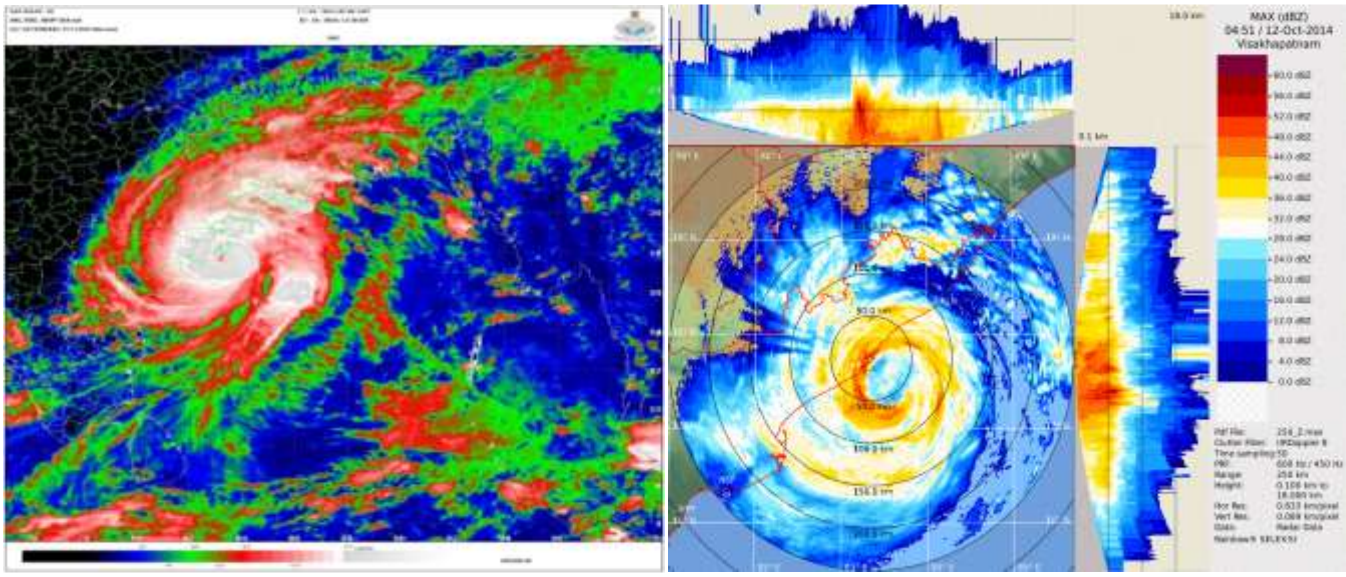
WMO/ESCAP
PANEL ON TROPICAL CYCLONES
ANNUAL REVIEW 2014



SATELLITE AND DWR IMAGERIES OF VERY SEVERE CYCLONIC STORM, HUDHUD"

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

WMO

ESCAP

WMO/ESCAP
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PREFACE

First commenced in 1997, the publication of ***WMO/ESCAP Panel*** *- Annual Review* has entered **eighteenth** year of issue for the year 2014. 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, 2014 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 NIO comprising of the Bay of Bengal & the Arabian Sea region, which is 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 show 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. The very severe cyclonic storm, 'Nargis' crossed Myanmar coast near Irrawaddy delta on 2nd May 2008 and caused loss of about 138,000 lives in Myanmar.

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 (PTC) 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;
- ► To plan 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 PTC 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 and cyclone advisories from a central location having the required facilities for this purpose, for the benefit of the region and strengthening of the operational plan. Further the Panel agreed upon the issue of tropical cyclone advisory bulletin for use of aviation as per recommendation No. 1/21 of International Civil Aviation Organisation (ICAO) in its 12th meeting of 161st session held at Montreal, Canada during 09-26 September, 2002

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 of the plan to be kept up to date by the member country concerned.

RSMC- Tropical Cyclone, New Delhi:

Regional Specialized Meteorological Centre (RSMC) - Tropical Cyclones, New Delhi, which is co-located with Cyclone Warning Division of IMD came into the existence in 1988 as per the recommendation of first session of WMO/ESCAP Panel on Tropical cyclones held in January,1973. It has the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the World Meteorological Organization (WMO)/ Economic and Social Co-operation for Asia and the Pacific (ESCAP) Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Maldives, Myanmar, Pakistan, Sultanate of Oman, Sri Lanka and Thailand. It has also the responsibilities as a Tropical Cyclone Advisory Centre (TCAC) to provide Tropical Cyclone Advisories to the designated International Airports as per requirement of International Civil Aviation Organization (ICAO).

The area of responsibility of RSMC- New Delhi covers Sea areas of north Indian Ocean north of equator between 45^0 E and 100^0 E and includes the member countries of WMO/ESCAP Panel on Tropical Cyclones viz. Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman and Thailand

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

- Round the clock watch on weather situations over the entire north Indian Ocean.
- Analysis and processing of global meteorological data for diagnostic and prediction purposes.
- Detection, tracking and prediction of cyclonic disturbances in the Bay of Bengal and the Arabian Sea.
- Running of numerical weather prediction models for tropical cyclone track and storm surge predictions.
- Interaction with National Disaster Management Authority and National Disaster Management, Ministry of Home Affairs, Govt. of India to provide timely information and warnings for emergency support services. RSMC-New Delhi also coordinates with National Institute of Disaster Management (NIDM) for sharing the information related to cyclone warning.
- Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel.
- Issue of Tropical Weather Outlook and Tropical Cyclone Advisories to the Panel countries in general.
- Issue of Tropical Cyclone advisories to International airports in the neighbouring countries for International aviation.

- Collection, processing and archival of all data pertaining to cyclonic disturbances viz. wind, storm surge, pressure, rainfall, damage report, satellite and Radar derived information etc. and their exchange with Panel member countries.
- Preparation of comprehensive annual reports on cyclonic disturbances formed over North Indian Ocean every year.
- Preparation of annual review report on various activities including meteorological, hydrological and disaster preparedness and prevention activities of panel member countries.
- Research on storm surge, track and intensity prediction techniques.

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Vice-Chairman : Dr. L. S. Rathore(India)
Chairman drafting committee: Mr D.J. Ajith Weerawardena(Sri Lanka)

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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-2012 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 2014 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 2014. Based on the real time and climatological data available with India Meteorological Department (IMD), India, special features of the 2014 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 2013-2014

CHAPTER-I

WMO/ESCAP PANEL ACTIVITIES IN 2014

1.1 METEOROLOGICAL ACTIVITIES

Activities of member countries on WMO/ESCAP Panel for the year 2014 were presented at the forty second session of the WMO/ESCAP Panel on tropical cyclones held at Dhaka, Bangladesh from 9-13 February 2015. 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:

1.1.1 India

A brief description of the observational network of IMD and types of observations collected from the network are given below:

1.1.1.1 Surface Observatories

The network of surface meteorological observatories consists of total 709 Stations. The break-up 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 (Deptt.)	57	53	31	29	17	17	204
II (b), II (c), II (d), III & IV, V, VI Io & EMO (Non Deptt.)	106	71	47	30	47	25	326
V (Non Deptt. HMO)	64	17	54	21	12	11	179
TOTAL	227	141	132	80	76	53	709

1.1.1.1.1 High Wind Speed Recorders (HWSRs)

a. Real time HWSR data through GPRS modules is available on www.imdaws.com site for the stations: Goa, Dwarka, Karaikal, Kakinada, Gopalpur, Visakhapatnam, Machilipatnam, Chennai, Puri, Sagar Island, Kalingapatanam, Haldia, Balasore, Puri and Nellore

b. New Installations planned during 2014-15 : Bhuj, Naliya, Porbandar, Veraval and Paradip.

c. The on-line data will be made available on www.imdaws.com site shortly for above four stations.

1.1.1.1.2 Rainfall instruments

- Daily high resolution rainfall data at spatial grid of 0.25º X 0.25º for the period 1901-2013 was provided to operational and research groups and supplied to user community on demand.
- Online inventory management of the instruments at IMD Surface Observatories (including Airports) started. This also includes their functional status and reporting, etc

1.1.1.2 Upper Air Observatories

There are at present 62 Pilot Balloon Observatories, 37 Radiosonde/ Radio wind observatories and 02 Radiosonde Observatory. Among the 37 Radiosonde/Radiowind observatories, 17 stations are GPS based stations, 8 with Sameer instruments, 7 with IMS-1500 instruments and 5 with RSGE instruments. The pilot balloon observation network and RS/RW network of IMD is shown in fig 1.4

To monitor the daily ascent status and the stock of various consumables the observatory performance monitoring system has been started on the intra IMD portal metnet.imd.gov.in/ual

The upper air meteorological data collected all over the country are used on real time basis for operational forecasting.

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

- Integrated Himalayan Meteorology Programme for Western & Central Himalaya" covering four states namely Jammu & Kashmir, Himachal Pradesh, Uttarakhand, and Sub Himalayan West Bengal with Commissioning of 9 Doppler Weather Radars (DWRs) , 15 Micro Rain Radars (MRRs), 09 GPS based UA Systems along with GPS radiosonde, 230Surface Observing equipment consisting of Automatic Weather Stations, Automatic Rain Gauges & Snow Gauges, 12 Compact Severe Weather Detection Radar Systems to develop appropriate system of 24×7 monitoring and early warning for extreme weather.
- Development of High Impact Severe Weather Warning System with Mesonet Observation Test bed (Supersite) around NCR-Delhi and Eastern India (for Nor'westers) with various surface and upper air observation network including development of high resolution mesoscale model with assimilation of various observations for high impact weather forecast.

- Agromet advisories through SMS and IVR technology are being disseminated to 5.34 million farmers in the country including other modes of dissemination like TV, Radio and Print media.

1.1.1.2.1 Radars

1.1.1.2.1.1 Current status

Weather radar network of India is managed by India Meteorological Department, and consists of twenty three radars presently spreading across the country. There are sixteen sites with Doppler Weather Radars, including fourteen sites operating in S-band and two sites with C-band Polarimetric Doppler weather radars. Nine more sites have analogue non Doppler Weather Radars. Two indigenously manufactured S-band Doppler weather radars, which have been installed at Mumbai and Bhuj are undergoing tests before being put to operational use.

S-band Doppler Weather Radars are installed at Agartala, Bhopal, Chennai, Hyderabad, Kolkata, Lucknow, Machilipatnam, Mohanbari, Nagpur, New Delhi, Patna, Patiala, Sriharikota and Visakhapatnam. C-band Polarimetric Doppler weather radars are installed at Jaipur and New Delhi. The Supply Order for one X-Band transportable radar for Srinagar has been placed and the installation of the same is expected within next two months.

Two Nos. of DWRs are being installed at Gopalpur and Kochi under ISRO and IMD Memorandum of understanding

Analogue types of S-band radars are installed at Jaisalmer, Karaikal and Kochi. X-band weather radars are installed at Ahmedabad, Bhubaneswar, Guwahati, Kolkata, Mangalore, Ranchi and are being phased out.

Conventional radar provides information only on reflectivity whereas Doppler weather radars provide information on reflectivity, velocity and spectral width.

Radars of IMD are being used for detection of dust storms, thunder storms and tracking of cyclonic storms. They also detect rainfall and hail. Various meteorological, hydrological and aviation products derived from Doppler weather radar data using software algorithms are extremely useful to the forecasters for estimating the storm's center, intensity, location and for forecasting its future path for safe navigation of aircrafts and ships. The existing digital Doppler weather radars have also been networked to super computers for numerical weather prediction models for now casting. Composite images are being generated centrally. Data is also converted to scientific formats such as NetCDF, HDF5, and Opera BUFR for assimilation Numerical Weather Prediction (NWP) models.

Future Plan

The Radar division is involved in implementation of the work of modernization of Radar Network by replacing old conventional Radars with state of art Doppler Weather Radar. IMD has a plan to induct more than 55 DWRs in its network in the phased manner to bring entire Country and coasts under Doppler Network Radar coverage. For improved efficient management, there are also plans, to establish a Weather Radar

Operation Center, which would be responsible for weather radar related activities of the department. It will manage radar network, archival, dissemination of data, development of algorithms, network planning and related R&D.

1.1.1.2.2 Meteorological Satellite

Satellite Monitoring

1.1.1.2.2.1 Current status

At present IMD is receiving and processing meteorological data from three Indian satellites namely Kalpana-1, INSAT-3A & INSAT-3D. Kalpana-1 was launched on 12th September, 2002 and is located at 74.0°E. INSAT-3A was launched on 10 April, 2003 and is located at 93.5°E. INSAT-3D has been launched on 26 July 2013. Kalpana-1 and INSAT-3A both have payload of Very High Resolution Radiometer (VHRR) for imaging the earth in three channels viz. Visible (0.55-0.75 µm), Infra-Red (10.5-12.5µm) and Water vapour (5.7-7.1µm) having resolution of 2X2 km in visible and 8X8 km in Water vapour (WV) and Infra-red (IR) channels. In addition, the INSAT-3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62- 0.69um), Near IR (0.77-0.86µm) and Short Wave IR (1.55-1.77µm) bands of Spectrum.

The Resolution of CCD payload in all the three short wave (SW) channels is 1KmX 1 Km. INSAT-3D has an advanced imager with six imagery channels {(Visible, Short wave Infra-Red (SWIR), Medium Infra-Red (MIR), Thermal Infra-Red-1(TIR-1), TIR-2, & WV} and a nineteen channel sounder (18 IR &1 Visible) for derivation of atmospheric temperature and moisture profiles. It provides 1 km. resolution imagery in visible band, 4 km resolution in IR band and 8 km in WV channel.

At Present about 48 nos. of satellite images are taken daily from Kalpana-1, approximately 20 images are taken from INSAT-3A. Imaging from CCD is done 5 times during daytime only. Half hourly satellite imageries are also obtained from all the six imager channels and hourly images from the sounder channels of INSAT-3D satellite. All the received data from the satellite are processed and archived in National Satellite Data Center (NSDC), New Delhi. INSAT-3D 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.

The following products derived from the satellite are useful for monitoring of tropical cyclones

1. Outgoing Long wave Radiation (OLR) at 0.250X0.250 resolution
2. Quantitative Precipitation Estimation (QPE) at 10 /10 resolution
3. Sea Surface Temperature (SST) at 10 /10 resolution
4. Cloud Motion Vector (CMV)
5. Water Vapour Wind (WVW)
6. Upper Tropospheric Humidity (UTH)
7. Temperature, Humidity profile

8. Value added parameters from sounder products
    a. Geo-potential 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

At present Dvorak technique is used but manually applied. Recently efforts have been made for automation of this technique. Automated Dvorak technique is running in experimental mode at Synoptic Application Unit, Satellite Meteorology Division. Satellite Application Unit is also using Microwave imageries operationally from NOAA, Metop's DMSP satellites for locating the tropical systems. Satellite Application Unit issues three hourly bulletins in general and hourly and half hourly bulletins in case of tropical cyclones and other severe weather events. The unit is modifying these bulletins from time to time.

With the Web Archival System developed at IMD, KALPANA-1/INSAT-3A/INSAT- 3D products & imageries are archived. The automatic script is being used to keep and update the images/products on the website for 6 months. These are available to all users.

On 23rd Sept 09, polar orbiting satellite OCEANSAT–II was launched by Indian Space Research Organisation (ISRO) which carried a ku band pencil beam scatterometer to provide ocean surface winds at 10 m height for early detection of tropical cyclones. Winds from this satellite were used regularly for locating the Center and intensity of the tropical systems in the formative stage. The OSCAT suffered an anomaly early in February 2014, which could not be recovered and ceased operations on April 2, 2014.

Space Application Center (SAC), ISRO, Ahmedabad developed a technique to predict the formation of tropical cyclones over north Indian Ocean before 24-96 hrs based on OCEANSAT-II Scatterometer wind. Satellite Division of IMD acquired the software and validated the technique. However as Oceansat-II has become defunct and no more data is available from the satellite, the technique is not being used for predicting cyclogenesis.
INSAT 3D Satellite data based real time analysis of products and information dissemination (RAPID) system made operational.

Future Plan

It has been planned to procure software for better monitoring & warning of severe weather events.
There is a plan for automization of Advanced Dvorak Technique and objective tracking of thunderstorms.

1.1.1.3 Performance of operational NWP models for tropical cyclones for the year 2014

India Meteorological Department (IMD) operationally runs two regional models, WRF and HWRF for short-range prediction and one Global model T574L64 for medium range prediction (7 days). The WRF-Var model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^{o} S to 45^{o} N long 40^{o} E to 120^{o} E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 23 km. The boundary conditions are updated at every six hours interval. The HWRF model (resolution 27 km and 9 km) is a specialised model for tropical cyclone (TC) track and intensity prediction adapted from NCEP/Environmental Modelling Center (EMC), USA for IMD operational TC track and intensity prediction upto 5 days. 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), UKMO (UKMet), JMA (Japan Meteorological Agency). Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones.

In addition to the above NWP models, IMD also run operationally “NWP based Objective Cyclone Prediction System (CPS)”. The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, GFS (NCEP), ECMWF, UKMO and JMA. The SCIP model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). Decay model is used for prediction of intensity after landfall.

During the cyclone season - 2014 all NWP deterministic and statistical-dynamical models based track and intensity forecast guidance upto 120 hours was provided in real-time to operational forecasters and other users. Based on GFS model cyclogensis forecast was provided 120 hours advance for all the major systems from the stage of low pressure system. The track and intensity forecasts upto 120 hours are provided based on 00 & 12 UTC forecasts of GFS, HWRF and statistic guidance based on MME forecasts, SCIP, GPP, RII and Decay models are provided. It is observed that during 2014, there is an improvement in intensity forecasts by the numerical models compared to the 2013. The average track and intensity forecast errors during 2014 are discussed here in brief.

Future Plan:

- HWRF model (27/9/3 km) installed at IITM, Pune computer under MoES-NOAA TC project. Ocean coupling to HWRF was in progress in collaboration with EMC/INCOIS to make operation from pre-monsoon cyclone season.
- WDSS-II system to be made operational at remaining 9 DWR stations for Nowcast guidance.
- GFS models upgradation with EnKF (80 mem) GSI analysis, WRF with 9/3 km resolution to cover over RSMC/India region to be taken up from March 2015 and upgradation o GFS from T574 to T1534 compatible with NCEP modeling system by November 2015 after validation of NCEP T1534 model for Indian region during the Monsoon – 2015.
- Implementation of Physical Initialization in high resolution WRF model using DWR data for short range prediction of high impact weather and implementation of comprehensive bias removal procedure in GFS to be taken up under the Monsoon Mission Programme.
- Centralized Radar Data Processing for WDSS-II, ARPS and WRF model data assimilation to be implemented at IITM HPC.
- Implementation of tools for extended range prediction and seasonal prediction at subdivision scale through analysis of CFSv2 models developed under monsoon mission for extended and long range prediction.

1.1.1.4 Telecommunication Network in IMD

Present Status of Circuits in the GTS connected with RTH, New Delhi

1. India Meteorological Department has its National Meteorological Telecommunication Centre (NMTC) with an Automatic Message Switching computer System (AMSS) which is connected to WMO Centers on the GTS. The existing RTH switching system “TRANSMET” is the state-of-the-art technology system. It consists of two Separate Automatic Message Switching System (AMSS) for National and International data exchange. Each AMSS works in hot standby mode for 100% redundancy in case of any failure.

During the period 2013-2014 following new data sets were received from different circuit and submitted on GTS

a. BUFR data from Pakistan
b. Storm Information, Forecast and Advisories messages from RSMC NEW Delhi in Text and Graphical form.
c. ASCII & BUFR AWS/ARG data are shared on GTS.
d. Sixteen(16) operational RADAR data are received in NETCDF and BUFR format and routed to users as per their requirement.
e. Forecast via SMS during AMARNATH Yatra gets disseminated through RTH to the users concerned.

f. Warning messages such as Tsunami and Cyclone messages received from INCOIS and RSMC are disseminated via SMS as per the user requirement.
g. INSAT-3D wind data is being shared on GTS.
h. Data received from NAVY for Porbandar station and disseminated for FDP (CTCZ).
i. RMDCN link has been upgraded to 4 Mbps RMDCN-NG(Next Gen) which handles 6 circuits viz. Tokyo, Moscow, Beijing , Germany, Exeter and Toulouse. This has improved the data exchange between these GTS centres.
j. New Delhi- Bhutan link established for Meteorological data exchange on GTS.
k. MPLS VPN link at HQ New Delhi has been upgraded to 8 Mbps for smooth catering of data requirements to the national users. This will help in faster data reception at Head Quarter from DWR stations & NWP Centres to various users.

1.1.1.4.1 VPN Circuits

Fifty four, IMD stations are connected with IPVPN connectivity speeds ranging from 256 Kbps to 8 Mbps. These VPN circuits are connected with Synergie Systems at various out stations, Doppler Weather Radar Stations, AMSS Centres and Regional Centres.

1.1.1.4.2 IVRS

Popularly known as “Weather on telephone”, the Interactive Voice Response System (IVRS) is functioning with effect from July, 2000. One can access current weather and forecast for major Indian cities and air quality of some selected cities by dialing Toll free number 1800 180 1717 (List of IVRS stations enclosed as Annexure III).

1.1.1.4.3 Internet Services

At present IMD has two independent Internet leased links of 100 Mbps and 60 Mbps from different Internet service providers. IMD is also connected to 1 Gbps NKN (National Knowledge Network) link of NIC for internet, data exchange within Close User Group (CUG), Video conferencing & Telepresence services.

1.1.1.4.4 **GMDSS**

India has been designated as an issuing authority under the GMDSS programme for Meteorological Area VIII (N). This covers the area of the Indian Ocean enclosed by the lines from Indo-Pakistan frontier in 23°45’N 68°E; 12°N 63°E, thence to Cape Gardafui; the east African coast south to equator, thence to 95°E to 6°N, thence to the Myanmar / Thailand frontier in 10° N 98° 30’ E.

India Meteorological Department is transmitting daily two GMDSS bulletins for Met. Area VIII(N), one at 0900 UTC and other at 1800 UTC. During Cyclone Season additional bulletins (4) are also being issued for GMDSS broadcast depending on the requirement. GMDSS bulletins are transferred to Earth Station of Tata Communication Ltd. at Pune through email as well as uploaded on IMD Website at URL *http://www.imd.gov.*in. Pune Earth Station uplinks this information to INMARSAT satellite for broadcast to all ships in Met Area VIII(N).

1.1.1.4.5 Regional Telecommunication Hub (RTH)

Regional Telecommunication Hub (RTH), New Delhi came into existence in the year 1971. It was automated and first DS- 714 Philips Computer System became operational in the year 1974. This RTH Computer was replaced by VAX- 11/ 750 Computer in 1988. In July, 2000 RTH New Delhi has installed a SUN E- 250 Computer. Now the latest system has been installed in the year 2009 by Meteo France International (MFI). This is connected to WMO Centres on the GTS. The existing RTH computer system is driven primarily by dual HP server working on the state-of-the-art distributed networking technology. The whole system has been designed to handle high speed data circuits, message exchange through web interface, SMS & Email. It has also fax interface and audio alarm. NMTC New Delhi is connected to HPCS of NCMRWF Noida, IITM Pune through NKN and the HPCS computer at Regional Specialised Meteorological Centre (RSMC) New Delhi for instantaneous transmission of global observational data and processed information received via GTS. Moreover, NWP division of IMD is utilizing the resources of IITM HPCS to run their various models for product generations through CUG link of NKN. As regards the Meteorological Telecommunication Networks within the GTS, New Delhi telecommunication center is a designated RTH located on the Main Trunk Network (MTN). The MTN is the core network of GTS. It links together three World Meteorological Centers (WMCs) and 14 other RTHs on the MTN. The Centre is also a National Meteorological Centre (NMC) for telecommunication purposes within the framework of GTS. RTH New Delhi is directly connected with Tokyo, Exeter, Offenbach, Cairo, Jeddah, Beijing, Dhaka, Bangkok, Karachi, Male, Moscow, Oman, Colombo, Melbourne, Toulouse, Katmandu and Yangoon with different protocol and speed.
Automatic Message Switching Systems (AMSS) are also operational at the major International airports of India viz. Mumbai, Delhi, Kolkata, Chennai, Nagpur and Guwahati. The circuits linking New Delhi (Palam), Mumbai, Kolkata, Chennai, Nagpur and Guwahati Airport computers with the NMTC New Delhi are working at 512 kbps speed.

1.1.1.4.6 On line Briefing System at Chennai & Delhi (Palam) has been commissioned and functional.

Under the Modernization programme of India Meteorological Department, following systems have been installed at RTH New Delhi:-

a. **Central Information Processing System (CIPS):** High end database management system having task centre to develop, test and operationalize meteorological tasks for real time generation of meteorological products.
b. **Transmet:** Automatic Message Switching System (AMSS) to receive, check and route the meteorological data and products according to WMO standards/requirements.
c. **Public Weather System (PWS):** To deliver High quality weather products and alerts to end users like print media and Television.

d. **Clisys:** Climatological data storage system with scalable management tool for effective utilization of these data.
e. **Synergie:** Decision support system for forecasters to gather, visuslize, interact and value add meteorological forecasts and products.

The Mirror RTH at Pune is functional to act as Disaster Recovery Centre (DRC) which would be able to take over all the responsibilities of RTH New Delhi in case of any catastrophe at RTH New Delhi. This will also function as WMO WIS GISC for South East Asia and cater to all data needs for Indian users and all other WMO GISC centres in real time with 24 hours cache for all data.

1.1.1.4.7 Website of IMD

Website of IMD is operational since 1st June, 2000. It contains static & dynamically updated information on all India Weather and forecasts, special monsoon report, local weather forecasts for 300 cities, satellite cloud pictures (updated every half an hour), animated satellite cloud pictures, NWP models like GFS, WRF etc. and prognostic charts, special weather warnings, tropical cyclone information and warnings, daily, weekly and monthly rainfall distribution maps, earthquake reports, etc. This also contains a lot of static information including temperature and rainfall normals over the country and a brief overview of the activities and services rendered by India Meteorological Department. This site can be accessed round the clock with the URL: http://www.imd.gov.in . The Regional Meteorological Centres have also their own websites. IMD is also providing 100 Indian city forecast on the WMO Website daily at http://worldweather.wmo.int/066/m066.htm .

IMD has also launched a new user-friendly website for the public with URL: http://www.indiaweather.gov.in

India Meteorological Department developed its own intranet website with the address http://metnet.imd.gov.in exclusively for the use of IMD officials. All employees can access this site using their login ID. This is a very useful site and all IMD officials are accessing this site all over the country for numerous applications on official matters. The list of email addresses of senior officers are available at IMD website.

1.1.1.4.8 Information Technology Cell

Considering the ever growing influence of Information Technology in day–to-day affairs of the department, IT cell carries out the following activities:-

a) Coordination of IT initiatives of the department.

b) Supervise various IT projects to be implemented.

c) Asserting the IT literacy and imparting suitable mechanisms for its improvement.

d) Development of various in-house softwares for routine activities.

Conforming to these objectives, IT Division has developed an intra - IMD Portal, which is considered as the first step towards e-governance implementation in the department.

1.1.1.4.9 Global Data Monitoring

Special Antarctica Monitoring during the period 1-15th January, 2015 and the result was uploaded to WMO. The reception of SYNOP was 97%.

1.1.1.4.10 Ongoing projects:

1.1.1.4.10.1 Provision of adequate communication system for data and product transmission:

a. Mirror RTH and Global Information System Centre (GISC) has been installed at Pune as a part of the WMO Information System (WIS) implementation, which includes design, development, integration with existing systems like CIPS, Clisys, AMSS, HPCs. These systems act as GISC and Data Collection and Processing Centre(DCPC) with disaster recovery centre (DRC) Pune for RTH New Delhi.
   - As per guideline of WMO, RTH New Delhi applied for GISC as well as DCPC for South Asia. Upgradation of RTH New Delhi as GISC is under process
   - After installation Mirror RTH Pune, **Audit team from WMO visited RTH/GISC New Delhi at Pune and submitted their report to WMO. After acceptance of the report by WMO, the centre shall become an operational GISC.**
   - Mirror GISC is also under process.
   - All the national VPNs are under process for upgradation from 512 Kbps to 10 Mbps.

b. Up Gradation of AMSS (Automatic Message Switching Systems) at Delhi-Palam, Kolkata, Mumbai and Chennai.
c. Development of Centralized GIS Based content managed Website of IMD under process.
d. Development of Met GIS – Web based GIS Portal under process.

1.2 HYDROLOGICAL ACTIVITIES

1.2.1 India

1.2.1.1 Flood is one of the natural calamity which causes huge loses of life and property in each year. In India Flood Forecast is the joint responsibility of India Meteorological Department (IMD) and Central Water commission (CWC). IMD is the nodal agency for issuing Quantitative precipitation Forecast (QPF) for river basins/ sub-basins where as CWC is the nodal agency for issuing Flood Forecast. The QPF is used as the input in the Flood Forecasting model of CWC.

There are 10 Flood Meteorological Offices (FMOs) at different parts of flood prone areas of the country which are located at Agra, Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna in the flood prone areas namely the river catchments Yamuna, Narmada, Tapi, Ajoy, Mayuraksi and Kangasbati, Mahanandi, Brahmani and Subernarekha, Brahmaputra, Dhansiri and Barak, Godavari and Krishna, Teesta, Ganga and Sharada, and Sahibi, Kosi, Baghmati, Gandak etc. IMD also provides similar support to Damodar Valley Corporation (DVC) for the river basins Barakar and Damodar.

Flood Meteorological Service is provided daily, consisting of following inputs to Central Water Commission (CWC) issuing Hydromet Bulletins which contains the following information:

i. Sub-basin wise QPF,
ii. Synoptic situations,
iii. Spatial and temporal distribution of rainfall,
iv. Heavy rainfall warnings,
v. Sub-basin wise past 24 hr realized rainfall.

QPF bulletin is issued at 930hrs IST and Hydromet Bulletin at 1230 hrs IST by FMOs. Forecast for a lead time of 5-days (forecast for 2 days and outlook for subsequent 3 days) are issued daily during flood season which may be modified in the evening when situation warrants. In the flood season, year 2014, 22679 no of QPF have been issued out of which 13660 are correct over the river catchment and in annual consolidated forecast report "Correct Forecast" has been found about 60% . QPF Bulletins including heavy rainfall warning are also issued by concerned FMOs during cyclonic period or when there is a chance of heavy rainfall leading to flood. From flood season 2015 onwards, FMOs will issue QPF for 3 days and outlook for subsequent 4 days in place of present QPF for 2 days and outlook for subsequent 3 day.

The are operational run of sub-basin-wise WRF (00UTC & 12UTC) and MME (00UTC) models' output (1-day, 2-day and 3-day) for rainfall are generated and uploaded on IMD website for 122 sub-basins under FMO which is an additional guidance to forecaster for issuing QPF. In the flood season 2015, IMD GFS model rainfall products will be operational for basin/sub basin level for 7 days which will be very useful for water management.

1.2.1.2 **Major New Initiatives**

1.2.1.2.1 **A project entitled "**Modeling of changing Water Cycle and Climate" (Rs. 89.90 Crores) approved for implementation jointly with NCMRWF **during XII FYP.**

The main objective of the program are as follows:

i. To augment the present hydro-meteorological observing systems especially in the Himalayan glacier region. Two river basins **Narmada** and **Satluj** has been chosen for this pilot study.
ii. To develop basin scale high-resolution modelling system to enhance predictions of hydro-meteorological variables
iii. To develop integrated basin-scale hydrological modelling system by incorporation of conventional and satellite data and to generate a quantified estimate of water balance in the river catchment basins of Narmada and Satluj
iv. Creation of hydro-meteorological information system at basin scale
v. To investigate the impact of climate variability and change scenarios on hydrological response at basin level

(I) GIS based customized rainfall information system (CRIS) made operational for processing real time rainfall data to generate state, sub-division, district and river basin wise products for operational use.

1.2.1.2.2 NWP

NWP Division using Quality Controled DWR data in WDSS-II Nowcasting system and ARPS model 3D Var for very short-range forecasting. In addition, NWP Division also using these data sets in WRF model experimentaly. The same will be made operational after validation. Presently IMD operates two Nowcast Systems based on DWR data input (1) Warning Decision Support System Integrated Information (WDSSII) (updated every 10 minutes) for Metropolitan City Forecast and Aviation forecast (Single Radar Products) at Delhi, Chennai, Hyderabad and Kolkata forecast for next 2 hours (2) Advanced Regional Prediction System (ARPS) (thirty minutes updates) for NW, South, NE regions for forecast for next 9 hours.

- INSAT 3D AMV data assimilation in GFS model and MEGHA-TROPIQUES satellite SAPHIR Radiance (6 channel) INSAT 3D Sounder Radiance (5 Channels) in WRF model initiated. DWR data assimilation in WRF model started in experimental mode.
- GFS model (T574/L64) and WRF model (27/9 km) installation completed at IITM HPC from analysis to 7-days/3-days forecast and product generation. A parallel system to the existing NWP system at IMD, New Delhi to be established at IITM, Pune by the end of February 2015 to optimize resources utilization to provide uninterrupted NWP product delivery for real-time utilization of NWP guidance.
- Experimental dynamical extended range forecast based on multi model ensemble (MME) for 4 weeks rainfall using model outputs from IITM CFS V2 and other global centres prepared every week and made available through IMD website.
- Experimental Monthly and seasonal global forecasts for temperature and rainfall was prepared every month and made available through IMD website.
- Establish a state-of the-art climate data centre with advanced climate data management system with observation Quality Control as per WMO standard.
- Increased city Forecast to 310 cites, Tourist city Forecast from 87 to 107 destinations and validity of local forecast increased from 5 to 7 days.

1.3 DISASTER PREVENTION AND PREPAREDNESS

1.3.1 India

1.3.1.1 Cyclone Warning Services

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 India Meteorological Department (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.

- Accurate prediction of Hudhud, Nilofar and other cyclonic storms and Region-wise Severe Weather Warnings
- Introduction of Seasonal Prediction (Experimental and in house) of Cyclonic Disturbances over the Bay of Bengal During the Post-Monsoon Season of 2014
- Introduction of Probabilistic Cyclogenesis Forecast upto 3 days (from 1 June 2014)
- Introduction of hourly update on day of landfall of cyclone
- Lead period increased to 7 days (two days outlook and five days forecast)
- Uncertainty of cyclone track forecast was reduced by 20-30% for 24-120 hr forecasts with effect from HUDHUD due to reduction in error in last five years
- Improvement in Track forecast accuracy by 7.6 km per year and landfall point forecast accuracy improved by 30 km per year in 24 hr forecast
- Intensity forecast improved by about 20 kmph in past five years
- Heavy rainfall and Storm surge warning accuracy and lead period improved substantially since 2009 with 72 hr lead period and coastal inundation forecast commenced in 2013
- Warning dissemination:
- SMS to Disaster Managers at National level and upto District Collector level
- SMS through INCOIS Tsunami Warning System to the fishermen
- SMS through various service providers to the farmers

- Warning message to the local population through Electronic Display Boards (EDB) of INCOIS.
- A new dedicated website for cyclone (www.rsmcnewdelhi.imd.gov.in) has been developed on 3 April 2014 and was fully operational during VSCS HUDHUD.
- Internet Lease Line Bandwidth was upgraded from 60mpbs to 100 mpbs during the cyclonic storm 'HUDHUD' for IMD website failure free accessibility.
- Cyclone Hudhud stands in 9th position in Top Searched New Events in Google Search in 2014 (Source : TOI: 17 Dec 2014)

1.3.1.2 Outcome:

- Drastic Reduction in Loss of Lives. Example : Cyclone Phailin and Hudhud,
- A lot of Appreciations to IMD from national and international agencies including Prime Minister.
- Advances in cyclone forecasting and warning is appreciated by Prime Minister address at the 102nd Indian Science Congress on 3rd January, 2015. Also on the occasion of Prawasi Bhartiya Diwas (7-9 Jan 2015) accurate cyclone forecasting is identified as one of the new order of S&T emerging from roots of Indian Knowledge.
- AWS observational data to be utilized for generating hourly contours of rainfall and temperature and overlaying on Nowcast page, along with overlay of Satellite pictures for Emergency Management under the MHA Disaster Risk Reduction Project, in collaboration with NRSC.

1.3.1.3 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 Maritime Distress and Safety System (GMDSS). Broadcast through Indian 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 Meteorological Offices).
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 in 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 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.

1.3.1.4 Cyclone Warning Dissemination

Cyclone warnings are disseminated through a variety of communication media, such as, radio, television, print media, telephones, fax, telex, telegrams, police, wireless network. 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 250 analog and 100 digital CWDS receivers have been employed in vulnerable coastal areas in the east and west coast. Steps are being taken for introduction of shortly for 500 new CWDS (Cyclone Warning Dissemination Systems), which are based on DTH concept through cable network.

1.3.1.5 Disaster Management

1.3.1.5.1 Institutional and Policy Framework

1.3.1.5.1.1 The institutional and policy mechanisms for carrying out response, relief and rehabilitation have been well-established since Independence. These mechanisms have proved to be robust and effective in so far as response, relief and rehabilitation are concerned.

1.3.1.5.1.2 At the national level, the Ministry of Home Affairs is the nodal Ministry for all matters concerning disaster management. The Central Relief Commissioner (CRC) in the Ministry of Home Affairs is the nodal officer to coordinate relief operations for natural disasters. The CRC receives information relating to forecasting/warning of a natural calamity from India Meteorological Department (IMD) or from Central Water Commission of Ministry of Water Resources on a continuing basis. The Ministries/ Departments/Organizations concerned with the primary and secondary functions relating to the management of disasters include:

India Meteorological Department, Central Water Commission, Ministry of Home Affairs, Ministry of Defence, Ministry of Finance, Ministry of Rural Development, Ministry of Urban Development, Department of Communications, Ministry of Health, Ministry of Water Resources, Ministry of Petroleum, Department of Agriculture & Cooperation. Ministry of Power, Department of Civil Supplies, Ministry of Railways, Ministry of Information and Broadcasting, Planning Commission, Cabinet Secretariat, Department of Surface Transport, Ministry of Social Justice, Department of Women and Child Development, Ministry of Environment and Forest, Department of Food. Each Ministry/Department/Organization nominate their nodal officer to the Crisis Management Group chaired by Central Relief Commissioner. The nodal officer is responsible for preparing sectoral Action Plan/Emergency Support Function Plan for managing disasters.

1.3.1.5.1.3 National Crisis Management Committee (NCMC):

Cabinet Secretary, who is the highest executive officer, heads the NCMC. Secretaries of all the concerned Ministries /Departments as well as organizations are the members of the Committee The NCMC gives direction to the Crisis Management Group as deemed necessary. The Secretary, Ministry of Home Affairs is responsible for ensuring that all developments are brought to the notice of the NCMC promptly. The NCMC can give directions to any Ministry/Department/Organization for specific action needed for meeting the crisis situation.

1.3.1.5.1.4. Crisis Management Group:

The Central Relief Commissioner in the Ministry of Home Affairs is the Chairman of the CMG, consisting of senior officers (called nodal officers) from various concerned Ministries. The CMG's functions are to review every year contingency plans formulated by various Ministries/Departments/Organizations in their respective sectors, measures required for dealing with a natural disasters, coordinate the activities of the Central Ministries and the State Governments in relation to disaster preparedness and relief and to obtain information from the nodal officers on measures relating to above. The CMG, in the event of a natural disaster, meets frequently to review the relief operations and extend all possible assistance required by the affected States to overcome the situation effectively. The Resident Commissioner of the affected State is also associated with such meetings.

1.3.1.5.1.5 Control Room (Emergency Operation Room):

An Emergency Operations Centre (Control Room) exists in the nodal Ministry of Home Affairs, which functions round the clock, to assist the Central Relief Commissioner in the discharge of his duties. The activities of the Control Room include collection and transmission of information concerning natural calamity and relief, keeping close contact with governments of the affected States, interaction with other Central Ministries/Departments/Organizations in connection with relief, maintaining records containing all relevant information relating to action points and contact points in Central Ministries etc., keeping up-to-date details of all concerned officers at the Central and State levels.

1.3.1.5.2 National Disaster Management Authority (NDMA)

About 8% of the area in the country is prone to cyclone-related disasters. Recurring cyclones account for large number of deaths, loss of livelihood opportunities, loss of public and private property and severe damage to infrastructure, thus seriously reversing developmental gains at regular intervals.

Broad-scale assessment of the population at risk suggests that an estimated 32 crore people, which accounts for almost a third of the country's total population, are vulnerable to cyclone related hazards. Climate change and its resultant sea-level rise can significantly increase the vulnerability of the coastal population.

As mandated by Disaster Management Act, 2005, the Government of India (GoI) created a multi-tiered institutional system consisting of the National Disaster Management Authority (NDMA) headed by the Prime Minister, the State Disaster Management Authorities (SDMAs) by the respective Chief Ministers and the District Disaster Management Authorities (DDMAs) by the District Collectors and co-chaired by Chairpersons of the local bodies. These bodies have been set up to facilitate a paradigm shift from the hitherto relief centric approach to a more proactive, holistic and integrated approach of strengthening disaster preparedness, mitigation and emergency response.

1.3.1.5.2.1 Guidelines for the Management of Cyclones

The NDMA has prepared Guidelines for the Management of Cyclones to assist ministries and departments of GoI and state governments to prepare their DM plans. The guidelines are presented in nine chapters as detailed below:

i. Chapter 1 provides an introductory overview that reflects the risk and vulnerability of the country to cyclones, including the dimensions and magnitude of the problem.
ii. Chapter 2 discusses the Early Warning Systems (EWS) for cyclones. In this chapter, the present status of EWSs has been discussed and the gaps have been identified. Requirement to bring them up to international standards and making them state-of-the-art systems has been recommended.
iii. Chapter 3 deals with the present status of Warning Communication and Dissemination, its gaps and future improvements required towards making it fail-proof and modern.
iv. Chapter 4 covers structural measures for preparedness and mitigation, covering cyclone shelters, buildings, road links, culverts and bridges, canals, drains, saline embankments surface water tanks, cattle mounds and communication/power transmission networks.
v. In Chapter 5, important aspects of the management of coastal zones and its relevance to CDM, including some other non-structural mitigation options have been presented. This chapter discusses issues related to coastal zone management, sustainability of coastal resources, bioshields, coastal flood plain management, coastal erosion, natural resources management, etc.
vi. Chapter 6 deals with various aspects of awareness generation related to CDM as an important preparedness measure.
vii. Chapter 7 covers Disaster Risk Management (DRM) issues, risk assessment and vulnerability analysis, hazard zoning and mapping, data generation, including the use of GIS tools, and capacity development.
viii. Chapter 8 deals with CDM-related response and relief strategies. A detailed account of several issues related to effective response such as response platforms, linking risk knowledge with response planning, evolving disaster response capabilities, etc., is brought out in this chapter.
ix. In Chapter 9, guidelines and implementation strategies have been discussed.
x. Salient initiatives recommended for implementation as part of the National Guidelines for Management of Cyclones are listed for undertaking action by various relevant Departments.
xi. The detail Guideline is hoisted in the NDMA website.

1.3.1.5.2.2 Current Status

(i) Meetings related to cyclone preparedness and disaster management conducted by the State Govt. departments are regularly attended by IMD officers to provide necessary briefings and inputs.

(ii) Frequent lectures on Disaster Preparedness and Mitigation are delivered to educate the State Govt. officials and NGOs.

(iii) Exhibits on Statistics on frequencies of landfalling Tropical Cyclones over the coastal belts of North Indian Ocean, Cyclone Warning procedures employed by IMD, Damages caused due to landfalling cyclones etc. are prepared every year with updated data and displayed in the meteorological exhibition conducted during the WMO Day, National Science Day and Indian Science Congress.

(iv) Exhibits are also supplied to schools and other academic/ govt. institutions for display during scientific programmes. IMD officials also participate in such exhibitions.

1.3.1.5.2.3 National Disaster Response Force (NDRF)

Two national calamities in quick succession in the form of Orissa Super Cyclone (1999) and Gujarat Earthquake (2001) brought about the realization of the need of having a specialist response mechanism at National Level to effectively respond to disasters. This realization led to the enactment of the DM Act on 26 Dec 2005. The NDMA was constituted to lay down the policies, plans and guidelines for disaster management.

The DM Act has made the statutory provisions for constitution of National Disaster Response Force (NDRF) for the purpose of specialized response to natural and man-made disasters. Accordingly, in 2006 NDRF was constituted with 08 Bns (02 Bn each from BSF, CRPF, ITBP and CISF). As on date NDRF is having strength of 10 Bns. Each NDRF Bn consists of 1149 personnel. Union cabinet has also approved the conversion/up-gradation of 02 Bns from SSB.

The force is gradually emerging as the most visible and vibrant multi–disciplinary, multi-skilled, high-tech, stand alone force capable of dealing with all types of natural and man-made disasters.

The DM Act, 2005 envisages a paradigm shift from the erstwhile response centric syndrome to a proactive, holistic and integrated management of disasters with emphasis on prevention, mitigation and preparedness. This national vision inter alia, aims at inculcating a culture of preparedness among all stakeholders.

NDRF has proved its importance in achieving this vision by highly skilled rescue and relief operations, regular and intensive training and re-training, capacity building & familiarization exercises within the area of responsibility of respective NDRF Bns, carrying out mock drills and joint exercises with the various stakeholders.

Vision of NDRF is to emerge as the most visible and vibrant multi-disciplinary, multi-skilled, high-tech force capable to deal with all types of natural as well as manmade disasters and to mitigate the effects of disasters.

1.3.1.5.2.3.1 Role and Mandate of NDRF

- Specialized response during disasters
- Proactive deployment during impending disaster situations
- Acquire and continually upgrade its own training and skills
- Liaison, Reconnaissance, Rehearsals and Mock Drills
- Impart basic and operational level training to State Response Forces (Police, Civil Defence and Home Guards)
- Vis-à-vis Community- All NDRF Bns are actively engaged in various:
- Community Capacity Building Programme
- Public Awareness Campaign
- Exhibitions : Posters, Pamphlets, literatures

1.3.1.5.2.3.2 Unique Force

- The only dedicated disaster response force of the world.
- The only agency with comprehensive response capabilities having multi-disciplinary and multi-skilled, high-tech, stand alone nature.
- Experienced paramilitary personnel specially trained and equipped for disaster response.
- Capabilities for undertaking disaster response, prevention, mitigation and capacity building

1.3.1.5.2.4 National Institute of Disaster Management (NIDM)

- The National Institute of Disaster Management (NIDM) was constituted under an Act of Parliament with a vision to play the role of a premier institute for capacity development in India and the region. The efforts in this direction that began with the formation of the National Centre for Disaster Management (NCDM) in 1995 gained impetus with its redesignation as the National Institute of Disaster Management (NIDM) for training and capacity development. Under the Disaster Management Act 2005, NIDM has been assigned nodal responsibilities for human resource development, capacity building, training, research, documentation and policy advocacy in the field of disaster management.
- Both as a national Centre and then as the national Institute, NIDM has performed a crucial role in bringing disaster risk reduction to the forefront of the national agenda. It is our belief that disaster risk reduction is possible only through promotion of a "Culture of Prevention" involving all stakeholders. We work through strategic partnerships with various ministries and departments of the central, state and local governments, academic, research and technical organizations in India and abroad and other bi-lateral and multi-lateral international agencies.
- NIDM is proud to have a multi-disciplinary core team of professionals working in various aspects of disaster management. In its endeavour to facilitate training and capacity development, the Institute has state-of-the-art facilities like class rooms, seminar hall, a GIS laboratory and video-conferencing facilities etc. The

Institute has a well-stocked library exclusively on the theme of disaster management and mitigation. The Institute provides training in face-to-face, on-line and self-learning mode as well as satellites based training. In-house and off-campus face-to-face training to the officials of the state governments is provided free of charge including modest boarding and lodging facilities.

- NIDM provides technical support to the state governments through the Disaster Management Centres (DMCs) in the Administrative Training Institutes (ATIs) of the States and Union Territories. Presently NIDM is supporting thirty such centres. Six of these centres are being developed as Centres of Excellence in the specialised areas of flood risk management, earthquake risk management, cyclone risk management, drought risk management, landslides risk management and management of industrial disasters. Eleven larger states (Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal and Odisha) have been provided with additional centres to cater their needs in this area.
- NIDM hosts the SAARC Disaster Management Centre (SDMC) and works as its national focal point.
- The vision is to create a Disaster Resilient India by building the capacity at all levels for disaster prevention and preparedness.

1.3.1.5.2.5 Common Alert Protocol (CAP)

Guidelines of implementation of Common Alert Protocol (CAP) have been received from WMO and India Meteorological Department (IMD) already is taken action for implementation of CAP with respect to cyclone, thunderstorm & earthquake. Initially it is palnned to introduce Google Alert for cyclones from 2015.

Current Status

1. SOP for Post De-Warning Procedures after the landfall of cyclone is prepared.
2. Cyclone Hazard Maps for coastal zones is made available on IMD Website.
3. Efforts are on to increase the number of SMS users to whom messages are sent during cyclone.
4. Meetings related to cyclone preparedness and disaster management conducted by the State Govt. departments are regularly attended by IMD officers to provide necessary briefings and inputs.
5. Frequent lectures on Disaster Preparedness and Mitigation are delivered to educate the State Govt. officials and NGOs.
6. Dr. S. Balachandran, Scientist-E has been included as a core group member for the preparation of **Tamil Nadu State Disaster Management Plan**. Necessary input material for the same is being prepared.
7. Exhibits on Statistics on frequencies of landfalling Tropical Cyclones over the coastal belts of North Indian Ocean, Cyclone Warning procedures employed by IMD, Damages caused due to landfalling cyclones etc. are prepared every year

with updated data and displayed in the meteorological exhibition conducted during the WM Day and National Science Day.

8. 45 exhibits (15 permanent) were prepared and put up for display at the exhibition hall of the newly constructed building for FMC Kanyakumari for the benefit of students and other visitors**.**
9. Exhibits are also supplied to schools and other academic/ govt. institutions for display during scientific programmes.
10. IMD officials also participate in exhibitions conducted during National Science Congress and Science festivals organised by State Govt. and scientific institutions.
11. The names, addresses and telephone Nos. of the Officers were sent to all concerned offices as a Pre-cyclone exercises.

1.4 TRAINING

1.4.1 India

Human resource development has always been one of the prime thrust areas of the India Meteorological Department for capacity building and to keep pace with latest trends in various activities of the Department. The Meteorological Training Institute (MTI) of the India Meteorological Department (IMD) is always fulfilling this need by conducting following regular courses.

1.4.1.1 Regular Courses nn General Meteorology

S.No.	Departmental/Non Departmental courses	Duration	Training centres	Eligibility Criteria
1.	Advanced Met. Training Course (Non-Departmental)	1 Year	Pune	B.Sc*. (with Physics or Maths as main subject) /M.Sc./B.E./ B.Tech.
2.	Forecasters Training course	6 months	Pune	B.Sc. (with Physics or Math as main subject) and after successful completion of Intermediate Met. Training course
3.	Intermediate Training course including one month on the Job training.	3 months	Pune, Delhi, Kolkatta & Chennai centres.	B.Sc. (with Physics or Maths as main subject) after successful completion of Basic Met. Training course.
4.	Integrated Meteorological Training course.	4 months	Pune , Delhi, Chennai and Kolkata	Fresh recruited Scientific Asst.with B.Sc.(Phy., Math/ BE/B. Tech. qualification
5	LA's Modular Course	2 Months	Delhi & Kolkotta.	Departmental Met. Attendant who have

				passed SSC and working in same cadre for 5 years

1.4.1.2 Additional courses conducted on demand from users end:-

WMO group training Course on Instrument Maintenance and Calibration conducted during 3 to 28 November, 2014. 24 International and 3 Indian participants attended the course.

1.4.1.3 Other Trainings

- Training Programs, Seminars and Workshops are conducted to operational forecasters for improvement of forecast skills in real-time forecast. Capacity Development of personnel from IMD, NCMRWF, IAF, Indian Navy, Coast Guard, NDMA, Indian Army, ICAR, DRDO, Universities, Research Institutes and other National/International Organizations was undertaken.
- Imparted training from 27 countries in the area of instrument, cyclones, climate, forecasting and general meteorology.
- IMD has published 117 research papers in various reputed National and International Journals and 8 Met. Monographs and Reports during 2014-15.
- Satellite Meteorology Division, India Meteorological Department, New Delhi-110003 organized a Training Workshop on INSAT-3D Satellite Data Products from 30th April, 2014 to 1st May, 2014 at MoES, New Delhi. Number of Scientist/Officers from the department participated in Training Workshop on INSAT-3D Satellite Data Products during the period.

1.4.1.4 Future Plans:

1.4.1.4.1 Training Related with ongoing project:-

Under World Bank aided Hydrology Project Phase II**,** the following regular courses are being conducted by MTI, on demand from user end.

i. Basic Hydromet Observer's Course for Observers
ii. Hydromet Supervisor Course for Asst/Section Engineers
iii. Senior Level Refresher Course for Executive Engineers The approval for Phase III is awaited to prepare the training calendar for 2015 - 2016.

2 Approval for the project "Training in Operational Meteorology" is received from the competent authority. Action for various activities under this project is initiated.
3 To upgrade the infrastructure of training institute & Trainees Hostel, action is in progress.
4 Revision of the syllabus /Course contents of the different training courses is in progress.
5 e-Learning method in training programme is already introduced by MTI. Action towards introduction of distance learning in the IMD's training programs by the provision of virtual class room facilities is already initiated. Under this proposal,

provision is also there to share the digital content of the lectures in broadcast mode between centres through internet based software.

6 Approval for conduction of three refresher courses on Tropical Cyclone, Climate science & Numerical Weather Prediction is already received. Approval for conduction of a refresher course on Doppler Weather Radar is awaited.
7 One year ab-initio training for Group A officers (direct recruit) of the department to be conducted in this year.
8 Action towards publication of lecture notes in respect of Integrated Meteorological Training Course is in progress.

1.5 RESEARCH

1.5.1 India

1.5.1.1 Current Status

Research works pertaining to statistical, climatological and dynamical aspects of Tropical Cyclones of North Indian Ocean are undertaken regularly. Some recent efforts are listed below:

1.5.1.1.1 Project TCRAIN

Tropical Cyclone Rainfall Analytical tool for the North Indian Ocean – **TCRAIN** that depicts rainfall characteristics Tropical Cyclones over North Indian Ocean was developed by CWRC, RMC Chennai for the period 2000-2010 based on TRMM data and the application was hosted in the web at the URL: www.imdchennai.gov.in/. The web page was enhanced with facilities for further updating and the updated products up to the year 2013 were uploaded in the web.

1.5.1.1.2 Research Papers

(b) The following research papers were published:

i. Decadal variations in translational speeds of cyclonic disturbances over North Indian Ocean by B. Geetha and S. Balachandran – published in Mausam (2014), **65**,1, 115-118.
ii. Energetics of super cyclone 'gonu' and very severe cyclonic storm 'Sidr' by Sunitha Devi S., Somenath Dutta and k. Prasad published in Mausam (2014), 65, 1, 37-48
iii. Characterisation and Asymmetry analysis of Rainfall distribution associated with Tropical Cyclones over Bay of Bengal: NISHA(2008), LAILA (2010) and JAL(2010)" by S. Balachandran and B. Geetha – published in Mausam (2014), **65**,4, 481-496.
iv. Eddy Angular Momentum Fluxes in relation with Intensity Changes of Tropical Cyclones JAL(2010) and THANE(2011) in North Indian Ocean" by S. Balachandran and B. Geetha – published in the Book on **High Impact Weather Events over SAARC region** (Ed. Kamaljit Ray et al.), Capital Publishing Co., New Delhi (2014)and Springer, Netherlands, 164-176.

v. TCRAIN – A database of tropical cyclone rainfall products for North Indian Ocean" by S. Balachandran, B. Geetha, K. Ramesh and N. Selvam – published in Tropical Cyclone Research and Review (2014), **3**,2, 122- 129.

vi. Movement of Low Pressure systems over Eastern Antarctic region and their influence on the Rainfall over India during Southwest Monsoon by P. Chandrashekhara Rao and M.M. Bongale - published in Vayumandal, Vol. 38, No. 1-4, Jan-Dec 2012.

vii. Real-Time Track Prediction of Tropical Cyclones over the North Indian Ocean Using the ARW Model by Krishna K. Osuri, U. C. Mohanty, A. Routray, M. Mohapatra, Dev Niyogi – published Journal of Applied Meteorology and Climatology, 52, 2476-2492

viii. Cyclone hazard proneness of districts of India by M Mohapatra published in Journal of Earth System Sciences (JESS), Accepted

ix. Evaluation of landfall forecast over North Indian Ocean issued by India Meteorological Depart by M Mohapatra, DP Nayak, Monica Sharma, RP Sharma, BK Bandyopadhyay published in Journal of Earth System Sciences (JESS), Accepted

x. Utility of automatic weather station (AWS) data for monitoring and prediction of cyclonic disturbances during monsoon season, 2013 by M. Mohapatra and Manish Ranalkar published in IMD Met. Monograph, Synoptic Meteorology No. 1/2014, pp. 161-172. IMD, Pune

xi. Early Warning Services for Management of Cyclones over North Indian Ocean : Current status and future scope by M Mohapatra, B.K. Bandyopadhyay, Kamaljit Ray and L. S. Rathore published in High Impact Weather Events over SAARC Region, Ed. Kamaljit Ray, M. Mohapatra, B.K Bandyopadhyay and L.S. Rathore, Published by Capital Publishing Co. and Springer Publications Ltd

1.5.1.1.3 Participation in Seminar / Symposium / Conference

- **Dr M Mohapatra attended as a Member of working groups of WMO's workshops for IWTC-8 and IWTCLP-3** held at Jeju, South Korea during 2-10 December 2014
- Dr.S.Balachandran, Scientist-E participated in the **8th International Workshop on Tropical Cyclones (IWTC-VIII)** at Jeju, South Korea during 1-6 December 2014. He also served as a working group member for the topic *Tropical Cyclones and Climate Change* and provided the necessary inputs.
- IMD and DIAL have jointly organized Sixth one day annual Fog Workshop for the winter 2013-2014 with theme as "Fog Monitoring and Forecasting Services" on 16 January, 2014 at IGI Airport, Auditorium Udan Bhavan, IGI Airport, New Delhi. Objective of this Workshop was to further improve fog services of IGI Airport and other airports through intensive discussion between forecaster, observer and researcher and promote its effective use through a close co-ordination and discussion with various stake holders and users' communities and

fog researcher. There were detail interact on various new technology/tools available in India for better monitoring and forecasting of Fog.

- The Indian Meteorological Society (IMS) has organizing an International Symposium on Tropical Meteorology, INTROMET – 2014, on Monsoons – Observations, Prediction and Sustainability (MOPS) during 21-24 February, 2014 to assimilate the present as well as the evolving concepts related to Indian and other monsoons of the world. Dr. Shailesh Nayak, Secretary, MoES inaugurated the symposium at SRM University, Kattankulathur on 21st February, 2014. It has provided a unique opportunity for the operational meteorologists, researchers, planners, hydrologists, agriculturists, disaster managers and instrumentation scientists to exchange their views on the Indian monsoons and their related aspects with monsoons elsewhere. The symposium focused on the following sub - themes of monsoons viz. Observing systems and techniques, Monsoon prediction, and Teleconnections, Aerosols, Clouds and Regional climate forcing, Ocean - Land - atmosphere coupling extreme events Climate, Agriculture and Water resources etc. Many scientists of IMD participated in this Seminar and presented their papers. Exhibits of IMD activities were displayed and explained to the international participants.
- The 6th International Verification Methods Workshop was held in New Delhi, India, from 13-19 March, 2014 and was jointly organized by WMO, NCMRWF and IMD. This International Workshop was attended by about 120 experts from 25 countries and leading Institutes from India. The Workshop was inaugurated by Dr. Shailesh Nayak, Secretary, MoES with address from Dr. L. S. Rathore, DGM, IMD, Dr. Swati Basu, Director (NCMRWF), E. Ebert, Chair- Scientific Programme Committee and welcome by Dr. S.D. Attri, DDGM (O). The goal of the workshop was to promote recent advances in the theory and practice of verification of weather and climate forecasts worldwide. The participants were from operational, research and forecast user communities to discuss methods for more effectively measuring and conveying the accuracy and utility of forecasts and warnings. The workshop was divided in two sessions a tutorial session (March 13-15) and scientific program (March 17-19). The scientific program covered keynote addresses as well as contributed talks and posters on new verification techniques and issues related to the practice of forecast verification.
- IMD organized a Capacity Building Training Workshop on "Operational Climate Prediction of summer monsoon rainfall over South Asia" at Pune during 14-21 April, just prior to SASCOF-5. Participants from eight South Asian countries, *viz*., Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Sri Lanka, Dhaka and UKMO London attended this workshop. Experts from the IMD, IITM- Pune, United Kingdom Meteorological Office-U.K, APCC-Korea, NOAA-U.S. and World Meteorological Organization-Geneva participated in the training workshop as the resource persons.
- A Capacity Building Training Workshop on "Operational Climate Prediction for South Asia" was conducted at the India Meteorological Department (IMD), Pune for participants from the South Asian countries. The training workshop was

attended by representatives from eight South Asian countries, *viz*., Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Sri Lanka, Dhaka and UKMO London. Experts from the IMD and IITM, Pune and international experts from United Kingdom Meteorological Office, U.K, APCC, Korea, NOAA, U.S. and World Meteorological Organization, Geneva participated in the training workshop as the resource persons. Two days SASCOF-5 meeting co-hosted by IMD was held at IITM, Pune during 22-23 April, 2014.

- ❖ One day training workshop on “IMD Weather Forecasting System” was conducted on 10th June, 2014 at RMC Kolkata Alipore. Twenty Officers of Irrigation Department and twelve from Damodar Valley Corporation attended the training workshop. Dr. D. Pradhan, DDGM, inaugurated the workshop and delivered the lecture on “Application of DWR in Hydrology and Prediction of Quantitative Estimates of Rainfall”. Dr. S. Bandopadhyay, Scientist ‘E’, Dr. G. C. Debnath, Scientist ‘E’ and Shri Animesh Chanda, Scientist ‘D’ also delivered lectures on various topic related to QPF, forecasting system and AWS/ARG respectively.
- ❖ Dr. L. S. Rathore, DGM inaugurated “Summer Training” of 6-8 weeks during June-July, 2104, wherein 106 MSc / B. Tech students of different Colleges, Universities, IITs etc pursued projects in different division of IMD, New Delhi.
- ❖ A two day workshop on ‘Enhanced and Unique Cyclonic Activity during 2013’ was organised by Cyclone warning Division, India Meteorological Department, New Delhi on 24 & 25 July, 2014 at New Delhi. It was participated by 80 delegates from various institutes of the country including the renowned scientists in the field. 54 papers were presented in the workshop on various themes. A book of abstract and a book on Climatology of Jammu and Kashmir were released by Prof. S.K. Dube, Vice Chancellor, Amity University, Rajsthan, who was the chief guest during the inaugural session. Number of recommendations has been adopted for future action so as to improve further the cyclone forecast and warning services of IMD.
- ❖ IMD in collaboration with Rajasthan Agricultural Research Institute, Durgapura, Jaipur (KNAU, Jobner) organized a working group meeting cum workshop on use of crop simulation model for decision making and yield forecasting at Jaipur during 15-19 Sep, 2014. Sixteen Technical officers from AMFUs participated in this workshop.
- ❖ Nowcast Training Workshop was organised on 22 and 23 December, 2014. Around 50 delegates including incharges of Meteorological centres and senior forecasters from Regional Meteorological centres participated in the workshop. The Objectives of the training was building of human resource at outstations. This was a training of Trainers. The operational forecasters keep on changing in outstations and therefore this training capacitated the In charges for training the forecasters in their region. To meet the increase in demand of Nowcast by various stakeholders, the improvement in skill score was discussed. Skills to be improved using WDSS-II and TITAN softwares. Nowcast should have higher accuracy as compared to other forecasts therefore FAR to be reduced to less

than 0.2 and POD more than 0.8. Dr. Ashok Kr. Das, Sc-D attended the 'Nowcast Training Workshop' at ARNAV Hall, MoES, New Delhi arranged by NWFC, IMD, New Delhi during December, 22-23, 2014.

1.5.1.1.4 Ongoing Projects

1. A project on development of a Tropical Cyclone Data Portal (**TCDaP**) for the North Indian Ocean is being co-ordinated by CWRC, RMC Chennai.
2. A project on development and execution of a software tool **TCWIND** - for depicting winds associated with 43 Tropical Cyclones over North Indian Ocean during 2000-2010 (time series of maximum sustained wind speed, vertical wind shear, tangential and radial velocities) based on IMD's best track data and 6-hrly NCEP FNL data is in progress.
3. Research works on short-lived, suddenly intensifying cyclonic disturbances near the panel member countries' coasts are being undertaken. A paper titled "***Diagnostics of diabatic heating during rapid intensity changes of Tropical Cyclones GONU(2007), PHAILIN(2013) and MADI(2013)***" by S. Balachandran and B. Geetha has been accepted for presentation in the seminar on Tropical Meteorology (TROPMET-2015) to be held in Chandigarh in Feb 2015. A few more works are in progress.
4. **FDP on landfalling cyclones over the Bay of Bengal**
5. Cyclone Warning Research Centre (CWRC, Regional Meteorological Centre, Chennai is functioning as the Field Operational Centre (FOC) for the FDP(Cyclones) 2014 campaign w.e.f 15th October. FOC's report on the status of observational data received was sent to the National Operations Centre (NOC), IMD New Delhi daily. Daily observational data are archived as per the FDP implementation plan.
6. ***Cyclone eAtlas – IMD***, a software for generation of tracks and statistics of cyclones and depressions over the North Indian Ocean was brought out in CD form by IMD during 2008 and subsequently hosted in the web at the URL: www.rmcchennaieatlas.tn.nic.in. The database for the software was updated for the year 2013 and uploaded in the web.
7. **Statistical prediction of seasonal cyclonic activity over the North Indian Ocean**
8. An experimental outlook on the seasonal cyclonic activity over the North Indian Ocean for the period October-December 2014 was prepared on real-time basis (during September 2014) and communicated to the Area Cyclone Warning Centre, Chennai for briefing the Tamil Nadu government officials regarding the ensuing cyclone season. The prediction was validated at the end of the season. Efforts are on for improving the prediction model.
9. Experimental efforts are on for **Cyclone Intensity and Track prediction based on WRF model**. Track and Intensity predictions were generated on real time

basis (experimental) and validated during October-December 2014, the chief cyclone period for the North Indian Ocean.

1.5.1.1.5 Future Plans

Cyclone Warning Research Centre, functioning from the Regional Meteorological Centre, Chennai is proposed to be upgraded as **National Tropical Cyclone Research Centre**, during the next five years.

1.6 Publication

- Annual RSMC Report on Cyclonic Disturbances
- Annual Cyclone Review Report of WMO/ESCAP Panel countries
- Annual Tropical Cyclone Operation Plan (TCP-21)
- WMO/ESCAP Panel News
- Annual Report of Cyclone Warning Division, IMD and MoES
- News Letters : IMD, MoES, SMRC
- Preliminary reports of cyclonic disturbances
- A special issue on Tropical Cyclones was released by magazine Geography and You with Dr. M. Mohapatra, Head RSMC as the Guest Editor and various resource persons from IMD.
- A book on selected papers presented during second WMO International Conference on Indian Ocean Tropical Cyclones and Climate Change held at New Delhi during 14-17 Feb 2014 was published as WMO Technical document
- High impact weather events over the SAARC region Ed. Kamaljit Ray, M Mohapatra, B.K. Bandyopadhyay and L.S. Rathore

1.7. REVIEW OF THE TROPICAL CYCLONE OPERATIONAL PLAN

The Panel appreciated Dr. M. Mohapatra of RSMC New Delhi for his valuable services extended in updating the Operational Plan of the PTC. Dr. Mohapatra, rapporteur of Tropical Cyclone Operational Plan (TCOP) in 2014, with the support of the PTC Secretariat and in response to the recommendation of the Panel made at the 41st Session in Bangladesh.

The PTC Secretariat requested the Panel Members to make a careful review of TCOP and inform to the RSMC New Delhi and PTC Secretariat about the updates/additions/amendments, if any, before mid of March 2015.

1.8. 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. Imran Akram, Meteorologist of PTC on the activities of PTC Secretariat during the inter-sessional period. The Panel expressed its satisfaction with the work of the PTC Secretariat. The summary of the activities of PTC Secretariat is given in **CHAPTER V**.

The PTC Secretariat provided the Panel with a detailed breakdown of its expenses incurred during the Inter-sessional period (**Appendix I**). Upon request of the

PTC Secretariat, the Panel agreed to provide US$ 4,000 to support the activities of the PTC Secretariat 2015.

1.9 SUPPORT FOR THE PANEL'S PROGRAMME

The Panel agreed to the participation of Secretary of PTC in the 48th Session of ESCAP/WMO Typhoon Committee as well as in the Annual Session of UN-ESCAP through PTC Trust Fund.

1.10 SCIENTIFIC LECTURES

Presentations of scientific lectures were held during the Joint Session of PTC and TC. The detail is depicted in the Joint Session report.

Other issues:

1 Maldives showed its concern about maintaining and sustaining regional observation, monitoring system to ensure un-interrupted flow of data and inter-operable of data management etc. that warrants regional intervention.

Maldives managed regional mechanism provides cost effective and sustainable solutions to some of the PTC and TC Member countries to address existing gaps in sustaining observation and monitoring system, upkeep of data communication systems, data processing and forecast development and its communication . Maldives would like to offer its services to PTC and TC to complement existing arrangements and addressing gaps through well-articulated project based support.

2 Thailand proposed to use social media like Facebook to exchange of ideas and knowledge among cyclone forecasters of the PTC Member countries.

1.11 DATE AND PLACE OF THE FORTY-THIRD SESSION

The Panel noted and appreciated that the Government of India has offered to host the 43rd Session of the PTC in New Delhi, India in 2016. Dates will be determined in consultation with WMO, ESCAP and PTC Secretariat.

1.12 ADOPTION OF THE REPORT

The report of the forty-second session was adopted at 12:00 hours on Friday 13th February, 2015.

1.13 CLOSURE OF THE SESSION

The session closed at 12:00 hours on 13th February, 2015

CHAPTER-II

(A) CYCLONIC ACTIVITIES OVER NORTH INDIAN OCEAN DURING 2014.

During the year 2014, 8 cyclonic disturbances developed over north Indian Ocean including one Very Severe Cyclonic Storm (VSCS) and one Cyclonic Storm (CS) over Arabian Sea, one land depression (D) and 5 cyclonic disturbances over Bay of Bengal. Out of 5 disturbances over Bay of Bengal, one intensified into Very Severe Cyclonic Storm, two into Deep Depression (DD) and two into Depression. Considering season-wise distribution, out of eight disturbances, one developed during winter, one in pre-monsoon, three during monsoon and three during post-monsoon season. Salient features of cyclonic disturbances during 2014 are given below.

i. There was one cyclones over the Bay of Bengal and two over the Arabian Sea against the long period average of 5 per year over the entire north Indian Ocean including about four over Bay of Bengal and one over Arabian Sea. Thus the cyclonic activity was subdued in the Bay of Bengal during the year 2014. However, the frequency of very severe cyclonic storms was near normal (two)
ii. Though there were three cyclones, only one cyclone (Hudhud) crossed coast and other two (Nanauk and Nilofar) dissipated over the Sea.
iii. The tracks of all the storms were recurving in nature. While Hudhud recurved northwards after landfall, Nilofar recurved northeastwards after attaining maximum intensity and only the remnant of the Cyclone Nanauk recurved northeastwards.
iv. Velocity Flux, Accumulated cyclone energy and Power Distribution Index of the period 2014 are 2970, 206850 and 16004250 against long period average based on the data of 1990-2013 and 2117, 130867 and 9673246 respectively.
v. The total duration of cyclonic disturbances during 2014 was 30.4 days against the long period average of 29.4 days based on data of 1990-2013.

Brief descriptions of the disturbances with intensity cyclonic storm and above are given in the following sections.

(a) Cyclonic Storm, 'NANAUK' over the Arabian Sea (10-14 June 2014)

A Cyclonic Storm (CS) **'NANAUK'** originated from a low pressure area over east central Arabian Sea which developed on 9th June, 2014. It concentrated into a depression over the same region in the afternoon of 10th June, 2014. Moving north-northwestwards, it intensified into a CS **'NANAUK'** in the early morning of 11th June 2014. It weakened into a deep depression in the afternoon of 13th June, 2014 over westcentral Arabian Sea and into a depression in the evening of 1.3 June, 2014 and further into a well marked low pressure area over the same region in the morning of 14th June, 2014. The salient features of CS, Nanuak are given below.

i. It developed in association with the southwest monsoon surge over Arabian Sea during the onset phase
ii. It caused temporary hiatus in progress of monsoon over south India
i. It weakened over the northwest Arabian Sea on 14th June and its remnant moved northeastwards leading to revival and progress of monsoon along the west coast of India

(b) Very Severe Cyclonic Storm, HUDHUD over the Bay of Bengal (07-14 October 2014)

The Very Severe Cyclonic Storm 'HUDHUD' (07-14 Oct. 2014) developed from a low pressure area which lay over Tenasserim coast and adjoining North Andaman Sea in the morning of 6th Oct. 2014. It concentrated into a Depression in the morning of the 7th Oct. over the north Andaman Sea. Moving west-northwestwards, it intensified into a CS in the morning of 8th Oct. and crossed Andaman Islands, close to Long Island between 0300 and 04000 UTC of 8th Oct. It then emerged into Southeast Bay of Bengal and continued to move west-northwestwards. It intensified into a Severe Cyclonic Storm (SCS) in the morning of 09th Oct. and further into a Very Severe Cyclonic Storm (VSCS) in the afternoon of 10th Oct. It continued to intensify while moving northwestwards and reached maximum intensity in the early morning of 12th with a maximum sustained wind speed (MSW) of 185 kmph over the West Central Bay of Bengal off Andhra Pradesh coast. It crossed north Andhra Pradesh coast over Visakhapatnam (VSK) between 0630 and 0730 UTC of 12th Oct. with the same wind speed. After landfall, it continued to move northwestwards for some time and weakened gradually into SCS in the evening and further into a CS in the same midnight. It then, weakened further into a Deep Depression in the early morning of 13th and weakened into a depression in the evening of 13th. Thereafter, it moved nearly northward and weakened into a well-marked low pressure area over East Uttar Pradesh and neighbourhood in the evening of 14th Oct. 2014.

The salient features of this VSCS are as follows.

ii. HUDHUD is the first cyclone that crossed Visakhapatnam coast in the month of Oct., after 1985 and it made landfall on the same day as VSCS Phailin did in 2013.
iii. At the time of landfall on 12th Oct, the estimated maximum sustained surface wind speed in association with the cyclone was about 100 Knots.
iv. The estimated central pressure was 950 hPa with a pressure drop of 54 hPa at the centre compared to surroundings.
v. It caused very heavy to extremely heavy rainfall over North Andhra Pradesh and South Odisha and strong gale winds leading to large scale structural damage over North Andhra Pradesh and adjoining districts of South Odisha and storm surge over North Andhra Pradesh coast.
vi. Maximum 24 hour cumulative rainfall of 38 cm ending at 0300 UTC of 13 October was reported from Gantyada (dist Vizianagaram) in Andhra Pradesh. Maximum storm surge of 1.4 meters above the astronomical tide has been reported by the tide gauge at Visakhapatnam.

vii. The numerical weather prediction (NWP) and dynamical statistical models provided good guidance with respect to its genesis, track and intensity. Though there was divergence in model guidance with respect to landfall point and time in the initial stage, the consensus among the models emerged as the cyclone moved closer to the coast.

viii. India Meteorological Department (IMD) accurately predicted the genesis, intensity, track and point & time of landfall and also the adverse weather like heavy rainfall, gale wind and storm surge 5 days in advance.

(c) Very Severe Cyclonic Storm (VSCS) NILOFAR over the Arabian Sea (25-31 October 2014)

The very severe cyclonic storm, Nilofar developed from a low pressure area which lay over southeast Arabian Sea in the morning of 21st October. It moved northwestwards and concentrated into a Depression in the early morning of 25th over westcentral and adjoining southwest Arabian Sea. It intensified into a CS over the same region in the morning of 26th. It then moved nearly northwards and further intensified into a SCS over westcentral Arabian Sea in the early morning of 27th and into a VSCS around noon of the same day. It continued to move nearly northwards and reached its maximum intensity around midnight of 28th with wind speed of 205 kmph. It then moved north-northeastwards and started to weaken rapidly under

the influence of high vertical wind shear, entrainment of dry and cold air from the north and relatively lower ocean thermal energy. It weakened into a SCS during early hours of 30th October and into a CS in the afternoon of 30th October. It weakened into a Deep Depression in the early hours and into a Depression in the early morning of 31st October. It weakened into a well-marked low pressure area over northeast Arabian Sea off north Gujarat coast in the forenoon of 31st Oct.

The salient features of this system are as follows.

i. The track of the system was unique, as it initially moved northwestward on the day of formation and then re-curved northeastwards. It further moved nearly northwards very slowly upto 29th evening and then east-northeastwards.

ii. The estimated maximum sustained surface wind speed in association with the cyclone was about 110 kt (205 kmph).

iii. The estimated central pressure was 950 hPa with a pressure drop of 56 hPa at the centre compared to surroundings.

iv. It exhibited rapid intensification as well as rapid weakening. The maximum sustained wind increased from about 100 kmph in the early morning of 27th to about 205 kmph in the early evening of 28th (in 36 hours). It weakened rapidly from VSCS (wind speed of about 205 kmph) in the morning of 29th into SCS (wind speed of about 110 kmph) in the morning of 30th and further into a low pressure area (wind speed < 30 kmph) on 31st morning.

v. Though the re-curvature of the track could be predicted by NWP models 3 to 4 days in advance, there was large variation in the position and time of the landfall as well as re-curvature.

vi. Though genesis, track and intensification/weakening were predicted by IMD with reasonable accuracy five days in advance, prediction of rapid weakening and hence dissipation over the Sea were more challenging.

Details of the cyclonic disturbances formed over the north Indian Ocean and adjoining land areas are given in Table 2.1. The tracks of these disturbances are shown in Fig. 2.1

Table 2.1: Cyclonic disturbances formed over north Indian Ocean and adjoining land areas during 2014

1.	Depression over the Bay of Bengal	04-07 January, 2014
2.	Depression over the Bay of Bengal	21-23 May, 2014
3.	Cyclonic Storm 'NANAUK' over the Arabian Sea	10-14 June, 2014
4.	Land Depression over northeastern parts of Odisha and adjoining areas of Gangetic West Bengal	21-23 July, 2014
5.	Deep Depression over the Bay of Bengal	03-07 August, 2014
6.	Very Severe Cyclonic Storm, 'Hudhud' over the Bay of Bengal	07-14 October, 2014
7.	Very Severe Cyclonic Storm, 'Nilofar' over the Arabian Sea	25-31 October, 2014
8.	Deep Depression over the Bay of Bengal	05-08 November, 2014

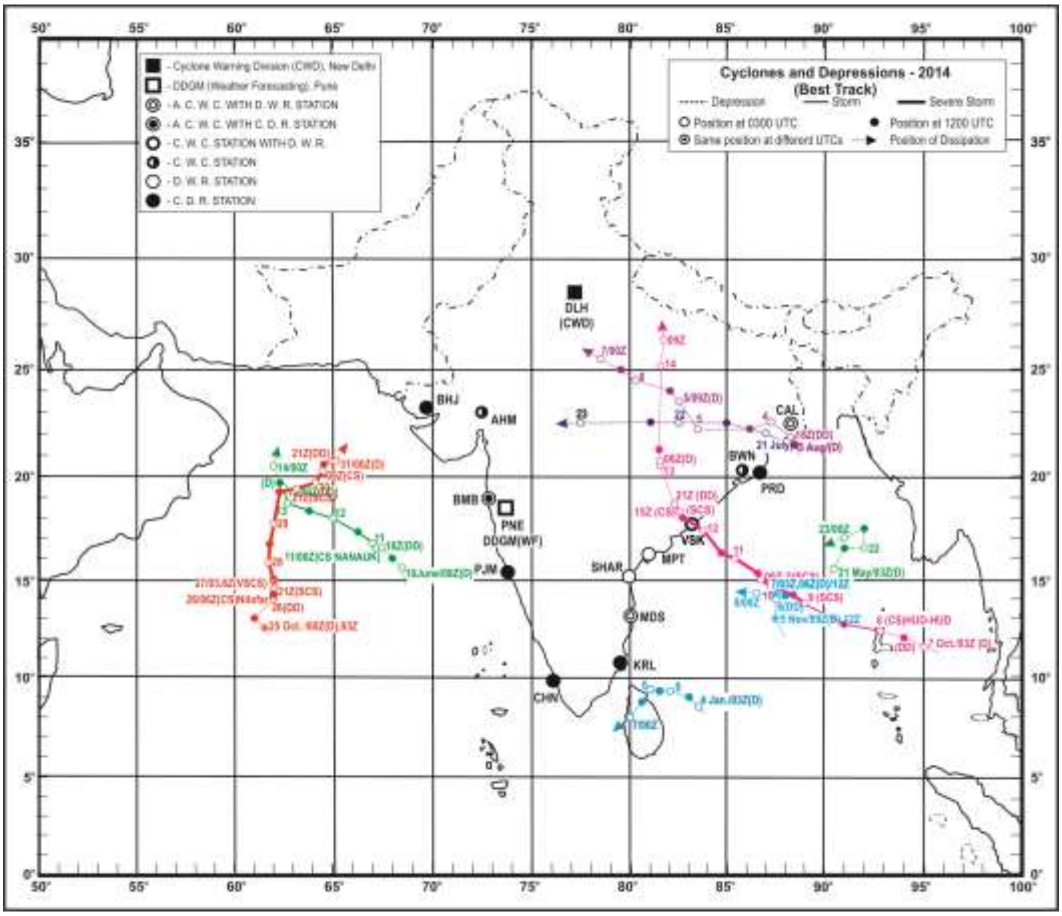


Fig. 2.1 Tracks of the cyclonic disturbances formed over the north Indian Ocean during the year, 2014

(B) Description of cyclonic storms during 2014

2.1 Cyclonic Storm, 'NANAUK' over the Arabian Sea(10-14 June 2014)

2.1.1 Introduction

A Cyclonic Storm (CS) **'NANAUK'** originated from a low pressure area over east central Arabian Sea which developed on 9th June, 2014. It concentrated into a depression over the same region in the afternoon of 10th June, 2014. Moving north-northwestwards, it intensified into a cyclonic storm (CS), **'NANAUK'** in the early morning of 11th June 2014. It weakened into a deep depression in the afternoon of 13th June, 2014 over westcentral Arabian Sea and into a depression in the evening of 1.3 June, 2014 and further into a well-marked low pressure area over the same region in the morning of 14th June, 2014. The salient features of this cyclone are given below.

i. It developed in association with the southwest monsoon surge over Arabian Sea during the onset phase
ii. It caused temporary hiatus in progress of monsoon over south India
iii. It weakened over the northwest Arabian Sea on 14th June and its remnant moved northeastwards leading to revival and progress of monsoon along the west coast of India

2.1.2 Monitoring and Prediction:

The cyclonic storm **'NANAUK'** was monitored & predicted continuously since its inception by the India Meteorological Department. The forecast of its genesis, track, and intensity, as well as associated adverse weather were predicted exceedingly well with sufficient lead time which helped the disaster managers to maximize the management of cyclone. The system was monitored mainly with satellite observations, supported by meteorological buoys and coastal and Island observations. Data from conventional observatories and Automatic Weather Stations (AWSs) were also used. The half hourly INSAT/ Kalpana imageries, available microwave imageries and scatteometry products were used for monitoring of the system. Various national and international NWP models and dynamical-statistical models including IMD's global and meso-scale models, dynamical statistical models for genesis and intensity and models run at NCMRWF were utilized to predict the genesis, track and intensity. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance and decision making process and warning product generation.

2.1.3 Genesis

Under the influence of the active southwest monsoon surge over the Arabian Sea during its onset phase, a low level cyclonic circulation formed on 9th June morning. It concentrated into a vortex (T=1.0 as per Dvorak's analysis) in the evening of 09th June, which corresponded to a low pressure area over the east central Arabian Sea. It became a well-marked low pressure area over the same region in the morning of 10th June. It concentrated into a depression over the same region in the afternoon of 10th June. According to satellite imagery and Dvorak's technique, the intensity was T1.5. The lowest cloud top temperature was about -75^{0}C. The maximum sustained wind speed was about 25 knots. However, the wind speed was higher in the southern sector in association with the southwest monsoon surge.

Considering the environmental conditions, the sea surface temperature (SST) was 30-32^{0}C. The tropical cyclone heat potential was about 60-80 kJ/cm^{2}. The vertical wind shear of horizontal wind was about 20-30 knots between upper and lower tropospheric level. There was increase in low level vorticity, lower level convergence and upper level divergence from 9th to 10th June favouring genesis of the depression. The Madden Julian Oscillation index lay in phase 3 (east equatorial |Indian Ocean) with amplitude less than 1. The past studies indicate that phase 3 is favourable for cyclogenesis. However, the amplitude was not favourable for further intensification.

The best track parameters are shown in Table 2.1.1 and the best track is shown in Fig. 2.1.

2.1.4 Intensification and movement

As the favourable environmental parameters like vorticity and divergence/convergence continued to prevail on 10th and 11th, even though the vertical wind shear and MJO index were not favourable, the depression moved west-northwestwards and intensified into a deep depression around midnight of 10th June, 2014 and further into a cyclonic storm (CS), **'NANAUK'** in the early morning of 11th June 2014. It continued to move west–northwestward for some more time till early morning of 13th June. It then moved northwestwards for some time and finally northwards to westcentral and adjoining northwest Arabian Sea till afternoon of 13th June, where it weakened into a deep depression and further weakened into a depression in the evening of 13th due to increase in vertical wind shear, entrainment of dry air and relatively colder SST. It then moved northwards to northwest and adjoining westcentral Arabian Sea. It weakened into a well marked low pressure area over the same region in the morning of 14th June, 2014.

According to satellite imageries, the initial curved band pattern changed to central dense overcast (CDO) pattern as the system intensified into a cyclonic storm. The maximum intensity was T 3.0 corresponding to 45 knots. The lowest estimated central pressure was about 986 hPa. The CDO pattern changed to the shear pattern due to increase in vertical wind shear during the weakening of the system on 13th. The cloud mass was sheared to the southwest of the centre of low level circulation. There was rapid weakening as the cyclonic storm weakened into depression (40 kts to 25 kts) during six hrs (from 0600 UTC to 1200 UTC of 13th June). It was mainly due to high vertical wind shear which was about 30-40 knots. To highlight the satellite features, the typical satellite imageries are shown in Fig. 2.1.1. The IMD GFS analyses based on 0000 UTC of 10th to 14th June are shown in Fig. 2.1.2 to highlight the dynamical features.

Table 2.1.1. Best track positions and other parameters of the Cyclonic Storm 'NANAUK' over the Arabian Sea during 10-14 June, 2014

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
10/06/2014	0900	15.5/68.5	1.5	998	25	3	D
	1200	16.0/68.0	1.5	996	25	3	D
	1800	16.5/67.5	2.0	994	30	5	DD
11/06/2014	0000	16.5/67.2	2.5	992	35	8	CS
	0300	16.7/67.0	2.5	992	35	8	CS
	0600	16.9/66.7	3.0	990	45	10	CS
	0900	17.0/66.5	3.0	990	45	10	CS
	1200	17.3/66.2	3.0	988	45	10	CS
	1500	17.5/66.0	3.0	988	45	10	CS
	1800	17.5/65.8	3.0	988	45	10	CS
	2100	17.5/65.7	3.0	988	45	10	CS
12/06/2014	0000	17.8/65.3	3.0	986	45	10	CS
	0300	18.0/65.0	3.0	986	45	10	CS
	0600	18.1/64.7	3.0	986	45	10	CS
	0900	18.3/64.3	3.0	988	45	10	CS
	1200	18.3/63.9	3.0	988	45	10	CS

	1500	18.3/63.6	3.0	988	45	10	CS
	1800	18.3/63.4	3.0	988	45	10	CS
	2100	18.4/63.3	3.0	988	45	10	CS
13/06/2014	0000	18.4/62.9	3.0	988	45	10	CS
	0300	18.7/62.7	3.0	990	45	10	CS
	0600	19.0/62.6	2.5	992	40	8	CS
	0900	19.5/62.5	2.0	994	30	5	DD
	1200	19.8/62.4	1.5	996	25	3	D
	1800	20.0/62.0	1.5	996	25	3	D
14/06/2014	0000	20.5/62.0	1.5	996	25	3	D
	0300	Weakened into a well-marked low pressure area over northwest and adjoining westcentral Arabian Sea.					

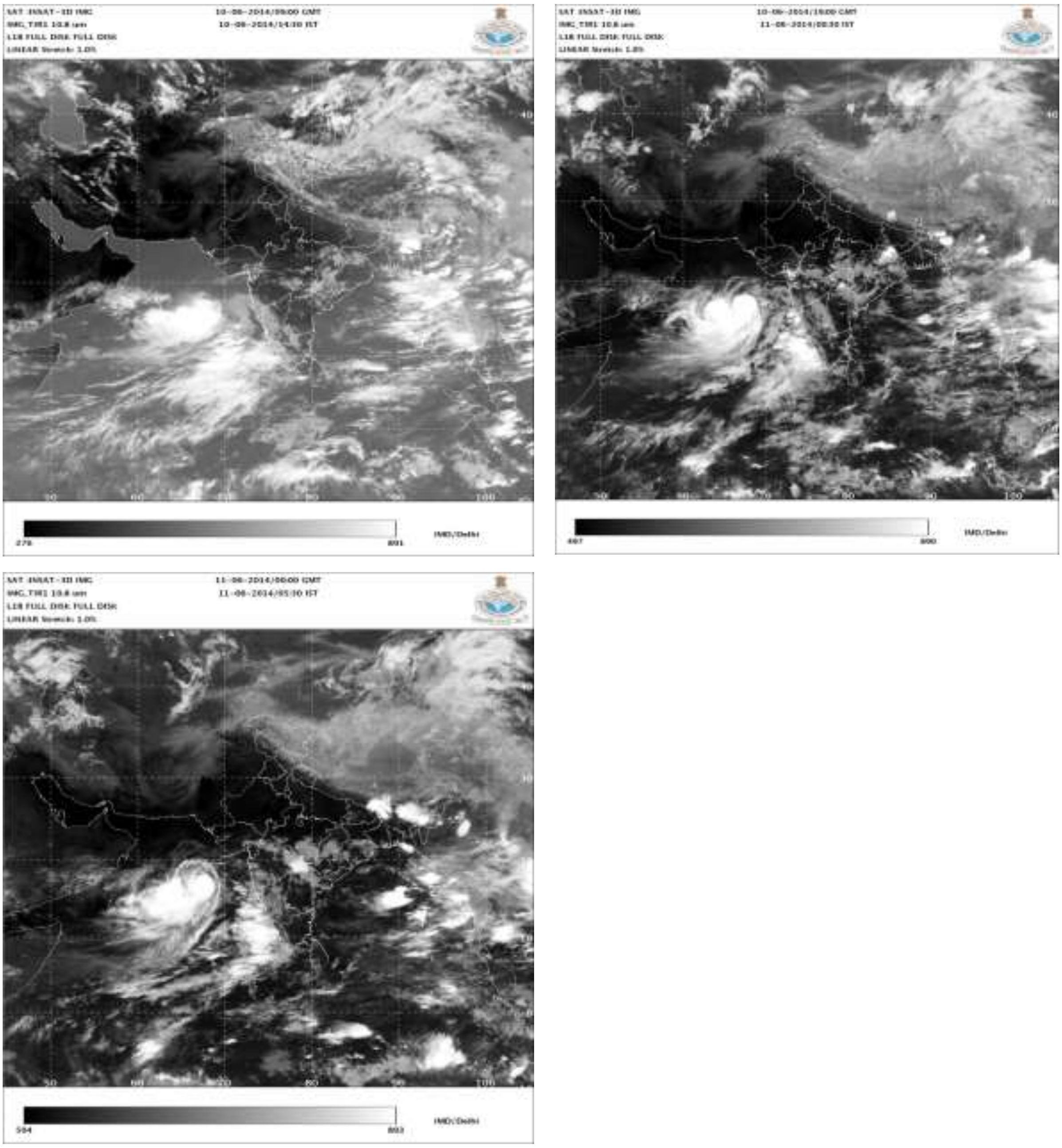


Fig. 2.1.1 Typical INSAT 3D imageries of cyclonic storm 'NANAUK' at 0900, 1900 UTC of 10th June and 0000 UTC of 11th June.

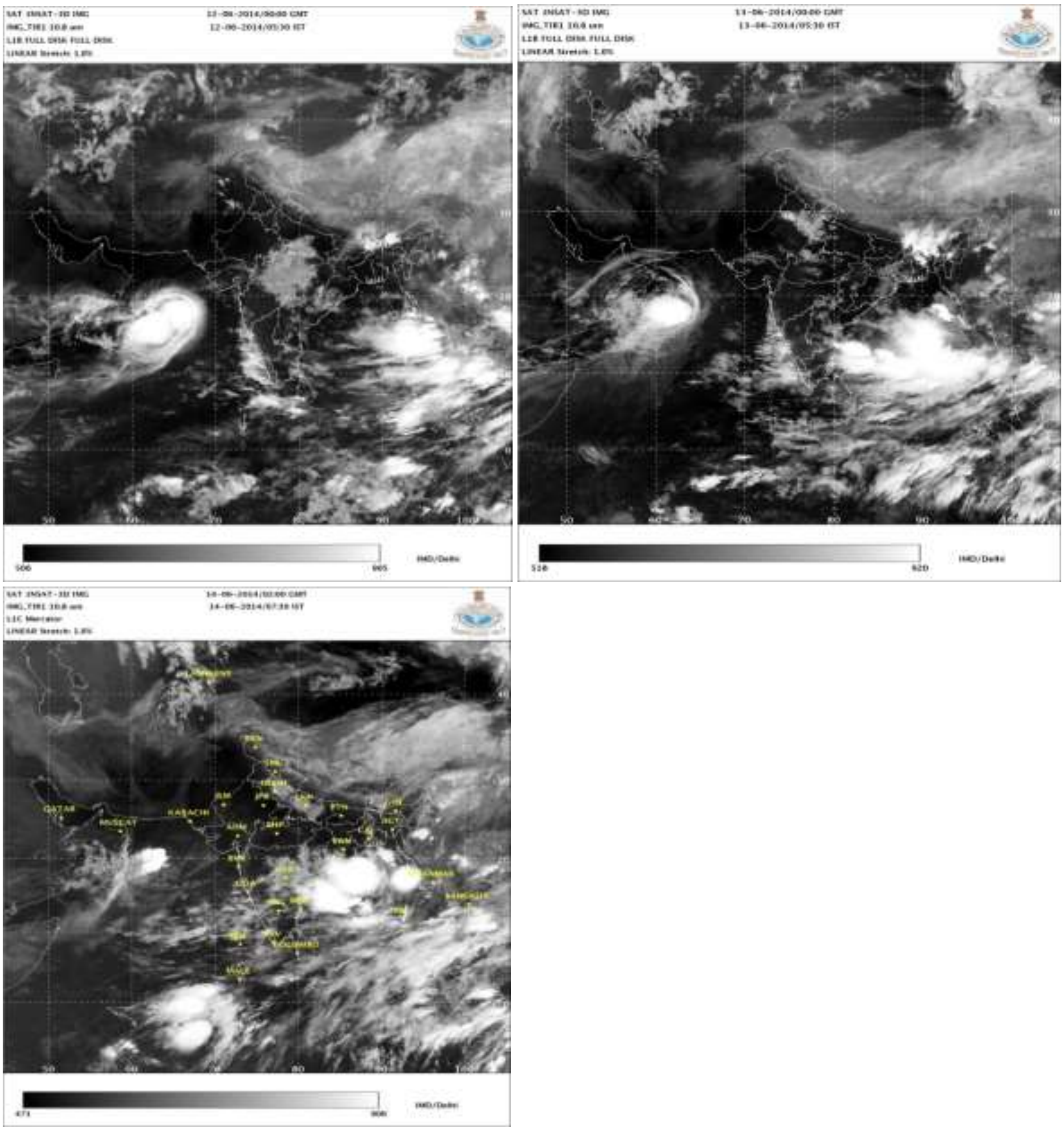


Fig. 2.1.1(Contd) Typical INSAT 3D imageries of cyclonic storm 'NANAUK' at 0000 UTC of 12 & 13th June and 0200 UTC of 14th June.

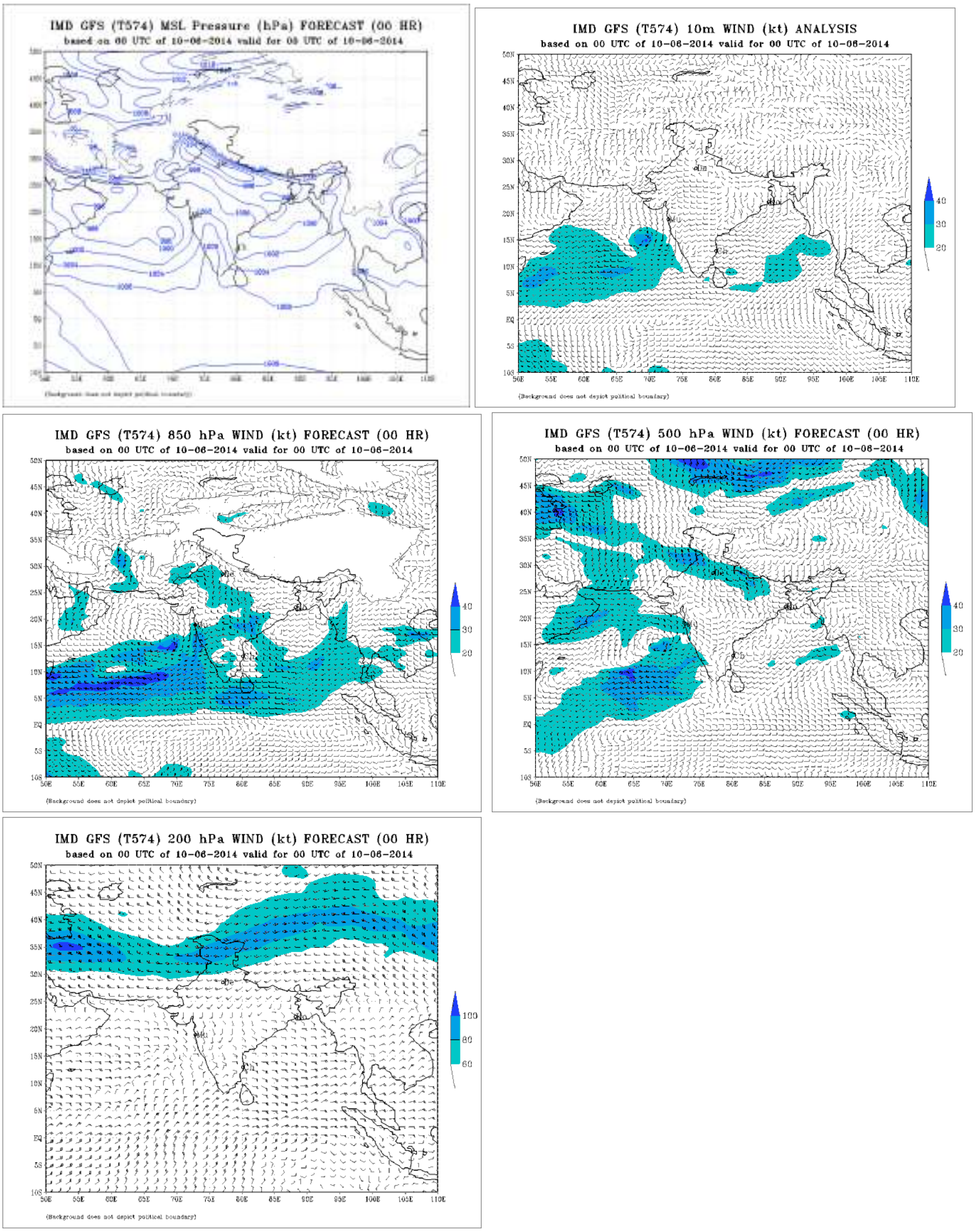


Fig. 2.1.2 (a) IMD GFS MSLP and winds at 850, 500 & 200 hPa levels analysis and 10meter wind based on 10th June 2014

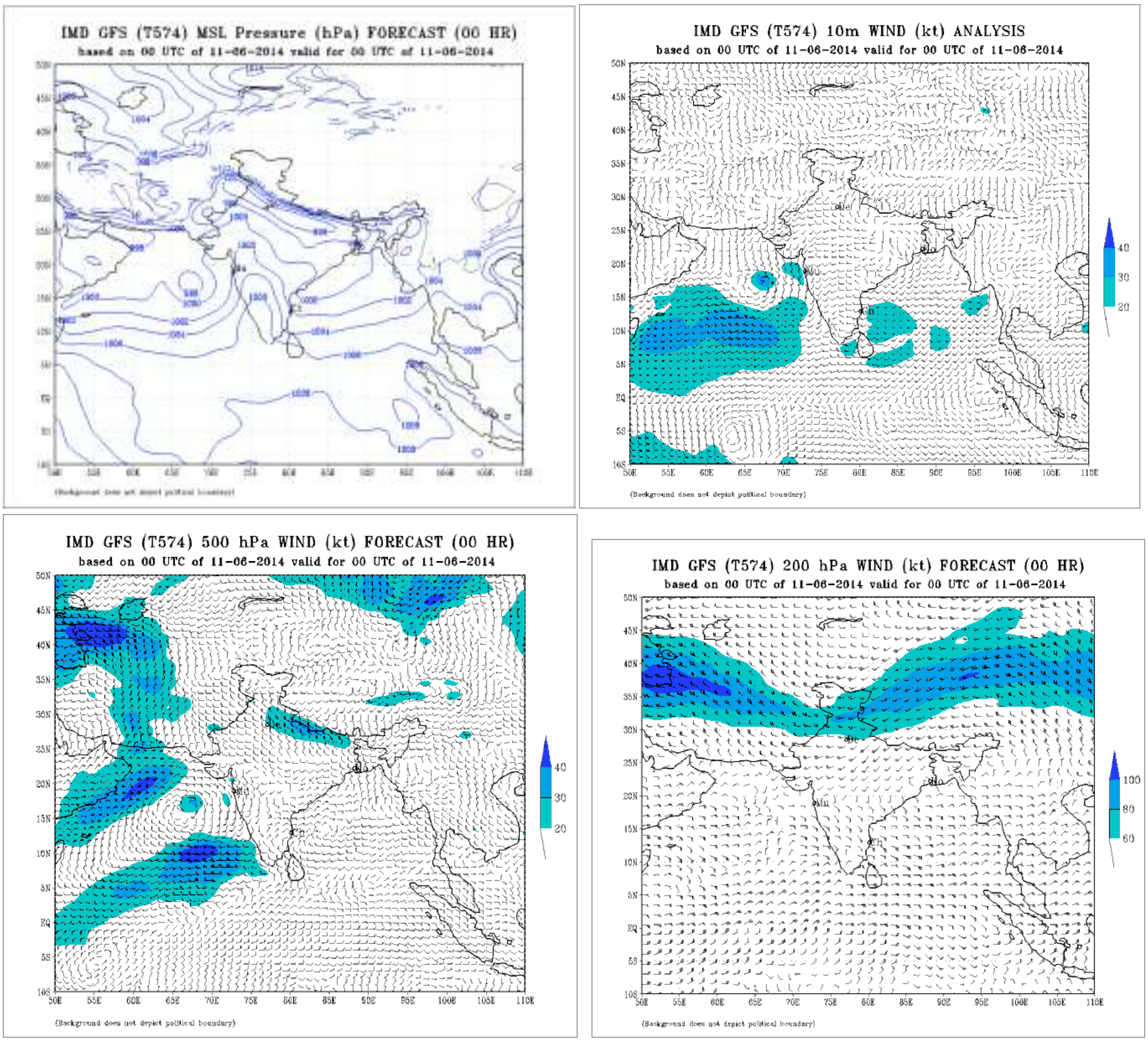


Fig. 2.1.2(b) IMD GFS MSLP and winds at 500 & 200 hPa levels analysis and 10 meter wind based on 11th June 2014

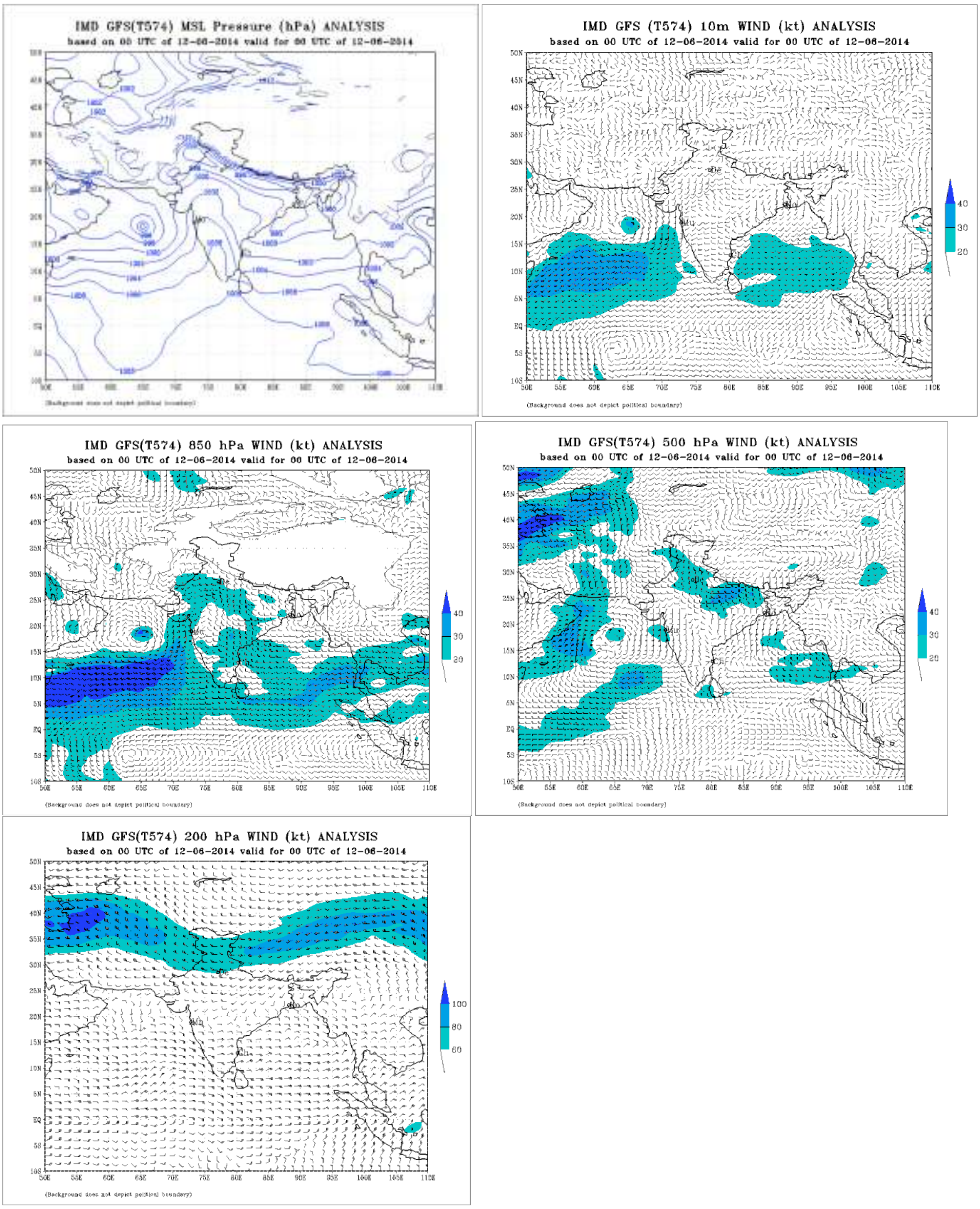


Fig. 2.1.2(c) IMD GFS MSLP and winds at 850, 500 & 200 hPa levels analysis and 10meter wind based on 12th June 2014

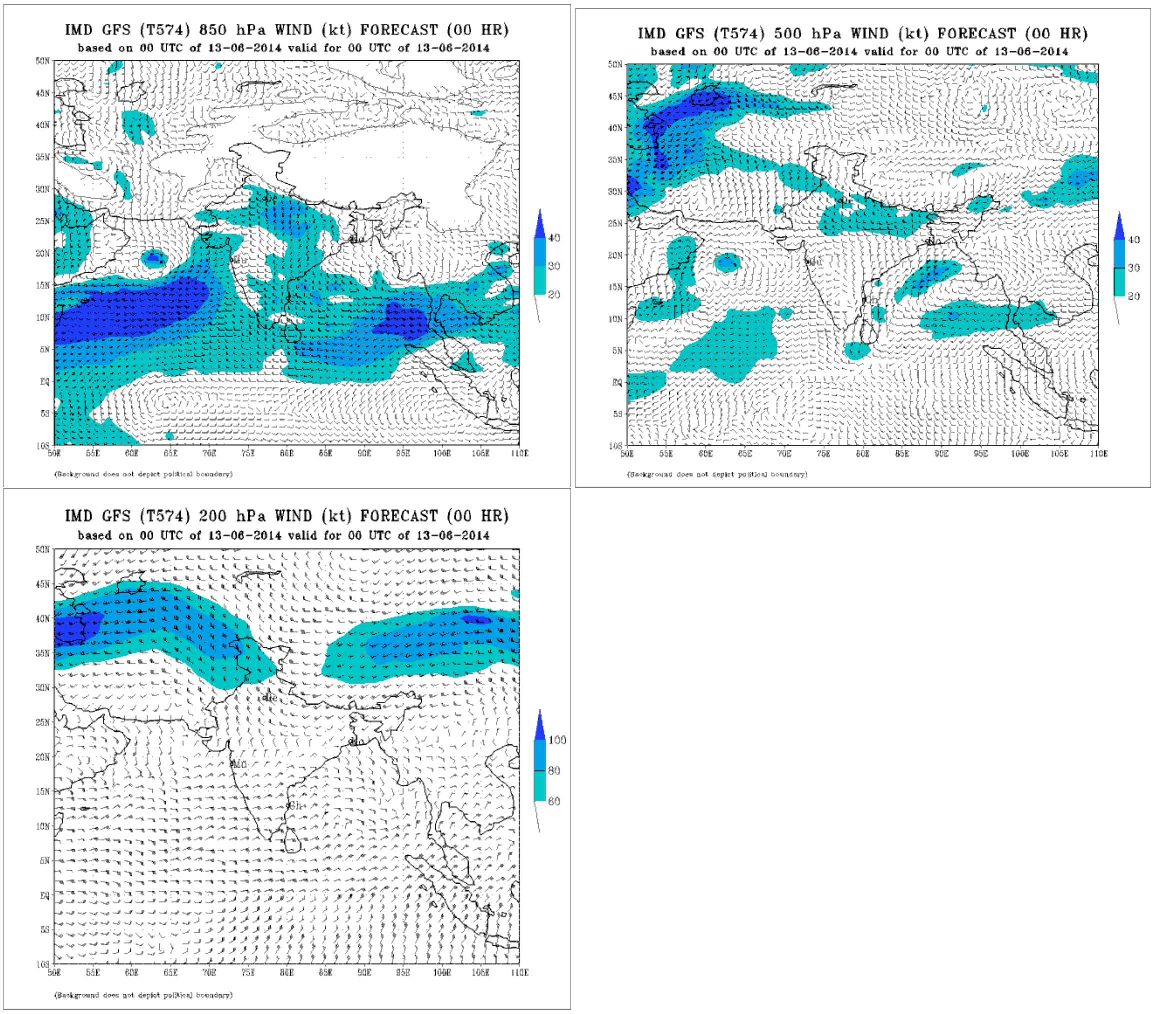


Fig. 2.1.2(d) IMD GFS MSLP and winds at 850, 500 & 200 hPa levels analysis and 10meter wind based on 13th June 2014

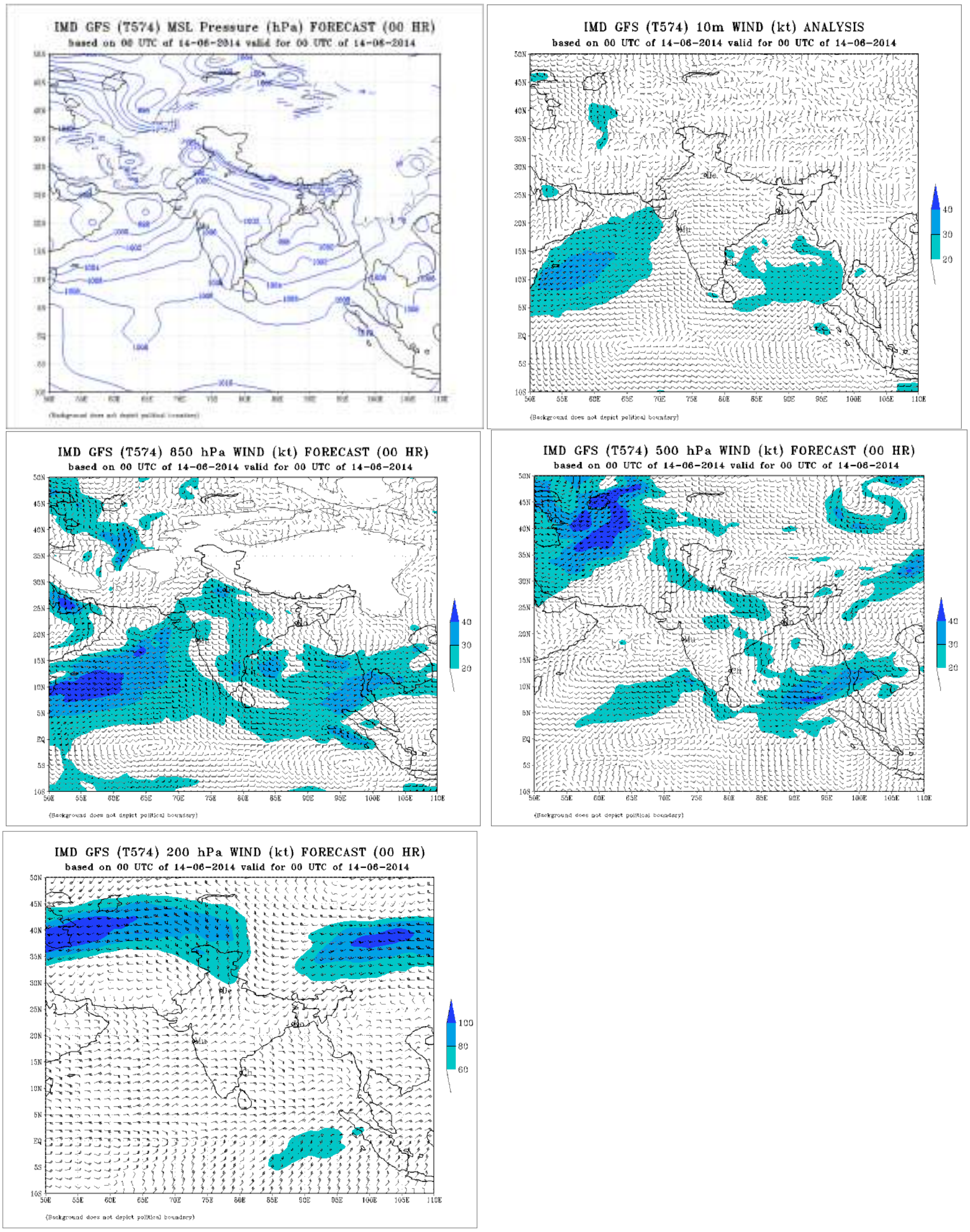


Fig. 2.1.2(e) IMD GFS MSLP and winds at 850, 500 & 200 hPa levels analysis and 10meter wind based on 14th June 2014

2.1.5. Realized Weather:

2.1.5.1. Rainfall: Chief amounts of 24 hrs. Rainfall (7 cm or more) ending at 0300 UTC from 10th to 14th June 2014 are given below:

10 June,

Lakshadweep: Agathi-8

11 June

Coastal Karnataka: Gokarna-8,

12 June

Coastal Karnataka: Bajpe Obsy-10, Bantwal, Mudubidre-9 each, Manki, Siddapura, Kollur-8 each, Kundapura, Mani-7 each,

Kerala: Ponnani-11, Taliparamba-10, Cheruthazham, Enamakkal, Hosdurg-9 each, Vadakara-8, Kannur, Mancompu, Tellichery-7 each.

13 June

Coastal Karnataka: Shirali-11, Bhatkal, Manki-9 each, Karkala, Udupi, Karwar-8 each, Honavar, MangalorePanambur Obsy, Mani, Bantwal, Bajpe Obsy, Gorsoppa-7 each,

Kerala: Cheruthazham-10, Kudulu, Kunnamkulam, Kodungallur-9 each, Vadakara-8, Enamakkal, Kozhikode, Kannur-7 each,

The rainfall distribution based on satellite estimate and station recorded data during 10-16 June 2014 are shown in Fig.2.1.3

2.1.5.2 Wind

Strong wind of about 35-45 kmph prevailed along and off Konkan, Goa and south Gujarat coast during 11-13th June 2014

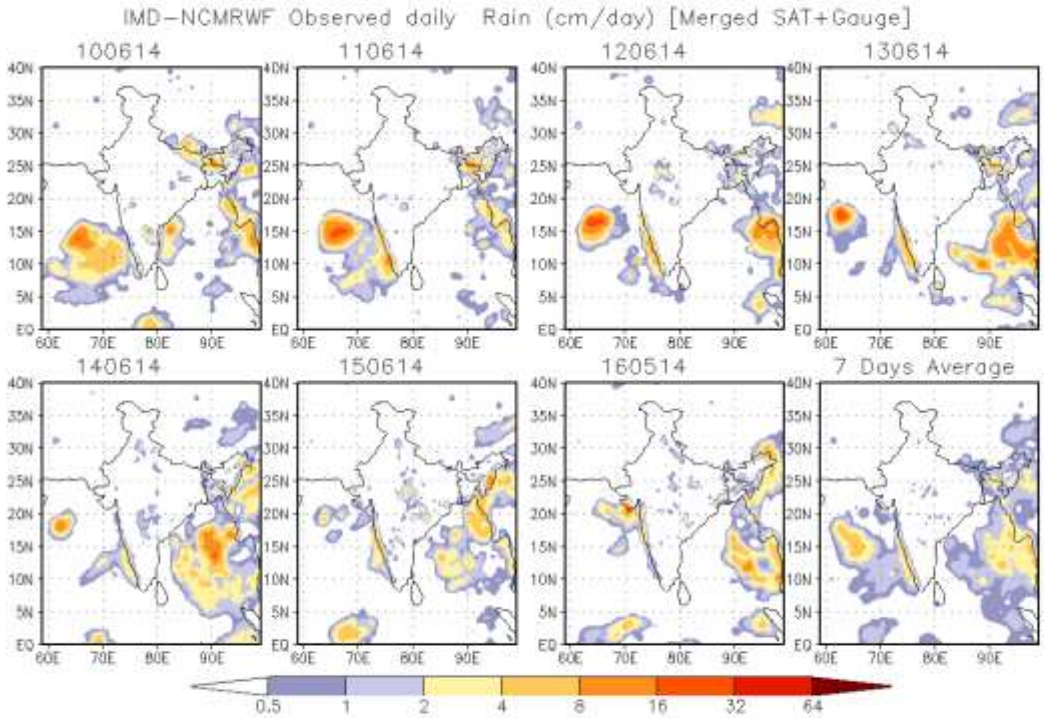


Fig. 2.1.3. Rainfall distribution based on satellite estimate and station recorded data during 10-16 June 2014

2.1.6. Damage:

As the cyclone dissipated over the sea, it did not cause any significant damage. However, as the cyclone developed during the full moon day and there was strong wind along west coast of India in association with cyclone and monsoon surge, the tidal wave inundated low lying areas in Konkan, including Mumbai. But no damage has been reported due to this system.

2.2 Very Severe Cyclonic Storm (VSCS) HUDHUD over the Bay of Bengal (07-14 October 2014)

2.2.1 Introduction

The Very Severe Cyclonic Storm 'HUDHUD' (07-14 Oct. 2014) developed from a low pressure area which lay over Tenasserim coast and adjoining North Andaman Sea in the morning of 6th Oct. 2014. It concentrated into a Depression in the morning of the 7th Oct. over the North Andaman Sea. Moving west-northwestwards it intensified into a Cyclonic Storm (CS) in the morning of 8th Oct. and crossed Andaman Islands close to Long Island between 0300 and 0400 UTC of 8th Oct. It continued to move west-northwestwards, intensified into a Severe Cyclonic Storm (SCS) in the morning of 09th Oct. and further into a Very Severe Cyclonic Storm (VSCS) in the afternoon of 10th Oct. It crossed north Andhra Pradesh coast over Visakhapatnam (VSK) between 0630 and 0730 UTC of 12th Oct. with the wind speed of 100 knots.

The salient features of this system are as follows.

i. HUDHUD is the first cyclone that crossed Visakhapatnam coast in the month of Oct., after 1985 and it made landfall on the same day as VSCS Phailin did in 2013.
ii. At the time of landfall on 12th Oct, the estimated maximum sustained surface wind speed in association with the cyclone was about 100 Knots.
iii. The estimated central pressure was 950 hPa with a pressure drop of 54 hPa at the centre compared to surroundings.
iv. It caused very heavy to extremely heavy rainfall over North Andhra Pradesh and South Odisha and strong gale winds leading to large scale structural damage over North Andhra Pradesh and adjoining districts of South Odisha and storm surge over North Andhra Pradesh coast
v. Maximum 24 hour cumulative rainfall of 38 cm ending at 0300 UTC of 13 October was reported from Gantyada (dist Vizianagaram) in Andhra Pradesh. Maximum of storm surge of 1.4 meters above the astronomical tide has been reported by the tide gauge at Visakhapatnam.
vi. The numerical weather prediction (NWP) and dynamical statistical models provided good guidance with respect to its genesis, track and intensity. Though there was divergence in model guidance with respect to landfall point and time in the initial stage, the consensus among the models emerged as the cyclone moved closer to the coast.
vii. India Meteorological Department (IMD) accurately predicted the genesis, intensity, track and point & time of landfall and also the adverse weather like heavy rainfall, gale wind and storm surge 4-5 days in advance.

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

2.2.2 Monitoring of VSCS HUDHUD

The VSCS HUDHUD was monitored & predicted continuously since its inception by the IMD. The forecast of its genesis on 7th Oct., its track, intensity, point & time of landfall, as well as associated adverse weather like heavy rain, gale wind & storm surge were predicted exceedingly well with sufficient lead time which helped the disaster managers to maximize the management of cyclone in an exemplary manner.

At the genesis stage, the system was monitored mainly with satellite observations, supported by meteorological buoys and coastal and island observations. As the system entered into the east central Bay of Bengal moving away from Andaman & Nicobar Islands, it was mainly monitored by satellite observations supported by buoys. From 11th Oct. early morning, as the system lay within the range of the Doppler Weather Radar (DWR) at Visakhapatnam, continuous monitoring by this radar started from 22 UTC of 11th Oct. when the system was at about 350 km east-southeast of Visakhapatnam coast and continued till 1020 hrs IST of 12th Oct. when the DWR Visakhapatnam products were not accessible due to disruption of telecommunication in association with the wall cloud region entering into North Andhra Pradesh. In addition, the observations from satellite and coastal observations, conventional observatories and Automatic Weather Stations (AWS) were used. While coastal surface observations were taken on hourly basis, the half hourly INSAT/ Kalpana imageries and every 10 minute DWR imageries, available microwave imageries and scatterometry products were used for monitoring of cyclone HUDHUD. DWR Machhilipatnam was also utilized for monitoring this system when VSCS HUDHUD was lying close to the Visakhapatnam coast on 12th Oct.

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

2.2.3 Major initiatives during VSCS, HUDHUD

Following are the major initiatives taken by IMD for monitoring, prediction and warning services of VSCS, HUDHUD.

(i) Observations:

- The products of INSAT-3D satellite were fully utilised for the first time with the development of new products like enhanced IR imageries and colored enhanced imageries and were made available through an exclusive page for cyclone images in IMD website (www.imd.gov.in). The satellite data was also ingested in model runs at NCMRWF.
- All the existing High Wind Speed Recorders (HWSR) were made operational around the path of cyclone HUDHUD. 1-min wind data from HWSR were recorded alongwith 1 second peak gust.

(ii) Monitoring and analysis:

- In addition to existing 3 hourly monitoring, hourly monitoring and analysis was carried out on the date of landfall.

(iii) Prediction Technique:

- During VSCS HUDHUD, Hurricane Weather Research Forecast (HWRF) model products from NCEP USA and IIT based on 00 and 12 UTC observations were used

(iv) Operational Forecasting:

- Hourly updates on the movement and intensity of VSCS HUDHUD were made available to the National and State level disaster managers and media persons on the day of landfall from 0000 UTC of 12th till landfall.

(v) Warning bulletins and Products:

- In view of the improvements in operational track forecast during last five years, the cone of uncertainty was reduced by about 20-30 % for 24-120 hr forecast period w.e.f. VSCS HUDHUD. The new radii of cone of uncertainty are 120, 200, 270, 320 and 360 km for 24-, 48-, 72-, 96- and 120- hrs respectively.

(vi) Warning Dissemination:

- During VSCS HUDHUD Agricultural Meteorology Division, IMD, Pune in coordination with Agromet Field Units and Cyclone Warning Division, IMD, New Delhi disseminated Alert and Agromet Advisory in the affected districts of Andhra Pradesh, Odisha from 9th October onwards and for the states of Telangana, Bihar, Chattisgarh, Jharkhand, East Uttar Pradesh, East Madhya Pradesh and Gangetic West Bengal from 11th onwards. Overall 1,91,4872 SMSs were sent to the farmers and local people of affected states.
- INCOIS, Hyderabad disseminated warnings through SMS and Electronic Display Boards (EDB) to coastal population especially meant for fishermen. Cyclone Warnings issued by IMD were also incorporated in the bulletins issued by INCOIS.
- SMS were sent by IMD to Disaster Managers at National level and upto District Collector level
- A new dedicated website for cyclone (www.rsmcnewdelhi.imd.gov.in) has been developed and was fully operational during VSCS HUDHUD.
- Internet Lease Line Bandwidth was upgraded from 60mbps to 100mbps during VSCS 'HUDHUD' leading to failure-free accessibility of IMD website.

2.2.4 Brief life history

2.2.4.1 Genesis

The VSCS HUDHUD originated from a low pressure is over Tenasserim coast and adjoining North Andaman Sea on 6th Oct. 2014. It concentrated into a depression over North Andaman Sea on 7th Oct. morning over the North Andaman Sea while moving west-northwestwards.

On 7th Oct. morning, scatterometry data indicated the cyclonic circulation over the region and associated wind speed was about 25-30 knots. The wind speed was relatively higher in northern sector of the system. According to satellite observation, intense to very intense convection was seen over Andaman Sea and adjoining area between lat 9.0^0N to 16.0^0N and east of long 90.0^0E to Tenasserim coast at 0300 UTC of 7th Oct. The associated convection increased gradually with respect to height and organisation during previous 24 hrs. The lowest cloud top temperature (CTT) was about -70^0C. The convective cloud clusters came closer and merged with each other during past 24 hrs ending at 0300 UTC of 7th Oct. According to Dvorak's intensity scale, the intensity of the system was T 1.5. The system showed curved band pattern with convection dominating in the southwest area of low level circulation centre. The SSMIS microwave imagery depicted increased banding features along the southern periphery of the low level cyclonic circulation (LLCC). Considering all these, the low pressure area was upgraded as a depression over the north Andaman Sea at 0300 UTC of 7th with its centre near latitude 11.5^0N and longitude 95.0^0E, about 250 km east-southeast of Long Island. Maximum sustained surface wind speed was estimated to be about 25 knots gusting to 35 knots around the system centre. A buoy located near 10.5^0N and 93.9^0E reported southwesterly winds of 25 KTs supporting the upgradation of the system to depression on 7th morning. The observed track of the system is shown in fig. 2.1.

2.2.4.2 Intensification and movement

On 7th Oct. morning, the upper tropospheric ridge at 200 hPa level ran along 19^0N and was providing poleward outflow in association with the anticyclonic circulation located to the northeast of the system centre. Hence upper level divergence was favourable for intensification. The low level convergence along with low level relative vorticity increased in the previous 24 hrs ending at 0300 UTC of 7th Oct.. The sea surface temperature based on satellite and available buoys and ships observation was about $30-32^0$C and ocean thermal energy was about 60-80 KJ/cm^2. The vertical wind shear of horizontal wind was about 10-20 knots (low to moderate). The Madden Jullian oscillation (MJO) index lay over phase 6 with amplitude greater than 1. All these environmental, atmospheric and oceanic conditions suggested further intensification. Accordingly the depression moved west-northwestwards and intensified into a deep depression at 1200 UTC of 7th Oct. over North Andaman Sea near 12.0^0N and 94.0^0E about 130 km east-southeast of Long Island. It further intensified into a cyclonic storm HUDHUD at 0300 UTC of 8th Oct. and crossed Andaman Islands close to Long Island (near latitude 12.4^0N and longitude 92.9^0E) between 0300-0400 UTC of 8th Oct. with maximum sustained wind speed of 70-80 kmph gusting to 90 kmph. Port Blair reported 88 kmph at 0300 UTC of 8th Oct. It then continued to move west-northwestwards and intensified into a severe cyclonic storm (SCS) and lay centred at 0300 UTC of 9th Oct. over eastcentral Bay of Bengal (BoB) near 13.8^0N and 89.0^0E about 750 km east-southeast of Visakhapatnam. On 9th the vertical wind shear slightly increased and became moderate (15-20 Kts) about the system centre which inhibited the rapid intensification of the system, though predicted by most of the NWP models. However, the SCS continued to intensify gradually while moving slowly west-northwestwards and intensified into a VSCS at 0900 UTC of 10th Oct. due to favourable poleward outflow leading to increase in upper level divergence and favourable lower level inflow coupled with warmer sea surface temperature (SST) and moderate ocean thermal energy. It lay centered at 0900 UTC of 10th Oct. over westcentral BoB near 15.0^{0}N and 86.8^{0}E, about 470 km east-southeast of Visakhapatnam. Thus the VSCS moved slowly with an average translational speed of about 10 kmph from 9th to 10th Oct. It further slowed down thereafter and moved west-northwestwards with a speed of about 5 kmph till midnight of 11th Oct. It remained almost stationary around early hrs. of 12th Oct. Thereafter the northerly component of the movement and the translational speed increased gradually. Since the morning of 12th, the translational speed of the cyclone was about 15 kmph with northwestward movement. It also gained intensity and maximum sustained wind speed picked up in the early hrs. of 12th Oct. to about 100 kts gusting to 110 kts. Thereafter, as the system came closer to the coast it experienced relatively lower ocean thermal energy with some pockets of the area reporting less than 50KJ/cm^2 and the system interacted with land surface, with its outer spiral band engulfing north Andhra Pradesh & South Odisha coast. As a result, the VSCS did not intensify further & crossed north Andhra Pradesh over Visakhapatnam (near latitude 17.7^{0}N and longitude 83.3^{0}E) with a maximum sustained wind speed of 100 kt gusting to 110 kt between 0630-0730 UTC of 12th Oct.. After the landfall, the system continued to move northwestward for some time and weakened into a SCS at 1200 UTC of 12th Oct. over North Andhra Pradesh close to South Odisha near latitude 18.0^{0}N and longitude 82.7^{0}E. It then moved north-northwestward and weakened into a CS at 2100 UTC of 12th in the border of South Chhattisgarh and South Odisha near latitude 18.7^{0}N and longitude 82.3^{0}E. It then recurved northwards and weakened into a deep depression at 0000 UTC of 13th Oct. over South Chhattisgarh and further into a depression at 1200 UTC of 13th Oct. over central part of Chhattisgarh and neighbourhood. It continued to move northward upto the morning of 14th Oct. across east Madhya Pradesh and then north-northeastwards across east Uttar Pradesh and weakened into a well-marked low pressure (WML) area at 1200 UTC of 14th Oct. over East Uttar Pradesh and neighbourhood (Fig.2.1). The best track parameters of VSCS 'HUDHUD' are shown in Table 2.2.1.

Table 2.2.1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'HUDHUD' over the Bay of Bengal during 07-14 October, 2014

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
07/10/2014	0300	11.5/95.0	1.5	1004	25	3	**D**
	0600	11.7/94.8	1.5	1004	25	3	D
	1200	12.0/94.0	2.0	1000	30	5	**DD**
	1800	12.0/93.5	2.0	1000	30	5	DD
08/10/2014	0000	12.2/93.0	2.0	1000	30	5	DD

	0300	12.3/92.9	2.5	998	35	7	**CS**
	The system crossed Andaman & Nicobar islands near Long island (near Lat. 12.4° N and Long. 92.9° E) between 0300-0400 UTC						
	0600	12.5/92.5	2.5	996	40	8	CS
	0900	12.7/91.7	2.5	996	40	8	CS
	1200	12.8/91.0	2.5	996	40	8	CS
	1500	13.0/90.5	2.5	996	40	8	CS
	1800	13.2/90.2	3.0	994	45	9	CS
	2100	13.5/89.6	3.0	992	45	10	CS
09/10/2014	0000	13.7/89.2	3.0	990	45	12	CS
	0300	13.8/89.0	3.5	988	55	16	**SCS**
	0600	13.9/88.8	3.5	988	55	16	SCS
	0900	14.0/88.6	3.5	988	55	16	SCS
	1200	14.1/88.4	3.5	988	55	16	SCS
	1500	14.1/88.1	3.5	988	55	16	SCS
	1800	14.1/87.9	3.5	988	55	16	SCS
	2100	14.3/87.7	3.5	988	60	16	SCS
10/10/2014	0000	14.4/87.6	3.5	988	60	16	SCS
	0300	14.7/87.2	3.5	988	60	16	SCS
	0600	14.8/87.0	3.5	986	60	18	SCS
	0900	15.0/86.8	4.0	984	65	22	**VSCS**
	1200	15.2/86.7	4.0	982	70	26	VSCS
	1500	15.4/86.5	4.0	980	75	28	VSCS
	1800	15.5/86.4	4.0	978	75	30	VSCS
	2100	15.7/86.1	4.0	974	75	30	VSCS
11/10/2014	0000	15.9/85.7	4.0	970	75	30	VSCS
	0300	16.0/85.4	4.5	968	80	34	VSCS
	0600	16.1/85.1	5.0	966	90	40	VSCS
	0900	6.1/85.0	5.0	964	90	42	VSCS
	1200	16.2/84.8	5.0	962	95	44	VSCS
	1500	16.2/84.8	5.0	960	95	46	VSCS
	1800	16.4/84.7	5.0	954	100	50	VSCS
	2100	16.7/84.4	5.0	952	100	52	VSCS
12/10/2014	0000	17.2/84.2	5.0	950	100	54	VSCS
	0300	17.4/83.8	5.0	950	100	54	VSCS
	0600	17.6/83.4	5.0	950	100	54	VSCS
	The system crossed Andhra Pradesh coast over Visakhapatnam (near Lat 17.7° N and Long. 83.3° between 0630-0730 UTC						
	0900	17.8/83.0	-	960	90	42	VSCS
	1200	18.0/82.7	-	982	60	20	**SCS**
	1500	18.3/82.5	-	986	45	15	**CS**
	1800	18.7/82.3	-	987	40	14	CS

	2100	18.7/82.3	-	988	40	13	**DD**
13/10/2014	0000	19.5/81.5	-	994	30	8	DD
	0300	20.5/81.5	-	996	30	6	DD
	0600	20.7/81.5	-	998	30	5	**D**
	1200	21.3/81.5	-	998	25	4	D
	1800	22.3/81.5	-	1000	25	4	D
14/10/2014	0000	24.8/81.5	-	1000	25	4	D
	0300	25.1/81.6	-	1000	20	3	D
	0600	25.6/81.7	-	1000	20	3	D
	0900	26.3/81.8	-	1000	20	3	D
	1200	Weakened into a well-marked low pressure area over east Uttar Pradesh and neighbourhood					

The place and time of landfall was determined through monitoring of hourly observations from the coastal stations as shown in Fig. 2.2.1. The veering of wind over Visakhapatnam and backing of wind over Tuni along with the lowest pressure and maximum sustained surface wind over Visakhapatnam clearly suggested the landfall over Visakhapatnam between 0630-0730 UTC of 12th Oct. Similar was the case considering the landfall near Long Island on 8th Oct. between 0300-0400 UTC of 8th Oct. 2014 as Long Island reported lowest mean sea level pressure and veering of wind.

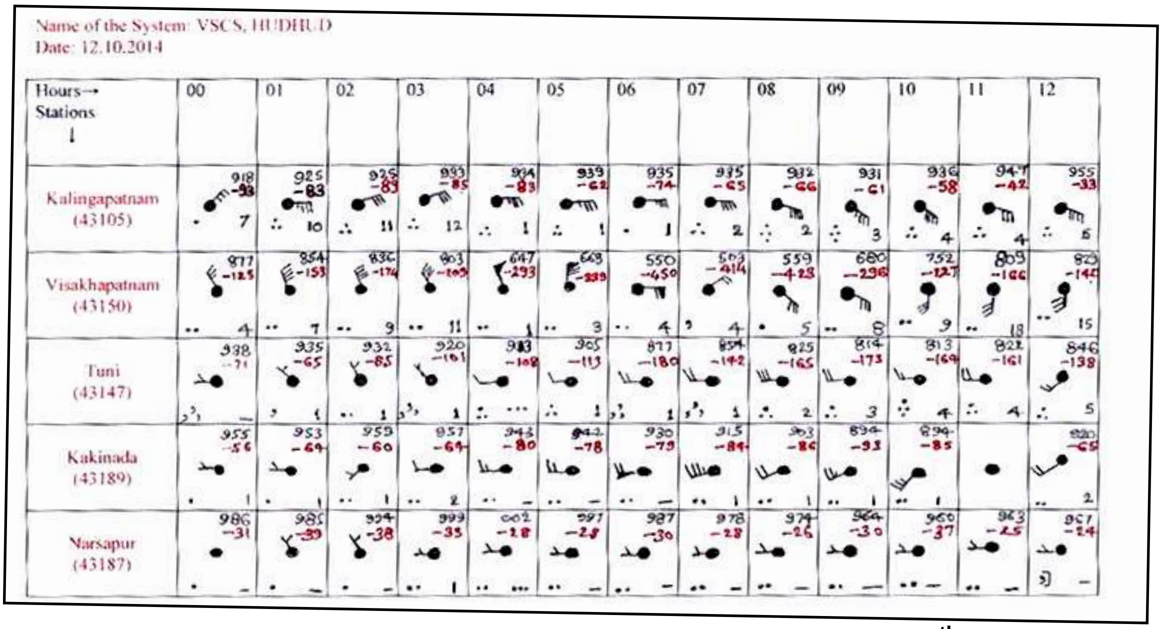


Fig. 2.2.1: Hourly observations from coastal stations on 12th October 2014.

2.2.5 Maximum Sustained Surface Wind speed (MSW) and estimated central pressure at the time of landfall:

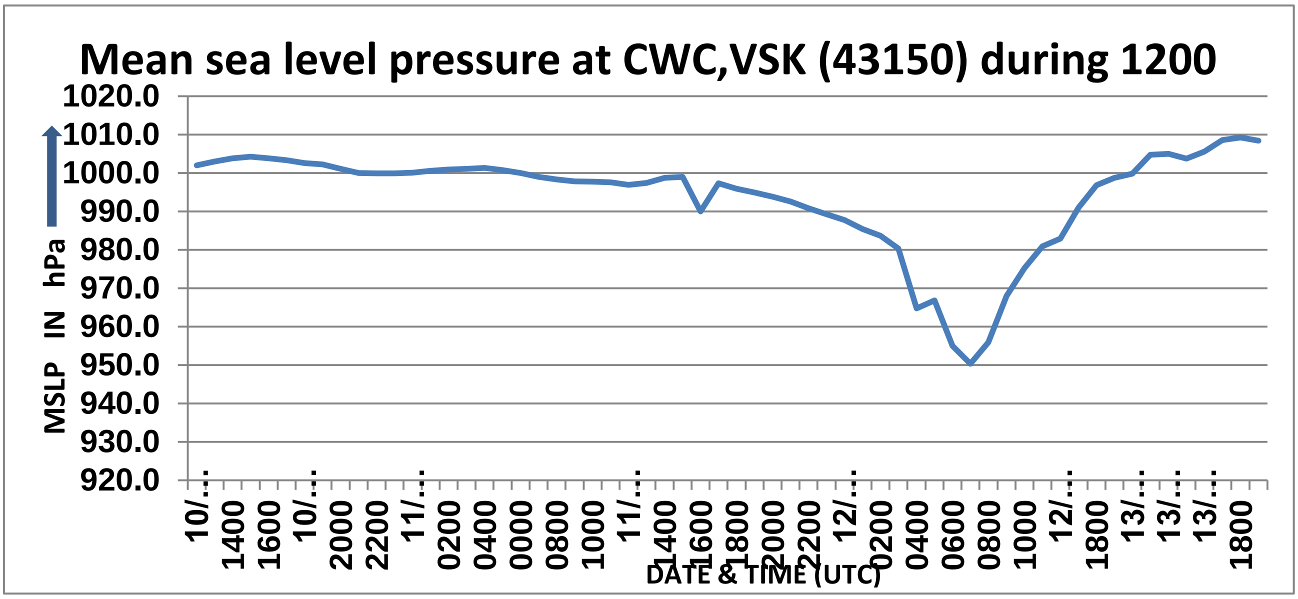
The MSW in association with a cyclone affecting Indian coasts is defined as the average surface wind speed over a period of 3 minutes measured at a height of 10 meters. The MSW is either estimated by the remotely sensed observations or recorded by the surface based instruments. As the VSCS, Hudhud crossed Andhra Pradesh coast over Visakhapatnam, the MSW in its association at the time of landfall has been observed and recorded by the High Wind Speed Recorder (HWSR) located at the

Cyclone Warning Centre (CWC), (IMD), Visakhapatnam. It has also been observed by an Automatic Weather Station (AWS) installed in a ship located near Visakhapatnam port by the Indian National Centre for Ocean Information System (INCOIS), Hyderabad.

The Doppler Weather Radar (DWR) of IMD at Kailasagiri, Visakhapatnam also continuously monitored the VSCS, Hudhud and measured the MSW in terms of radial velocity. Based on satellite imagery, an empirical technique known as the Dvorak technique is utilized worldwide to estimate the intensity of cyclone and hence the associated MSW. Further, the IMD observatory at the CWC, VSK continuously monitored the Mean Sea Level Pressure (MSLP) during the landfall of cyclone, Hudhud. Based on the observation of the pressure drop at the centre, MSW can also be estimated using the empirical pressure-wind relationship (MSW= 14.2* √ pressure drop at the centre). These are the basic standard methods used worldwide to estimate the MSW or intensity of the cyclone.

2.2.5.1 Estimated central pressure of VSCS, HUDHUD

The hourly MSLP as recorded by Visakhapatnam is shown in Fig. 2.2.2a which clearly indicates that the pressure fell gradually from 11th onwards and fall became rapid from the early morning of 12th Oct. As a result, 24-hour. pressure fall ending at 0600 UTC of 12th was 45 hPa and the lowest pressure was 950.3 hPa as recorded at 0700 UTC over Visakhapatnam (time of landfall). Thereafter the pressure rose sharply as the VSCS



crossed coast and filled in due to increase in surface pressure and cut off from moisture supply.

Fig. 2.2.2a: Hourly MSLP recorded at Visakhapatnam during 10-12th Oct. 2014

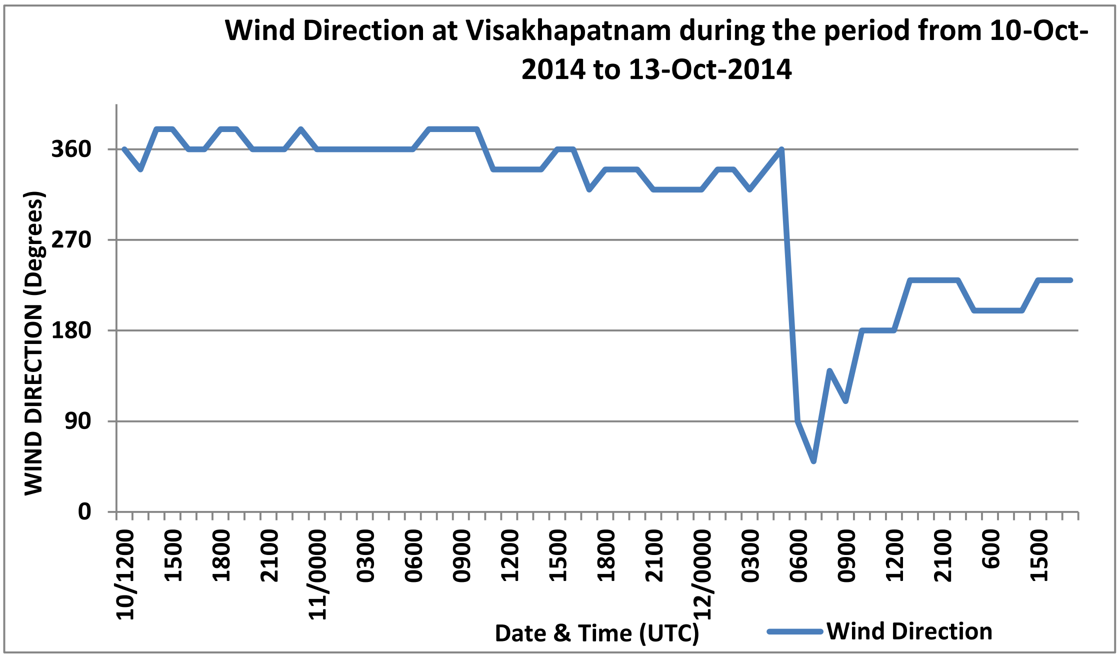


Fig. 2.2.2(b) Hourly wind direction reported by Visakhapatnam Observatory during the period from 1200 UTC of 10th October 2014 to 2100 UTC of 13th October 2014.

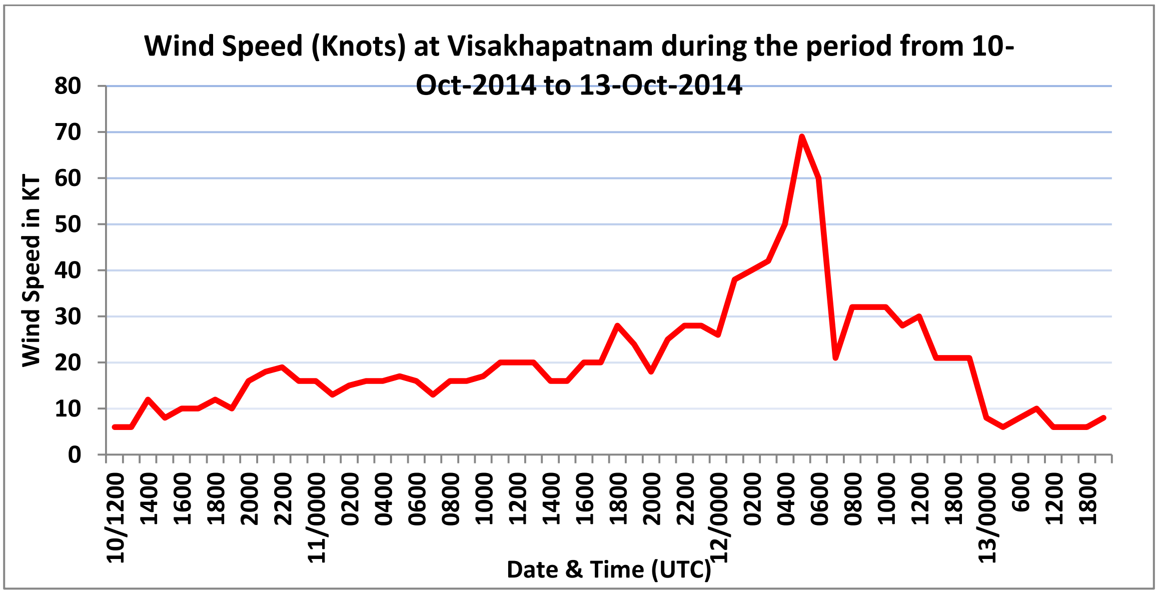


Fig. 2.2.2(c) : Hourly wind speed reported by Visakhapatnam Observatory during the period from 1200 UTC of 10th October 2014 to 2100 UTC of 13th October 2014.

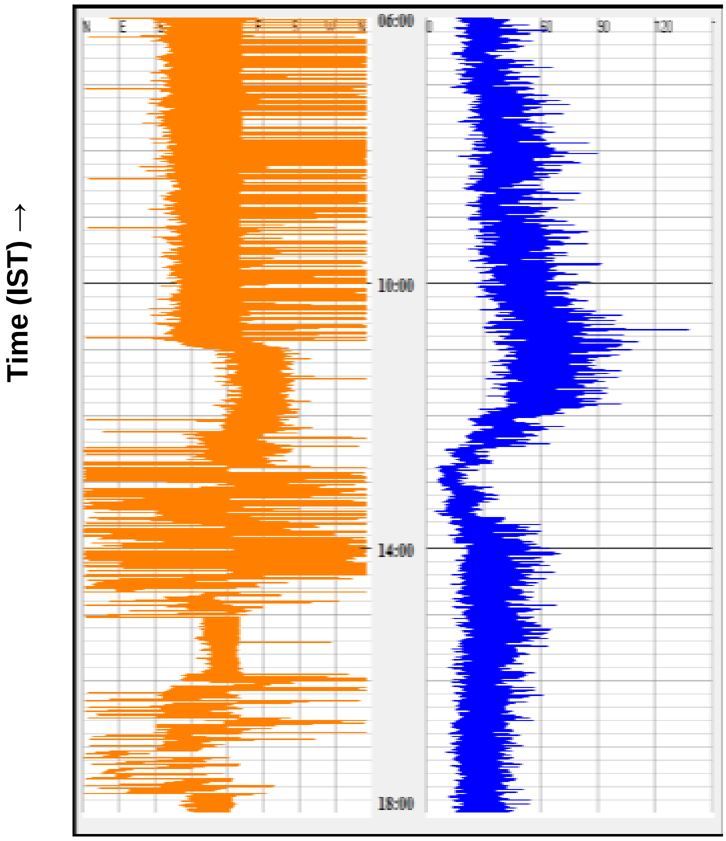


Fig. 2.2.2d Wind speed and direction recorded by HWSR, Visakhapatnam on 12 October 2014

2.2.5.2 MSW over Visakhapatnam as measured by HWSR:

According to HWSR located at the CWC, IMD, Visakhapatnam, one -minute average MSW was about 74 knots (137kmph) at 0531 UTC and the 3-minute average MSW which is the standard practice of the IMD was about 69 knots (128kmph) at 0533 UTC of 12th October, 2014 (Fig. 2.2.3b).

2.2.5.3 MSW based on observation by the AWS:

The AWS installed at a ship near Visakhapatnam port recorded one-minute average MSW of 181.6kmph around the time of landfall on 12th October 2014.

2.2.5.4 Satellite based MSW over Visakhapatnam:

According to interpretation of satellite imageries, as per Dvorak technique by the IMD, the tropical cyclone intensity was T5.0 on intensity scale. T5.0 corresponds to an MSW of about 90-100 knots (167-185 kmph).

2.2.5.5 MSW over Visakhapatnam based on radar:

The DWR, VSK recorded 67 meters per second or 130knots (241kmph) at a height of about 200 meters. When converted or reduced to the surface level, it is estimated to be around 90 knots. (167kmph)

2.2.5.6 MSW based on pressure drop:

According to the observation taken in the IMD observatory at Visakhapatnam, the lowest central pressure of 950.3hPa was recorded at Visakhapatnam at the time of landfall. Hence, the lowest central pressure can be considered as 950hPa. Thus, the pressure drop at the centre was 54hPa as the outermost pressure in the cyclone was 1004hPa. According to Mishra and Gupta formula, the MSW=14.2*SQRT (pressure drop) = 14.2*SQRT (54) = 104knots. (193kmph)

Considering all these observations and estimates, it can be concluded that the MSW at the time of landfall of Hudhud was about 185kmph (100 knot). The gust which is a sudden rise in wind speed in association with a cyclone can reach upto a factor of 1.2 times the MSW, according to the standard specified by the WMO, Geneva. However, according to the HWSR, Visakhapatnam, the one second peak gust wind speed was 140.6 knots (260 kmph) at 0512 UTC of 12th October, 2014.

2.6.6 Characteristic observed by buoy

OMNI buoys deployed in the Bay of Bengal have captured the signals of cyclone passage and the time series observations clearly exhibit the importance of the proximity of the location to the cyclone track. The buoy BD12 &BD13 is closer to the track and met and surface observations show its severity. The buoy BD11 and BD14 are far away from the cyclone track and hence the response is less even though it is located at the left side of the track. The buoy BD08, BD09 and BD10 are also away from the cyclone track and it is located at the right side of the track. Table 2.2.2 shows the distance between cyclone track and OMNI buoy location.

Table 2.2.2 Distance of buoys from track of cyclone Hudhud

Sl. No	Buoy ID/Position	Distance between cyclone track and Buoy position	Remarks
1	BD12	66 nm	Captured on 7th and 8th Oct 2014
2	CB01	44 nm	Captured on 7th and 8th Oct 2014
3	BD13	47 nm	Captured on 9th and 10th Oct 2014
4	BD10	117 nm	Captured on 10th Oct 2014
5	BD09	235 nm	Variation observed
6	BD08	249 nm	Variation observed
7	BD11	160nm	To be observed

Fig. 2.2.3 indicates the Atmospheric Pressure recorded at the three OMNI buoy locations in the Bay of Bengal with a maximum drop observed at BD13 recorded a minimum pressure of 994.6 hPa on October 10, 2014.

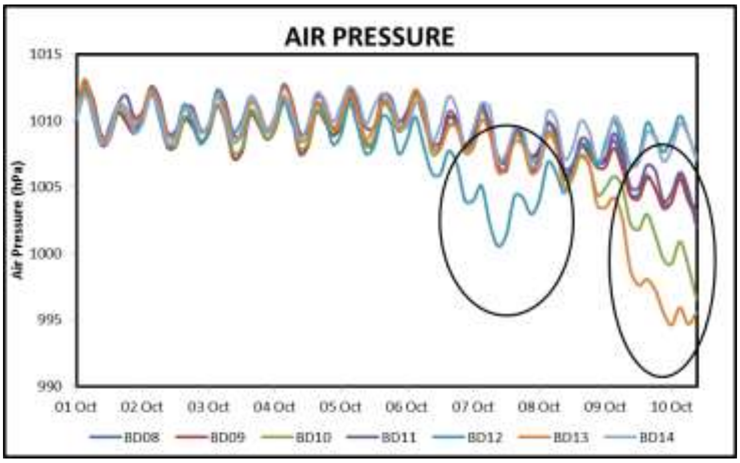


Fig. 2.2.3 Time series of MSLP as recorded by the buoys during 1-10 October

Fig. 2.2.4 indicates the wind speed recorded at three OMNI buoys and one coastal buoy in the Bay of Bengal, with BD13 which is on the track of the cyclone recorded a maximum wind speed of 20.5 m/s on October 10, 2014.

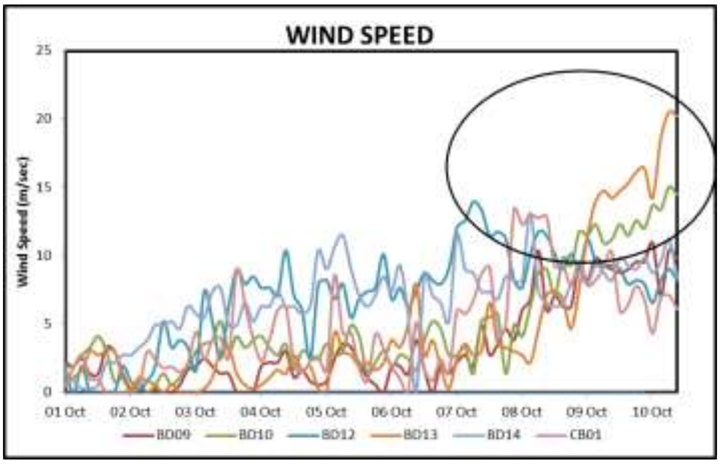


Fig. 2.2.4 Wind speed recorded by the buoys during 1-10 October

Fig. 2.2.5 indicates that BD08 recorded a maximum significant wave height of 3.75 m on 10th October, 2014

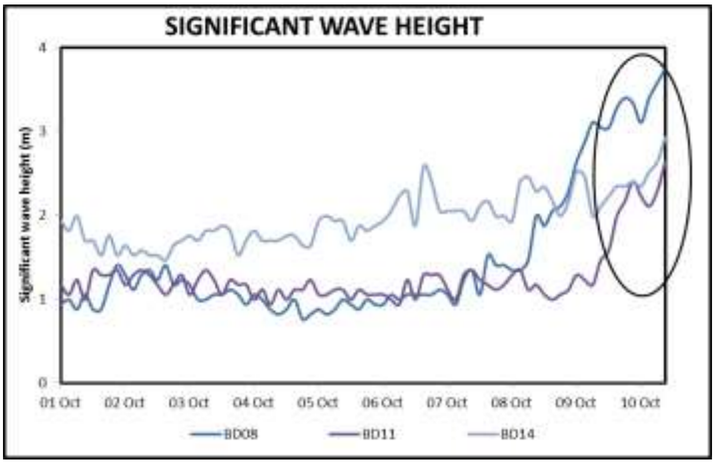


Fig. 2.2.5 wave height recorded by the buoys during 1-10 October

Fig. 2.2.6 The decrease in the surface temperature by 1.1 °C

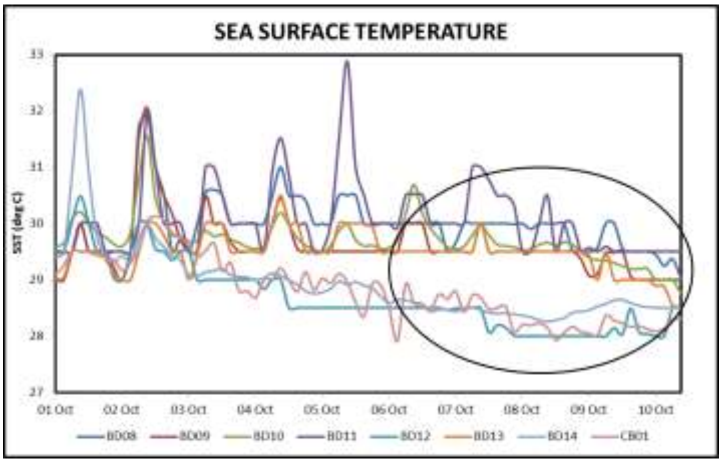


Fig. 2.2.6 Sea Surface Temperature recorded by the buoys during 1-10 October

Fig. 2.2.7 indicate the increase in surface current speed was recorded maximum at BD13 location with a speed of 100.09 cm/s on 10th October, 2014.

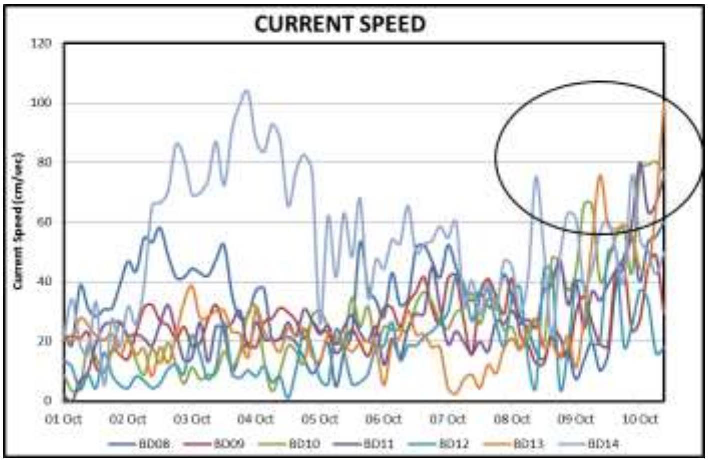


Fig. 2.2.7 Surface Ocean current recorded by the buoys during 1-10 October

2.2.7 Features observed through satellite

Monitoring of the cyclone was mainly done by using half hourly Kalpana-1, INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries of VSCS HUDHUD representing the life cycle of the cyclone are shown in Fig. 2.2.8-2.2.10.

According to INSAT-3D imageries and products, a low level circulation developed over Tenasserim coast in the morning of 6th Oct. 2014. It intensified into a vortex with intensity T1.0 and centre near 11.5°N/95.2°E at 0300 UTC of 7th October over north Andaman Sea. The pattern was of shear type at this stage. Initially it moved in westerly direction. The system intensified again at 1130 UTC of 7th October with centre near 11.5°N/94.7°E and intensity T1.5. The shear pattern changed to curved band pattern with maximum cloud mass in southern sector. Moving in the westwards direction it intensified with intensity of T2.0 and centre 11.5°N/94.2°E at 1200 UTC of 7th Oct. The curved band pattern with maximum cloudiness in southern sector continued. However, the convection became more compact and organized around the low level cyclonic circulation centre. The intensity became T 2.5 at 0300 UTC of 8th October with centre near 12.4°N/92.5°E. At this time it was of curved band pattern and the band wrapped 0.5 degree in the logarithmic spiral. It remained with intensity of T2.5 for 11 hours and intensified to T3.0 at 1800 UTC of 8th Oct. It further intensified to T3.5 at 0300 UTC of 9th Oct. corresponding to SCS intensity and lay centred near 13.7°N/89.2°E. The curved band pattern changed to Central Dense Overcast (CDO) pattern. The intensification to T4.0 occurred at 0600 UTC of 10th October and centre at this time was located near 15.0°N/87.0°E. The spiral bands were more organized and well defined CDO was observed. It further intensified into T4.5 at 0300 UTC of 11th and further to T5.0 at 0600 UTC of 11th near 16.1°N/85.2°E. The eye was clearly visible at 0000 UTC of 11th and continued to be distinct till the morning of 12th. VSCS HUDHUD maintained its intensity of T5.0 till the time of landfall. According to satellite imagery, the VSCS HUDHUD crossed Andhra Pradesh coast near 17.9°N/83.2°E.

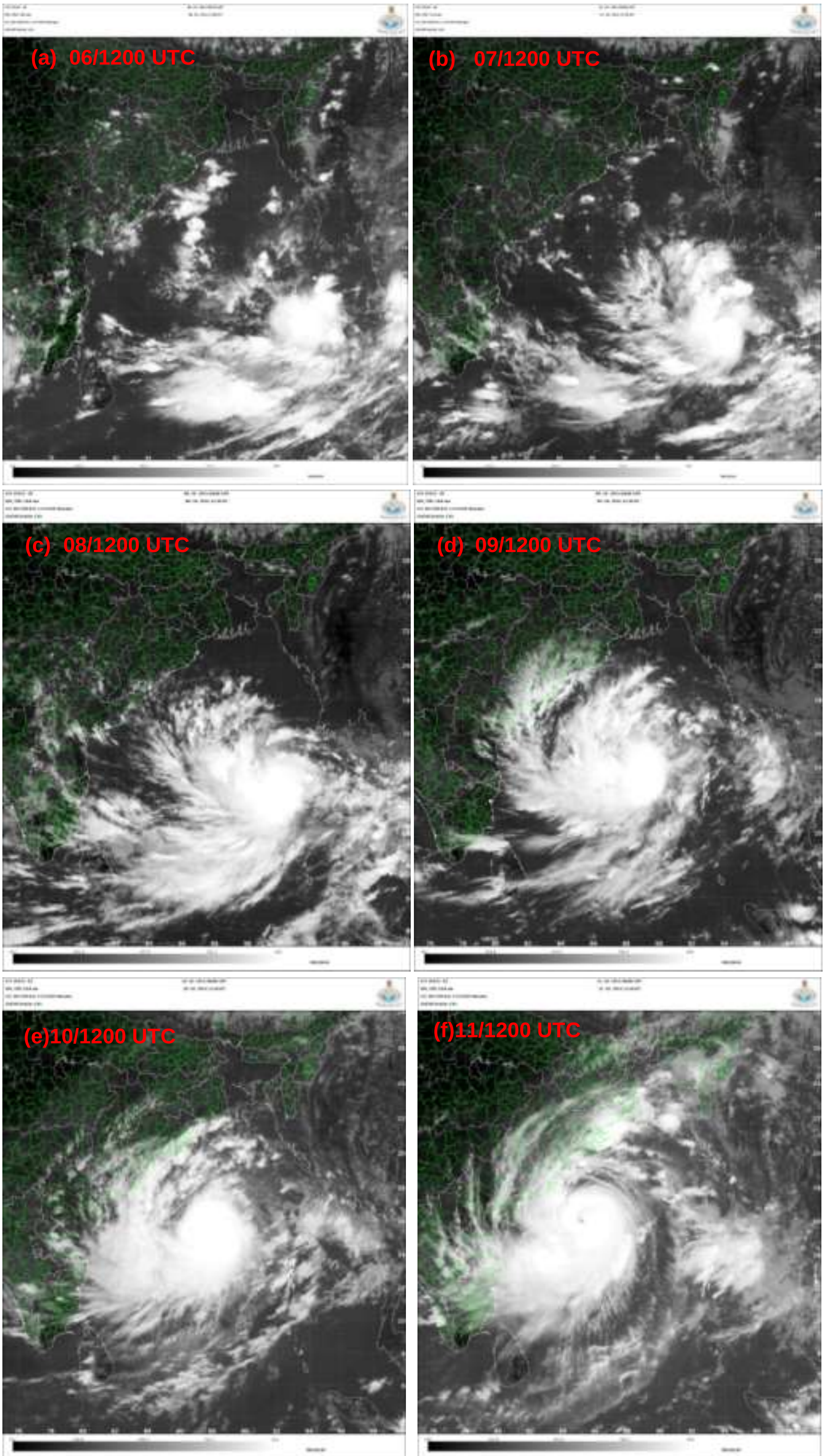


Fig. 2.6.8: Typical INSAT-3D Infra-red (IR) imageries based in association with VSCS HUDHUD during 06-14 October 2014

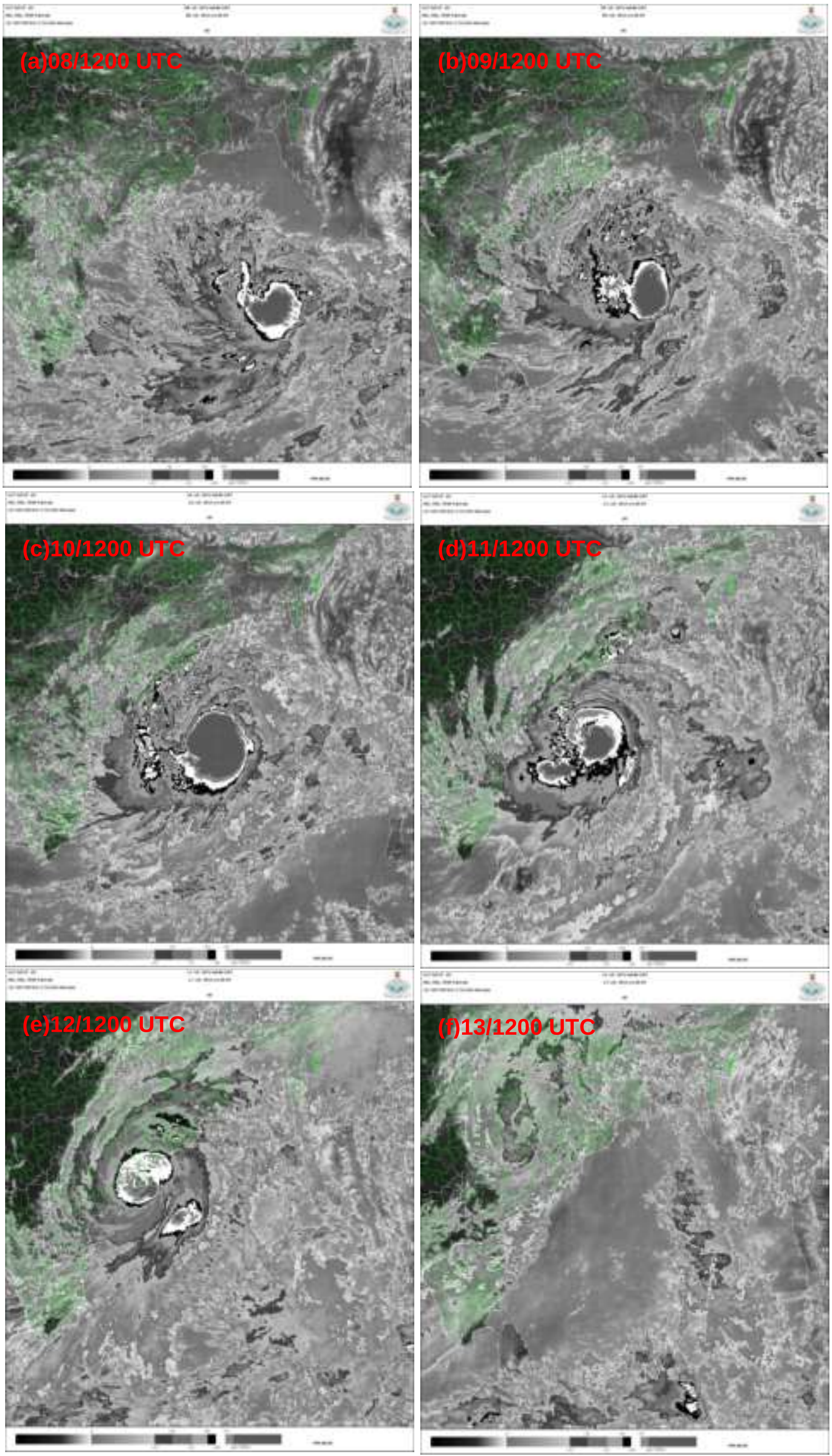


Fig. 2.2.9 INSAT-3D enhanced IR imageries in association with VSCS HUDHUD during 08-13 October 2014

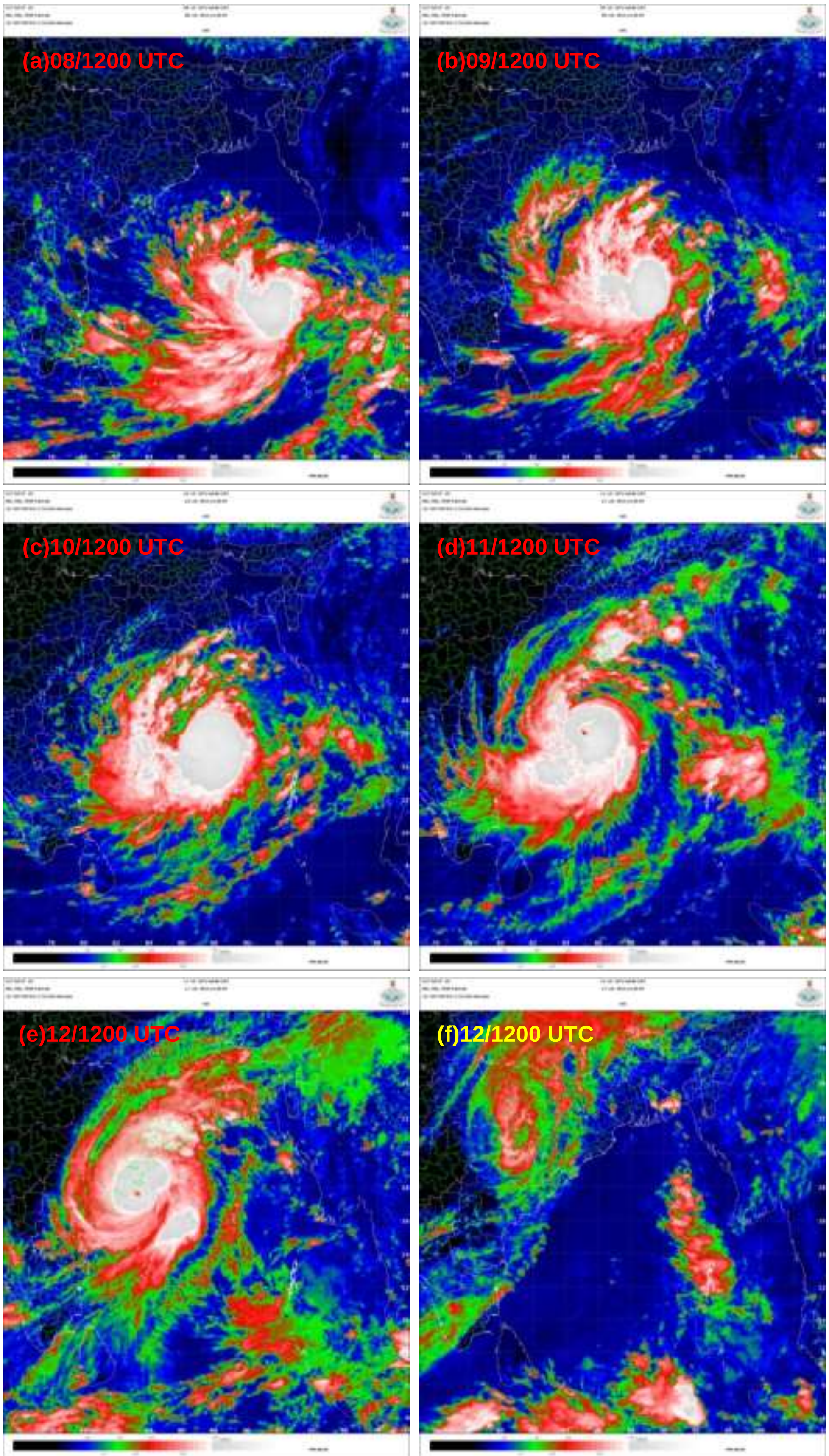


Fig. 2.2.10 INSAT-3D coloured enhanced IR imageries based on 0600 UTC in association with VSCS HUDHUD during 08-13 October 2014

2.2.8 Features observed through Radar

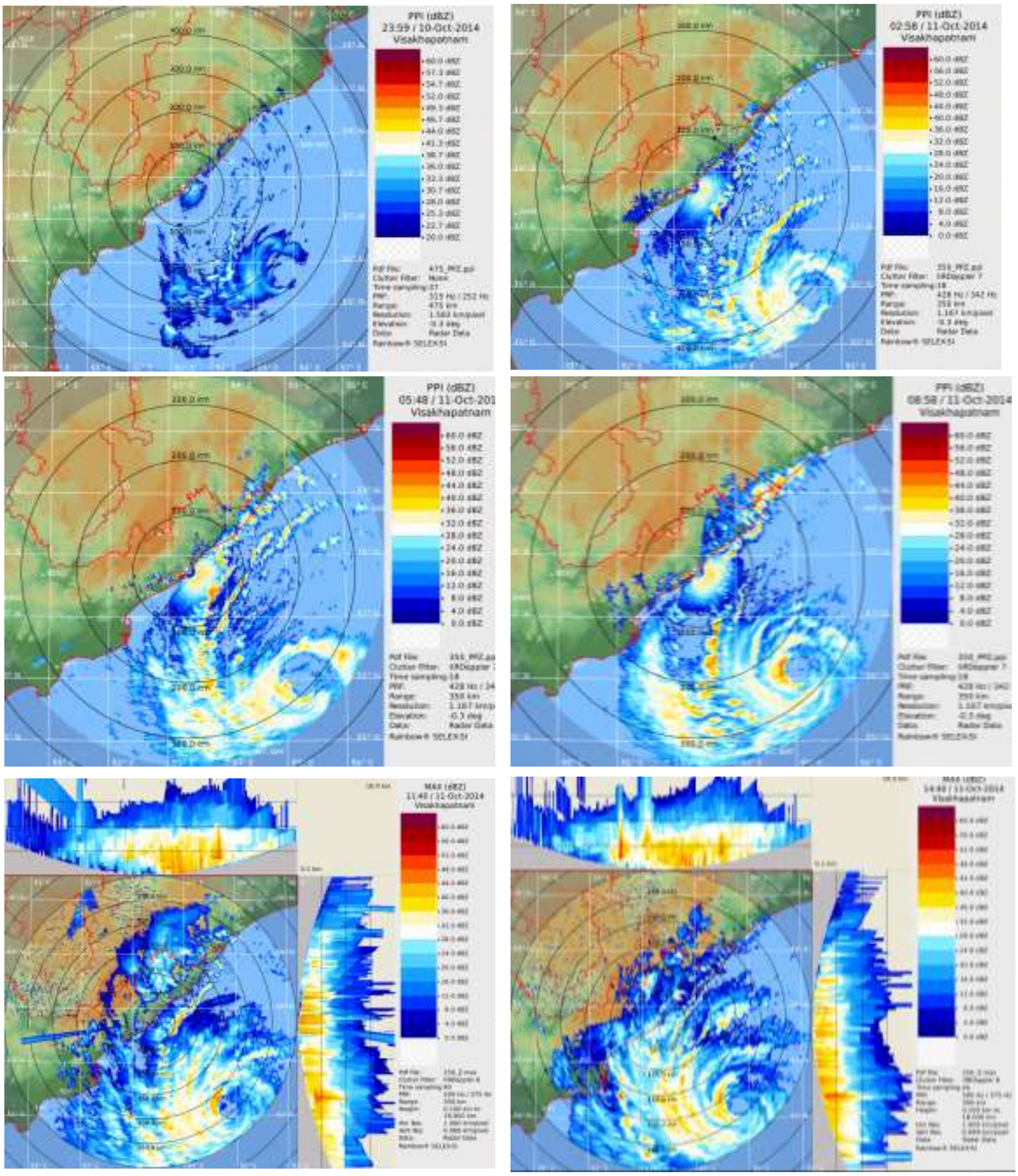
VSCS HUDHUD was monitored by DWR Visakhapatnam continuously and observations were taken every 10 min. and bulletins were issued hourly till 0450 UTC of 12th. After that telecommunication was disrupted and the issue of bulletins was stopped. However, the observations from DWR Machillipatnam were used to monitor the cyclone till 12th evening. The initial cloud echoes were observed at 2200 UTC of 11th October, 2014 in Special 400 PPI Scan when the first half eye was observed with an estimated diameter of about 30 km located at a distance of about 334 km. The bulletins were issued based on maximum reflectivity (Max. Z) products and radial velocity. The Maximum wind speed of 67mps (130kts) at 200 m height was reported near Visakhapatnam at 0300 UTC of 12th (Table 2.2.2). When reduced to surface level, it is about 90 kts. The half eye of the cyclone was visible till 0130 UTC of 11th Oct. By 0730 hrs IST, it became closed with a diameter of 52 km. The closed eye was present for a temporary period and became open eye again during 1030-1230 UTC of 11th. By 1100 UTC of 11th, it was again a closed eye and the same continued till 0000 UTC of 12th. It became a weak eye during 0000-0200 UTC and became elliptical at 0200 UTC of 12th. The eye became ill defined from 0300 UTC onwards. The eye diameter increased initially reaching the maximum of 52 km at 0200 UTC of 11th Oct. Thereafter, it decreased upto 0500 UTC and then increased again till 1100 UTC of 11th. Thereafter, it decreased slightly and varied between 36-46 km. The detailed position of the VSCS HUDHUD along with the eye characteristics and radial velocity are shown in Table 2.2.2. A few DWR imageries are shown in Fig. 2.2.11 to illustrate the structural characteristics of VSCS HUDHUD including eye, wall cloud, spiral bands as observed through reflectivity imageries. The maximum convective band in the wall cloud region was limited to northwest sector and adjoining southwest sector around the centre initially on 11th. It encircled the complete southern sector by 0430 UTC of 12th Oct. The outer band caused rainfall activity along the coast of north Andhra Pradesh and adjoining coastal Odisha from the afternoon of 11th.

Table-2.2.3. Position of VSCS HUDHUD based on DWR, Visakhapatnam

SN	Date and time (UTC)	Lat deg N	Long deg E	Range kms	Azimuth deg	Radial wind speed/ Maximum Velocity (mps) in any other area and height (km) above msl	Diameter of Eye (km)	Shape of eye
1	10.10.14 2200	15.7	85.7	334.2	131.1	-/30.5	30.4	Half eye
2	10.10.14	15.8	85.7	334.2	131.0	35.0	38.0	Half eye
3	11.10.14 0000	15.8	85.7	334	131	-/35.0	42.7	Half eye
4	11.10.14	15.8	85.6	325	131	-/35.0	50.0	Half eye

	0100							
5	11.10.14 0200	15.83	85.51	314	132.3	-/44.0 at 3.81 km	52.0	Closed eye
6	11.10.14 0300	15.86	85.41	303	133.3	/40.8 at 3.70 km	41.0	Closed eye
7	11.10.14 0400	15.86	85.38	301	133.3	42.2 at 4.0 km	47.0	Closed eye
8	11.10.14 0500	15.7	85.7	334	131.1	/30.5	30.4	Half eye
9	11.10.14 0500	15.8	85.7	334	131	/30.5	38.0	Half eye
	11.10.14 0600	16.00	85.230	279.4	133.6	42.2 at 3.2 km	43.0	Closed eye
10	11.10.14 0700	16.0	85.20	281.9	133.6	42.2 at 2.9 km	42.0	Open eye
11	11.10.14 0800	16.13	85.12	260.4	133.0	42.5 at 2.4 km	45.0	Open eye
12	11.10.14 0900	16.12	85.01	252.9	135.0	46.0 at 2.6 km	41.3	Open eye
13	11.10.14 1000	16.15	84.92	243.7	136.5	46.0 at 4.6 km	42.1	Open eye
14	11.10.14 1100	16.17	84.86	238.2	137.2	46.0 at 4.3 km	48.7	Closed eye
15	11.10.14 1200	16.15	84.83	237.6	138.1	43.0 at 4.1 km	31.0	Closed eye
16	11.10.14 1300	16.19	84.79	232.0	138.1	46.0 at 3.9 km	40.4	Closed eye
17	11.10.14 1400	16.198	84.77	230.7	138.9	46.0 at 3.8 km	36.1	Closed eye
18	11.10.14 1500	16.23	84.80	229.7	137.3	46.0 at 3.5km	38.1	Closed eye
19	11.10.14 1600	16.32	84.8	221.0	135.9	46.0 at 3.9 km	46.0	Closed eye
20	11.10.14 1700	16.43	84.81	212.6	133.9	49.0 at 3.6 km	41.8	Closed eye
21	11.10.14 1800	16.57	84.75	198.8	131.1	48.6 at 2.8 km	40.6	Closed eye
22	11.10.14 1900	16.71	84.66	180.8	129.4	51.8 at 3.0 km	40.1	Closed eye
23	11.10.14 2000	16.77	84.57	170.0	129.8	48.2 at 3.1 km	38.7	Closed eye

24	11.10.14 2100	16.86	84.47	155.1	129.5	49.8 at 1.9 km	40.8	Closed eye
25	11.10.14 2200	16.99	84.41	140.3	126.6	49.5 at 1.7 km	37.2	Closed eye
26	11.10.14 2300	17.17	84.29	118.7	122.3	49.0 at 1.2 km	44.2	Closed eye
27	12.10.14 0000	17.26	84.17	103.1	121.1	54.0 at 1.0 km	66.0	Closed eye
28	12.10.14 0100	17.17	84.05	98.3	130.9	57.0 at 0.8 km	30.1	Weak eye
29	12.10.14 0130	17.34	83.93	77.0	126.6	58.6 at 0.6 km	27.5/18.5	Weak eye
30	12.10.14 0200	17.27	83.83	73.8	136.4	52.0 /-	24.2/21.8	Weak elliptic eye
31	12.10.14 0230	17.38	83.78	61.5	130.6	65.0/-	41.0	Weak elliptic eye
32	12.10.14 0300	17.39	83.8	61.5	132.7	67.0	-	Ill defined eye
33	12.10.14 0330	17.33	83.67	57.8	136.1	65.0/	-	Ill defined eye
34	12.10.14 0400	17.37	83.71	57.3	138.0	65.0/	-	Ill defined eye



2.2.11 Visakhapatnam RADAR imageries based on 0000 UTC to 1500 UTC of 11th October 2014

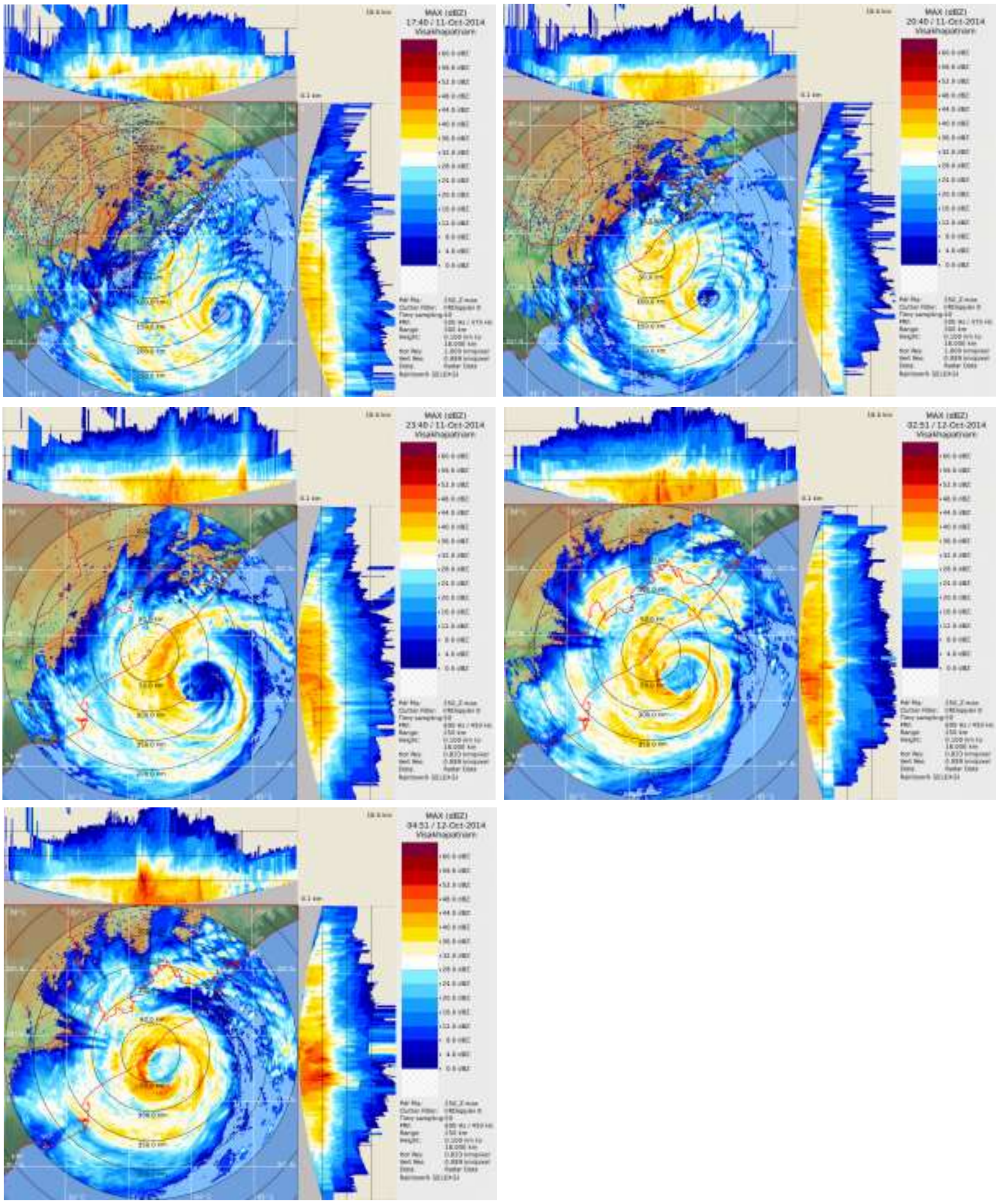


Fig. 2.2.11 (contd.): Visakhapatnam RADAR imageries based on 1800 UTC of 11th October 2014 to 0500 UTC of 12th October 2014

2.2.9 Dynamical features

To analyse the dynamical features, the Mean Sea Level Pressure (MSLP), surface winds at 10 m height and winds at 850 hPa, 500 hPa and 200 hPa levels during the period 7 – 14 October 2014 are presented in Fig. 2.2.12. based on IMD-GFS analysis.

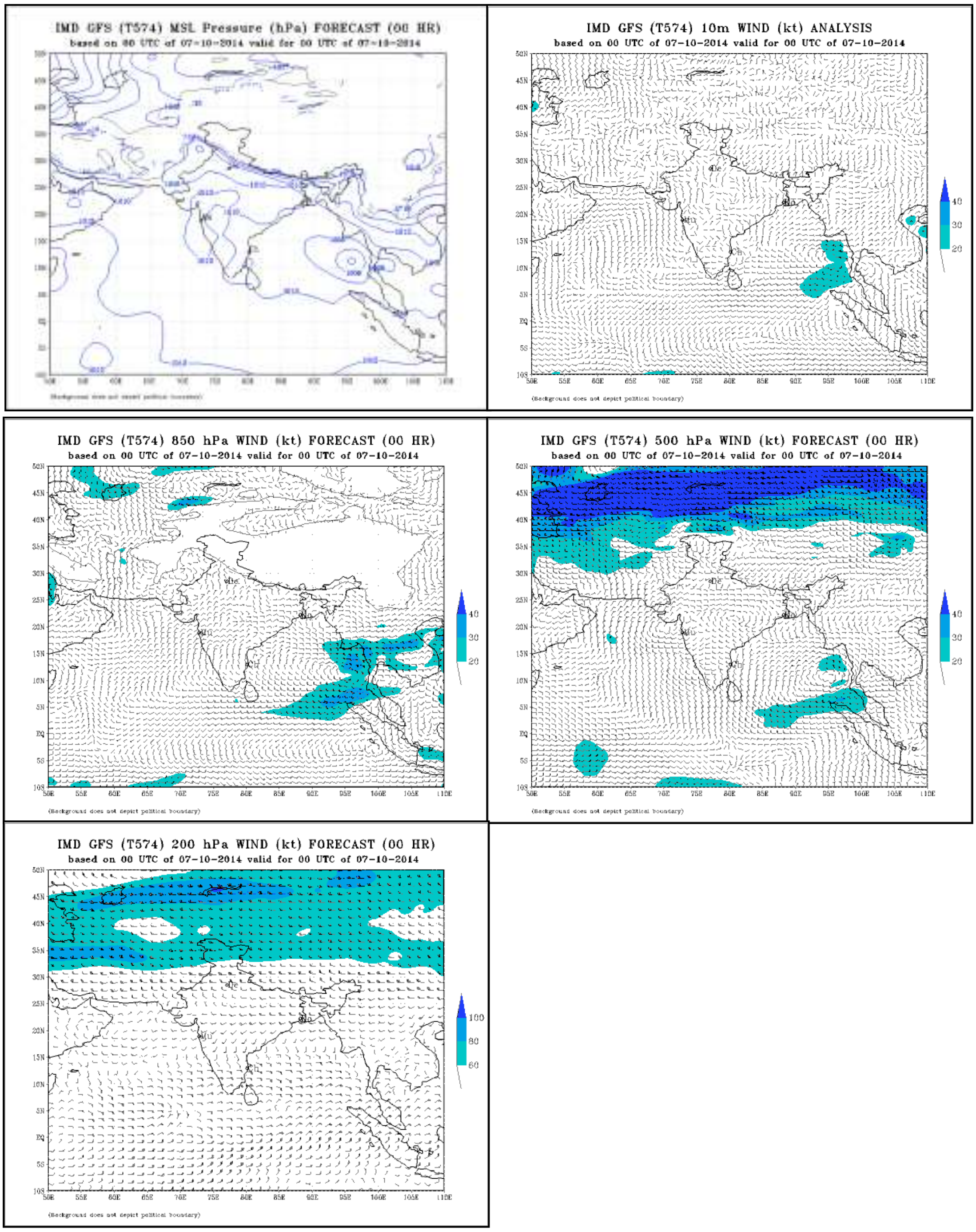


Fig 2.2.12 IMD-GFS Analysed charts on 7th MSLP Analysis, 10 m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

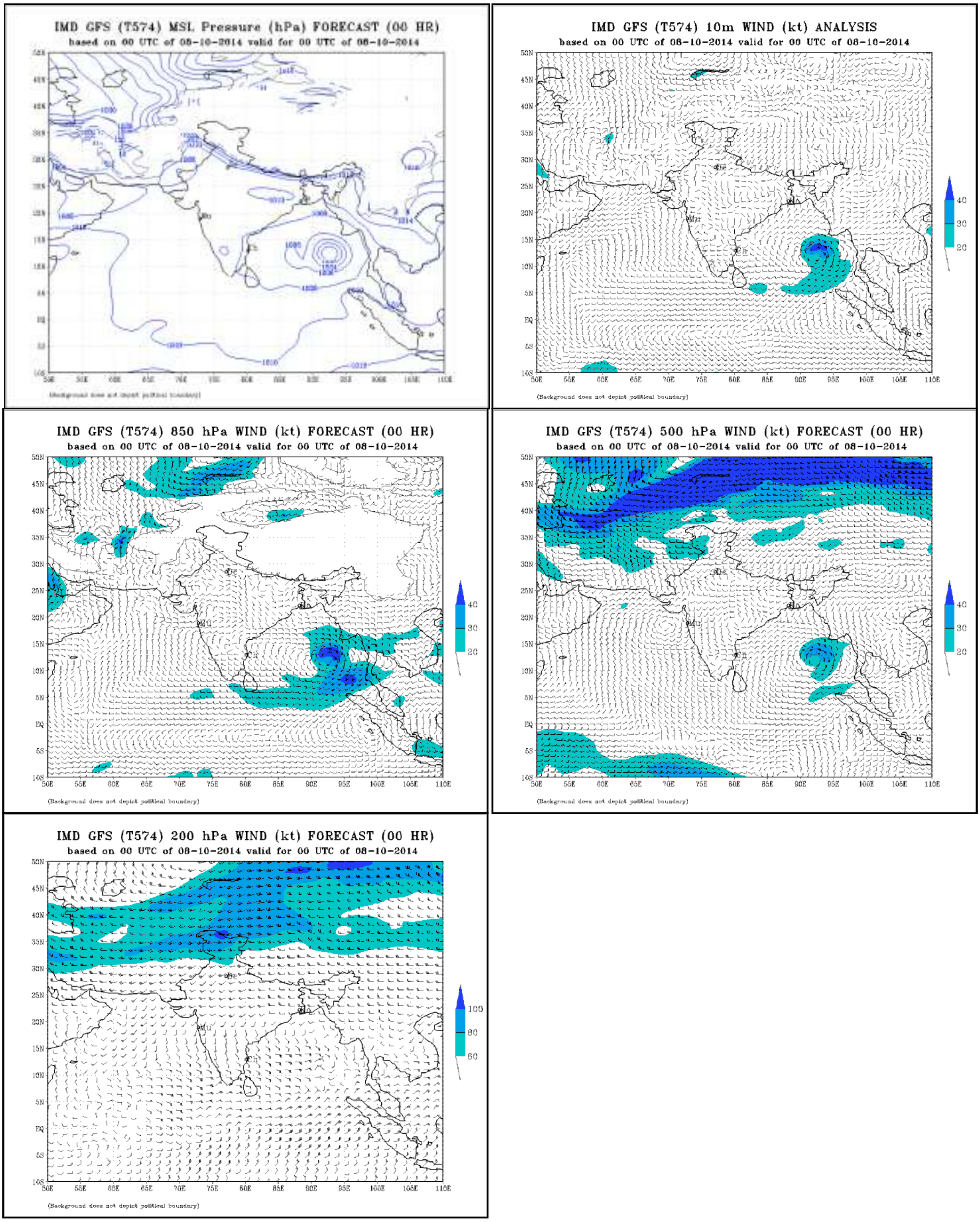


Fig. 2.2.12 (contd.) IMD-GFS Analysed charts on 8th MSLP Analysis, 10 m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

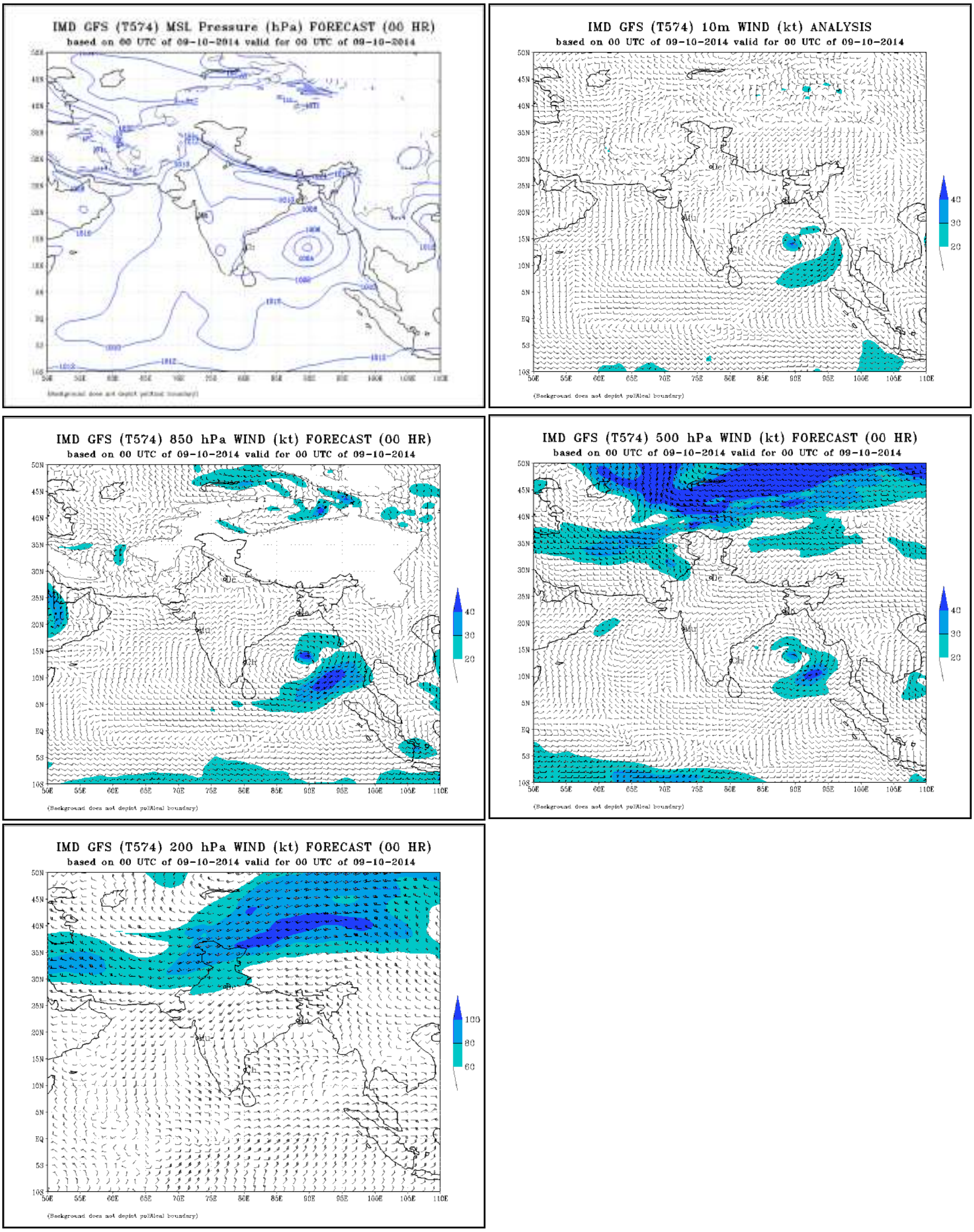


Fig. 2.2.12(contd.): IMD-GFS Analysed charts on 9th MSLP Analysis, 10 m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

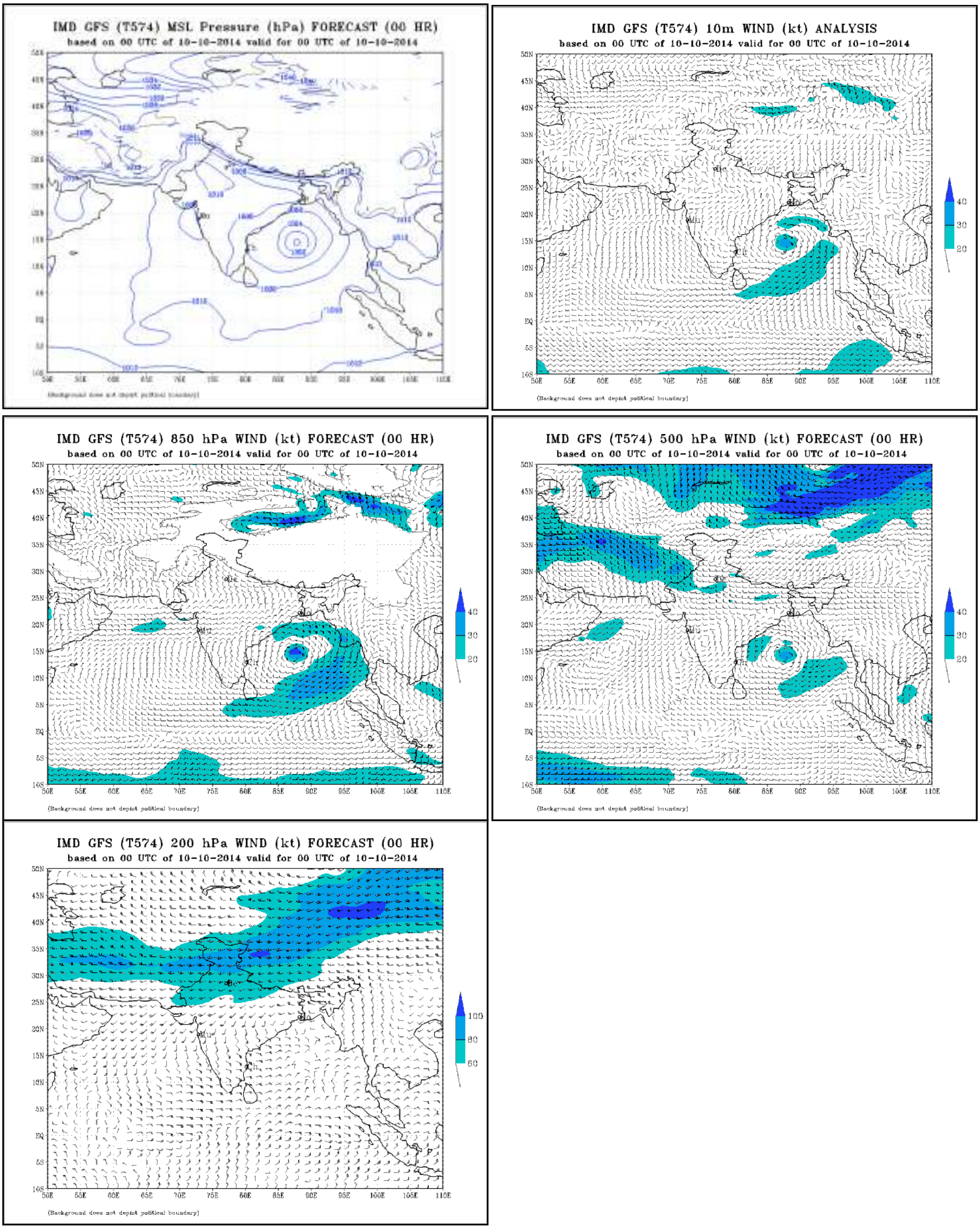


Fig. 2.2.12 (contd.)IMD-GFS Analysed charts on 10th MSLP Analysis, 10 m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

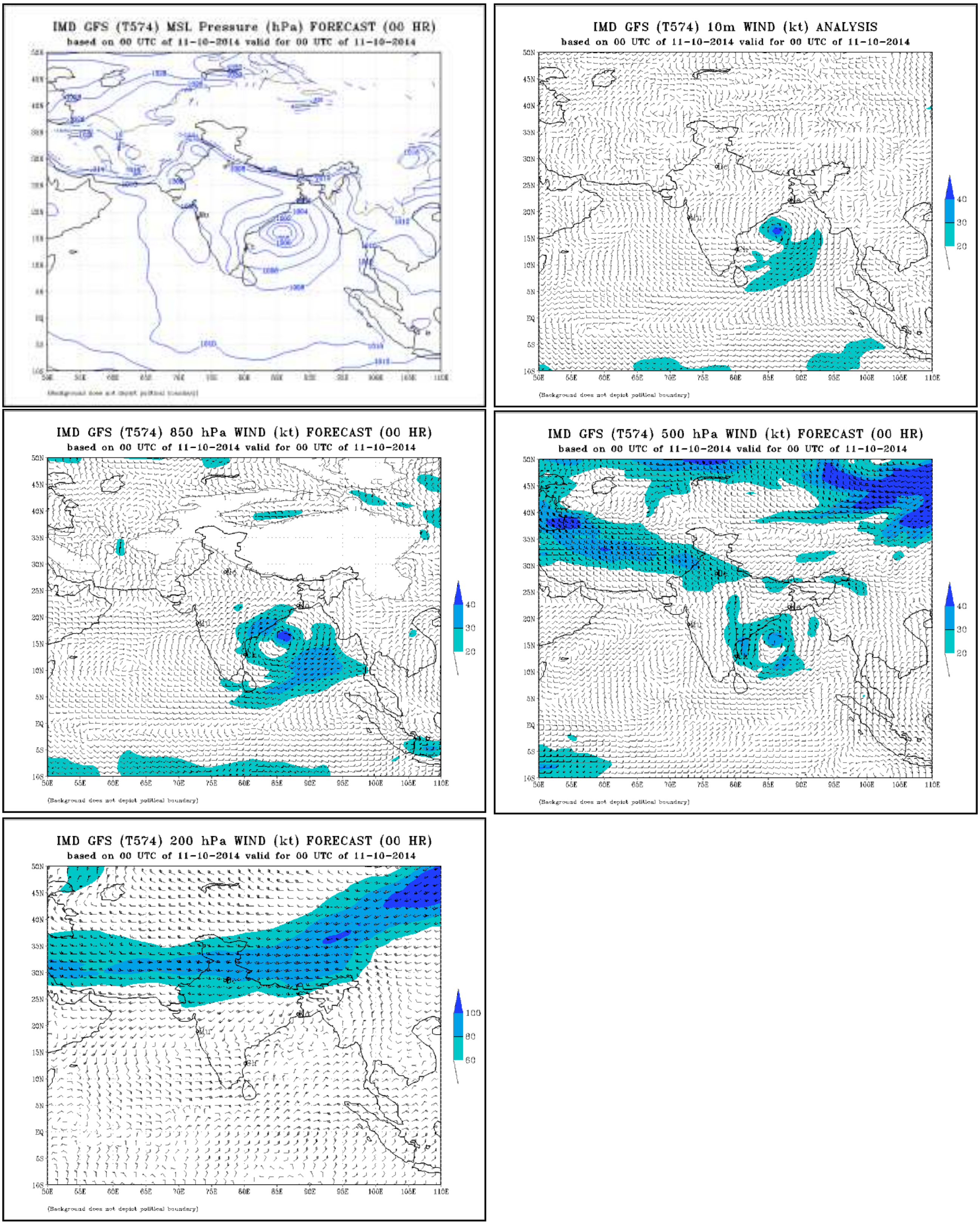


Fig. 2.2.12 (contd): IMD-GFS Analysed charts on 11th October 2014 MSLP Analysis, 10 m winds, 850 hPa winds, 500 hPa winds and 200 hPa winds

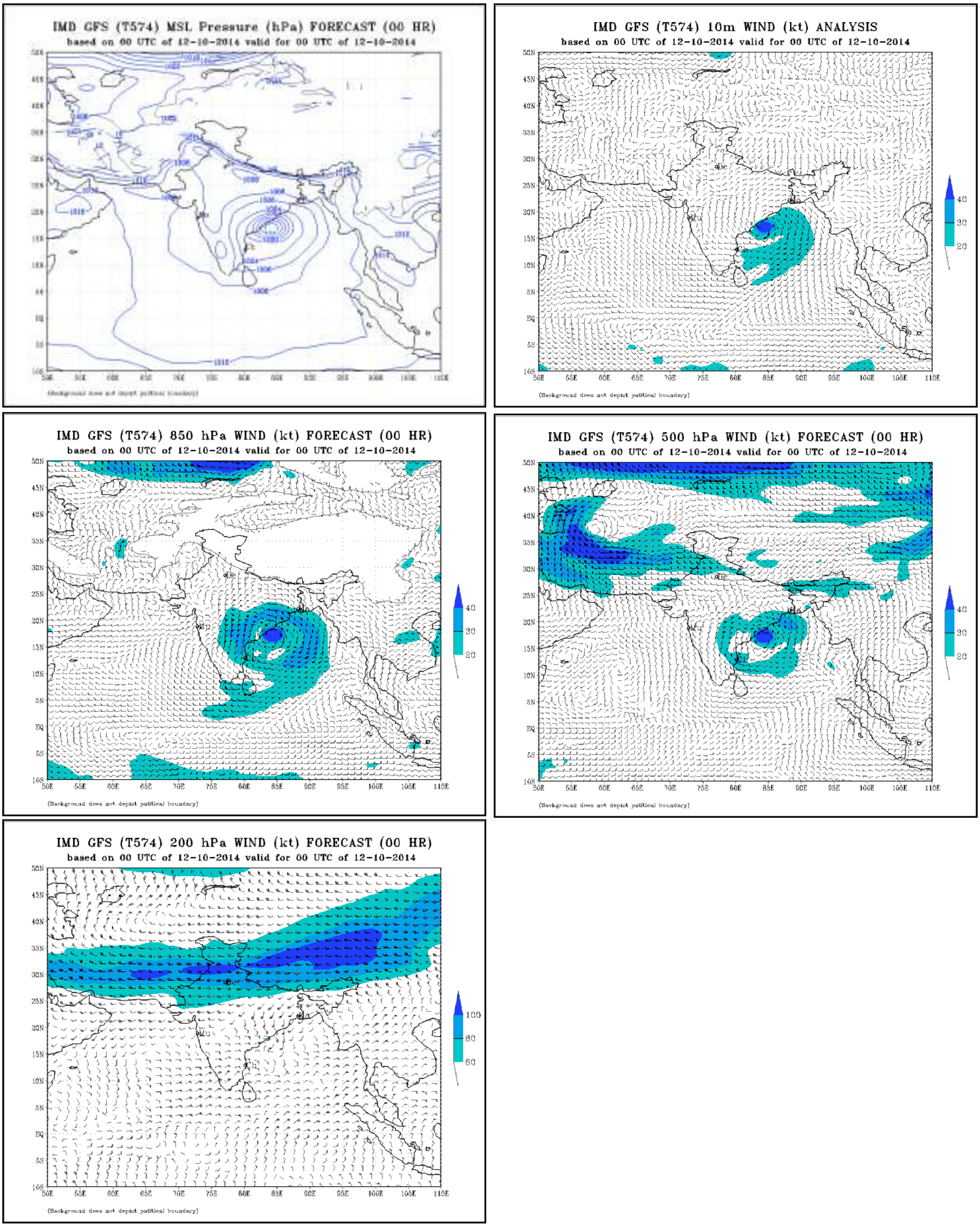


Fig. 2.2.12 (contd.) IMD-GFS Analysed charts on 12th October MSLP Analysis, 10m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

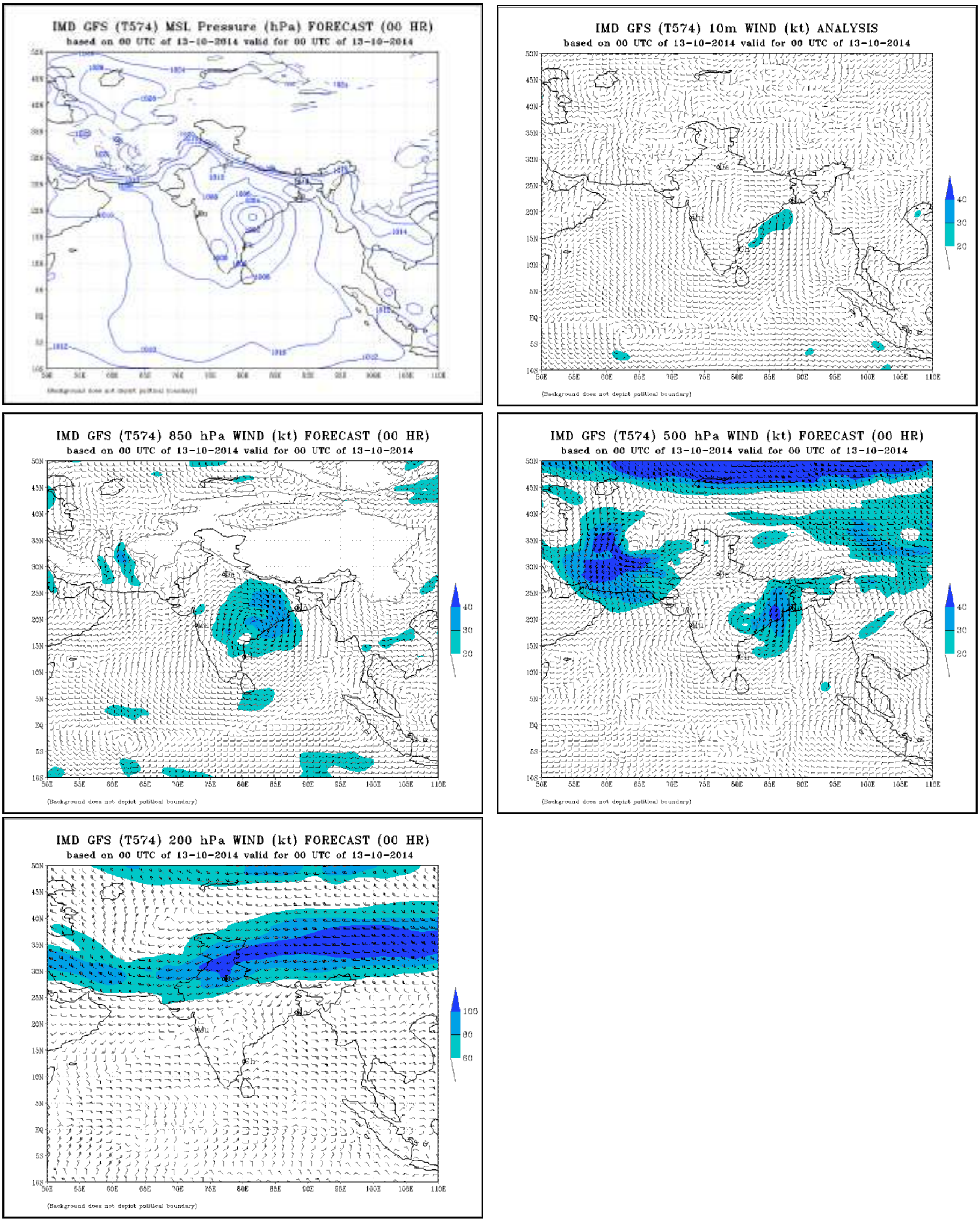


Fig. 2.2.12 (contd.) IMD-GFS Analysed charts on 13th October MSLP Analysis, 10m winds, 850 hPa winds, 500 hPa winds & 200 hPa winds

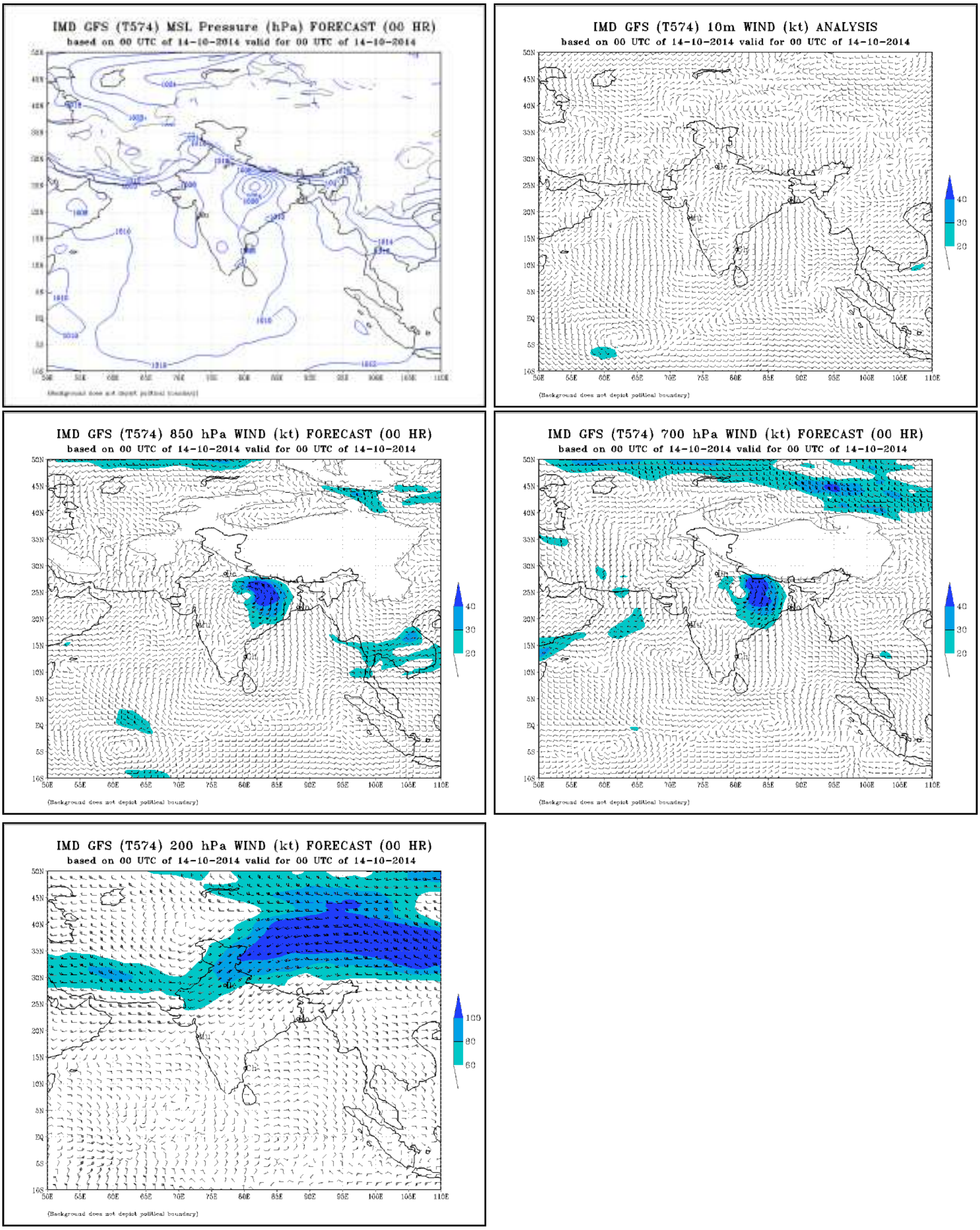


Fig. 2.2.12 (contd.) IMD-GFS Analysed charts on 14th October MSLP Analysis, 10m winds, 850 hPa winds, 700 hPa winds & 200 hPa winds

As it can be observed, the wind speed was higher on the northeastern and the southern sectors at the time of genesis of Depression. With the intensification of the system into Cyclonic Storm on 8th October 2014, wind was significantly higher in the northern sector. Thus, the model could capture the initial condition as discussed in section 2.2.4.1. Similar conditions continued on 9^{th} October 2014. However, the size of the gale wind relatively increased in the northeastern and the southeastern sector on 9^{th} and 10^{th}. On 11^{th} October 2014, when it was VSCS, the core wind became almost symmetric around the centre. However, the gale wind had maximum radial extent in the southeastern sector. On 12^{th} October 2014, the day of landfall when the system was lying near to the coast asymmetry also increased in the northeastern sector with the extension of gale winds whereas the core wind remained symmetric around the centre, with slight increase in size. The cyclonic circulation in association with the system extended vertically upto 300 hPa during the genesis phase and upto 200 hPa in the mature stage on 11^{th} and 12^{th}. The analysis could very well capture the genesis and track of the system. However, the intensity was underestimated.

2.2.10 Realized Weather:

2.2.10.1. Heavy rainfall due to HUDHUD:

The VSCS, HUDHUD caused isolated heavy to very heavy rainfall over Andaman & Nicobar Islands, heavy to very heavy rainfall at a few places with isolated extremely heavy rainfall over North Andhra Pradesh and South Odisha, heavy to very heavy rainfall over a few places of Chhattisgarh, East Uttar Pradesh, East Madhya Pradesh, isolated heavy to very heavy rainfall over Jharkand and Bihar and isolated heavy rainfall over Sub-Himalayan West Bengal (Description of rainfall terminologies: **Heavy**: 64.5 to 124.4 mm; **Very Heavy**: 124.5 to 244.4 mm and **Extremely Heavy**: ≥244.5 mm) as well as spatial distribution [**Isolated (ISOL)**: (1-25% of stations reporting rainfall); **Scattered (SCT / A few places)** : 26-50% of stations reporting rainfall; **Fairly WideSpread (FWS/ Many places)**: 51-75% of stations reporting rainfall; **Widespread (WS/ Most places)**: 76-100% of stations reporting rainfall during the last 24 hours ending at 0300 UTC of every day).

The chief amounts of past 24 hr rainfall realised (≥ 7 cm) ending at 0300 UTC of date during the period of VSCS HUDHUD are furnished below:

8 October 2014

Andaman And Nicobar Islands: Port Blair-21 cm, Long Islands-15.

12 October 2014

Andhra Pradesh: Itchapuram (dist Srikakulam) 14, Visakhapatnam Ap (dist Vishakhapatnam), Kalingapatnam (dist Srikakulam) 12 each, Visakhapatnam (dist Vishakhapatnam) 11, Pusapatirega (dist Vizianagaram), Vizianagaram (dist Vizianagaram), Ranasthalam (dist Srikakulam) 10 each, Nellimarla (dist Vizianagaram), Tekkali (dist Srikakulam), Palasa Mandal(arg) (dist Srikakulam) 9 each, Sompeta (dist Srikakulam), Palasa (dist Srikakulam), Cheepurupalli (dist Vizianagaram) 8 each, Mandasa (dist Srikakulam), Denkada (dist Vizianagaram), Garividi (dist Vizianagaram) 7 each

Odisha: Mahendragarh-12, Basudevpur (AWS)-11, Tihidi (ARG), Marsaghai (ARG)-each, Garadapur (ARG) &Paradeep-9 each, Paralakhemundi & Udala 8 each, Tirtol (ARG), Jaipur, Berhampur, Nischintakoili (ARG) & Bhuban (ARG)-7 each

13 October 2014

Andhra Pradesh: Gantyada (dist Vizianagaram) 38, Srungavarapukota (dist Vizianagaram) 34, Nellimarla (dist Vizianagaram) 24, Gajapathinagaram (dist Vizianagaram) 22, Pusapatirega (dist Vizianagaram), Bondapalle (dist Vizianagaram), Garividi (dist Vizianagaram), Palakonda (dist Srikakulam) & Denkada (dist Vizianagaram) 19 each, Anakapalle(a) (dist Vishakhapatnam) 18 & Salur (dist Vizianagaram) 18 each, Vepada (dist Vizianagaram) 16, Mentada (dist Vizianagaram) 15, Seethanagaram (dist Vizianagaram) & Merakamudidam (dist Vizianagaram) 14 each, Araku Valley(arg) (dist Vishakhapatnam), Vizianagaram (dist Vizianagaram) & Parvatipuram (dist Vizianagaram) 13 each, Jiyyamma Valasa (dist Vizianagaram), Bobbili (dist Vizianagaram) & Palasa (dist Srikakulam) 12 each, Ranasthalam (dist Srikakulam), Cheepurupalli (dist Vizianagaram), Veeragattam (dist Srikakulam) & Garugubilli (dist Vizianagaram) 11 each, Balajipeta (dist Vizianagaram), Therlam (dist Vizianagaram), Pathapatnam (dist Srikakulam), Mandasa (dist Srikakulam) & Tekkali (dist Srikakulam) 9 each, Komarada (dist Vizianagaram), Palasa Mandal(arg) (dist Srikakulam) & Tuni (dist East Godavari) 8 each, Kurupam (dist Vizianagaram) & Kalingapatnam (dist Srikakulam) 7 each.

Odisha: R.Udaigiri-26, Pottangi-24, Kalinga-24, Mahendragarh-23, Mohana-22, Similiguda (AWS)-21, Malkangiri-18, Tikarpara-17, Nuagada (ARG)-17, Chandanpur-17, G Udayagiri (AWS)-17, Daringibadi-17, Belaguntha (ARG)-16, Khandapara-16, Kashipur-15, Jhorigam (ARG)-15, Raikia (ARG)-15, Barmul-15, Tikabali-14, Banki (ARG)-13, Rayagada-13, Jhumpura-12, Bhanjnagar-11, Digapahandi (ARG)-11, Ghatagaon-11, Danagadi (ARG)-11, Nayagarh-11, Tentulikhunti (ARG)-10, Kantapada (ARG)-10, Jagannath Prasad (ARG)-10, Madhabarida-10, Keonjhargarh-10, Banpur-10, Daspalla-10, Narsinghpur-9, Phiringia (ARG)-9, Rajkishorenagar-9, Odagaon (ARG)-9, Hindol-9, Bissem-Cuttack-9, Aska-9, Paralakhemundi-9, Nawana-9, Joda (ARG)-9, Koraput-9, Betanati (ARG)-9, Sorada-9, Jeypore-8, Angul-8, Bangiriposi-8, Gunupur-7, Rairakhol-7, Kashinagar-7, Gania (ARG)-7, Chandahandi (ARG)-7, Harabhanga-7, Tigiria (ARG)-7, Umarkote-7, Sukinda-7, Talcher-7, Naktideul-7, Samakhunta (AWS)-7

Chhattisgarh: Sukma- 17, Narayanpur- 8, Jagdalpur- 8, Kondagaon- 7.

Jharkhand: Jamshedpur-15, Hazaribagh-12, Jamshedpur Aero-12, Ramgarh-9, Ghatsila-9, Ranchi Aero-8, Chandil-8

14 October 2014

Andhra Pradesh: Denkada (dist Vizianagaram) 19, Cheepurupalli (dist Vizianagaram) 12, Garividi (dist Vizianagaram) 10, Pathapatnam (dist Srikakulam) 9

Odisha: R.Udaigiri-19, Paralakhemundi-11, G Udayagiri (AWS)-8, Nuagada (ARG)-8

Chhattisgarh: Manendragarh- 17, Pendra Road-17, Pali- 15, Kawardha- 12, Janakpur-11, Katghora-11, Simga- 9, Mungeli- 9, Bilaspur-8, Bemetara- 8, Janjgir- 7, Durg- 7.

East Uttar Pradesh: Patti-13, Pratapgarh-13, Chhatnag-13, Bara-12, Koraon-12, Salempur-12, Karchhana-12, Phoolpur-11, Kunda-11, Allahabad Sadar-11, Akbarpur-11, Allahabad -10, Soraon-9, Mau Tehsil-9, Handia-9, Meja-9, Sultanpur

Obsy-9, Faizabad-8, Varanasi/Bab Aero-8, Jaunpur (CWC)-8, Haraiya-8, Rae Bareli (CWC)-7, Beberu-7, Fursatganj-7, Ayoadhya-7, Sultanpur (CWC)-7, Tarabganj-7

East Madhya Pradesh: Amarkantak-28, Sidhi (AWS)-19, Kotma-18, Hanumana-18, Pushpajgarh-16, Maihar-16, Anuppur (AWS)-13, Rewa (AWS)-11, Sohagpur (AWS)-11, Gudh-11, Jaithari-10, Bichhia-10, Satna (AWS)-10, Dindori (AWS)-9, Malanjkhand-8, Nagode-7, Umaria (AWS)-7,

15 October 2014

Bihar: Tribeni/Balmiki-18 cm, Sheohar-17, Sonbarsa-16, Dhengbridge-15, Gaunaha-14, Lalbegiaghat-12, Saulighat-12, Ramnagar-11, Chanpatia-11, Kamtaul-10, Chatia-10, Jainagar-7, Ahirwalia-7

East Uttar Pradesh: Maharajganj-15, Bansi (CWC)-12, Regoli-12, Pharenda-12, Gorakhpur-11, Hata-11, Kakrahi-11, Birdghat-10, Domeriaganj-9, Basti (CWC)-9, Utarala-9, Bansgaon-9, Khalilabad-8, Sardanagar-8, Chanderdeepghat-8, Ayoadhya-7, Mukhlispur-7, Chandauli-7, Katerniaghat-7

Sub-Himalayan West Bengal & Sikkim: Bagdogra - 8

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

The daily rainfall figures in terms of actual, normal and percentage departures from normal over the meteorological sub divisions of Coastal Andhra Pradesh, Odisha, Telangana, Chhattisgarh, Jharkhand, East Uttar Pradesh, Bihar and East Madhya Pradesh during the period 12-15 October 2014 are presented in the Table 2.2.4. The district-wise distribution of daily rainfall over Andhra Pradesh during 13-14 October 2014 is presented in Fig. 2.2.13.

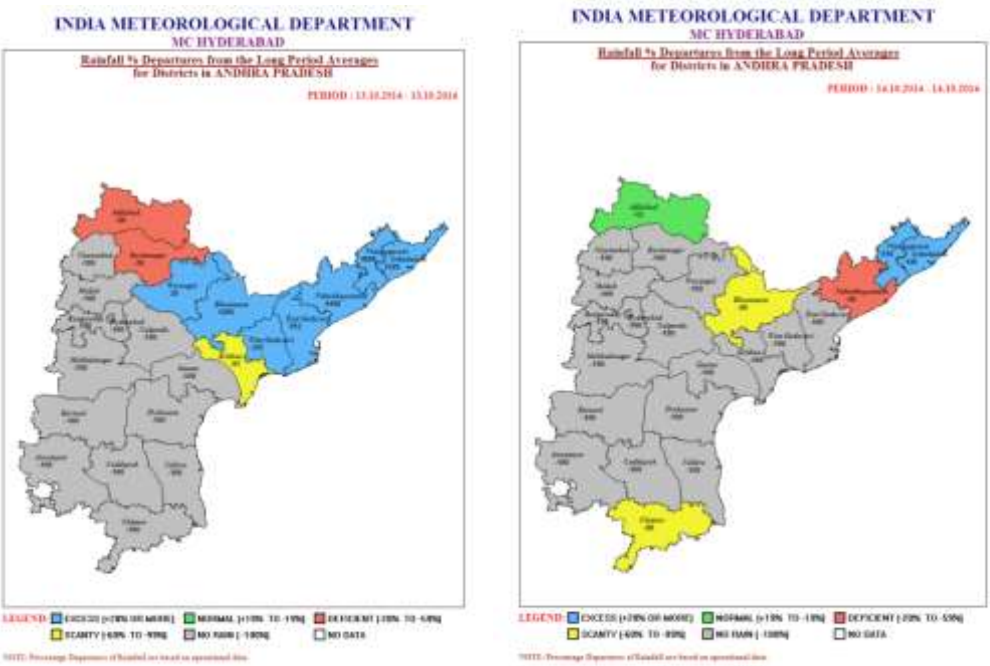


Fig. 2.2.13 District-wise distribution of daily rainfall over Andhra Pradesh during 13-14 October 2014

Table 2.2.4 Excess rainfall figures over various meteorological sub divisions in association with passage of VSCS HUDHUD

Date		CAP	ODISHA	TELANGANA	CHHATTISGARH	JHARKHAND	BIHAR	EMP	EUP
	ACT (mm)	13.3	17.3						
	NOR (mm)	3.7	3.7						
12.10.2014	PDN	259%	369%						
	ACT (mm)	30.9	63.4	2.3	33.0	26.3	5.6		
	NOR (mm)	3.0	2.5	1.2	1.6	1.7	1.6		
13.10.2014	PDN	931%	2437%	92%	1964%	1446%	252%		
	ACT (mm)		5.5		32.6	3.0	7.0	49.5	41.9
	NOR (mm)		2.8		1.5	1.7	1.7	0.5	1.8
14.10.2014	PDN		98%		2070%	75%	310%	9792%	2225%
	ACT (mm)						30.5		27.8
	NOR (mm)						1.4		0.6
15.10.2014	PDN						2078%		4535%

Act: Actual; Nor: Normal; PDN: Percentage Departure From Normal; CAP: Coastal Andhra Pradesh; EMP: East Madhya Pradesh; EUP: East Uttar Pradesh

Rainfall associated with the cyclone when it was out in the sea is also determined based on satellite-gauge merged rainfall dataset generated by IMD and NCMRWF (Mitra et al, 2009) for the North Indian Ocean region from 2013 onwards using the TRMM data. 24-hour accumulated rainfall associated with the VSCS HUDHUD during the period 08-14 October 2014 as well as the 7-day average rainfall during the same period are furnished in the Fig. 2.2.14.

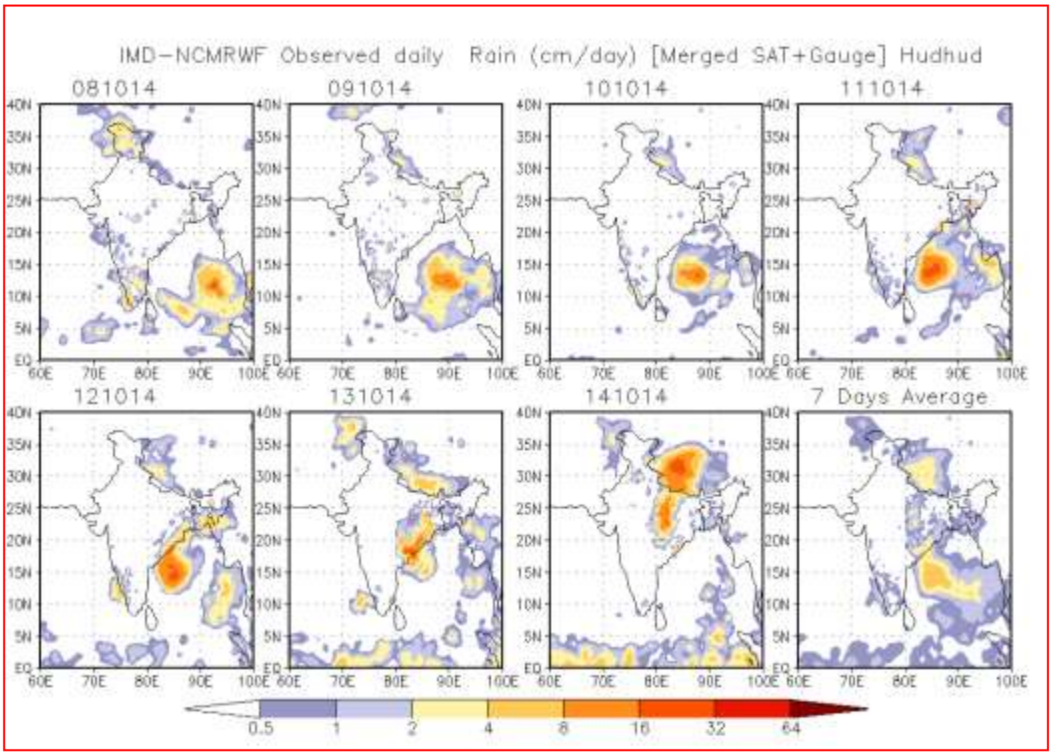


Fig. 2.2.9.14 IMD-NCMRWF satellite-gauge merged daily rainfall (in cm) during the period 08-14 October 2014 and the 7-day average rainfall during the same period.

The above rainfall figures indicate that rainfall was high in the southwest sector of the TC when it was over the sea. During landfall, the maximum rainfall region shifted to northeast sector leading to high rainfall figures over North Andhra Pradesh and South Odisha. This shift in the maximum rainfall regime is associated with gradual recurvature of the TC from west-northwestward movement over the sea to northwest movement during landfall and northward movement thereafter. This spatial pattern of rainfall distribution was in expected lines as it has occurred in a similar fashion in earlier cases also including the VSCS Phailin (2013). Apart from North Andhra Pradesh and South Odisha, there has been good rainfall activity over Chhattisgarh, East Uttar Pradesh Bihar and over Nepal. The rainfall over Nepal on 14th October has been significantly higher under the influence of (i) orographic effect of the Himalayas and (ii) interaction with mid-latitude westerly trough lying to the west of the cyclone. Intensity of rainfall in the inner storm region has been of the order of 16 cm/day and above and in the outer storm region, it has been of the order of 2-16 cm/day.

2.2.10.2 Gale Wind

Maximum gale wind of 185 kmph prevailed over Visakhapatnam district and adjoining areas at the time of landfall. It was about 70-80 gusting to 90kmph over Andaman Islands during first landfall

2.2.10.3 Storm Surge

Observed Storm Surge recorded by the tide gauge (INCOIS) at Visakhapatnam was 1.4m as recorded by the tide gauge at Visakhapatnam port against the forecast of 1-2m.

2.2.11. Damage due to Cyclone 'HUDHUD'

The VSCS, 'HUDHUD' mainly affected North Andhra Pradesh and adjoining south Odisha. Details of the damages in Andhra Pradesh are given in Table 2.2.5. As per the report of the Government of Andhra Pradesh. A few damage photographs are shown in Fig. 2.2.15

Table -2.2.5 Damages associated with VSCS Hudhud

S No.	ITEM	Quantity
1	Districts Affected	4
2	Block Affected (Nos.)	65
3	Village Affected(Nos.)	4484
4	Families affected	20,93,508
5	Persons evacuated	135262
6	Persons rescued	**146**
7.	Human Loss/Injured	
	(a) Number of Deaths(no.)	46
	(b) Number of injured (no.)	43
8.	Loss of livestock	
	(A) Number of animal perished (no.)	2831
	(B) poultry/duck	2443701
9.	Agriculture	237854 Hect.
	Expected production loss (tons)	
	(a) Food Grains & Cash crops	2214000 in Tons
	(b) Horticultural crops	6.89 Tons
10.	Housing	
	Number of Affected houses (no.)	41269
	kuchha	18886
	(ii) pucca	12264
	(iii) Hut	10119
11.	Infrastructure	
	(A) Roads	
	(a) Road length damaged (km)	
	(i)National highway	Not estimated
	(ii)state highway	2250.00
	(iii)P.R. Road	3176.7 km
	(iv)others(municipal Roads)	648.73 km
	(b) Villages disconnected to transportation facility	

	(i) Number	73
	(ii) Days	2
	(B) Water supply system	
	(a) pipe line	
	(i) Trunk (Fully/ Partially damaged no)	194 No /39.40 km
	(ii) Distribution (Fully/ Partially damaged no)	35
	(b) pumping station (no.)	102
	(c) overhead reservoirs(Fully damaged)	197
	(e) Drinking water (Tanks Partially damaged no.)	7
	(f) Drinking water wells Fully/ Partially damaged (no.)	33
	[E] IRRIGATION	
	(a) breach of canal damaged (No.)	55
	(b) breaches to dams(No.)	1847
	(d) irrigation wells damaged(No.)	16
	[F] Eletrctricity supply*	27041 poles
	(a) high tension lines damaged (km)	506 km
	(b) low tension lines damaged (km)	7500 km
	(c) transformers damaged (No.)	7300
	(d) substation damaged	1526
	[G] Building	455 Nos.
	(a) Primary schools (Partially/Fully)	80
	(b) Secondary schools (Partially/ully.)	237
	(c) Community Center (Partially)	23
	(e) Other Government Building (Partiall)	8
	(H) Shops and others commercial building damaged	
	(a) shops (Partially)	70
	(b) other commercial buildings(Partially)	73
	[I] Other utilities	
	(a) Land telephone disrupted(no. of days)	2

	(b) Mobile phones disrupted (no. of days)	1
	(c) villages disconnected to communication facilities	
	(i) Number	73
	(ii) days	2
8	Handlooms	
	Damaged looms	15
	Loss of raw materials / Goods in process / finished goods	32
9	Fisheries	
	Loss of Boat/missing	1110
	Catamaran	698
	Net	2129
10	Street vendors	10
	Loss of push carts(number)	85
11	Artisans'	70

(Source: Govt. of Andhra Pradesh)

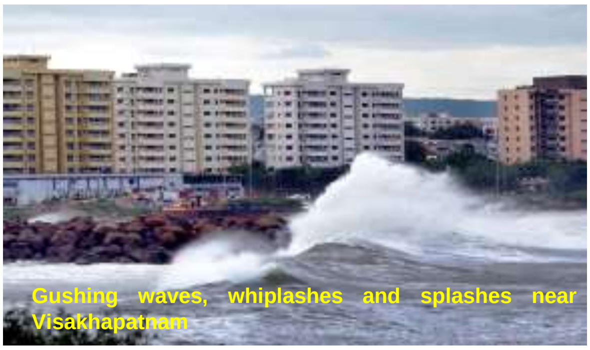
The ravaged Visakhapatnam Airport

A boat was turned turtle at Visakhapatnam Port

The collapsed telephone tower near Visakhapatnam

The Visakhapatnam beach-front was eroded by surge and waves

A fallen tree damaging house in Jeypore town of Koraput district of Odisha



Gushing waves, whiplashes and splashes near Visakhapatnam

Overturned college bus and uprooted electric poles

Fig. 2.2.15: Few Damage photographs associated with VSCS Hudhud

2.3 Very Severe Cyclonic Storm (VSCS) NILOFAR over the Arabian Sea (25-31 October 2014)

2.3.1. Introduction

The very severe cyclonic storm, Nilofar developed from a low pressure area which lay over southeast Arabian Sea in the morning of 21st October. It moved northwestwards and concentrated into a Depression in the early morning of 25th over westcentral and adjoining southwest Arabian Sea. It intensified into a Cyclonic Storm over the same region in the morning of 26th. It then moved nearly northwards and further intensified into a Severe Cyclonic Storm (SCS) over westcentral Arabian Sea in the early morning of 27th and into a Very Severe Cyclonic Storm (VSCS) around noon of the same day. It continued to move nearly northwards and reached its maximum intensity around midnight of 28th with wind speed of 205 kmph. It then moved north-northeastwards and started to weaken rapidly under the influence of high vertical wind shear, entrainment of dry and cold air from the north and relatively lower ocean thermal energy. It weakened into a Severe Cyclonic Storm during early hours of 30th October and into a Cyclonic Storm in the afternoon of 30th October. It weakened into a Deep Depression in the early hours and into a Depression in the early morning of 31st October. It weakened into a well marked low pressure area over northeast Arabian Sea off north Gujarat coast in the forenoon of 31st Oct.

The salient features of this system are as follows.

i. The track of the system was unique, as it initially moved northwestward on the day of formation and then re-curved northeastwards. It further moved nearly northwards very slowly upto 29th evening and then east-northeastwards.
ii. The estimated maximum sustained surface wind speed in association with the cyclone was about 110 kt (205 kmph).
iii. The estimated central pressure was 950 hPa with a pressure drop of 56 hPa at the centre compared to surroundings.
iv. It exhibited Rapid Intensification as well as Rapid Weakening. The maximum sustained wind increased from about 100 kmph in the early morning of 27th to about 205 kmph in the early evening of 28th (in 36 hours). It weakened rapidly from VSCS (wind speed of about 200 kmph) in the morning of 29th into SCS (wind speed of about 110 kmph) in the morning of 30th and further into a low pressure area (wind speed < 30 kmph) on 31st morning.
v. Though the re-curvature of the track could be predicted by NWP models 3 to 4 days in advance, there was large variation in the position and time of the landfall as well as re-curvature.
vi. Though the genesis, track and intensification/weakening were predicted by IMD with reasonable accuracy five days in advance, rapid intensification and rapid weakening prediction was very challenging.

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

2.3.2 Monitoring and prediction of VSCS NILOFAR

The VSCS Nilofar was monitored & predicted continuously since its inception by the IMD. IMD could predict well in advance the genesis, intensification, weakening as well as the re-curvature of the track towards Gujarat coast. The VSCS Nilofar was monitored mainly with satellite observations, supported by meteorological buoys and ship observations. OMNI buoys deployed in the Arabian Sea captured the signals of the NILOFAR cyclone passage and the time series observations clearly exhibit the importance of the proximity of the location of the buoys to the cyclone track.

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

2.3.3. Brief life history

2.3.3.1. Genesis

Under the influence of the active northeast monsoon, a cyclonic circulation extending upto mid – tropospheric level lay over Lakshadweep area and adjoining Kerala in the morning of 19th October. It lay over southeast Arabian Sea and adjoining Lakshadweep on 20th October. Under its influence, a low pressure area formed over southeast Arabian Sea in the morning of 21st October. It persisted over the same region and became well marked in the early morning of 23rd October. It concentrated into a Depression in the early morning of 25th October and lay centered at 0000 UTC of 25th over westcentral and southwest Arabian Sea near Lat. 12.5°N/ Long. 61.5°E. According to the satellite imagery intensity was T 1.5. The convection increased from 24th to 25th with increase in organization and depth of cloud. The associated cloud showed shear pattern with major convection being shifted to west of the low level circulation centre. The associated maximum sustained wind speed was 25 kts. However, the winds were higher in the northern sector due to prevailing northeast monsoon circulation. A ship located near Lat. 12.5°N/ Long. 60.3°E reported MSLP of 1001 hPa and surface wind speed of 330°/20 kts indicating the fact that areal extent of the strong winds in the northwestern sector was less compared to the northeast and southwest sector.

Considering the environmental condition, the SST was 28-30°C around the system centre prior to the genesis of Depression. Ocean thermal energy was 60-80 kJ/cm^2 and vertical wind shear was moderate 10-20 kts around the system centre. The low level convergence was about $15*10^{-5}s^{-1}$ and vorticity was about $200 *10^{-5}s^{-1}$. The upper level divergence was about $30*10^{-5}s^{-1}$. The low level relative vorticity and convergence as well as the upper level divergence increased from 24th to 25th. There was poleward favourable outflow in association with an anti-cyclone to the east-northeast of the system. The upper tropospheric ridge at 200 hPa level ran along 15°N. The MJO was located in Phase 1 with amplitude greater than 1. The observed track of the system is shown in fig. 2.1.

2.3.3.2. Intensification and movement

In association with the favourable environmental and meteorological conditions as mentioned in previous section, the Depression moved north-northwestwards and intensified into a Deep Depression at 0300 UTC of 26th over westcentral and adjoining southwest Arabian Sea near Lat. 14.0°N/ Long. 62.0°E. It intensified into a cyclonic storm over the same region at 0600 UTC of 26th. As the system was lying close to the ridge, it moved slowly northwards and intensified into an SCS over west central and adjoining southwest Arabian Sea at 2100 UTC of 27th and into a VSCS at 0600 UTC of the same day and lay centred over westcentral Arabian Sea near Lat. 14.9°N/ Long. 62.0°E. It continued to intensify further and reached the peak intensity with T 5.5 at 1800 UTC of 29th and lay centred over westcentral Arabian Sea near Lat. 17.6°N/ Long. 61.8°E.

The system exhibited Rapid Intensification as well as Rapid Weakening. The maximum sustained wind increased from about 100 kmph in the early morning of 27th to about 205 kmph in the evening of 28th (in 36 hours) because of low vertical wind shear and increase in vorticity. It weakened rapidly from VSCS (wind speed of about 200 kmph) in the morning of 29th into SCS (wind speed of about 110 kmph) in the morning of 30th and further into a low pressure area (wind speed < 30 kmph) on 31st morning under the influence of high vertical wind shear, entrainment of dry and cold air and relatively lower ocean thermal energy. Also the convection was highly sheared from the low level circulation centre. The best track parameters of VSCS 'NILOFAR' are shown in Table 2.3.1.

Table 2.3.1 Best track positions and other parameters of the Very Severe Cyclonic Storm, 'NILOFAR' over the Bay of Bengal during 25-31 October, 2014

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
25/10/2014	0000	12.5/61.5	1.5	1004	25	3	**D**
	0300	12.5/61.5	1.5	1004	25	3	D
	0600	12.5/61.5	1.5	1004	25	3	D
	1200	13.0/61.0	1.5	1003	25	3	D
	1800	13.0/61.0	1.5	1003	25	3	D
26/10/2014	0000	14.0/62.0	1.5	1002	25	4	D
	0300	14.0/62.0	2.0	999	30	5	**DD**
	0600	14.1/62.0	2.5	998	35	6	**CS**
	0900	14.1/62.0	2.5	996	35	7	CS
	1200	14.2/62.0	2.5	994	40	8	CS
	1500	14.3/62.0	3.0	994	40	8	CS

	1800	14.4/62.0	3.0	994	45	10	CS
	2100	14.5/62.0	3.0	994	50	12	**SCS**
27/10/2014	0000	14.8/62.0	3.5	990	55	16	SCS
	0300	14.9/62.0	3.5	990	60	18	SCS
	0600	14.9/62.0	4.0	986	65	20	**VSCS**
	0900	14.9/62.0	4.0	984	65	22	VSCS
	1200	15.0/62.0	4.0	982	70	24	VSCS
	1500	15.1/62.0	4.0	981	70	25	VSCS
	1800	15.3/62.0	4.0	980	70	26	VSCS
	2100	15.6/61.8	4.0	979	75	27	VSCS
28/10/2014	0000	15.7/61.8	4.0	978	75	28	VSCS
	0300	15.8/61.7	4.0	977	75	29	VSCS
	0600	15.9/61.6	4.5	974	80	32	VSCS
	0900	16.3/61.6	5.0	966	90	40	VSCS
	1200	16.7/61.8	5.5	954	100	52	VSCS
	1500	17.2/61.8	5.5	952	105	54	VSCS
	1800	17.6/61.8	5.5	950	110	56	VSCS
	2100	18.0/61.8	5.5	950	110	56	VSCS
29/10/2014	0000	18.2/62.0	5.5	954	105	52	VSCS
	0300	18.7/62.0	5.0	958	100	48	VSCS
	0600	18.9/62.0	5.0	962	95	44	VSCS
	0900	19.0/62.0	5.0	968	90	40	VSCS
	1200	19.2/62.2	4.5	974	80	32	VSCS
	1500	19.4/62.5	4.0	980	70	26	VSCS
	1800	19.4/62.8	4.0	986	70	24	VSCS
	2100	19.4/63.1	3.5	988	60	20	**SCS**
30/10/2014	0000	19.5/63.6	3.5	990	60	18	SCS
	0300	19.8/64.1	3.0	994	50	14	SCS
	0600	20.2/64.3	3.0	998	45	10	SCS
	0900	20.2/64.5	2.5	1000	40	9	**CS**
	1200	20.5/64.6	2.5	1001	40	8	CS
	1800	20.6/64.7	2.5	1002	35	7	CS
	2100	20.7/65.0	2.0	1003	30	5	**DD**
31/10/2014	0000	20.7/65.1	1.5	1004	25	4	**D**
	0300	Weakened into a well-marked low pressure area over northeast Arabian Sea off Gujarat coast.					

2.3.4. Maximum Sustained Surface Wind speed (MSW) and estimated central pressure at the time of landfall:

The MSW in association with a cyclone affecting Indian coasts is defined as the average surface wind speed over a period of 3 minutes measured at a height of 10 meters. The MSW is either estimated by the remotely sensed observations or recorded by the surface based instruments. Based on satellite imagery, an empirical technique known as the Dvorak technique is utilized worldwide to estimate the intensity of cyclone and hence the associated MSW. Based on the observation of the pressure drop at the centre, MSW can also be estimated using the empirical pressure-wind relationship (MSW= 14.2* √ pressure drop at the centre).

The lowest Estimated Central Pressure (ECP) of the system was 950 hPa at 1800 UTC of 28th Oct. with a pressure drop of 56 hPa. The estimated MSW was 110 kts. The variations in ECP and MSW are shown in Fig. 2.3.1.

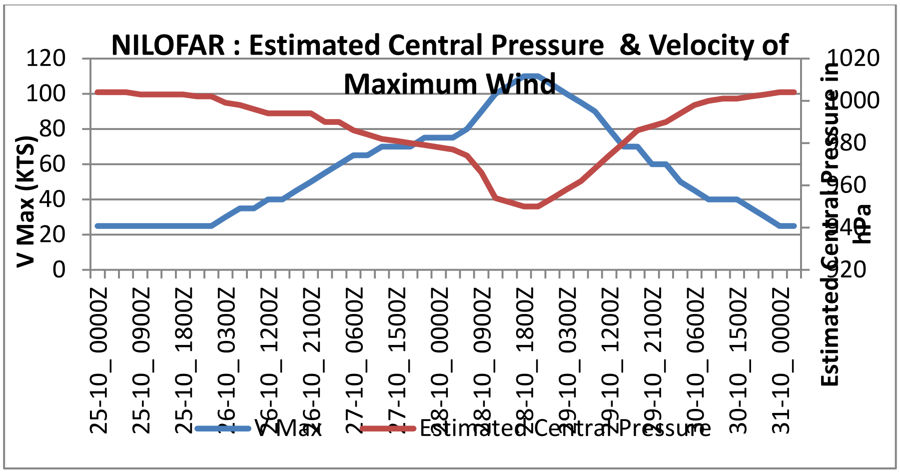


Fig. 2.3.1 Variations in ECP and MSW during VSCS Nilofar for the period 25 -31 Oct. 2014.

2.3.5 Characteristics observed by buoy

The buoys AD06, AD02 and AD07 were closer to the track. The buoys AD08, AD09 and AD10 were away from the cyclone track, with very less response in the met and ocean parameters. Table 2.3.2 shows the distance between NILOFAR cyclone track and OMNI buoy locations. Fig. 2.3.2-4 shows the atmospheric air pressure, wind speed and significant wave height during the period 22 Oct. – 2 Nov. 2014.

Table -2.3.2: Distance between NILOFAR cyclone track and OMNI buoy locations

Sl.No	Buoy ID	Distance between cyclone track and Buoy position
1	AD02	421 nm
2	AD04	876 nm
3	AD06	158 nm
4	AD07	417 nm
5	AD08	578 nm
6	AD09	897 nm
7	AD10	758nm

The Atmospheric Pressure showed a maximum drop observed at AD07 with recorded minimum pressure of 1004.46 hPa on October 26, 2014.

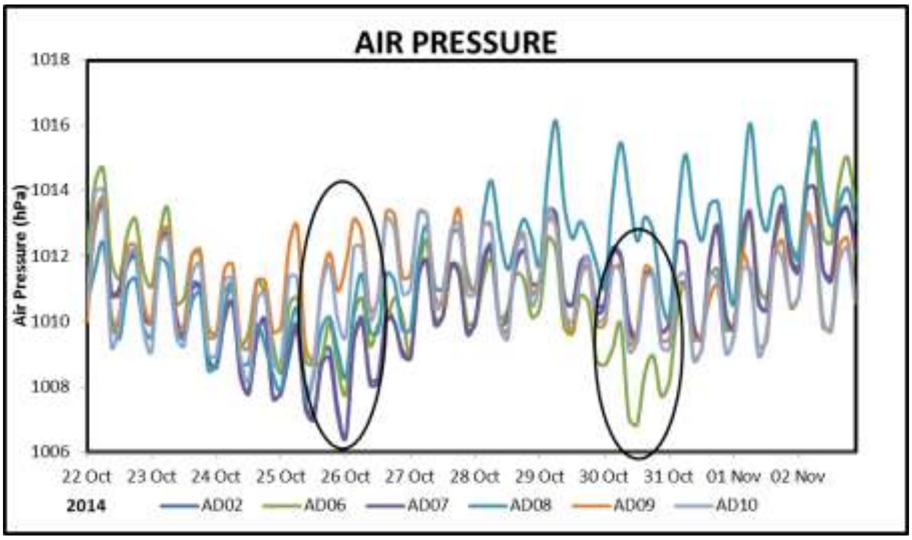


Fig. 2.3.2 Atmospheric Pressure recorded by the buoys during 22 Oct. – 2 Nov. 2014

The buoy AD06 which was near the track of the cyclone recorded a maximum wind speed of 11.4 m/s on October 24, 2014 and 11.2 m/s on October 30, 2014.

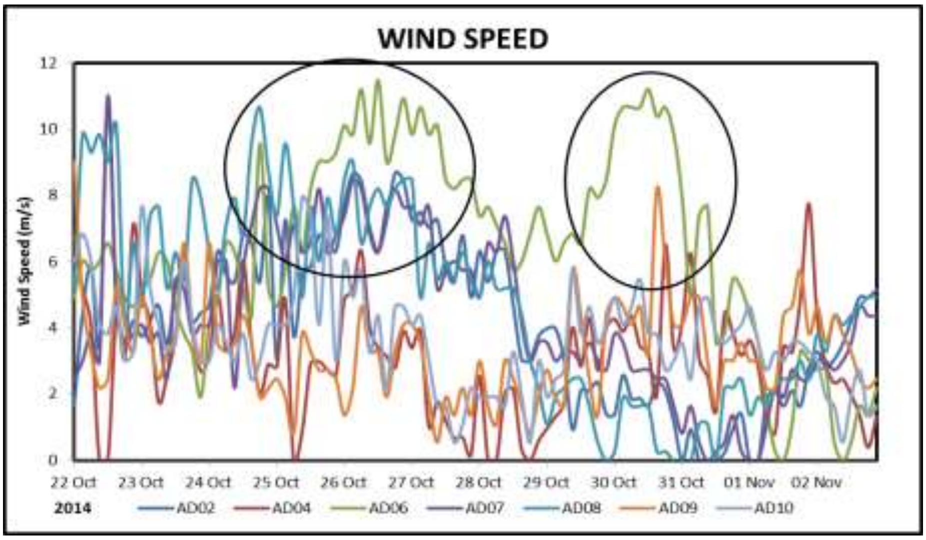


Fig. 2.3.3 Wind speed recorded by the buoys during 22 Oct. – 2 Nov. 2014

The increase in significant wave height was recorded maximum at AD07 and AD06 location with a significant wave height of 3.22 m and 3.16 m on 26^{th} and 30^{th} October, 2014 respectively.

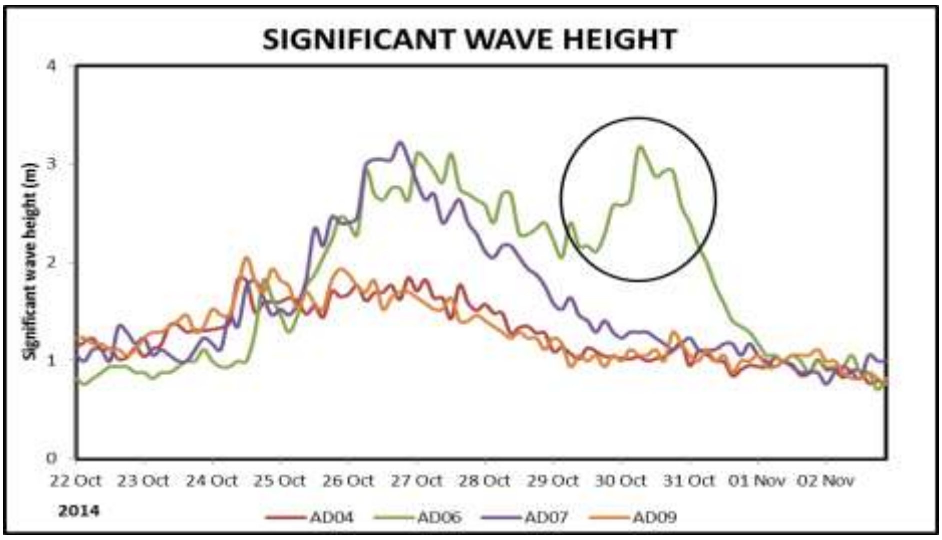


Fig. 2.3.4 Significant wave height recorded by the buoys during 22 Oct. – 2 Nov. 2014

2.3.6 Characteristic features observed through Satellite and RADAR

2.3.6.1 Features observed through satellite

Satellite monitoring of the cyclone was mainly done by using half hourly Kalpana-1, INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 and MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical satellite INSAT-3D imageries of VSCS NILOFAR representing the life cycle of the cyclone are shown in Fig. 2.3.5 - 2.3.7.

According to INSAT-3D imageries and products, a low level circulation centre (LLCC) attained intensity of T.1.5 over westcentral Arabian Sea and adjoining east-central and south Arabian Sea on 25th/0000 UTC. Associated broken low and medium clouds with embedded intense to very intense convection extended over 8-10° laittude/longitude box around the vortex centre over the Arabian Sea and adjoining Indian Ocean. Convection increased gradually and started organising. The system attained intensity of T.2.0 at 0300 UTC of 26th. It further intensified to T.2.5 at 0600 UTC of 26th and convection organised into a curved band pattern with the lowest cloud top temperature of -93.0°C. It intensified to T.3.0 and T.3.5 at 26th/1500 UTC and 27th/0000 UTC respectively. The convection showed eye pattern from 0000 UTC of 27th. It attained intensity of T.4.0 and T.4.5 around 0600 UTC of 27th and 28th respectively and further attained its peak intensity of T.5.5 within next 6 hours (28th/1200 UTC). On 29th/0300 UTC the system started showing signs of weakening with ragged eye pattern and intensity T.5.0. By 29th/1500 UTC, its intensity decreased further to T.4.0. By 30th/0300 UTC, its T. No. became T.3.0. At 2100 UTC of 30th, its intensity was T.2.0 and on 31st/0000 UTC, it was T.1.5. During weakening phase the cloud pattern changed from eye pattern to curved band pattern and finally to shear pattern on 30th and 31st Oct. 2014.

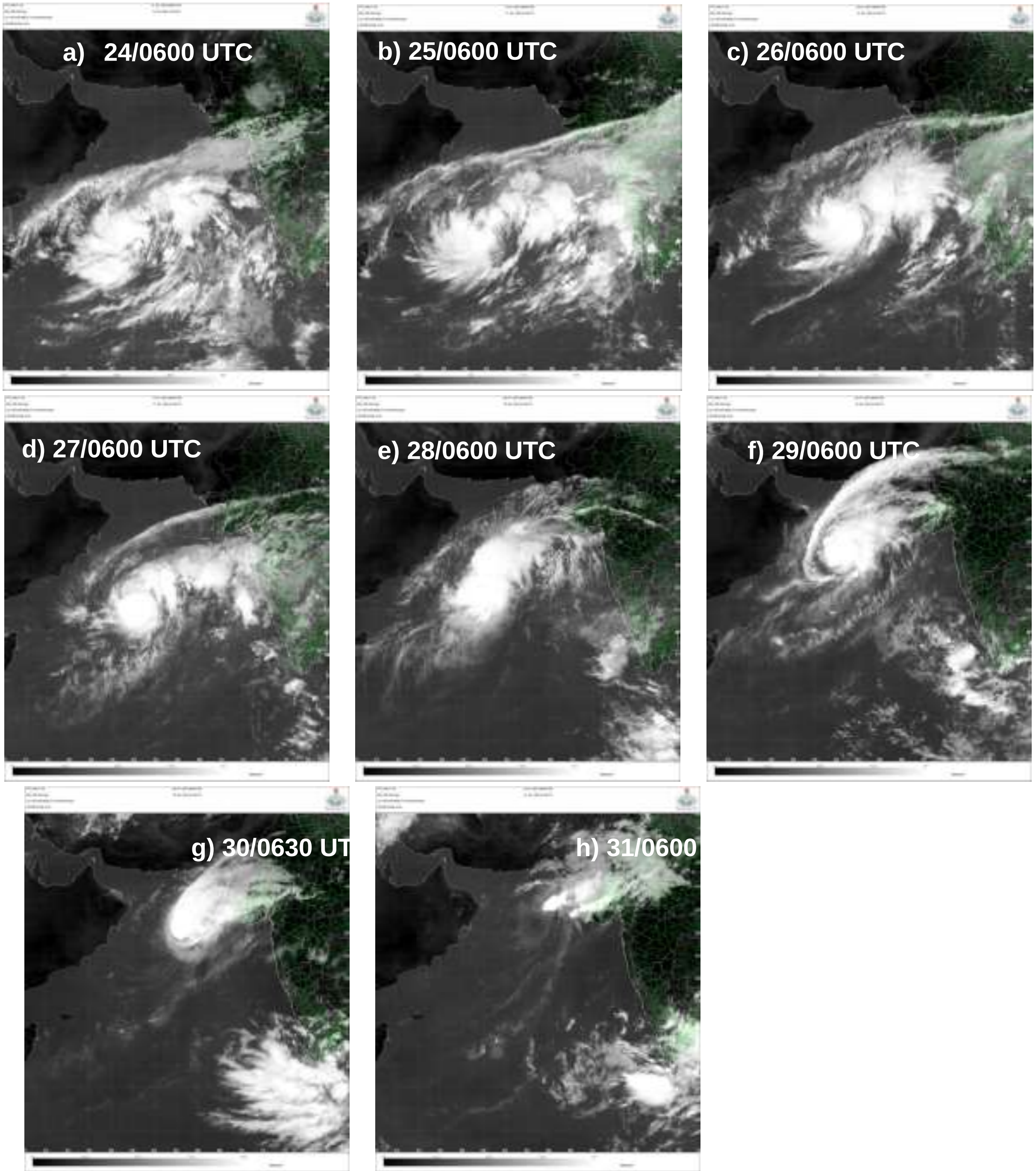


Fig. 2.3.5 Typical INSAT-3D IR imageries based on 0600 UTC in association with VSCS NILOFAR during 24-31 October 2014

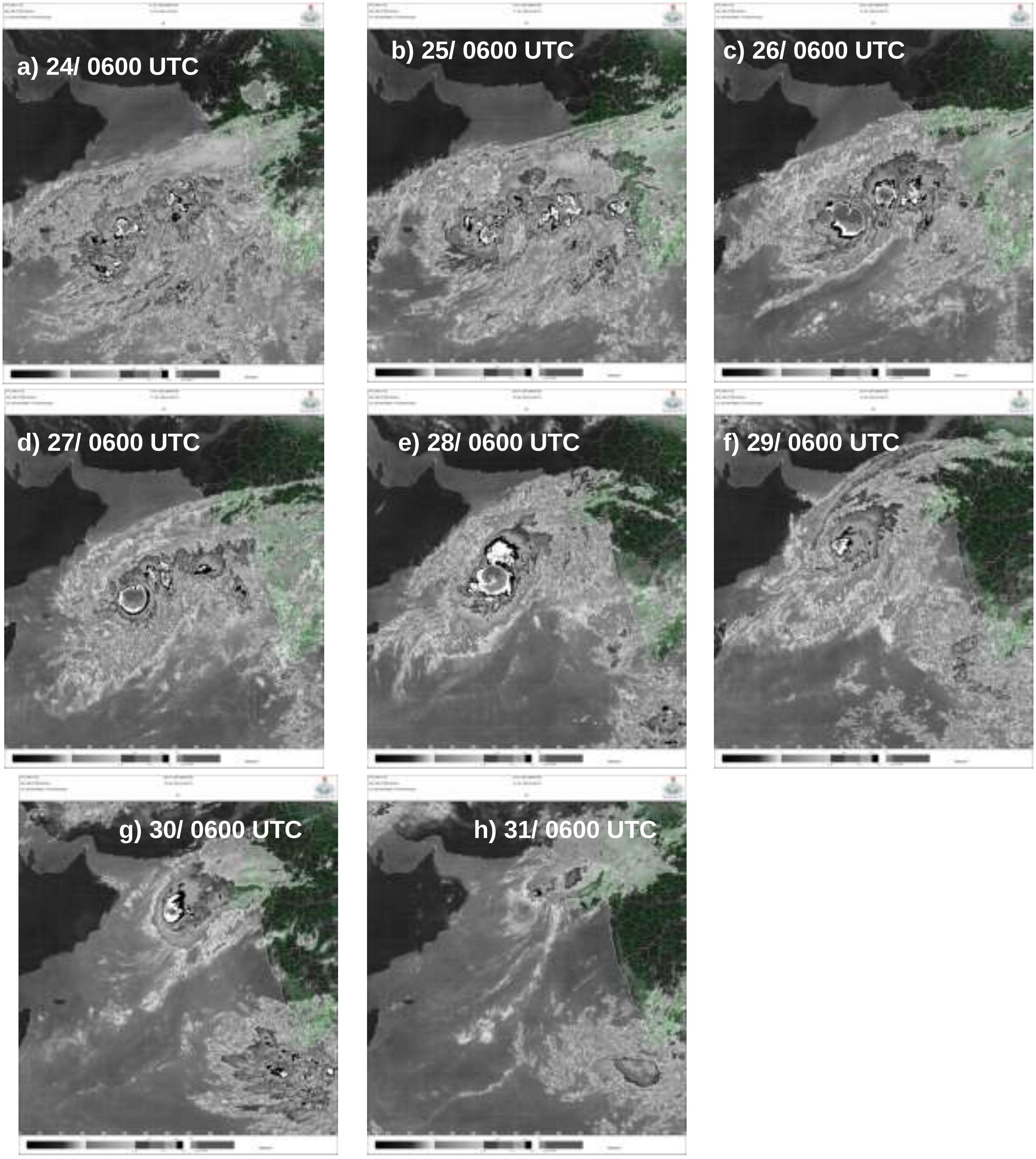


Fig. 2.3.7 INSAT-3D enhanced IR imageries in association with VSCS NILOFAR during 24-31 October 2014

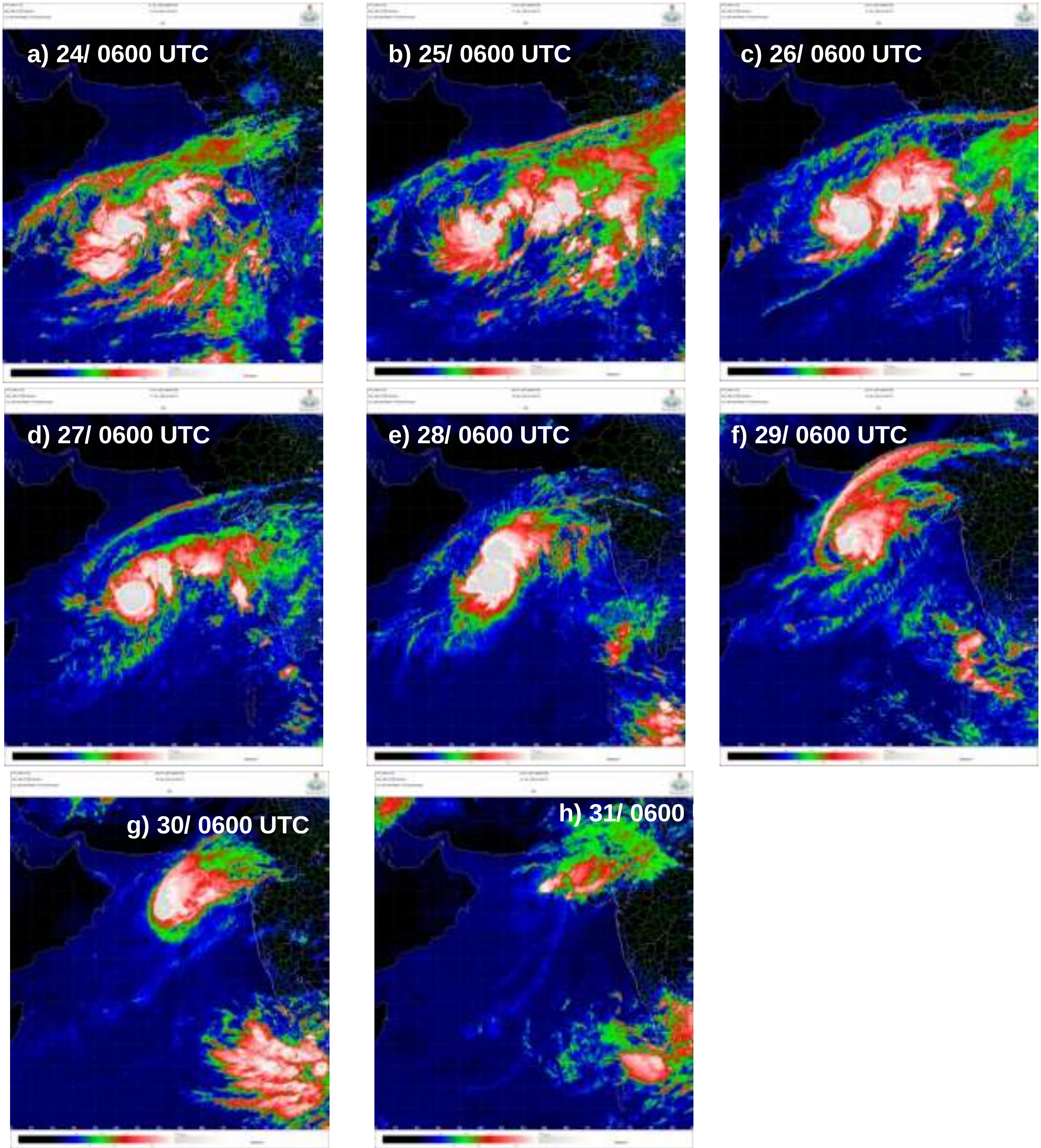


Fig. 2.3.7 INSAT-3D coloured enhanced IR imageries based on 0600 UTC in association with VSCS NILOFAR during 24-31 October 2014

2.3.6.2 Features observed through RADAR

Cyclone Detection Radar (CDR) Bhuj could monitor the system on 31st Oct. as the system came in its range. Due to weakening of the system the characteristic features like location and intensity could not be detected with RADAR. However, the convection in association with the system lying to the right of the system centre was well captured in the RADAR imagery as shown in Fig. 2.3.8.

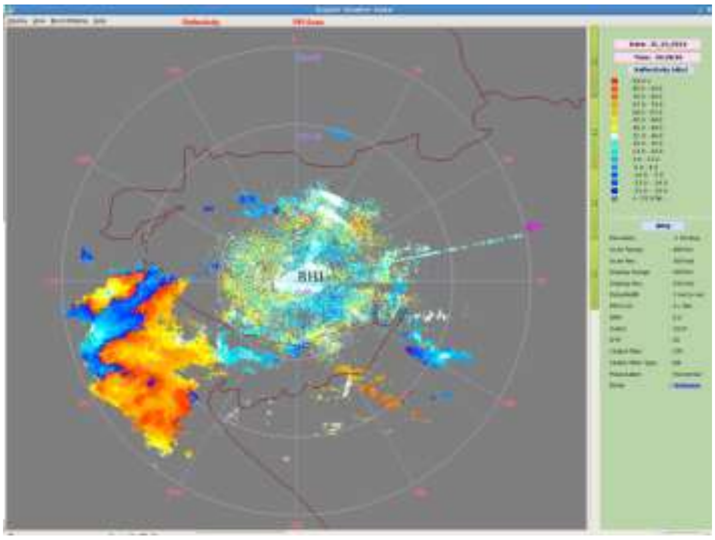


Fig. 2.3.8: RADAR Imagery from CDR Bhuj based on 0000 UTC of 31st Oct. 2014

2.3.7. Dynamical features

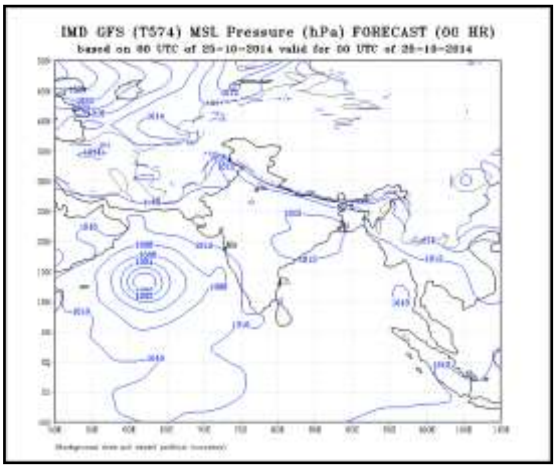
To analyse the dynamical features, the Mean Sea Level Pressure (MSLP), surface winds at 10 m height and winds at 850, 500 and 200 hPa levels during the period 25 – 31 October 2014 are presented in Fig. 2.3.9 based on IMD-GFS analysis.

The maximum wind at lower level was oriented north-south and active northeast monsoon flow prevailed to the north during genesis stage i.e., 25th Oct. The wind speed was little bit higher in the northern sector. Hence the wind distribution was asymmetric. While the size of the gale wind gradually increased with intensification of the system and continued to be asymmetric, the core wind became symmetric when system intensified into VSCS on 27th Oct. However, with the weakening of the system from 29th Oct., the size of the gale wind decreased in the northeast and southeast sector.

During 26-28th, the VSCS Nilofar was sandwiched between two anti-cyclonic circulation, one lying to the southeast and another to the west-northwest of the system centre. As a result, during 26-28th the system nearly moved northwards with very slow speed. At the same time it provided a very low vertical wind shear (5-10 kts) which resulted in rapid intensification.

A trough in the upper tropospheric westerly approached from west which led to increase in the westerlies in the storm region from 29th Oct. 2014. Subsequently, as the system moved to the north of the ridge line it steered northeastwards from 29th onwards towards Gujarat and adjoining Pakistan coast. However, as it moved northeastwards, it encountered high vertical wind shear, entrainment of dry and cold air towards to the core due to mid-latitude westerlies. Hence, it started weakening rapidly over the sea itself before reaching the Gujarat coast.

The analysis could very well capture the genesis and track of the system. However, the rapid intensification and rapid weakening before reaching coast could not be detected reasonably.



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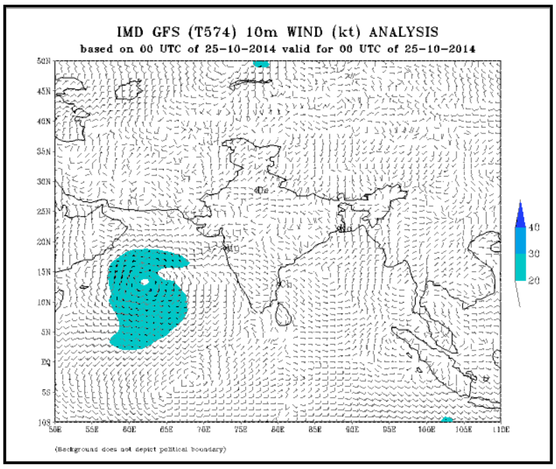

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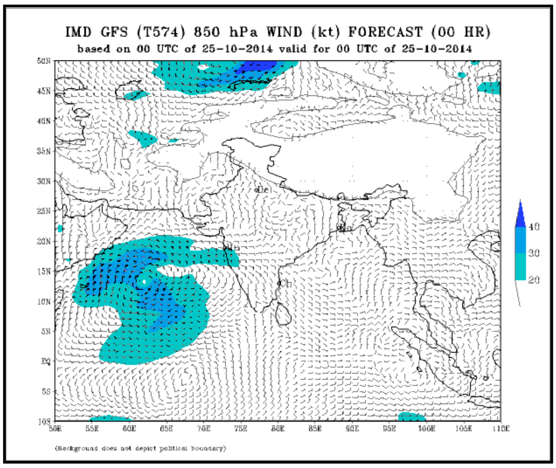

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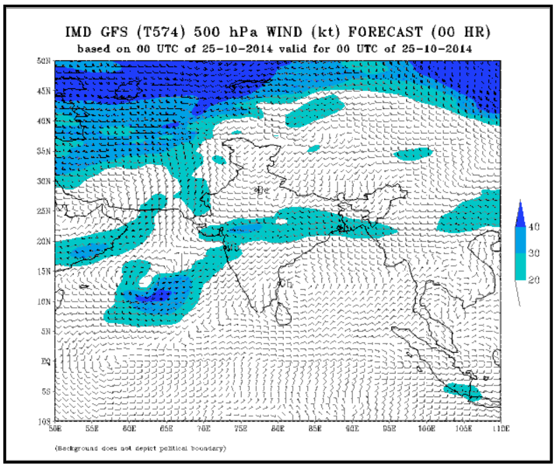

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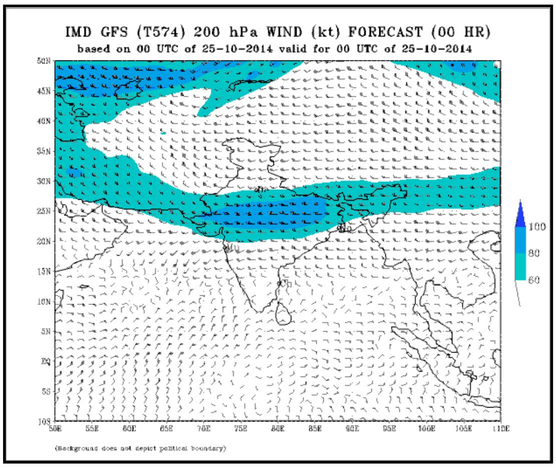
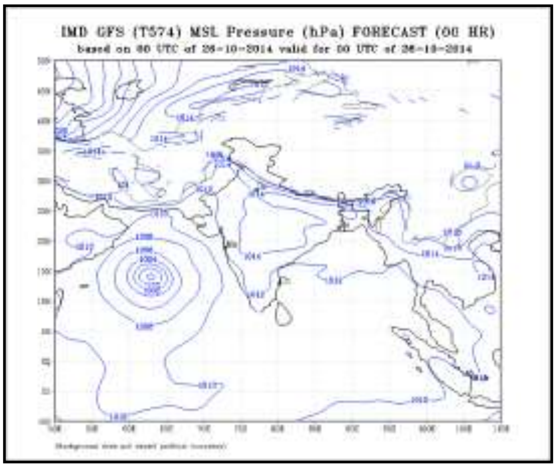


(e)

Fig. 2.3.9 IMD-GFS Analysed charts on 25th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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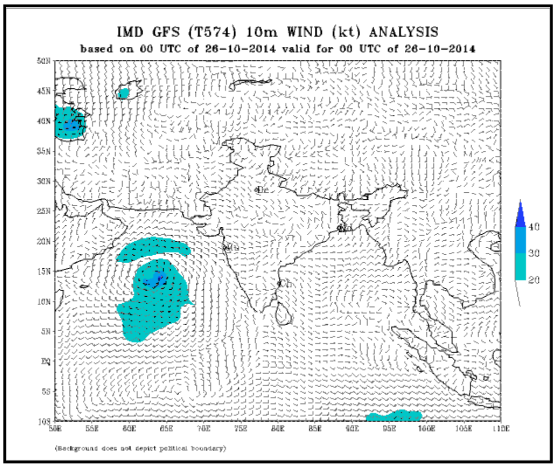

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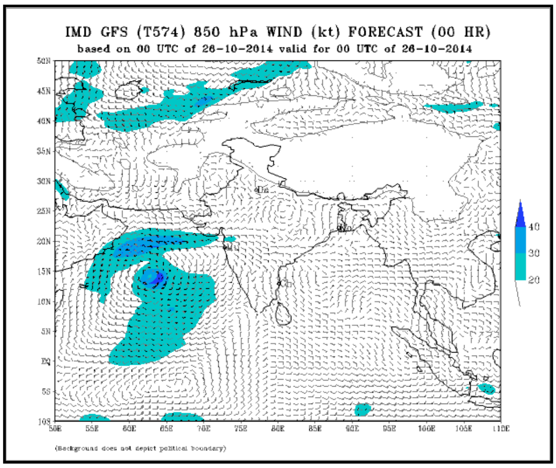

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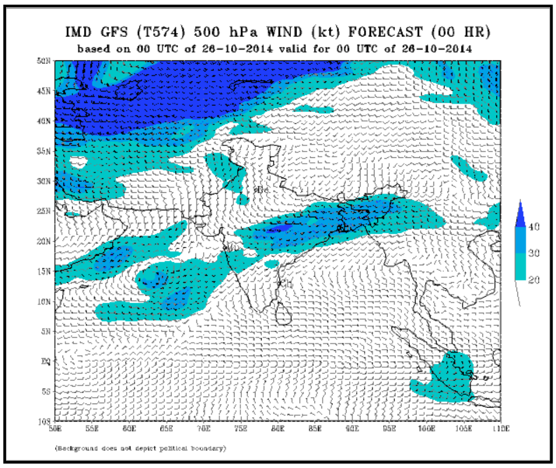

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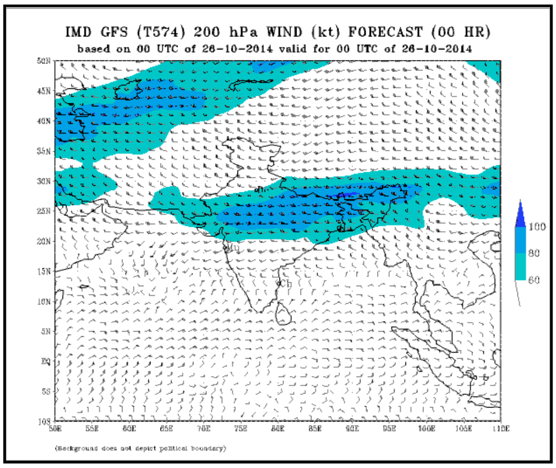

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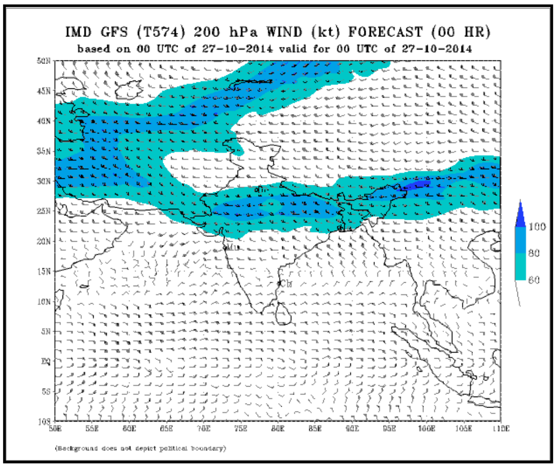
Fig. 2.3.9 (contd.) IMD-GFS Analysed charts on 26th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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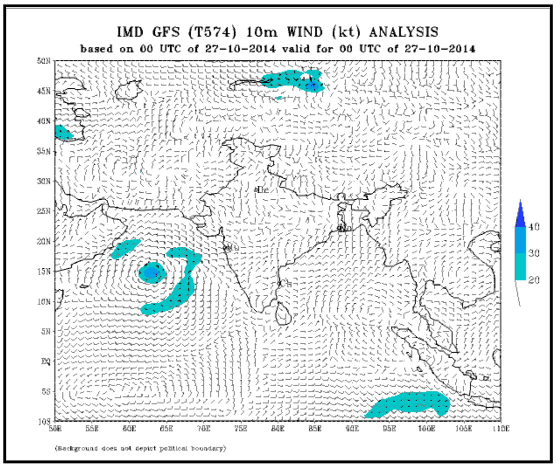

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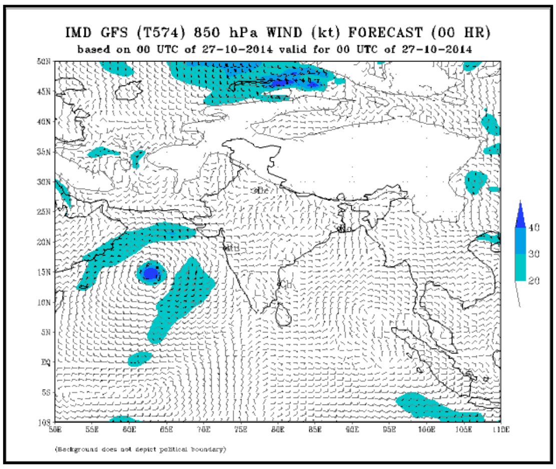

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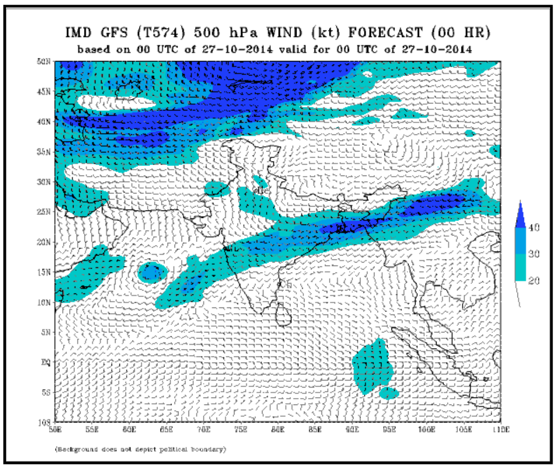

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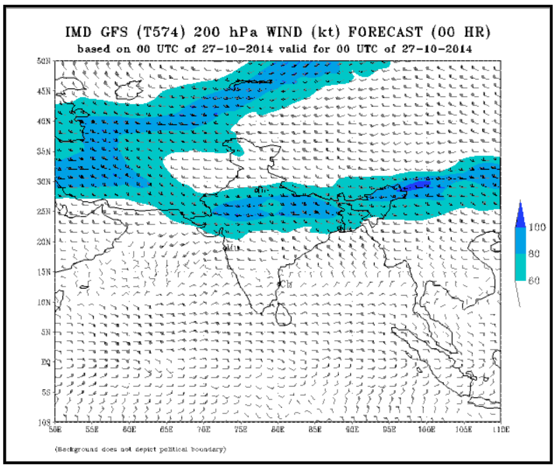
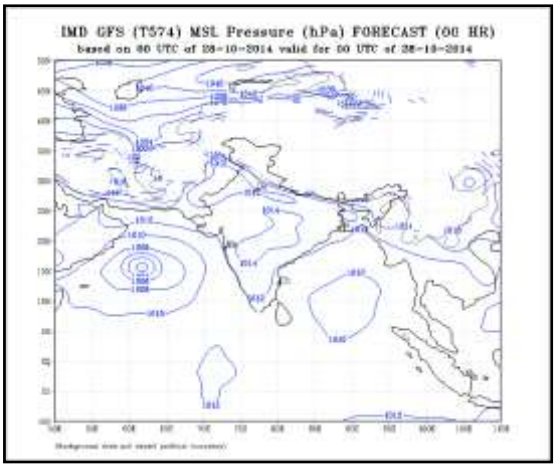


(e)

Fig. 2.3.9 (contd) IMD-GFS Analysed charts on 27th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



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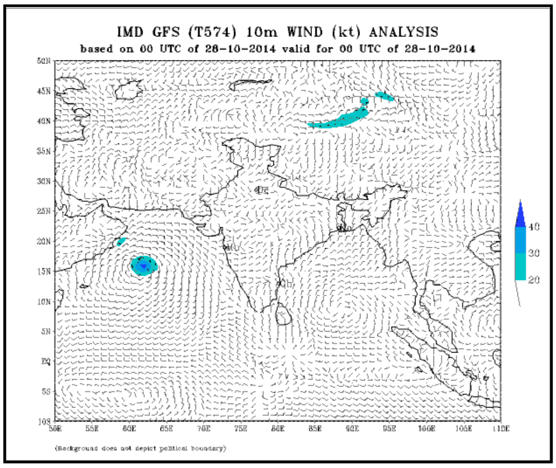

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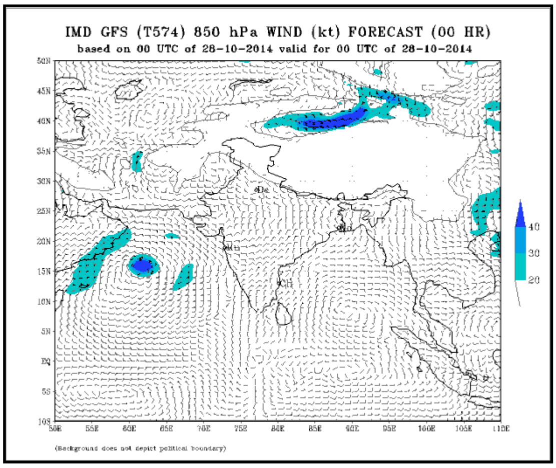

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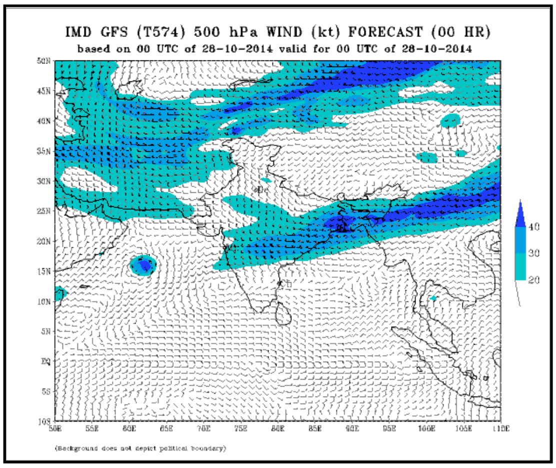
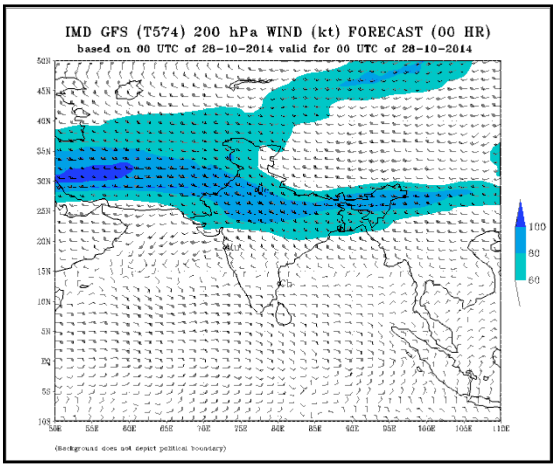
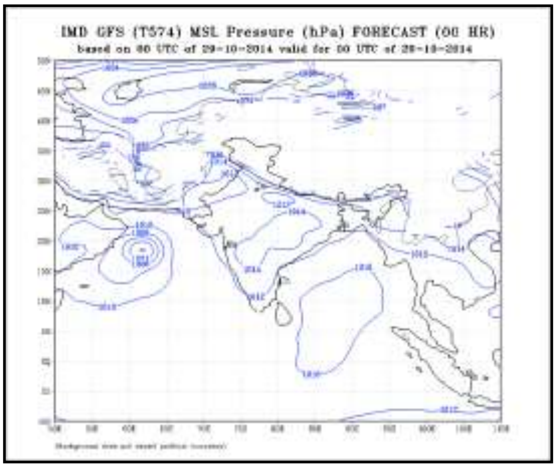


(d)

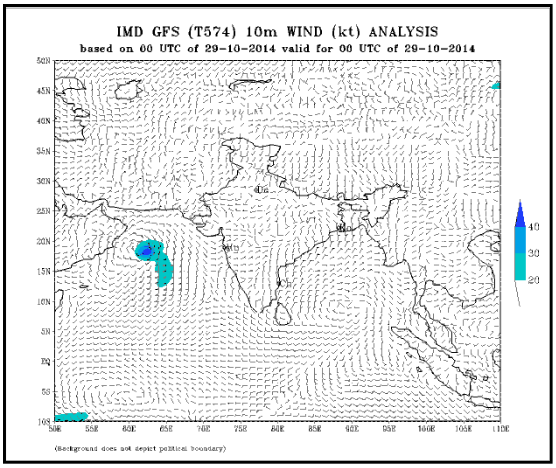


(e)

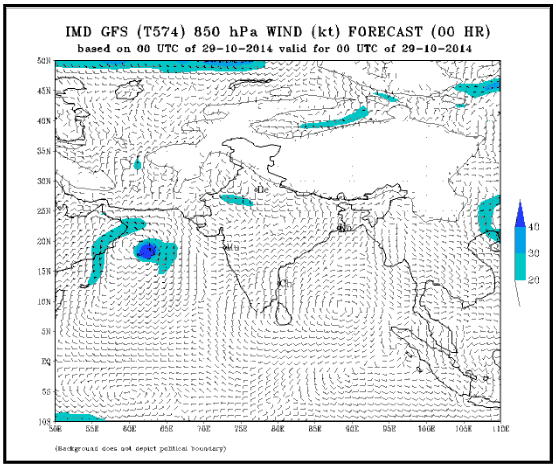
Fig. 2.3.9 (contd.) IMD-GFS Analysed charts on 28th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



(a)



(b)



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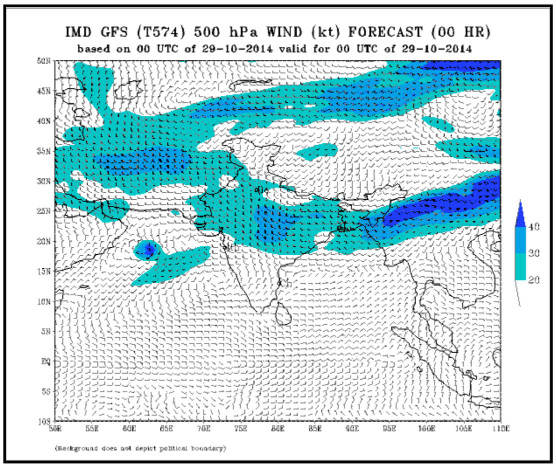

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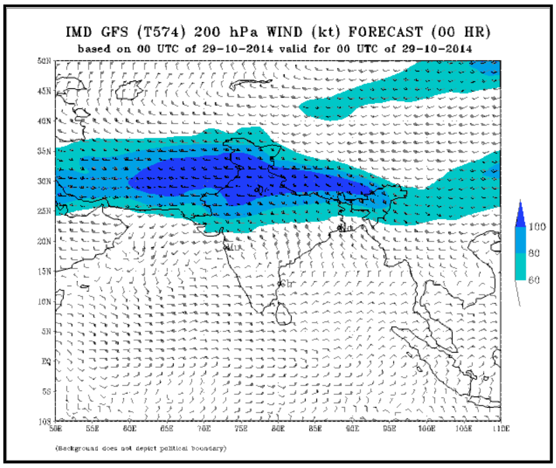
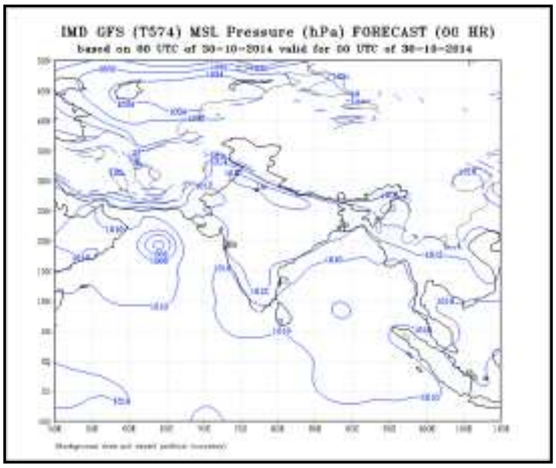
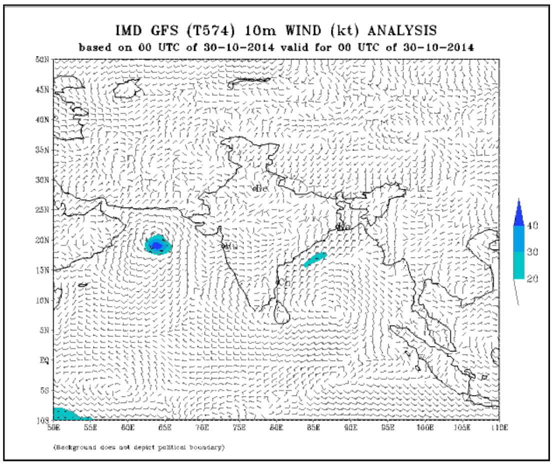


(e)

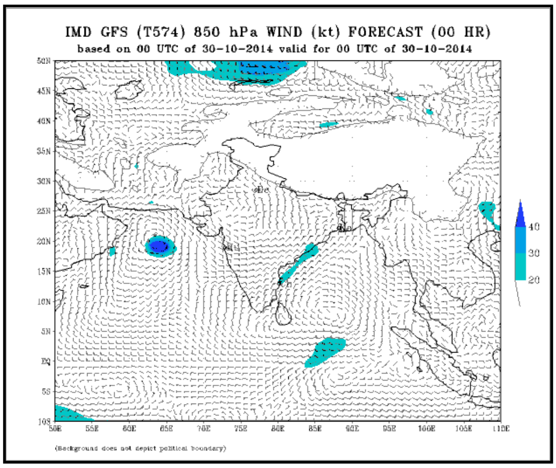
Fig. 2.3.9 (contd.) IMD-GFS Analysed charts on 29th October 2014 (a) MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



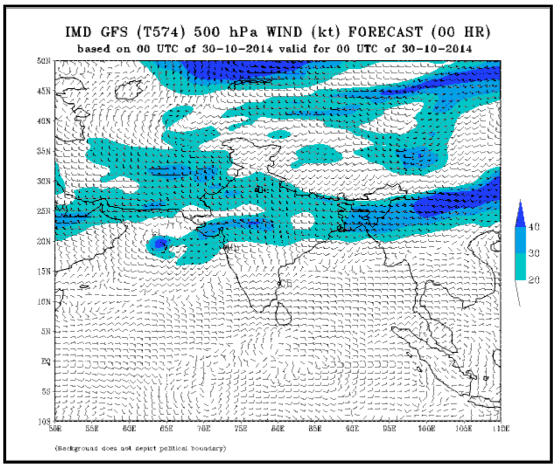
(a)



(b)



(c)



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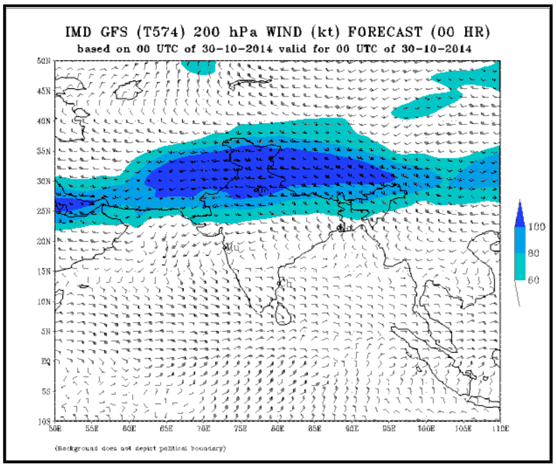
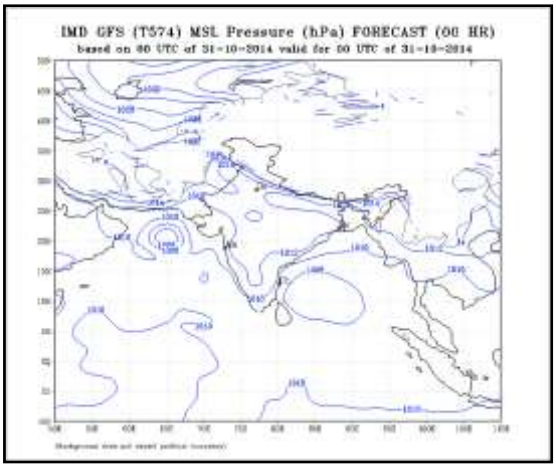
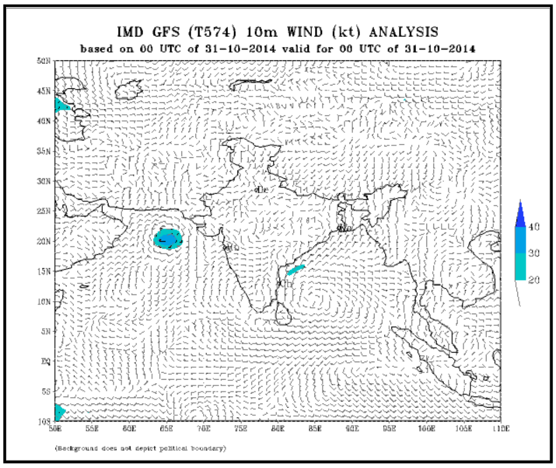


(e)

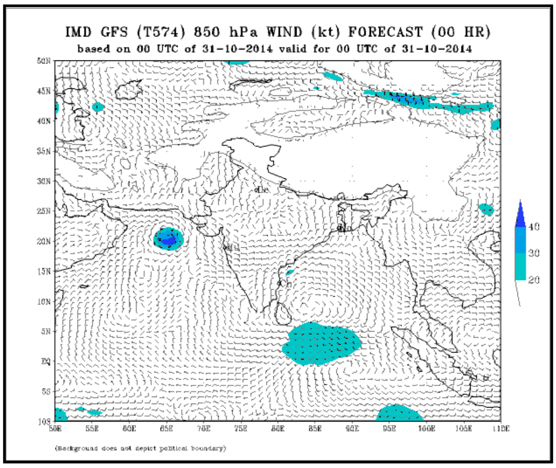
Fig. 2.3.9 (contd.) IMD-GFS Analysed charts on 30th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds



(a)



(b)



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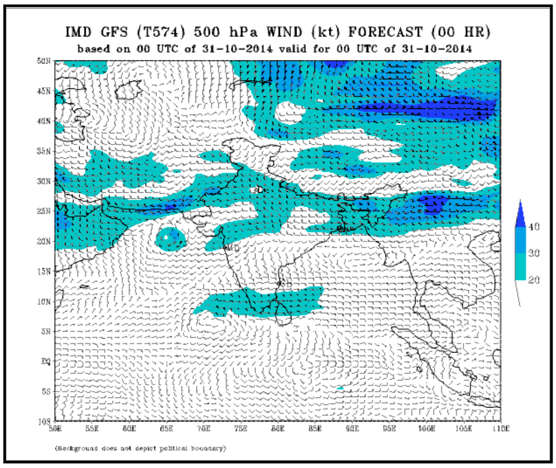

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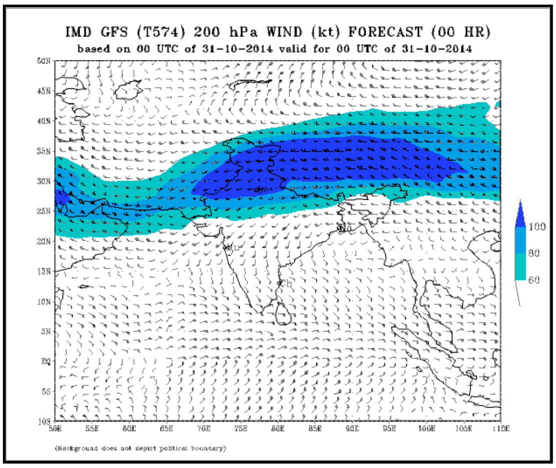

(e)

Fig. 2.3.9 (contd.) IMD-GFS Analysed charts on 31th October 2014 (a)MSLP Analysis, (b) 10 m winds, (c) 850 hPa winds, (d) 500 hPa winds, (e) 200 hPa winds

2.3.8. Realized Weather:

2.3.8.1. Heavy rainfall due to NILOFAR:

Under the influence of TC NILOFAR, Konkan and Goa region experienced widespread rain with heavy rainfall at isolated places on 25th, widespread rain with heavy to very heavy rainfalls at a few places on 26th. However, as the system started to weaken rapidly over the sea itself on 30th/31st, without crossing the coast significant rainfall was not realised over the Gujarat. Rainfall realised in association with the TC NILOFAR during the period 25-31 October 2014 is furnished below:

24 hrs cumulative rainfall amounts (≥ 7cm) ending of 0300 UTC of date realised in association with passage of TC NILOFAR' during 25-31 October 2014 are as follow

25 October 2014

Konkan & Goa:

Margaon-12

26 October 2014

Konkan & Goa: Margao-29, Marmugao, Mapusa & Panjim-14 each, Ponda-12, Dabolim N.A.S.- Navy-11, Quepem-11, Sanguem-10, Pernem-8, Vengurla-7.

Madhya Maharashtra: Chandgad-7

Rainfall associated with the TC NILOFAR when it was out in the sea is determined from satellite-gauge merged rainfall dataset generated by IMD-NCMRWF for the North Indian Ocean region from 2013 onwards based on TRMM data. 24-hour accumulated rainfall associated with the TC NILOFAR during the period 25 -31 October 2014 as well as the 7-day average rainfall during the same period are furnished in Fig. 2.3.10.

As can be seen, during the period 26-27 October, when the system was in its intensification phase, rainfall was observed over a wide area covering about 8-10° latitude / longitude belt in the vicinity of the TC centre and mainly in the northeast sector of the TC centre. Rainfall of the order of 2 - 8 cm are observed in the outer storm area covering regions of Konkan and Goa and adjoining areas of Madhya Maharashtra and Marathwada. However, after the recurvature on 29th, associated with the weakening of the system, area of rainfall activity during 29 October – 1st Nov is decreased to about 5° latitude/ longitude belt. No rainfall is observed over Gujarat region as the system weakened rapidly over the sea itself on 31st Oct. and 1st Nov. 2014.

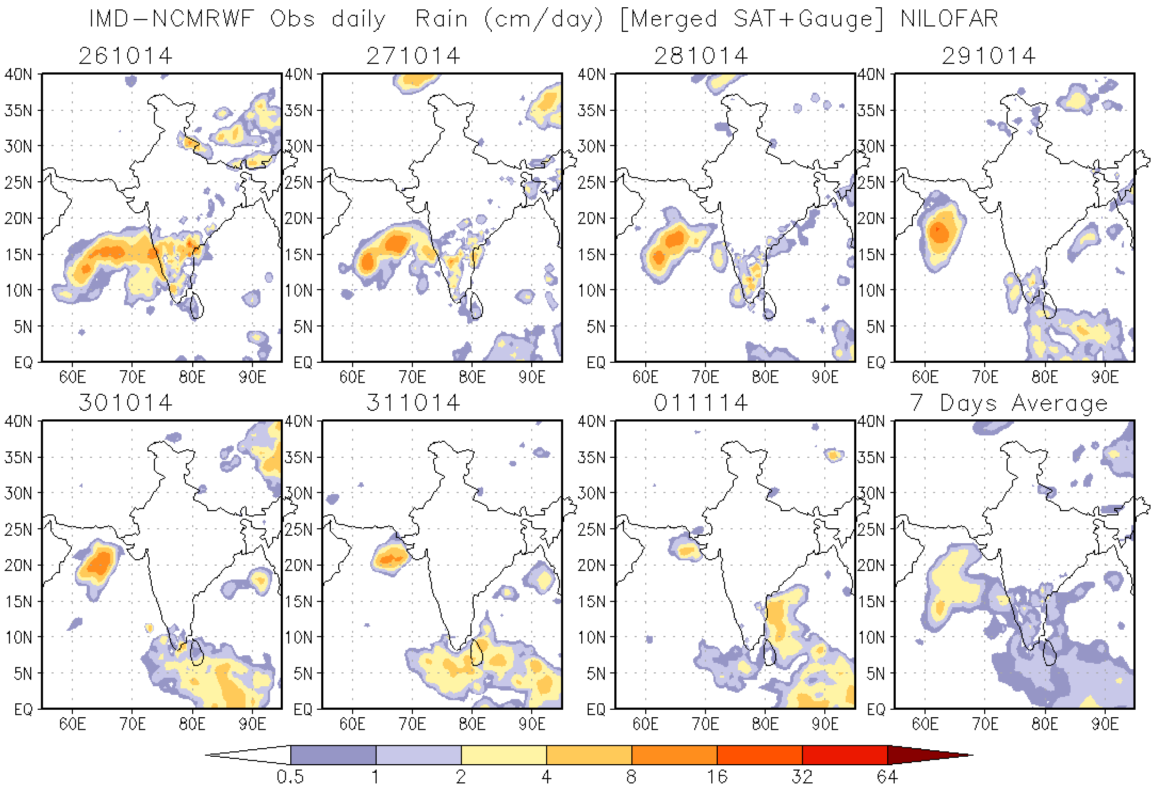

Fig. 2.3.10 IMD-NCMRWF satellite-gauge merged daily rainfall (in cm) during the period 25 October – 1 November 2014 and the 7-day average rainfall during the same period.

2.3.8.2 Gale Wind

As the system weakened over the sea, no gale wind was reported. However, strong winds with speed of 30 kmph at 0905 UTC and 25 kmph at 1258 IST was recorded by High Wind Speed Recorders (HWSRs) at Dwarka and Okha respectively on 31st Oct. (Fig. 2.3.11).

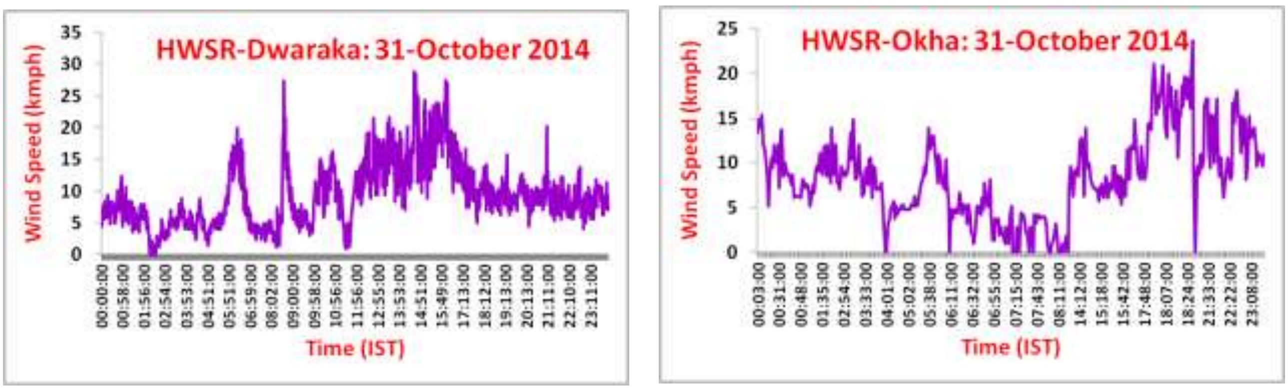

Fig. 2.3.11: Time series of wind speed recorded by HWSR at Dwarka and Okha on 31st October 2014.

2.3.8.3. Storm Surge

No storm surge has been reported due to weakening of the system over the sea.

2.3.8.4 Damage due to Cyclone 'NILOFAR'

No damage has been reported due to this system.

CHAPTER-III

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

1. Statistical prediction of movement of cyclonic storms and depressions over Bay of Bengal through LOESS technique

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India Meteorological Department, Chennai, India
e mail : **rmanramu@gmail.com**

ABSTRACT

Accurate cyclone track prediction has always been a challenge to the operational weather forecaster. An attempt has been made in this study for prediction of the cyclone track by employing three statistical techniques, *viz.,* analogue, analogue-cum-regression and Locally weighted Scatterplot Smoothing (LOESS). Track data of cyclonic disturbances which formed and moved in the Bay of Bengal during the period 1961-2008 has been used. A statistical model has been developed for comparison of the accuracy levels of track prediction through these three techniques and results have been discussed. It has been observed that the average track forecast error of 147 km calculated by LOESS technique is minimum compared to those obtained from analogue and analogue-cum-regression techniques. In the case of recurved systems also, the forecast error obtained through LOESS is minimum. Heidke Skill Score, Peirce Skill Score and Proportion Correct have been calculated for along-Track and Cross-Track components which indicate better accuracy and superiority of LOESS technique over the analogue and analogue-cum-regression techniques. Other skill score indices have also been computed and results presented.

Key words - LOESS, Analogue regression, Tropical cyclone, Along-Track error, Cross-Track error, Heidke skill score, Peirce skill score.

2. Characterisation and asymmetry analysis of rainfall distribution associated with tropical cyclones over Bay of Bengal : NISHA (2008), LAILA (2010) and JAL (2010)

S. Balachandran and B. Geetha
Regional Meteorological Centre, Chennai, India
email: balaimd@gmail.com

ABSTRACT

The precipitation characteristics and spatial rainfall asymmetry in respect of three tropical cyclones (TCs) of Bay of Bengal, *viz.,* NISHA (2008), LAILA (2010) and JAL(2010) that affected coastal Tamil Nadu are studied using TRMM based rain rate data. The analysis is carried out by dividing the life cycle of the TC into various stages of intensification and weakening. Percentage frequency distribution, radial profile and quadrant-wise mean rain rates are determined stage-wise for each TC. Further, spatio-temporal variations in the rainfall asymmetry is studied using Fourier analysis by computing the first order wave number-1 asymmetry around the IC centre. The results indicate a shifting of higher frequency rain rates from higher to lower rain rate side when the IC passes from intensification to weakening stages. The azimuthally averaged mean rain rates indicate a peak rain rate of 4-5 nun/hr over 50-100 km from the TC centre during intensification stages which decreases to a very low rate of about 1 nun/hr during the final stages of weakening. For the same intensity category, the radial profiles of mean rain rates show marked difference between the intensification and weakening stages. The quadrant mean rain rates show large asymmetries in the radial rainfall distribution with more rainfall concentrated in front left quadrant during the stages of intensification. Such TC rainfall asymmetries are shown to be influenced by the environmental vertical wind shear and translational speed of the TC. When the wind shear and storm motion vectors are in the same direction, a dominant down shear left asymmetry is observed. Evolution of wave number-1 asymmetry indicates that, by and large, asymmetry amplitude increases from the centre outwards and a cyclonic (anti-cyclonic) shift during the intensification (weakening) stages of the TCs.

Key words - Tropical cyclone, TRMM, Precipitation, Rainfall, Asymmetry, Fourier analysis, Vertical wind shear. Translational speed.

CHAPTER-IV

Activities of PTC Secretariat during the Intersessional Period 2014-2015

PTC Secretariat activities during the intersessional period are given as under:

- Pursuant upon the organization of 41st Session of the WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and the Arabian Sea (PTC-41) (Dhaka, Bangladesh, 2-6 March, 2014), PTC Secretariat collected input/feedback from the Panel Member countries and other participating international organizations under the auspicious of WMO and ESCAP and prepared / compiled the PTC-41 report. The same was circulated to all Panel members, WMO, ESCAP and other concerned international organizations.
- In connection to the updation of Tropical Cyclone Operational Plan (TCP-21) for 2014 version, PTC Secretariat collected feedback from PTC Member countries in order to assist Rapporteur of the Operation Plan in the early issuance of TCP-21 2014 version.
- As per recommendation of PTC at its 41th Session (Dhaka, Bangladesh from 2-6 March, 2014) WMO made arrangements of holding an International Training Workshop on Dvorak Technique and Tropical Cyclone Forecasting in Muscat, Oman from 28th September to 2nd October, 2014. The Government of Sultanate of Oman had very kindly offered to co-sponsor and host the workshop in Muscat, Oman from 28th September to 2nd October, 2014. PTC Secretariat extended invitation to the PTC Member countries for inviting suitable nominations. The workshop was attended by thirteen (13) participants from seven PTC Member countries besides representatives of Oman. The financial support in lieu of travel and per diem to the participants was provided by WMO through PTC Trust Fund.
- PTC Secretariat collected contributions from Member countries for PTC Newsletters and published PTC Newsletter "Panel News" (Issue No.37, 38) and distributed the e-version issues among the PTC Member countries, UNESCAP, WMO and the other concerned international organizations. The electronic versions of the PTC Newsletters were also uploaded on the PTC website at the following web link: www.ptc-wmoescap.org/newsletters
- With the support of the Panel, Secretary of PTC represented PTC at 70th Session of ESCAP (Bangkok, Thailand from 4-8 August, 2014). The opportunity was also used to share PTC programmes and activities, and to highlight the cooperation of PTC with the other regional body of WMO/ESCAP Typhoon Committee (TC) in the development of manual on integrated multi hazard early warning systems for both PTC and TC regions. At this important platform of ESCAP, the Secretary of PTC made the following statement:

  "On behalf of the WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and the Arabian Sea, I would like to highlight the need for the regional cooperation particularly in the field of Early Warning. The PTC is making determined efforts in this regard and has expanded close

collaboration with the ESCAP/WMO Typhoon Committee on Multi-hazard Synergized Standard Operating Procedures (SSOP) with support from ESCAP Trust Fund for Tsunami, Disaster and Climate Preparedness and is planning to hold a joint session of Panel on Tropical Cyclones and Typhoon Committee in February, 2015 in Bangkok, Thailand for obtaining goals of early warning in this region."

- Panel on Tropical Cyclones has been closely collaborating with the Typhoon Committee in the implementation of joint project "Synergized Standard Operating Procedures (SSOP) for Coastal Multi-Hazards Early Warning System (SSOP) which is funded by ESCAP Multi-Donor Trust Fund for Tsunami, Disaster and Climate Preparedness in Indian Ocean and South East Asia. The beneficiary countries include Bangladesh, Cambodia, China, India, Lao PDR, Malaysia, Maldives, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam.
- In connection to the organization of 3rd Joint Session of PTC and TC in Bangkok, PTC Secretariat has been extending full cooperation to the Typhoon Committee to make the event successful and fruitful.
- Concerning to the participation of Panel Members' representatives in the joint session of PTC and TC, PTC Secretariat extended invitations to the Panel Members for seeking their nominations. The invitations were also extended to other international organizations like IOC-UNESCO, ICAO, CMA, Tohoku University, for sharing of knowledge.
- PTC Secretariat collected input/feedback from PTC Member countries and prepare/arrange summary based on their report(s) in relation to meteorology, hydrology, DRR, training/research component for presenting it at the Joint Session of PTC/TC.
- Information regarding financial support by WMO from the PTC Trust Fund and detailed breakup of expenses incurred by PTC Secretariat during the intersessional period (2014-2015) is attached as **Appendix-I.**

APPENDIX-I

APPENDIX

Statement of PTC Secretariat Accounts

(2014- 2015)

Sr. No.	Opening Balance and Receipts	Amount (PKR)
1.	Balance after 41st Session of PTC	8500/-
2.	Amount received during the intersessional period (US$ 4000/- equivalent to PKR 393,800/- @US$ 1 = 98.45)	393,800/-
	Total	402,300/=
	Expenditures	
1.	Printing of 36th, 37th Issues of the Panel News.	85,000/-
2.	Services for compilation work of Panel News (Issues No. **36th, 37th and 38th**).	60,000/-
3.	Services for PTC website design / updation support	10,000/-
4.	Postage charges for despatch of Panel New No. 36	15,355/-
5.	Honorarium to Meteorologist-PTC Secretariat @ US$150/= per month (equivalent to Pak Rupees) *(for the period from August 2013 to June 2014).*	167,400/-
6.	Purchase of Colour Toner for Laser Jet printer	Nil
	Total	3,37,755/-
	Net Balance in hand	64,545/-

APPENDIX-II

World Meteorological Organization
Organisation météorologique mondiale
Secrétariat
7 bis, avenue de la Paix – Case postale 2300 – CH 1211 Genève 2 – Suisse
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PANEL ON TROPICAL CYCLONE TRUST FUND

Interim Statement of Income and Expenditure
For the period 1 January to 31 December 2014
Amounts in US dollars

1.	Balance of fund at 1 January 2014			62,525
2.	Income:			
	2.1 Contributions			
	2.1.1 Pakistan (8 January 2014)	2,820		
	2.1.2 Maldives (28 April 2014)	3,000		
	2.1.3 Thailand (15 July 2014)	2,000		
	2.1.4 Sri Lanka (25 August 2014)	2,000		
	2.1.5 Oman (22 October 2014)	3,000		
	2.1.6 India (10 November 2014)	2,950		
	2.1.7 Total contributions		15,770	
	2.2 Interest		43	
	2.3 Total revenue			15,813
3.	Total available funds during reporting period			78,338
4.	Expenditure:			
	4.1 Direct project costs:			
	4.1.1 Travel cost for KARUNANAYAKE, MAW and RAKSAPOL, Training on Operation Tropical Cyclone forecasting at RSMC Tropical Cyclone, New Delhi, India, 17-28 February 2014 (Activity no. 80069)	6,019		
	4.1.2 Temporary Support to the Panel of Tropical Cyclones Secretariat (Activity no. 80070)	4,013		
	4.1.3 Travel costs for RANA, TCP Missions for 2014 (Activity no. 40579)	2,505		
	4.1.4 Travel costs for ALFARSI and KYAW, Integrates Workshop of WMO/ESCAP Panel on Tropical Cyclones, Bangkok, 27-29 November 2013 (Activity 80067)	2,389		
	4.1.5 Letter of Undertaking WMO contribution the Indian Institute of Technology (IIT), to enhence the training on Storm Surge Forecasting at Indian Institute of Technology (IIT), New Delhi, India, 9-20 December 2013 (Activity no. 80068)	(66)		
	4.1.6 Total direct project costs		14,860	
	4.2 Indirect project costs			
	4.2.1 Support costs (13%)	1,932		
	4.2.2 Bank charges	68		
	4.2.3 Unrealized loss on exchange	a/ 4,543		
	4.2.4 Total indirect project costs		6,543	
	4.3 Total project expenditure			21,403
5.	Balance of fund at 31 December 2014			56,935

a/ WMO's official currency is the Swiss Franc (CHF). Accordingly, all transactions completed in currencies other than the CHF are converted to Swiss Francs at the United Nations Operational Rate of Exchange (UNORE) in force on the day of the transaction. Project account balances (in CHF) are translated to applicable donor reporting currencies based on UNOREs in force at the end of the month to facilitate reporting to donors. As the Swiss Franc has been appreciating against the US Dollar (the reporting currency for the Panel on Tropical Cyclone Trust Fund), foreign exchange gains resulted from conversion of net asset balances from CHF to USD as of the reporting date. This explains the foreign exchange gain. It should be noted that the gain was not realized as of the reporting date, i.e. they were not actual, as they resulted from (a) revaluing the Fund's assets and liabilities as of that date, and (b) converting the resulting CHF balances to USD.

Certified correct:

Luckson Ngwira
Chief, Finance Division
2 February 2015