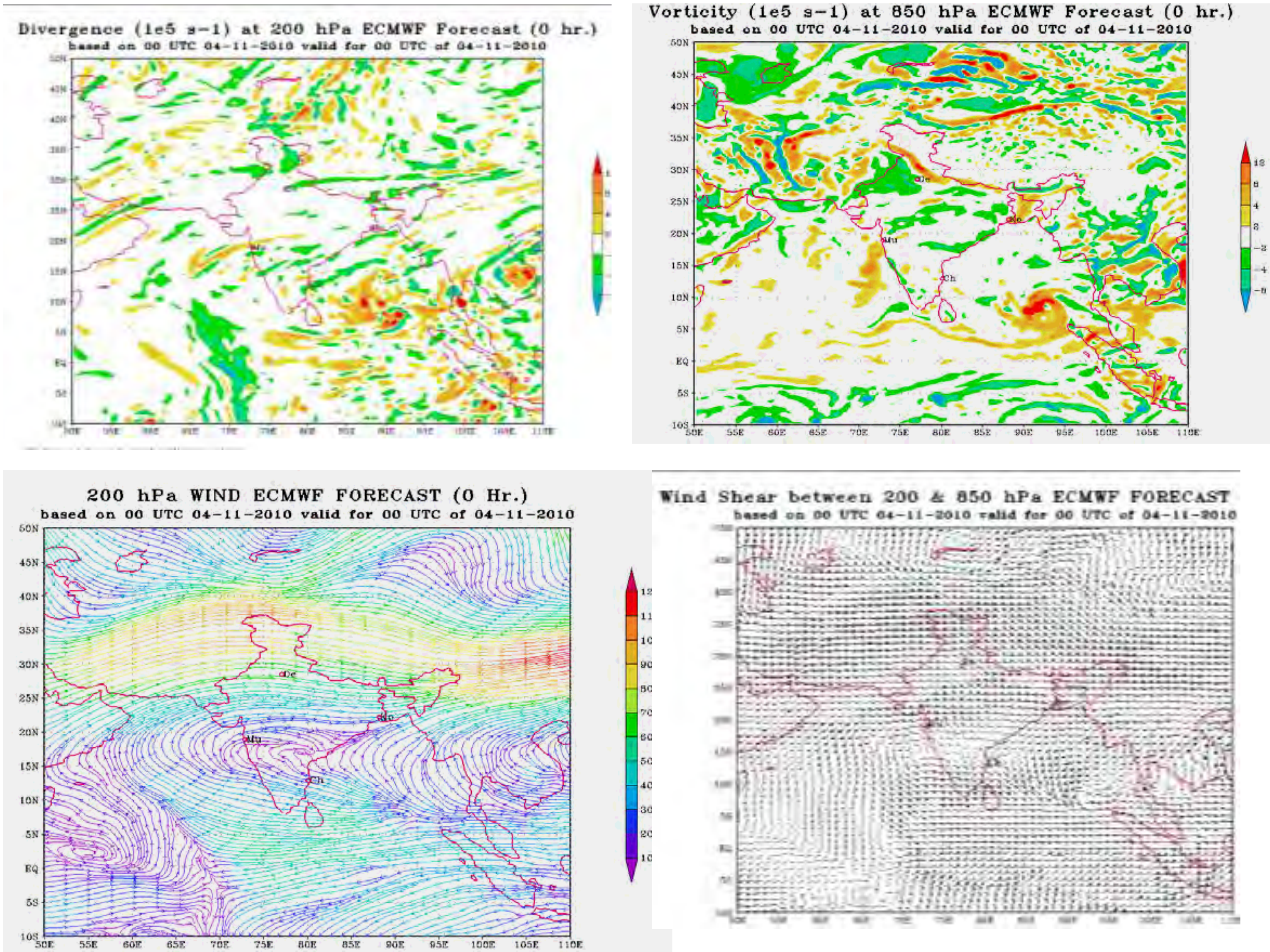


Fig. 2.34(a). ECMWF analyses (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 04 November 2010

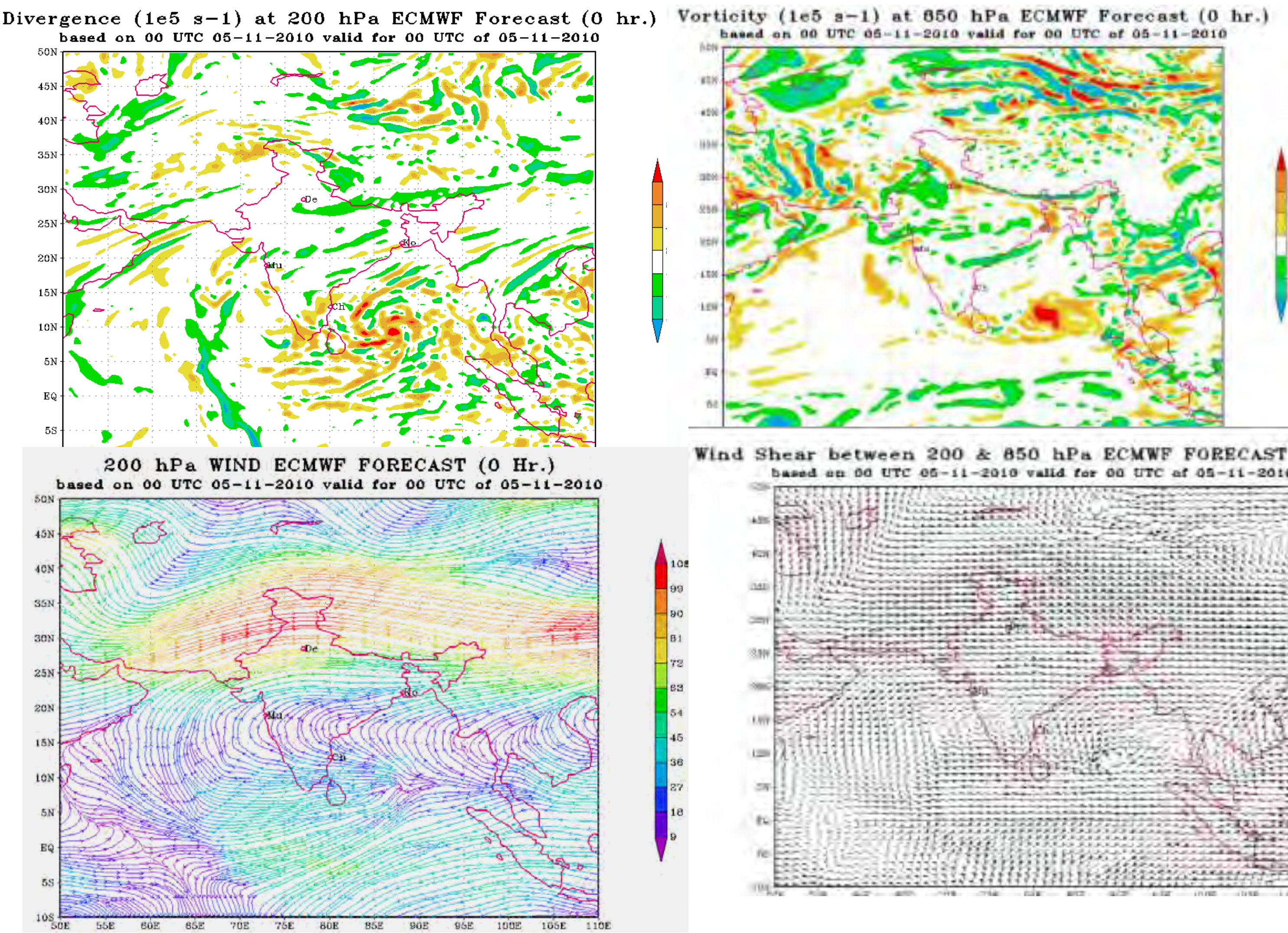


Fig. 2.34(b). ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 05 November 2010

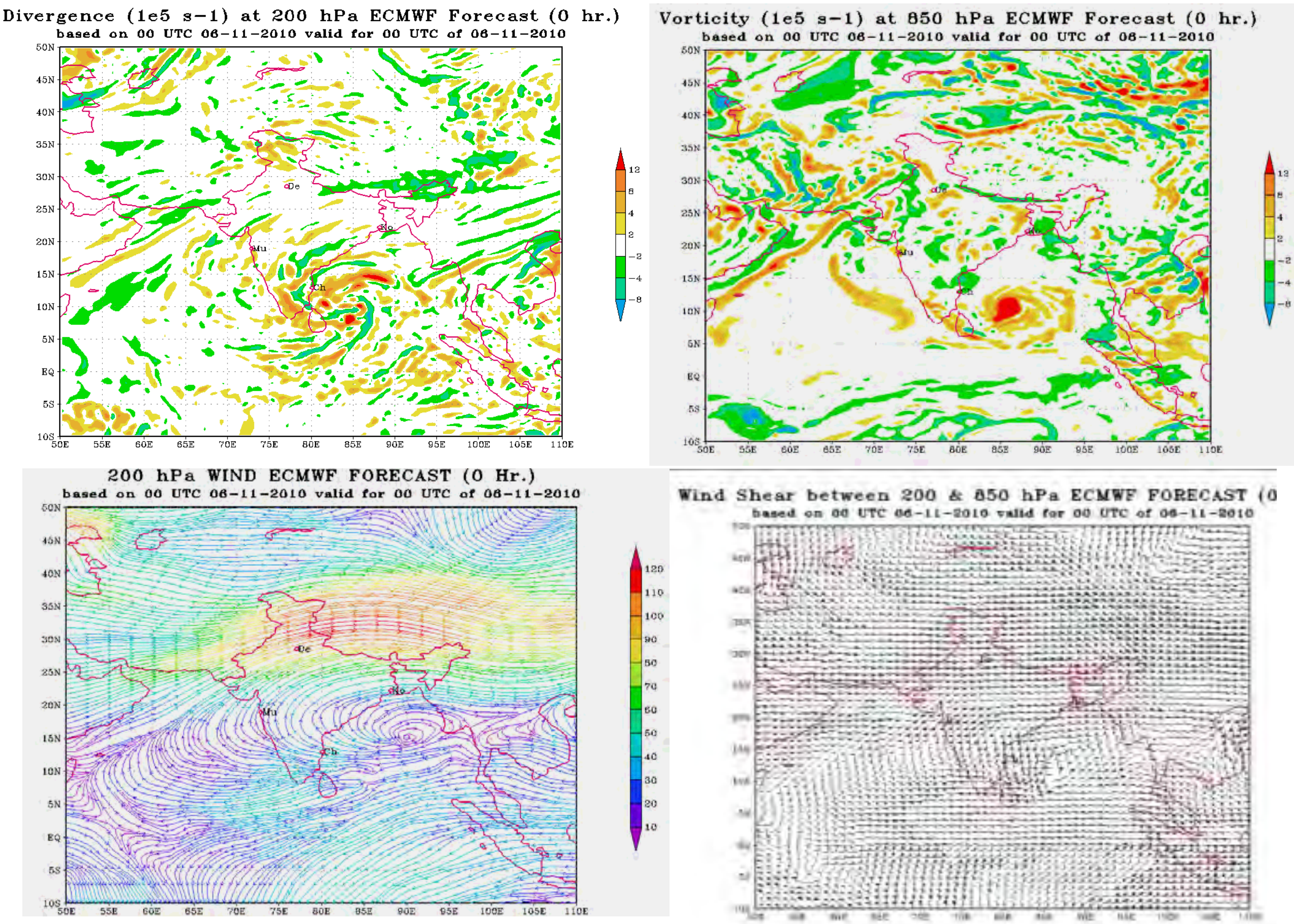


Fig. 2.34(c). ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 06 November 2010

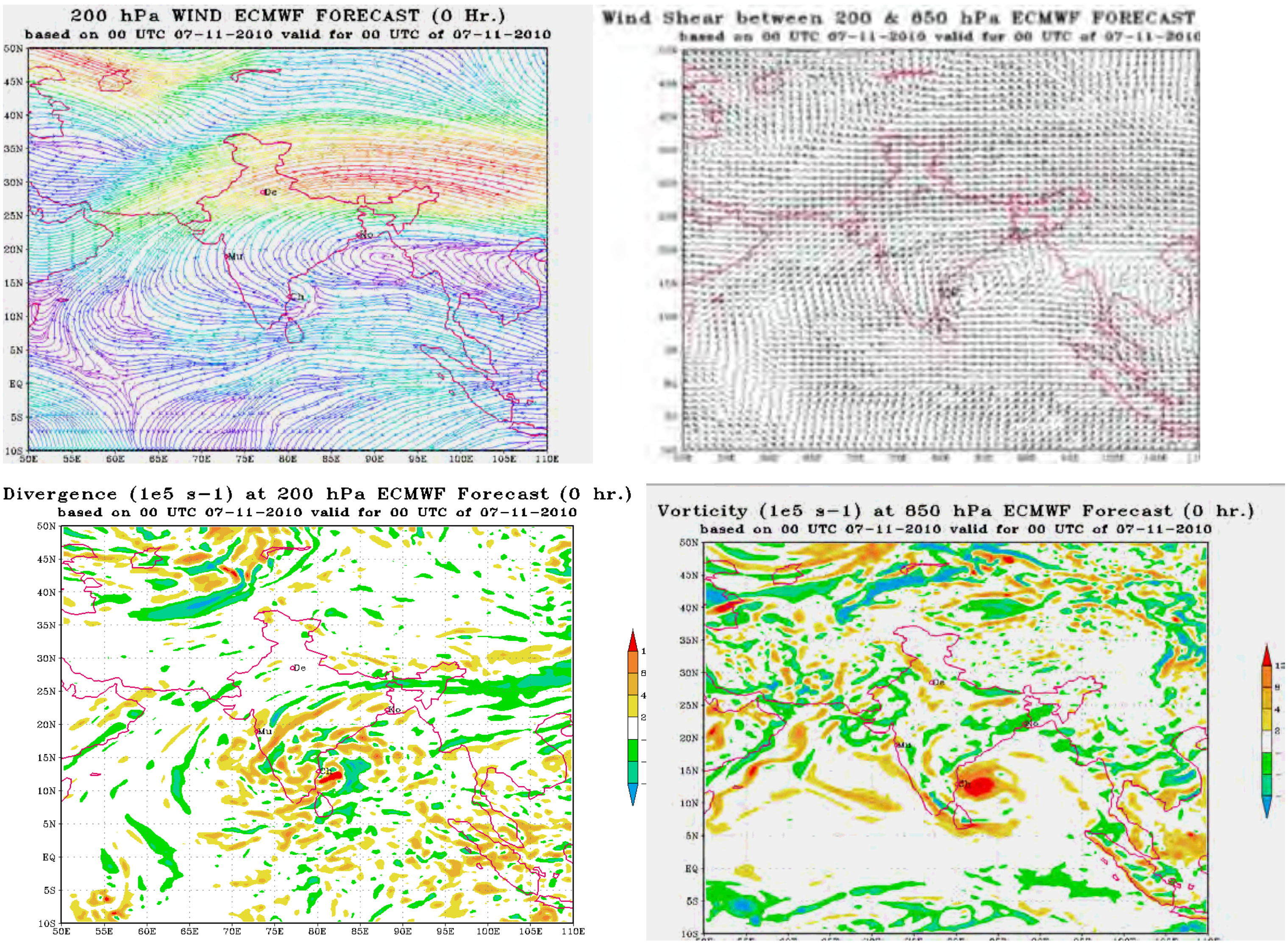


Fig. 2.34(d). ECMWF analysis (a) Divergence at 200 hPa level, (b) Vorticity at 850 hPa level, (c) wind at 200 hPa level and (d) Vertical wind shear between 200 and 850 hPa level at 0000 UTC of 07 November 2010

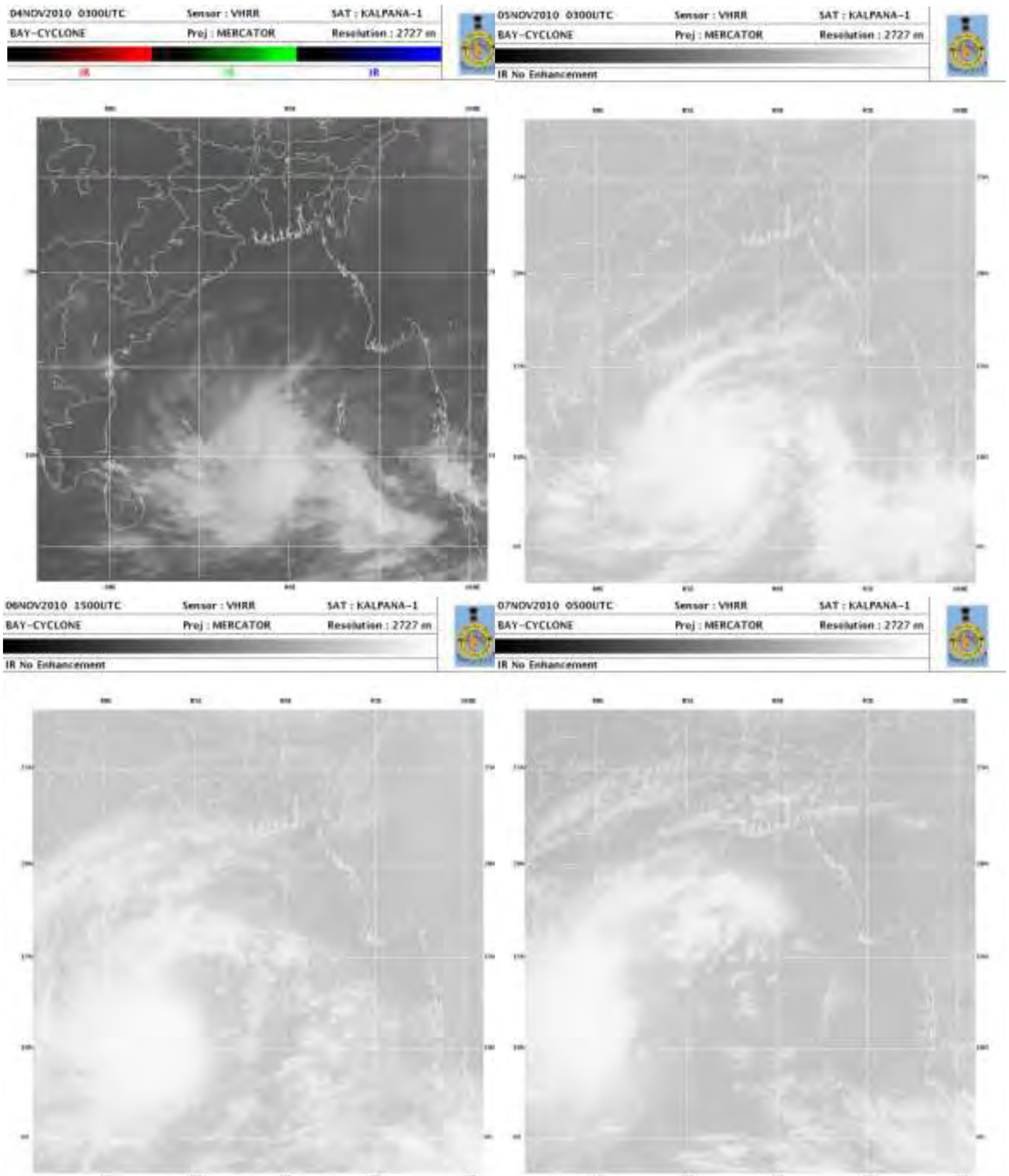


Fig. 2.35 Kalpana imageries of the cyclone, JAL at different stages on intensity

2.5.5 Realised Weather

(a) Rainfall

Rainfall occurred at most places with heavy to very heavy fall at a few places over north Tamil Nadu, Puducherry, coastal Andhra Pradesh, Rayalaseema, south Interior Karnataka and coastal Karnataka. Chief amount of 24 hrs accumulated rainfall (≥7 cm) as recorded at 0300 UTC of 8 and 9 November 2010 are as follows.

08.11.2010

Andhra Pradesh

Palasa-27, Sompeta-14, Itchhapuram-12, Puttur-11, Kalingapatnam, Rayacholi and Kuppam-10 each, Tekkali-9, Vempalli & Bhimunipatnam-8 each, Thambalapalli, Madakasira,Kadiri, Hindupur, Nellore, Anakapalli, Mandasa and Kandukur - 7 each.

Tamil Nadu and Puducherry

Gingee - 16, Panruti -15, Ambur- 13, Vaniyambadi- 12, Tiruvannamalai and Alangayam - 11 each, Tindivanam , Villupuram, Puducherry Airport 10 each, Cuddalore , Vanur and Thali- 9 each, Chengalpattu , Polur and Krishnagiri -8 each, Dharmapuri, Palacode , Tirukoilur , Vandavasi , Arakonam, Gudiyatham, Sholingur, Tirupattur and Vellore 7 each.

South Interior Karnataka

Lakkavalli 11; Chitradurga 10; Hesaraghatta, B Durga, YN Hoskote 8 each; Bangalore HAL AP, Hoskote, Holalkere, Bargur, Pavagada, Thondebhavi, Gowribidanur, Ramanagara 7 each

09.11.2010:

Coastal Karnataka:

Karwar 21; Ankola 11; Kota 10; Kumta 9; Honavar 8;

North Interior Karnataka:

Ramdurga, Ron 7 each;

(b) Wind

Squally winds with maximum speed reaching upto 60 kmph has been reported from the observatory stations of IMD along north Tamil Nadu – south Andhra Pradesh coast. Ennore Port in Tamil Nadu reported 33 knots (61 kmph) in the forenoon of 7 October 2010. The wind speed decreased at the time of landfall, as the system weakened gradually and crossed as a deep depression.

2.5.6. Damage:

Andhra Pradesh:

Eleven people died in Andhra Pradesh, Hundreds of houses were damaged and crops over about 15000 hectares were destroyed. A loss of about 83 crores was estimated.

Tamil Nadu:

Five persons lost their lives. About 100 pucca/kutcha houses were either fully or partially damaged. May boast were damaged and some were also missing due to floods. Rail, road and air transports were affected due to heavy rain. Sea water inundated low lying areas.

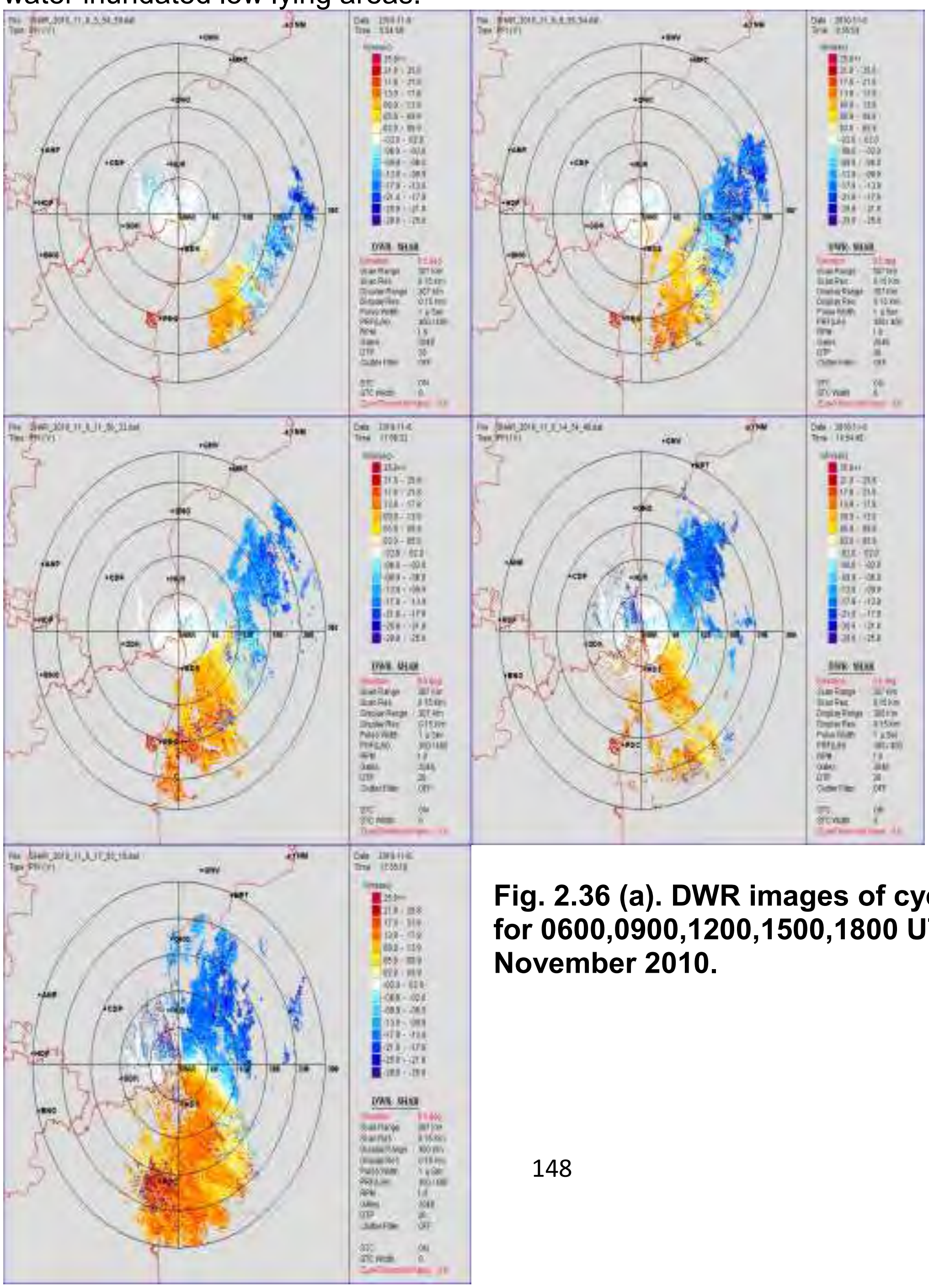


Fig. 2.36 (a). DWR images of cyclone JAL for 0600,0900,1200,1500,1800 UTC of 06 November 2010.

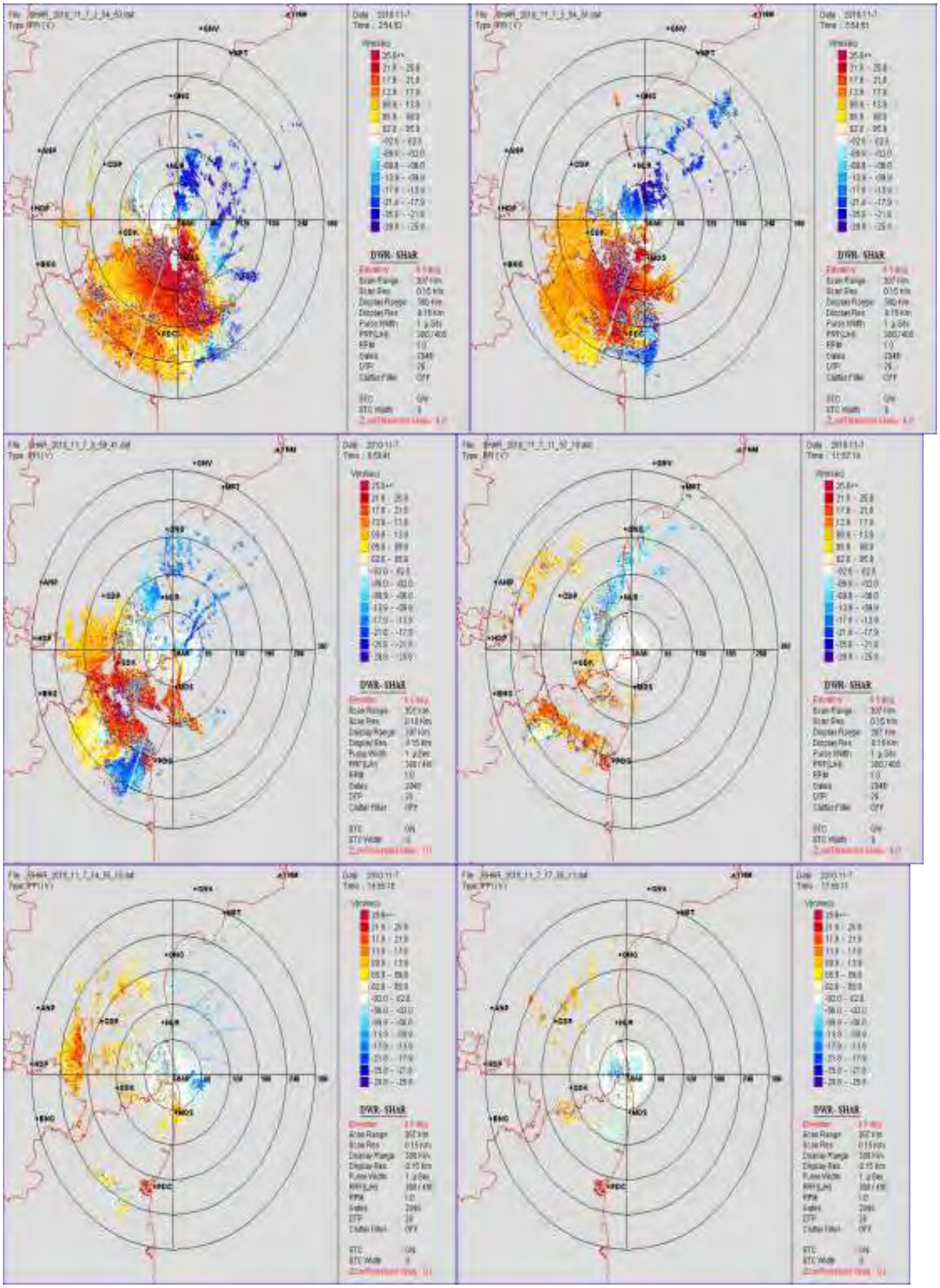


Fig. 2.36(b). DWR images of cyclone JAL for 0300,0600,0900,1200,1500,1800 UTC of 07-11-10

CHAPTER-III

CONTRIBUTED PAPERS *ON* CYCLONES & DEPRESSION
Abstract of Papers Published in Quarterly Journal, *'MAUSAM'*

1. Real time forecasting of the Bay of Bengal cyclonic storm "RASHMI" of October 2008 — A statistical-dynamical approach

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ABSTRACT. A four-step statistical-dynamical approach is applied for real time forecasting of the Bay of Bengal cyclonic storm "RASHMI" of October 2008 which made landfall near Khepupara (Bangladesh) around 2200 UTC of 26 October 2008. The four-step approach consists of (a) Analysis of Genesis Potential Parameter (GPP), (b) Track prediction, (c) Intensity Prediction by Statistical Cyclone Intensity Prediction (SCIP) model and (d) Prediction of decaying intensity after the landfall. The results show that the analysis of Genesis Potential Parameter (GPP) at early stages of development strongly indicated that the cyclone "RASHMI" had enough potential to reach its cyclone stage. The 48 hours landfall forecast position error based on 0000 UTC on 25 October shows that the error varies from around 10 km to 95 kin and landfall time error varies from 12 hours early to 23 hours delay by different numerical models (NWP). The consensus forecast (ensemble) based on these NWP models shows that landfall forecast position error is around 10 km and landfall time error is around 2 hours delay. The updated 24 hours forecast based on 0000 UTC of 26 October shows improvement in the forecast. The model predicted landfall position error varies from around 10 km to 55 kin with landfall time 6 hours early to 3 hours delay. The Multiple Model Ensemble (MME) forecast shows that the landfall forecast position is close to observed landfall point and the landfall time is early by 2 hours. The JMA (Japan Meteorological Agency) and ensemble forecasts are found to be consistent both in terms of 24-hourly forecasts position, landfall point and landfall time. The 12—hourly intensity prediction up to 24 hours forecasts based on 0000 UTC on 26 October show that the model (SCIP) could pick up the intensification of the cyclone. The model forecasts till the landfall point show that there is an underestimation of intensity by 2 knots and 8 knots at 12 hour and 24 hour forecasts respectively. The 6-hourly decaying intensity forecast after the landfall shows an overestimation of 6 knots and 10 knots at 6-hour and 12-hour forecasts respectively. The approach provided useful guidance to the forecasters for real time forecasting of the cyclone.

2. Diagnostic study of a recurving cyclone — 'MALA' over the Bay of Bengal

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ABSTRACT. A very severe cyclonic storm "Mala" (25-29 April 2006) developed over south east Bay of Bengal. Initially the system moved northwestwards while intensifying into the stage of cyclonic storm during 2526h April 2006. It then recurved and moved in a north-northeasterly direction and crossed Arakan coast as a very severe cyclonic storm on 29" April, 2006 causing loss of life and property over the region.

The unique features associated with this system was the continuous intensification after the recurvature.Various diagnostic features associated with intensification and movement of this system have been analysed and discussed. The study highlights the use of different dynamic and thermodynamic parameters as precursors for prediction of intensity and movement of the system. It also discusses the interaction of very severe cyclonic storm Mala with a vortex over the south Indian Ocean.

3. Relation between pressure defect and maximum wind in the field of a Tropical Cyclone – Theoretical derivation of proportionality constant based on an idealised surface pressure model

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ABSTRACT. The surface pressure defect ΔP and the surface maximum wind speed V_m of a tropical cyclone which are two important measures for the intensity of a tropical cyclone are related by the well known relation $V_m = K\sqrt{\Delta P}$ where K is the proportionality constant. Based on composites of observations of Vm and ΔP within the cyclone field, the empirical values of K have been derived in a large number of studies. The value of K thus derived has been found to vary in the range 10.5-16.0 when V_m and ΔP are measured in knots and hPa respectively. In this study the problem of estimating the value of K has been approached and treated from an entirely different angle. A general idealised pressure model derived using the concept of Pearson‘s Distributions in Statistical Distribution Theory has been initially assumed. Based on a few logical and acceptable assumptions such as - validity of cyclostrophic balance near the centre of the cyclone, existence of radius of maximum pressure gradient, convergence of integral defining cumulative surface pressure drop, relative vorticity to remain positive up to some distance from the centre, absolute vorticity to remain always positive within the cyclone field – the ranges of variables defining the general pressure model, and hence for K, have been derived without in any way relying upon actual observations of V_m or ΔP. After incorporating frictional forces, environmental flow and force due to translation speed

of a tropical cyclone, the final value of K has been derived as 11.0. This theoretically estimated K value compared very well with the empirically derived values but was slightly on the lower side. Apparently most of the empirical K values derived in other studies generated overestimated V_m values for given ΔP and this aspect has been discussed.

4. Signatures of northeast monsoon activity and passage of tropical cyclones in the integrated precipitable water vapour estimated through GPS technique

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ABSTRACT. Water vapour represents a key variable in the atmospheric processes. The importance of assessing water vapour availability in the atmosphere is indicated by the currently prevalent use of vast number of observing systems, both of *in-situ* and remote sensing types, designed to measure its distribution accurately over wide ranges of space and time scales. One of the widely used techniques world over is use of ground based GPS receivers for measurement of total precipitable water vapour in the atmosphere over the station. One such system is being operated at Chennai since 2007. An analysis of hourly Integrated Precipitable Water Vapour (IWV) data received from this system during Northeast Monsoon (NEM) season of 2008 shows the signatures of NEM activity and the passage of tropical disturbances like cyclonic storms and depressions in the vicinity of the GPS observation site. The GPS based IWV values are found to agree fairly well with radiosonde based IWV values and a good correlation exists between them. The IWV values obtained from GPS based system are found to be consistent with activity of Northeast monsoon with increase (decrease) of IWV during active (weak) phase of NEM 2008. The general expected trend of increase in IWV with approach of tropical systems in the vicinity of GPS station, reaching maximum during closest approach and again its decrease with increase of distance from the station is noticed. The diurnal variation of GPS based IWV estimates during NEM 2008 does not appear to be significant.

5. Seasonal prediction of cyclonic disturbances over the Bay of Bengal during summer monsoon season : Identification of potential predictors

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ABSTRACT. The cyclonic disturbances (CD) over the Bay of Bengal during monsoon season have significant impact on rainfall over India. On many occasions, they cause flood leading to loss of lives and properties. Hence, any early information

about the frequency of occurrence of such disturbances will help immensely the disaster managers and planners. However, the studies are limited on the seasonal prediction of CD over the Bay of Bengal unlike other Ocean basins of the world. Hence, a study has been undertaken to find out the potential predictors during the months of April and May for prediction of frequency of cyclonic disturbances over the Bay of Bengal during monsoon season (June – September). For this purpose, best track data of India Meteorological Department and large scale field parameters based on NCEP/NCAR reanalysis data have been analyzed for the period of 1948 – 2007. The linear correlation analysis has been applied between frequency of CD and large scale field parameters based on NCEP/NCAR reanalysis data to find out the potential predictors.

The large scale field parameters over the equatorial Indian Ocean, especially over west equatorial Indian Ocean and adjoining Arabian Sea (up to 15° N) should be favourable in April and May with lower mean sea level pressure (MSLP), lower geopotential heights and stronger southerlies in lower and middle levels, along with stronger northerly components at upper level for higher frequency of CD during subsequent monsoon season. Consequently, there should be increase in relative humidity (RH) and precipitable water content and decrease in outgoing longwave radiation (OLR) and temperature at lower levels over this region during April and May for higher frequency of CD during subsequent monsoon season. Comparing the area of significant correlation between frequency of CD and large scale field parameters and its stability from April to September, MSLP and geopotential heights are most influencing parameters followed by OLR, sea surface temperature, air temperature and RH at 850 hPa level.

CHAPTER-IV

Activities of PTC Secretariat during the Intersessional Period 2010-11

- As approved by the PTC during its 37th Session (Phuket, Thailand, 15-19 February, 2010), Secretary of PTC participated in the Seventh Session of the UNESCO Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) (Banda Aceh, Indonesia 14 -16 April, 2010) for making effective representation of PTC and for enhancing the visibility of PTC at ICG/IOTWS.
- PTC Member countries were coordinated and requested for sending their input, feedback and amendments (if any) with regards to Tropical Cyclone Operational Plan (TCP) to Mr. B.K. Bandayopadhyay (RSMC, New Delhi), the rapporteur of TCP for preparation of 2010 Edition of TCP. PTC Secretariat is thankful to PTC Members for their inputs towards TCP and Mr. Bandayopadhyay for his work as rapporteur of TCP which made 2010 Edition of TCP possible before the start of 2010 cyclone season.
- As per request made by PTC during its 37th Session (Phuket, Thailand, 15–19 February, 2010), a meeting of PTC Working Group on Disaster Prevention and Preparedness (WGDPP) was held at UN Building, in Bangkok, Thailand on 18th August, 2010 to finalize the Annual Operating Plan (AOP) related to DPP.The meeting was organized and supported by UNESCAP, Bangkok, Thailand and held back to back with Training on Preparation of Disaster Management Drills and Thailand's National Crisis Management Drill 2010 (C10) organized by the Department of Disaster Prevention and Mitigation (DDPM), Thailand on 19–20 August, 2010 in Chantaburi Province, Thailand. DPP experts and/or DPP focal persons for WGDPP from six out of eight PTC Member countries namely; Bangladesh, Maldives, India, Myanmar, Sri Lanka and Thailand attended the meeting and training, and also observe CMEX 10. Necessary financial support was provided to the experts by UNESCAP. PTC Secretariat is indebted to the UNESCAP and DDPM, Thailand for their continued support to PTC Members in capacity building activities related to DPP.
- PTC Secretariat published two issues of Panel News (Issue No.29 and 30) during the intersessional period. These issues have been distributed among the PTC Member countries, UNESCAP, WMO, representatives of other international organizations and other concerned during 38th Session of PTC (New Delhi, India, 21-25 February, 2011).
- As per request of PTC during its 37th Session (Phuket, Thailand, 15-19 February, 2010) WMO made arrangements with the Indian Institute of Technology (IIT), New Delhi for the attachment of two storm surge experts one each from Maldives and Sri Lanka. The training for storm Surge Experts was scheduled from 18 to 29 October, 2010 at IIT, Delhi. PTC Secretariat extended invitation for this attachment to both countries. Necessary funding was provided to the participants by WMO from PTC Trust Fund.

- Similarly, as per request of PTC during its 37th Session (Phuket, Thailand, 15–19 February, 2010), WMO made arrangements with the Regional Specialized Meteorological Centre (RSMC), New Delhi for provision of Training on Tropical Cyclone Forecasting to the nominees from Bangladesh, Myanmar and Oman. On invitation from PTC Secretariat, the nominations from the above mentioned countries have been received. The RSMC, New Delhi, India will host this training during the period from 28 February to 11 March, 2011. Necessary funding for the participants is to be provided by WMO from PTC Trust Fund.
- On the invitation of UNESCAP Bangkok, Secretary of PTC participated in the Preparatory Meeting of UNESCAP Expert Group Meeting on Pakistan Floods which was held in Nanjing, China on 16th September, 2010. UNESCAP experts on water security and disaster risk reduction (DRR) were also part of the WMO Expert Mission to Pakistan (8-9 November, 2010). UNESCAP in collaboration with Pakistan‘s National Disaster Management Authority (NDMA) organized an Expert Group Meeting on Reducing Flood Risk Reduction in Pakistan in Islamabad on 9-10 November, 2010. As a follow up of this Expert Group Meeting, Pakistan Meteorological Department and Space and Upper Atmospheric Commission (SUPARCO) are jointly hosting the UNESCAP Workshop on Developing Capacity Resilience to Water related Disasters in Pakistan through Space Application & Flood Risk Management, in Islamabad, Pakistan from 1 to 4 March, 2011. PTC Secretariat offers its sincere thanks to UNESCAP for its continued support to PTC Member countries in DRR activities especially for the initiatives and assistance to Pakistan in wake of 2010 super floods.
- Launching of new website of PTC is under process. In this connection, necessary Registration Form along with prescribed fee and the proposed webpage design/format has been submitted to the service providers in Islamabad. The address of the website has been proposed as: www.ptc.wmoescap.org. Some of its various web pages and links are under construction. For making the website more informative and useful, the PTC Members were requested to kindly send their views and comments to PTC Secretariat. The new email address of the PTC Secretariat has been proposed to be PTC.Sectt@ptc.wmoescap.org. In this regard, PTC Secretariat would formally inform the Members during coming days.
- Information regarding financial support by WMO from the PTC Trust Fund and detailed breakup of expenses incurred by PTC Secretariat during the intersessional period (2009-2010) is attached as **Appendix I.**

Appendix I.

Statement of PTC Secretariat Accounts (2010-11)

S.No.	*Opening Balance and Receipts*	*Amount in Pak. Rs.*
1.	Balance after 37 th Session of PTC	128,590/-
2.	Amount received during the intersessionalperiod (US$ 4000/= equivalent to Pak Rs.342,080/= @US$ 1 = 85.52)	342,080/
Total		**470,670/=**
Expenditures		
1.	Printing of 29 th and 30 th Issues of the Panel News and Letterheads.	95,000/
2.	PTC Website Hosting Fee etc.	12,000/
3.	Services for PTC Webpage design and construction etc.	20,000/
4.	Services for compilation work of Panel News Issues	20,000/
5.	Stationery, postages and other miscellaneous items etc.	9,000/
6.	Honorarium to Meteorologist PTC Secretariat @ US$100/= per month	102,000/
7.	Purchase of Colour Toner for Colour Laser Jet printer	Nil
Total		**258,000/=**
Net Balance in hand		**212,670/=**